# A Brief History of Science
# Part 8: The Development of Science in Ancient India

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IN THIS INSTALMENT of the essay I shall deal with the development of science that happened in ancient India. At the present time it has become all the more necessary for the people to understand the rich heritage of science in ancient India, because some unauthenticated claims are being made from different quarters that are undermining the actual contributions of ancient India in science and technology.

The term "ancient" is somewhat vague, as it can mean any time in the past. So, to make our discussion more concrete, we shall divide the time-span into three parts: (a) the period of the Indus Valley civilization, (b) the Vedic age, and (c) the post-Vedic period.

## The Indus Valley Civilization

The ancient civilization discovered through excavations in Harappa, Mahenjo-Daro, Dholavira, Lothal, and about a hundred other sites in Western India and Pakistan was, in the opinion of many experts, the most advanced civilization of the Bronze Age. Radiocarbon dating has revealed that this civilization, also known as the Indus Valley civilization, existed over a period from about 3500 BC to about 1800 BC, out of which the period from 2800 BC to 2500 BC was the time of maximum development.

Archaeologists were particularly surprised to see the planned layout of these ancient cities. Large and small roads (9 feet to 34 feet wide), brick houses built over square and rectangular plots of land, large granaries, public baths, arrangements of lighting the streets — all these indicate that civil engineering, town planning, and architecture were quite advanced in this civilization. There are many remarkable items of civil engineering, such as, drainage systems for water (open and closed), irrigation systems, river dams, water storage tanks carved out of rock, moats, homes with private bathrooms and drainage, multiple-storied buildings with stairs, and even a dockyard.

Such architecture requires knowledge of geometry, especially the construction of squares, rectangles, and rectangular parallelepiped. The Indus Valley people designed a ruler (Mahenjodaro ruler) that was divided into ten equal parts. All bricks had the ratio 1:2:4, regardless of their size and location. The seals also show intricate geometric patterns. It was an agriculture-based society. But the artefact discovered in these sites indicate significant advancement in textiles, pottery, and metallurgy (copper and brass) also.

Archaeological evidence indicates that by about 1700 BC, the Harappan civilization was on the verge of decline. The causes of

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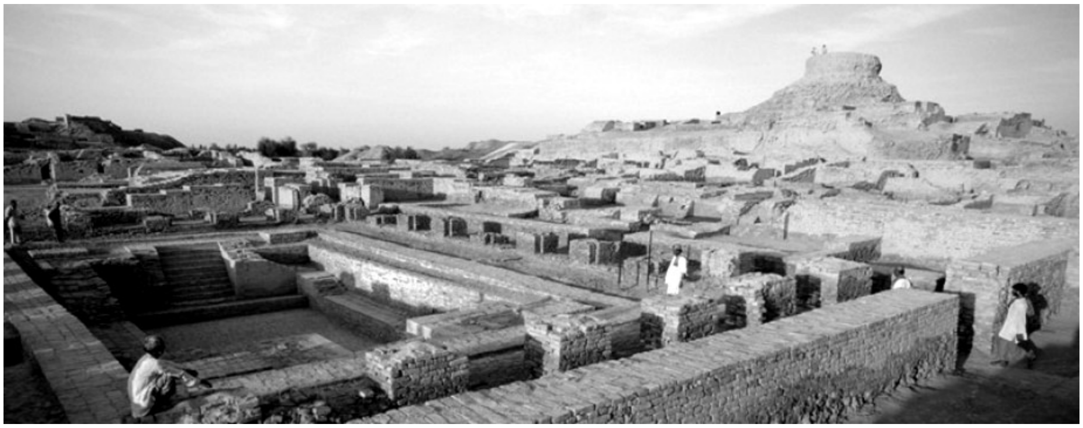


Picture of the Mohenjo-Daro ruins, with the great public bath in the foreground.

its decline are not certain. Climatic changes and long spells of draught (or flooding) may have led to the decline in agriculture. The increase in population and the decrease in agricultural output may have created economic problems leading to a gradual decay of culture. The physical existence of the civilization possibly ended when the inhabitants were forced to abandone the cities to move to other areas with better prospects of livelihood. Such decline and extinction of a culture are not uncommon in ancient civilizations; Inca and Maya civilizations of South America offer similar examples.

