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Science and technology in early India: An overview

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Abstract
The science and technology in ancient India was well cultivated and was based on innovative ideas and inventions. The progress in science and technology had begun with human civilization in general and with chalcolithic, bronze and stone age in particular. The archaeological remains of Harappa suggest that people had made immense progress in field of science and technology. Town planning, drainage, seals, terracotta figurines, dancing girl, bathroom etc gives us a high impression of their skill in science and technology. The Mauryan and the Gupta period was rich in science and technology as well. The mauryan buildings, potteries, terracotta figurines and inscriptions were of high degree of skill in science and engineering. The coins and mehrauli inscriptions of Gupta speaks of their high taste in science and technology. Aryabhatta, Varahamihra, Brahmagupta, Charaka, Susruta, Bhaskar were some of the popular names in the field of science. Their contributions not only benefited India but also abroad.

Keywords: Science, technology, coins, terracotta, potteries

1. Introduction

The present article gives an outline on the achievements made in field of pure and applied science, i.e. astronomy, cosmology, mechanical and civil engineering, mathematics, physiology, medicine, atomic theory etc. We start with the lithic technology in prehistoric India. Stone Age has been classified into four periods; Palaeolithic Age or Early Stone Age (ESA), Middle Stone Age (MSA), Late Stone Age (LSA) or Mesolithic Age and Neolithic age. A large number of Palaeolithic sites have been discovered in the recent past all over India. For example, Palaeolithic and Acheulian tools have been discovered from the deposits in Sohan Valley (Pakistan), Luni Valley and its tributaries (Rajasthan), Narmada, Bhimbetka (Madhya Praesh), Belan Valley, Chhota Nagpur (South-east Bihar) and rivers Godavari, Krishna and Eastern Ghats (Andhra Pradesh). Malaprabha (Karnataka) and Kaveri delta (Tamil Nadu) etc. Tools of the ESA period comprising hand-axes, cleavers, discoid, Chopper-chopping and the by-products of their manufacture, and those of the LSA comprising microliths made by a variety of techniques but principally based upon the production of blades from carefully prepared blade cores, have been identified in western and central India and the Deccan and in the Gangetic plains. MSA tools are generally made out of cryptocrystalline Silicas and the products comprise scrapers blades, burins points, borers, flakes and cores. Apart from the drastic climatic and environmental changes, the essential process of development is a progressive change in emphasis from core to flake tools, accompanied by a steady reduction in size and increasing refinement of technique manifested in the preparation of the core, the removal of a flake of carefully controlled shape and thickness, and the subsequent reworking of a small proportion of these flakes to produce various kinds of scrapers, borers etc.

The function of the ESA tools was perhaps digging roots, chopping meat and breaking bones. However MSA tools were probably used for scraping or cutting and boring a hole. It is generally assumed that food gathering was substantially more important than hunting in the ESA.

Radiocarbon dating is possible only up to 40,000 B.P. and therefore, the ESA is beyond its range. But we have dated several sediments associated with the MSA. The Carbon 14 (C-14) dating show that most of the MSA sites have come within a range of 37,000-11,000 B.P.

With the passage of time, there is a marked diminution in the size of stone tools, reaching its culmination in Micro lithic period. The Mesolithic was generally the period when glaciers were withdrawing to higher latitudes in the north. A number of Mesolithic sites have been

excavated in western and central India i.e. Langhnaj (Gujarat), Adamgarh (M.P), Bagor and Tilwara (Rajasthan).
Varied bone tools have been recovered from all excavations in Mesolithic period. The abundance of animal bones, both wild and domesticated, in Mesolithic period suggests that animal food was more important in the earlier stages of the settlements. Thus the economy during Mesolithic period seems to have been a combination of hunting, animal husbandry and some sort of primitive agriculture. The evidence of scrub burning together with the first occurrence of Cerealia-type pollen in the take profiles is dated 7500 B.C. of Lunkaransar and Sambhar in Rajasthan has shown that some sort of primitive agriculture was introduced in India. The earliest evidence of domestication of animals comes from Adamgarh and Bagor dated 5500 B.C and 4500 B.C respectively.

The Microlithic non-ceramic levels were followed by the Neolithic culture. Neolithic cultures are roughly contemporary with the Early Harappan Culture. A number of Neolithic sites have been discovered in various parts of India, e.g. Kili Gul Mohammad (Quetta), Burzahom (East of Srinagar), Chirand (Bihar), Chhota Nagpur, Kodekal, Utnur (Andhra Pradesh), Maski (Karnataka) and Paiyampalli (Tamil Nadu), From technological point of view a variety of ground stone tools were used by these Neolithic people, e.g. polished axes, harvesters, pounders, polishers, chisels and mace heads. The bone tool industry of Neolithic people was unique and the most well developed. It comprised harpoons, needles, awls, spearpoints, arrowheads, daggers and scrapers. The begining of pottery is traced in the Neolithic age. The Neolithic potters made graceful pots by a cooling technique. Pottery was handmade and the use of wheel was not known to them. The domestication of plants and animal was the base of Neolithic economy as compared to hunting and food gathering. Cultivation in the early Neolithic stage was restricted to a few edible plants, based on the use of polished stone and bone tools and some sort of slash-and-burn or "Jhum" method and every member of the community was actively involved in it. The domestication of plants and animals marked a notable stage in human progress, but from technical angle, the full-blooded agricultural revolution was yet to come, the draught potential of cattle was still unexploited, and there was no trace of the plough. The available C-14 dates show that the southern Neolithic time spread is confined to 2500-1000 B.C. The Neolithic/ Chalcolithic culture of Chirand, in Bihar, starts around 1600 B.C. and may go back even further. The Kashmir Neolithic had a bracket of 2400-1500 B.C. At Kili Gul Mohammad it starts around 3500 B.C. Full scale agricultural technology developed in Baluchistan and Indus region in the fourth and third millennium B.C. as a result of the spread of farming cultures across the Indo-Iranian Plateau. This is marked by the use of wheel, metal and settled village (3000-2700 B.C). We get settlements in Indus region and there is metallurgical progress and by (2700-2400 B.C) we get fortified settlements and metal craft makes some headway.

The first urban culture or Harappan culture gradually evolved from these pre-existing cultures. The earliest indigenous cultures which are of interest in the historical study of science and technology are those which centred upon Harappa in Punjab and Mohenjodaro in Sindh; the so called Indus valley civilisation represents the bronze age of India. In technology, the prominent characteristic is that of standardization. Cities built to a uniform plan, resembling the layout of a chess board and of well-fired bricks of a controlled size, and domestic pottery turned from the wheel in specific form and capacity. The suggest in turn a methodical system of weights and measures. Clearly there was a considerably big merchant class, through which commercial arithmetic developed. It will be seen that the above system of ratios may be based upon 16, an important number in ancient Indian numerology, and that certain others may be successively obtained by doubling or halving, also of interest in the use of fractional thirds and the development of a decimal for the higher numbers.

It is clear from the planning and architecture of the cities that there was a competent knowledge of simple geometry and surveying based upon two units of length, a 'foot' of about 13.2 inches and a 'cubit' of about 20.6 inches. We may add three another practical achievements of this civilization i.e., the construction of mail drains having brick 'manhole covers', the cultivation of cotton and the manufacture of cotton-cloth, and the working of copper, bronze and copper-arsenic alloy. The over-all picture is of a technology standardized through several centuries by an inflexible and authoritarian regime.

Archaeological excavations and explorations revealed the spread of Harappan culture over an area of about 840,000 square miles. Besides the Indus Valley proper, its spread includes Markran Coastal area in southern Baluchistan upto Sutkagendor near the Iranian border, northern Rajputana, Kutch, Saurashtra and Gujarat upto the Narmada and East Punjab, Uttar Pradesh and the region almost upto Delhi. Harappan culture (2300-1750 B.C.) died a mysterious death and for this various agencies have been attributed.