## The Vedic Age

Some tribes speaking Proto-Indo-Iranian languages migrated from Asia Minor into West Asia and Europe from around 2500 BC and a few influxes occurred into North-Western India sometime between 1800 BC and 1500 BC. These were horse-riding pastoral migratory tribes whose livelihood came mainly from animal husbandry. They did not create urban civilizations like Harappa and Mahenjo-Daro (cities grew in Aryan-speaking land only after 600 BC); they did not have a written script; they were also significantly backward in terms of science and technology in comparison to the people in the Indus valley civilization. But they fought and won against the non-Aryans, settled in the Indian subcontinent, and slowly gave birth to a very rich culture that was to have tremendous impact on the history of the subcontinent.

The thousand year span from the migration of the Aryan-speaking people till the onset of the Buddhist era (approximately from 1500 BC to 500 BC) is called the Vedic age. The Vedas are the highest cultural creations of that period. Even though rituals, worship, chants and hymns constitute a lion's share of the Vedas, these are also our prime sources for an objective assessment of the actual progress of science in that period.

From these works we see that the late Vedic people wrote numbers in a system that had 9 basic number-symbols. Zero had not been discovered and the place-value system has not been invented at that time. So they needed new symbols for 10, 20, 30, $\cdots$ 100, 1000, etc. There were also names for higher powers of 10. Historians are surprised by the fact that they could conceive large numbers in spite of the handicap of not being able to write such numbers. In the *Taittiriya Samhita* and *Shulvasutra* we see mention of arithmetic progression and geometric progression. They could add, subtract, multiply and divide simple fractions. We also see attempts to find the square root of 2 and 3 in terms of continued fractions.

The *Shulvasutras* are a collection of texts written between 800 BC and 200 BC, so these could be said to belong to the late vedic and early Buddhist periods. The oldest sutra attributed to Baudhayana is thought to be composed between 800-600 B.C. These are basically the laws of measurement with the aid of a rope (shulvasutra literally means "rules of the cord"), much of it meant for erecting sacrificial altars. In these texts, we find clear instructions of how to locate the East-West line at any place, how to construct a square, how to obtain the perpendicular bisector of a given line, etc. They had to solve some problems of geometry to tackle the construction of raised platform or *vedi* used in *yagnas*. For example, they had to construct platforms of circular, square, and rectangular shapes, of the same area. The *Sulvasutras* gave methods of geometric area-preserving transformations from one geometric shape to another, such as from a square to a circle and vice versa, from a square to an isosceles triangle, to a rhombus etc.

There is also indication that the theorem known by the name of Pythagoras was known to the writers of the *Shulvasutras*. Baudhayana gave the following general statement of the Pythagorus theorem: diagonal of a square produces double the area, and for a rectangle the squares produced by the length and breadth of the rectangle together equal the area produced by the diagonal. He also gave a set of numbers like (3, 4, 5), (5, 12, 13), (8, 15, 17), (7, 24, 25), and (12, 35, 37) which form "Pythagorian triads" — triplets of integers that follow the rule $x^2 + y^2 = z^2$. But no proof was given. It is now believed that people in many parts of the world, including India, Egypt, and Greece, knew about this result and made use of it in constructions of various sorts. Pythagoras in 6th century BC presented a rigorous mathematical statement and proof, which we find in Euclid's writings. Baudhayana also described a method for approximate calculation of the square root of 2:

$$\sqrt{2} = 1 + \frac{1}{3} + \frac{1}{3 \cdot 4} - \frac{1}{3 \cdot 4 \cdot 34} \approx 1.4142156$$

It should be noted, however, that these real developments have no link with what is taught nowadays in schools in some states in the name of "Vedic Mathematics".

In the late Vedic period agriculture was started in addition to animal husbandry, and they had to formulate a calendar in order to fix the timing of sowing, reaping, and other agricultural activities. That provided the primary motivation for studying the motion of the objects in the sky. In addition, fixing of the times of holy events like the performance of a *yagna* also induced people to look for auspicious events in the sky. The Vedic literature show that they counted months on the basis of the phases of the moon, and the year on the basis of the motion of the sun. Since a whole number of moon-months do not make a sun-year, the extra days were counted as "malmas", when no auspicious event could be held. The year was divided into two parts: when the sun moved towards the North (*uttarayana*), and when the sun moved towards the South (*Dakshinayana*), and they could identify the summer and winter solstices. In addition they named 27 stars along the path of the sun and the moon, and could specify the positions of the sun and the moon in the background of these stars. It is important to note that in the

Vedic period there was *no* astrology—in the sense of beliefs in the influence of planets on human lives. The word *Jyotisha* was used in the sense of astronomy.