The Chalcolithic culture in India traditionally include non-urban, non-Harappan culture characterized by the use of copper and stone. These cultures make their first appearance at the turn of the second millennium B.C. and are eventually replaced by the iron-using cultures. These are three mail Chalcolithic cultures, i.e. Banas culture (2000-1600 B.C.), Malwa culture (1700-1400 B.C.) and Jorwe culture (1400-1100 B.C.) probably using Ochre Coloured Pottery (OCP, Pre 1200 B.C.) were agricultural communities that raised rice and barley, but not wheat. A variety of copper tools, ring flat and shouldered Celts, trunion axes, anthropomorphism, swords, double-edged axes, harpoons, socketed axes, etc. Together with stone tools have been discovered from a number of sites in Uttar Pradesh, Bihar and Madhya Pradesh. These settlements could not multiply until the coming of iron technology. Iron being cheaper than copper, iron tools tend to be substituted for bronze as well as stone blades. Moreover, with iron, tools in other materials (such as bone arrowheads) too can be made easily.

Cultures associated with Black and Red Ware (BRW) and Painted Grey Ware (PGW) mark the coming of iron technology in India. Carbon-14 dated for PGW culture give them a period between 1025-500 B.C. Important PGW was sites include Ahichchhatra. Hastinapura, Ropar, Panipat, Indraprastha (Purana Qila), Mathura, Bairat, Sonipat, Atranjikhera, Alamgirpur and Sravasti in Doob Noh in Rajasthan. Further east the characteristic pottery is BRW and the important sites are Kaushambi II, Rajghat (Old Varanasi), Prahladpur, Buxar and Chirand. These can be given a start of 800 B.C. Iron appeared in the north-western part of the Indian sub-continent at the beginning of the first millennium B.C. Iron object used by the PGW people may be classified as under:

a) Weapons used for warfare or hunting and fishing VIZ, arrowheads, spearheads, daggers, lances and fish-hooks
b) Household objects like nails, pins, needles, knives, clamps, rings, bangles and tongs
c) Craft tools-VIZ, adze axe, chisels and borers
d) Objects used in agricultural operations including spade, sickle, hoe, axes socketed and plain and ploughshare.

But so far very few iron tools belonging to the first half of first millennium have been discovered, which suggests that at this stage iron did not contribute much to develop handicrafts and agriculture. In the first phase in India, the use of iron could not be extended to production because of its paucity of production in making their authority felt over the producers. However, in this phase, iron may have been used for purposes of warfare, for clearance, for making wheels and the body of carts and chariots and in the construction of houses. It is thus clear that the PGW iron period was, therefore primarily an age of iron weapons and not of iron tools.

The growth of Indian science is to be influenced by the Vedic people. In the hymns of the *Rig Veda* is to be found the first account of the way of life of the Aryans, their recognition of and devotion to one supreme cause, their realization that behind the phenomena of the natural world, which appear shifting and changeable, there is a constant principle (*Rita*) or order in events. Despite the gradual development of philosophy the personification of the primeval forces of nature, for instance, Sun god, Surya, or the god of fire, Agni, continued. Sacrificial altars, at first mere heaps of turf, evolved into elaborate designs demanding arithmetical and geometrical calculations. Vedic literature tells us only fragmentary information concerning the early stages of Indian science. The wisest procedure is to examine the whole evaluation in the light of Indian literature.

The fifth and fourth centuries B.C. are known to the archaeologists as the high age of the Northern Black Polished Ware (NBP). It was ceramic par excellence, which was traded presumably for wine or oil. It may roughly be divided into two phases. i.e. 600-300 B.C. and 300-100 B.C. while the second phase of the NBP is marked by the profuse use of NBP (especially around 300 B.C.) more coins, plenty of terracottas, more iron tools, burnt brick structures, occasional tiles and ring wells, the first phase is marked by the absence of burnt brick structures and ring wells and shows less of NBP shreds, coins, terracottas and iron tools, although semi-precious stone beads, glass and sometime ivory objects are also found in this phase.