The most remarkable developments happened in medical science. The Atharva-Veda contains many ideas about anatomy, physiology, and medicines which, though not quite correct in the light of modern science, were much advanced when compared to the knowledge of the other societies of the same period. The Ayurveda was written in the late Vedic period in continuation of this tradition. It is divided in eight chapters: medicine, surgery, treatment of eye, ear, nose, and throat diseases, treatment of psychological problems, treatment of children, poisons and their effects, chemistry and preparation of medicines, and treatment of sexual diseases. Such attempt to systematize the empirical knowledge of that period is undoubtedly remarkable.

Even though the main content of the *Rigveda* was chants and hymns in praise of the gods and asking material benefits in return, the gods of that period were actually embodiments of natural forces or deification of some Aryan leader (like *Indra*) successful in defeating the non-Aryans. That is why historians opine that the essential content of the thought process of men in *Rigvedic* times was materialistic, what anthropologists term as the "magic phase". That is why the *Rigvedic* hymns reflect a healthy curiosity about natural phenomena, which was conducive to development of scientific enquiry.

Many people carry a misconception that spiritualism is the only characteristic feature of the Vedic times. Actually many different philosophical currents were very much alive during this period. One of these philosophical currents is called *Lokayata* (sometimes also called *Charvaka*). It did not believe in the existence of *atma* or soul, refused to accept anything on the basis of belief, and theorized that everything in the world is made of four constituents or *chaturbhuta*: earth, water, air, and fire (a fifth one, sky, was added later). It believed that when a man dies, his body returns to these four constituents, and does not go to heaven or hell. Whether the ideas like *chaturbhuta* were correct in the light of modern science is not of our concern. What really matters is the fact that it sought to explain the world through material processes and phenomena. Other philosophical lines of thought like *Nyaya-Vaiseshika* and *Samkhya* also existed. Notwithstanding the differences between these lines of thought, at the basic level they were also materialistic philosophies. Under the influence of these philosophical currents, there was a healthy curiosity about the material world, and we see steady progress in man's understanding of it.

But the later Vedas laid too much emphasis on ritualistic practices like *yagnas*, *homas*, chants, and on prescribing what to do and what not to do. Such an environment hampered the natural enquiring mind of men, and so the scientific enquiries subsided. When the "end" of the Vedas or *Vedanta* came, it sought to create an alienation of the individual from the material world. Seeking nirvana away from life and society became the ideal for the learned people. This created a condition detrimental to scientific enquiry, and as a result, we do not see much development of science in the late Vedic period.

## Post-Vedic period

This condition began to change in the 6th century BC when a group of people, disenchanted by the suffocating intellectual atmosphere dominated by ritualistic practices, started looking for alternative philosophical ideas. Jainism and Buddhism

**The method of "squaring a circle" in Boudhayana *Shulvashutra***

"If you wish to square a circle, divide its diameter into eight parts; then divide one part into twenty-nine parts and leave out twenty-eight of these; and also the sixth part (of the preceding sub-division) less the eighth part (of the last)."
According to this prescription, the side of the square will be

$$a = \frac{7d}{8} + \frac{d}{8}\left(1 - \frac{28}{29} + \left\{\frac{1}{6}\left[1 - \frac{1}{8}\right]\right\}\right) = 0.87868 \times d$$

Now we know that the area of the square is $a^2$ and that of the circle is $\pi r^2 = \pi d^2/4$. As per modern calculation, the value of $a$ should be $0.8862 \times d$, and thus their prescription was reasonably good.

were born in this period. Even though we mainly hear of these two religions, historians have shown that the materialist philosophical thoughts like *Charvaka, Samkhya*, etc., that were born during the Vedic period found resurgence in this period through man's attempts to find alternate ways to interpret the world. Even Buddha did not believe in the existence of god. The presence of such rich array of philosophical currents and the clash of ideas created an intellectual atmosphere that aided scientific enquiries. That is why we see a resurgence of science starting from the 6th century BC. But this period can no longer be called the "Vedic" period.

The materialistic line of thinking was alive in India for a long time, and slowly died out after about 9th-10th century AD (we'll talk in detail about it later). And this 1600-year period from 6th century BC to about 10th century AD was the golden age of ancient Indian science. We shall discuss this era with reference to the different areas of human endeavour.

### Medical Science

After *Atharvaveda* and *Ayurveda*, medical science reached an altogether different dimension since the 6th century BC in the hands of a few eminent medical practitioners like Athreya and Susruta (6th century BC), Jivaka (566-486 BC) and Charaka (time controversial). The unusual aspect of this development is the practice of surgery which was unequalled in the world before the initiation of modern methods of surgery after the European renaissance. *Susruta Samhita* mentions 121 kinds of surgical instruments, and has detailed instruction on how to run the knife and other instruments on different organs, how to sew the wound with plant-fibre after a surgical procedure, what to do in case of broken bones, etc.

The most unusual aspect of these is the procedure to rejoin severed noses and ears. In those times a common punishment was to cut off the culprit's nose and ears. After this was carried out, if the King learned that the punished person is not really the criminal, then the doctor would receive instruction to rejoin the nose and ears. The detailed account of the procedure in the writings of both Susruta and Charaka indicates that they succeeded in some cases. However, there is no description or instruction on how to place the head of an elephant on a human torso, as claimed by Prime Minister Narendra Modi.

### Chemistry

Everywhere the primary motivation in the study of chemistry came from three directions. Medical practice demanded one to know the properties of different kinds of substances and mixtures that could be used for medical purposes. For that reason, wherever medical science had advanced, knowledge about the properties of the substances that have some medicinal use also advanced hand-in-hand. Second, the demands of metallurgy have induced man to experiment with different metals and their alloys in an attempt to obtain harder and non-brittle material. Third, the belief that it is possible to transform other substances into gold by chemical processes also prompted man to try out various things. In India the studies in chemistry were initiated from all these angles. Since medical science and metallurgy significantly advanced in this country, it is expected that knowledge of chemistry also must have advanced in step. That is what had actually happened.

*Susruta Samhita* and *Charaka Samhita* describe the properties of six metals (iron, tin, lead, copper, gold, and silver), five types of salts (depending on their source rather than their composition), and a few alkalis. They also give elaborate procedures for preparing mild and strong alkaline substances (potassium carbonate and sodium carbonate) which were used to treat wounds. Books written in the later periods also mention the use of mercury, zinc, and sulphur. A process called "killing" metals is described in some books, which is nothing but reactions that produce substances whose properties are different from those of the original metal. A detailed account of this knowledge can be found in Acharya Prafulla Chandra Ray's famous book "The History of Hindu Chemistry". Quite a few books on chemistry, like *Rasa-ratnakara, Rasa-hridaya, Rasarnava, Rasendra-churamani, Rasakalpa*, etc. were written between 11th and 14th century AD. But by then chemistry had become a part of mystic practices or *tantravidya*. That is why modern chemistry could not take birth from that.

Experiments in metallurgy have a very rich tradition in India. The extraction of metals from ores and the mixing of different metals to obtain brass and steel of the required strength demanded people to experiment with various ingredients and processes. Since all weapons are made of metals, this pursuit had patronage of the kings. That is why, even though the cultivation of knowledge subsided in India after the 10th century, the art of metallurgy could advance more or less unhindered for a long time. In many archaeological sites we see instances of specific metals prepared for specific purposes.

Out of these the famous iron pillar of Qutub Minar in Delhi demands special mention. The 24 foot tall pillar built in the 4th century AD has not rusted as yet. The preparation of the specific kind of metal and the technology of fashioning such a huge pillar are truly examples of technical excellence reached during the Gupta dynasty. But the *Hindutva* proponents go a bit far in claiming that modern science has not advanced enough to produce rust-less steel similar to that produced by the ancients. This is however not a fact. Scientists have examined the composition of that iron and have found that it has excessive quantities of phosphorous. This is not surprising, since phosphorous is naturally present in the iron ore and gets mixed with iron in the process of its extraction. Even though phosphorus prevents rusting, this phosphorus is removed by reacting with oxygen in the modern steel-making process, because phosphorus makes steel brittle. But for such a large pillar, it does not matter if the material is brittle, because the bulk holds it together. The iron for the pillar was prepared without removing the phosphorus, and that is why it does not rust. But the same material cannot be used to make swords, for which they adopted a different technique.

The technology of producing Wootz steel which was renowned for making swords with exceptional sharpness and toughness originated in India. This was exported to Europe and the Middle East where it was known as Damascus steel. Another important Indian contribution to metallurgy was in the isolation, distillation and use of zinc. There is evidence of zinc ore mining at Zawar in Rajasthan from the fifth century BC, The earliest confirmed evidence of zinc smelting by distillation is dated back to 9th century from Zawar.

**Linguistics**

It is known that Sanskrit was not a spoken language. It is a language created by "purifying" the spoken languages like Pali, Prakrit etc. Such purification itself is a feat in linguistics. But in the early stage, when the Vedas were initially composed, there was no standardization in its form. The feat of standardizing the language by extracting the rules of its grammar was performed by Panini (4th century BC), considered the greatest grammarian of antiquity. Because of this contribution, Sanskrit became easier to learn and post-Panini Sanskrit became the common medium of discourse and exchange among the learned section of the people of the entire subcontinent. The development of this common medium of exchange played a great role in further development of ideas in this multi-lingual region.