The early Buddhist and Brahmanical texts, and archaeological excavations have shown that the wide use of iron tools such as iron ploughshare, axe, borer, chisel, spade, sickle etc. For crafts and cultivation was introduced in sixth century B.C. Conditions were thus created for the transformation of the tribal, pastoral, almost egalitarian Vedic society into a full-fledged agricultural and class-divided social order during this period. Surplus plays a key role in the formation of class and leads to the erection of an entirely new type of power structure called the state. Among other factors associated with wider social changes some of which led towards second urbanization the gradual utilisation of iron can be cited as one of the increasingly noticeable technological changes. The importance of iron technology is not merely that it introduces, a change in the use of metals but that when the use of iron artifacts becomes more widespread, the pace of change as compared to other metal technologies is accelerated. One of the first indications of these developments is the construction of great mud or mud brick ramparts as defences for cities. Taking the country as a whole, sixty well-known towns spreading from Champa in the east to Bhrigukaccha in the west, from Kaveripattinam in the south to Kapilavastu in the north emerged. These towns owned their importance to their excellence in technical arts and crafts and eighteen such guilds were in existence. Each guild was presided over by a head and had its own laws, with king exercising control over them in a general sort of way. Coins both of cast copper and punch-marked silver made their appearance.

Towns and cities were now built according to a certain planning. In the first instance, the architectural layout was considered, followed by building houses of various types to suit various classes of people. Subsequently, arrangements were made to construct parks, water tanks and wells. All the ancient cities and towns were built on the geometrical basis and taking inspiration from *Dharmaśāstra*. The foundation of cities and towns had considerable bearing of geophysical environment, availability of natural sources of water, means of communication and taking into account the all important factor i.e. security during war. From time to time engineers laid down plans to build houses taking into consideration square, cube, and circle to suit the requirements of different classes of people. From the above stated facts, it is be clear that specialization in civil engineering, knowledge of geography, geology, geometry, metals and other technologies was very much in evidence.

The social outlook of early Buddhism has been explained in terms of the needs of iron-ploughshare based agriculture and the problems created by money lending and urbanization. Similarly, the foundation of sixteen *Mahajanapadas* and emergence of Magadha as the most powerful state ultimately becoming the nucleus of the Mauryan empire was perhaps the result of advance in NBP iron technology.

Perhaps the earliest source dealing exclusively with astronomy is the *Jyotisha Vedanga* (500 B.C.). One learns the rules for calculating the position of the new and full moon amongst the 27 *nakshatras*, and of the *aryanas* which will fall in cycles of 5 years each of 366 days. In 5 solar years were 67 lunar months so that if these are taken as equivalent to 62 synodic months, then a year of 12 months may be retained if the 31^{st} and 62^{nd} months are omitted from each cycle. This ancient system of lunar-solar reckoning was widely used in India and occurs also in Jains literature.

Early Indian cosmology is generally based upon the square and cube. 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 upto a point (or rather, to small square), on the top of this is the Mount Meru, a pyramid widening out as it rises, at a small angle homologous squares on a horizontal plane, above the Sun's plane is that of the moon with similar orbits. Associated with this early Meru cosmology were a series of numbers, such as 4, 12, 28, 60 obtained through sub-division of the square, or rectangle. The system was dictated by mathematical rather than by astronomical requirements. Thus a 'square' orbit of 28 could be represented by placing unit squares around the periphery of an original square of side 6 (containing 36 unit squares) and adding in the unit square at each corner, i.e. (4x6)+4, giving a geometrical picture of the alighting stations of the moon.

Later Meru cosmology, found in the Jaina and Buddhist texts, adopts the circle as the basic form. This radical departure occurs in the *Surya Prajnapti* (perhaps 200 B.C) where the earth is represented as a circular disc with Mount Meru as its centre and the pole-star directly above. Surrounding the earth are seven concentric oceans, and continents, whilst co-planner rotations of the planets are from east to west around Mount Meru. In the *Jambudvipa Jnaapti* further steps are taken when the detailed geometry and associated calculations of this circle made on the basis of the ratio i.e. circumference-diameter $= \sqrt{10}$. Numerical results are obtained for lengths of ares, sagittae and segments of chords, and in certain cases quadratic solutions are required. With slight modification Maha Meru, or Sineru cosmology, also occupies the central position in the Buddhist universe as described in the Pali scriptures.

We may now mention the doctrine of *paramanu*, better known as the atomic theory. Atoms could be grouped together to form molecules, and whilst the atoms envisaged by the Jains and Vaiseshikas were eternal, those of the Buddhists, being included in a phenomenalism view of nature, appear and disappear by cycles. In the *Kevaddha Sutta* appended to the *Digha Nikaya* we also find that all matter is ultimately formed from four elements i.e. fire, air, water and earth. To these is added, in the *Taittirya Upanishad*, a fifth 'element' non-material and all-pervading. The fully developed atomic theory in the *abhidharma Hridaya*, translated into Chinese in the third centure A.D. represents the refinement of a doctrine which had existed for several centuries.

Ancient Indian mathematics shows an early interest in large numbers expressed in powers of ten, in the nature of numbers and their factors, and in the division of time into its smallest units. These large powers occur in the *Vedic Samhitas*, *Brahamanas*, *Sutras* and in the epics i.e. Mahabharata and Ramayana. Of particular interest is the *Shatapatha Brahmana*, which lists all the factors of 720 as far as 24 and after stating that 360 nights and days contain 10,800 *muhurttas* proceeds by four successive multiplications by 15 to reach the ultimate *pranas* or breathings.

Of the greatest importance to the historian of mathematics are the *Sulva Sutras*, part of the *Kalpa Sutras* and deal with the construction of sacrificial altars used in the Vedic rituals. From the mass of literature which must have been the prerogative of the priesthood, seven *Sulva Sutras* have survived and =of these three are especially valuable-those of *Baudhayana*, *Apastamba* and *Katyayana*. They deal with such matters as the construction of squares and rectangles, the relations of the sides to the diagonals, the construction of equivalent squares and rectangles; the construction of equivalent square and circles, the construction of triangles equivalent to squares and rectangles, and the construction of squares equal to two or more given squares or equal to the difference between two given squares. In this connection we may note two interesting formulae, those giving the diagonal of a square and the squaring of the circle. This, according to *Baudhayana* and *Apastamba*, to obtain the *dvikarani* or diagonal increase the measure by its third part, and again by the fourth part (of this third part) less the thirty-fourth part of itself (i.e. of the fourth part). This gives a Value for $\sqrt{2}$ of 1+1/3+1/3.4-1/3.4.34 or 1.4142156... Diverging from modern calculation only in the sixth place of decimal.

Kautilya's Arthashastra is a unique work on statecraft, probably elaborated from the Mauryan original and containing references to the economics and technology till upto 300 A.D. It is a storehouse of information on land and sea communications, agriculture and irrigation, ores and mining, plants and medicine and especially mechanical contrivances or *Yantras*. Engines of war and *Yantras* of architecture are mentioned with emphasis mainly on the former, a whole chapter is devoted to armoury and the *Yantras* are classified as stationary or mobile, and even though their detailed operation can often be inferred, it is clear that the main descriptions refer to warfare, the role of elephants in war, catapult devices for hurling projectiles, and incendiary missiles, the composition of the inflammable materials used. In the furtherance of cultivation, irrigation, canals and large artificial reservoirs such as the lake of Girnar in Saurashtra were constructed.

Although urban elements appeared in India in pre-Maurya time, they reached their peak under the Shaka-Kushanas and the Satavahanas. For the first time the Kushanas issued numerous gold coins and minted large number of coppers that circulated for centuries. Numerous copper coins were also issued by other rulers and authorities. Terracotta coin moulds have been found in large number in the northern region, belonging roughly to the first three centuries of the Christian era. During this period manufacture of glass and ivory objects reached its zenith. Several iron crucibles and furnaces belong to this period, and the iron tools and implements are far more varied and numerous than those of earlier times. Shaka-Kushana levels show large brick structures and also the first use of baked tiles for roofing and flooring. The *Digha Nikaya* mentions about two dozen trade routes. Mahavastu gives list of trades of worker living in the town of Rajagriha, the *Milindapanha* enumerates 75 occupations of which 60 are connected with various varieties of crafts. Of those, eight crafts were associated with working of mineral products, e.g. gold, silver, lead, tin, copper, brass, iron and precious stones. A variety of brass (*arakta*) zinc, antimony and red arsenic are also mentioned. All this indicates considerable advance and an amount of specialization in the working of metals. In particular, technological knowledge about the working of iron had made considerable progress in varies field of science and created suitable condition for trade between southern India and the Roman Empire. Indian iron and steel are mentioned in the *Periplus* as imports into the Abyssinian ports.

The machines of the period of the *Arthashastra* and of the early centuries A.D. were useful devices of everyday life, such as the *Variyanitra*, probably a revolving water spray for cooling the air, mentioned by the poet Kalidasa in his *Malavikagnimitram*. References to *Yavanas*, who were often engineers in early Tamil literature, have shown that considerable progress was achieved in civil and mechanical engineering during this period. Engineering skill in the building of dams and irrigation tanks is evident from the remains of these and from the inscriptions relating to them. Geometry began as a practical aid in the building of altars and sacrificial structures but slowly came to be applied to more complex architecture.

Two of the sciences which benefited directly from familiarity with other parts of the world were astronomy and medicine. Deep-sea navigation required a reliable study of the stars, and no doubt mercantile patronage in the form of finance was forthcoming for this study, and communication with the western Asia led to a fruitful exchange of knowledge in this field.

The first major expositions of Indian astronomy is the last few centuries B.C. are recorded in two works, the *Jyotisha-Vedanga* and the *Surya-Prajnapti*. Contact with Greek world introduced a variety of new systems, some of which were assimilated and others rejected. Aryabhatta was the first astronomer (499 A.D.) to pose the more fundamental problems of astronomy. He was first Indian algebraist of whose mathematical work we have only thirty-three *Shlokas* which form a section of the astronomical writing *Aryabhattiya*. He had a prolonged influence in both astronomy and mathematics. It was largely through his efforts that astronomy was recognised as a separate discipline from mathematics. He calculated 77 to 3.1416 and the length of the solar year to 365.3586805 days, both remarkably close to recent estimates. He believed that the earth was a sphere and rotated on its axis and that the shadow of the earth falling on the moon caused eclipses.

The condensed form in which the mathematical knowledge of Aryabhatta appears serves mainly as a criterion of the state of the subject at the end of the fifth century A.D. but certain topics clearly emerge, e.g. square and cube roots, simple areas and volumes, the simpler properties of circles, sins, problems, arithmetical progressions, factors and simple algebraic identities whilst 77 is stated as 3-177/1250 (i.e. 3.1416). Algebra is now defined as a separate study (*Bija*) and there is given a general solution in whole numbers of the indeterminate equation of the first degree.

Although archaic Indian medicine and diseases, such as diarrhoea (*Asava*), fever (*Tapman*), dropsy (*Jalodara*) etc. mentioned in the *Atharva Veda*, Considerable progress in the medical science took place at the end of first century A.D. and onwards. The specialized surgical equipments in common use by the first century A.D. consisted of twenty types of knives and needles (*Shastra*), thirty probes (*salaka*), twenty tubular instruments and twenty-six articles of dressing (*upayantra*) affirm considerable progress in surgery during the period. The development of surgery is initially attributed to the genius of Sushruta (4th century A.D.) who may have taught and practised in Kashi. He incorporated surgery into the general field of medicine, advised wide training and experience gained under several teachers and stressed the importance of surgery.

The Indian medical system was based on the theory of the three humours-phlegm, gall and wind (or breath)-the correct proportions of these resulting in a healthy body. These proportions could be achieved by proper diet, an important consideration in a trying climate. The humours were forms of the life-energy and corresponded divine forces or agents in the macrocosm, i.e. outside the body, thus phlegm, cool and heavy, which resided in the chest and lungs, was associated with the moon. Indian interpretation gave wind prime significance among the humours, since it appeared to govern the dynamics of the body. Medical Encyclopedias and pharmacopoeias were composed at this time, the most famous being that of Charaka, a contemporary of the King Kanishka, and another of a slightly later date, that of Sushruta. Evidently, Indian knowledge had reached the western world, since the Greek botanist Theophrastus gives details of the medicinal use of various plants and herbs from India in his *History* of *Plants*.

With the spread of Buddhism hospitals expanded simultaneously. The second Rock Edict (256 B.C.) of the Mauryan Emperor Ashoka celebrates the begining of social medicine, whilst Ceylon, by the fourth century A.D. could boast of some hospitals and a medical service. By royal command each physician served the villages and veterinary officers tended the King's elephants and horses. Ample evidence of the treatment of out-patients in dispensaries occurs in the Sangam literature of Southern India.

At the end of Gupta Period and onwards urban centres in India were gradually on the verge of decay. Money based economy was on decline. It was the period of close commercial intercourse between Imperial Rome and the coasts of Kerala and Tamil Nadu in India. The partial feudalization of land system and the rise of local units of production of self-sufficient village economy were coming into existence. We find bronze utensils and bronze images of Buddhist and Brahmanical deities, but we do not find bronze or copper tools, for these were perhaps replaced by iron tools. The use of iron implements attained a new peak during this period. Iron artifacts were manufactured in plenty. They were used as beams for holding the roof and also as memorial pillars. Iron tools were largely used in agriculture production. Irrigation facilities were expanded. Tanks, wells, ponds, canals are mentioned in law-books during this period. Varieties of cereals including rice, wheat, lentils, fruits, legumes, vegetables etc. are mentioned in the *Amarakosha* and *Surya Puranas*. It is thus clear that the knowledge of irrigation techniques, paddy transplantation, preparation of fertilizers, weather conditions based on observations, various kinds of cereals as well as some other aspects of agriculture was systematized and diffused in various parts of the country.

With the agrarian expansion, botany made a significant progress in India. The *Vrksha Ayurveda* recommended recipes for treating the diseases affecting the plants. In the field of mathematics, considerable progress was made during this period. Whilst Aryabhatta excelled as an observer and in the classification of astronomical data, Brahmagupta was stronger as a mathematician. Brahmagupta is noted for his *Brahmasphuta Siddhanta* (A.D. 628), where in the 12th and 18th chapters important mathematical developments are mentioned and in his *Khandakhadyaka* (A.D. 665), with its supplement, Uttara *Khandakhadyaka*, he is found showing that:

(1) If the sides of a cyclic quadrilateral are of lengths a, b, c, d and its semi perimeter is S, then its area is

$$A = \sqrt{(s-a)(s-b)(s-c)(s-d)}$$

(2) If the diagonals of the same quadrilateral are of lengths x and y, then the relations between these diagonals and the sides of the quadrilateral are expressed by 'Brahmagupta's Theorem'

$$x^2 = (ad+bc)(ac+bd)(ab+cd)$$

$$y^2 = (ab+cd)(ac+bd)(ad+bc)$$

If a, b, c and p, q are the sides of two separate right-angled triangles, such that $a^2+b^2=c^2+p^2+q^2=r^2$, then if we make a quadrilateral of which the sides are the products ar, cq, br and cp, this quadrilateral, called 'Brahmagupta's

Trapezium', will be cyclic and its diagonals intersect at angles.

Using the newer concept of angles, Brahmagupta, in the 1st stanza of his chapter in the *Khandakhadyaka* on the rising and setting of planets, gives the formula which is now expressed as:

$$\frac{a}{SIN\Delta A}\ \frac{b}{SIN\Delta B}\ \frac{c}{SIN\Delta C}$$

Where a, b, c are the sides of the triangle ABC.

We may conveniently leave the ancient India via the *Siddhantas*, the astronomical treatises which in themselves exhibit a transition from the *Paitamaha Siddhanta* to the *Surya Siddhanta* of A.D. 400, which largely establishes the form of native astronomy for the duration of the Middle Ages. Varahamihira (A.D. 505) sssssummarized in his *Panchasiddhantika*, five *Siddhantas*-entitled *Paitamaha*, *Vasishtha*, *Paulisa*, *Romaka*, and *Surya* though his version of the last-named indicates the gradual changes in the text of this period in the most important *Surya Siddhanta* which must have occurred subsequently. This period coincides with that of the growth of the *Siddhanta* literature and the *Romaka Siddhanta* especially shows signs of Greek influence, an influence which is noticeably present in the terminology of astrological writings such as the *Brihajjataka* and *Laghujataka* of Varahamihira. Varahamihira did the study of astronomy and mathematics, horoscopy, astrology-a division which Aryabhatta would have rejected since Varahamihira's emphasis is on astrology rather than astronomy, an emphasis which was to destroy the scientific study of astronomy.

It is thus clear that the various branches of Indian sciences made significant progress with the development of technology from time to time.

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