Another remarkable achievement of this period is to arrange the consonants in a $5 \times 5$ matrix depending on which part of the mouth is touched by the tongue and how much air is exhaled while pronouncing an alphabet. This highly scientific way of arranging the alphabets is not found in any other language in the world.

**Mathematics and astronomy**

In ancient India, astronomy and mathematics progressed hand in hand, as the astronomers also practised mathematics and mathematicians cultivated astronomy. That is why these two subjects, where ancient Indians had made major contribution, will have to be discussed together.

We have already discussed the advances in these two subjects during the Vedic age, which are found in texts like *Shulvasutra*, the *Brahmana* literature, and the *Vedanga Jyotisha*. In the post-Vedic period, the Jain mathematicians (between 400 BC and 200 BC) initiated the process of freeing mathematics from religious and ritualistic motivations, and made it stand on its own ground. They were particularly interested in very large numbers, and could conceive infinity. In the writings of the mathematician Pingala (3rd century BC) we see important works on number theory including what are now known as Pascal's triangle and Fibonacci numbers. Important mathematical works of this period are *Surya Prajnapti, Vaishali Ganit, Sthananga Sutra, Anoyogdwar Sutra*, and the *Satkhandagama*.

In astronomy, we do not see any major work in the late Vedic period, and the first signs of resurgence in the post-Vedic period are visible in the texts written between 100 and 500 AD, which are collectively named as *Siddhanta-Jyotisha*, and the first major advancement in mathematics, after the *Shulvasutras*, can be found in the writings of Aryabhata (end of 5th century AD).

The Siddhanta Jyotisha is not one book. It is actually a common name given to a large number of books (like *Surya-siddhanta, Pitamaha-siddhanta, Vashista-siddanta*, etc.) of similar content. Out of these some books like the *Romaka-siddhanta, Poulish-siddhanta, Yavana-siddhanta* contain ideas culled from Greek and Roman astronomy of the post-Alexander period. These resulted from the opening of trade routes between India and Europe following Alexander's invasion, and the cultural exchanges resulting from that. It is in these books that astrology appears for the first time in Indian literature; so the superstition seems to have been imported from the West.

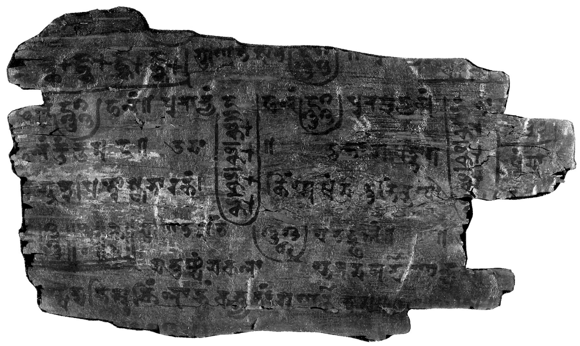
One important aspect of the *Siddhanta-Jyotisha* books is the attempt to find the periodicities of the motion of the sun, the moon, and the planets. But their way of expressing it was different. Today we know the period of revolution of the Earth around the sun is 365.24219 days (the day measured in terms of the earth's rotation around its own axis), and that of the moon around the earth is 27.3216 days. But in the time of *Siddhanta-Jyotisha* it was not known that Earth moves around the sun or that it spins around its own axis. People saw the sun going around the earth, but they noticed that it does not return to exactly the same position at sunrise every day. After every 365 days it comes to more or less the same position, and according to that the year was counted. But they had noticed that the position after 365 days was also not exactly the same. By noticing the shift after every year, they calculated the period after which it would return to exactly the same position. This "periodicity" of the sun's motion was called a *Mahayuga*. According to many *Siddhanta-Jyotisha* books, a *Mahayuga* contains 4,320,000 years. If one calculates the period of revolution of the earth around the sun from this figure, the length of the year becomes 365.258 days, which is very close to the modern estimate. Similarly they had calculated the periods of the moon and the planets — the period within which the object revolves a whole number of times. These come to be very large numbers, and historians were surprised to see the mention of such large numbers in astronomical literature of that time. Actually, before the invention of the place-value system of writing numbers, there was no way of expressing the periodicity of these bodies other than in whole numbers. That is why this ingenuous way was adopted.

Since Indian kingdoms of that time had trade relations with the kingdoms in Greece, Rome, and Arabia, there was exchange of knowledge between the scholars of these regions. Through these exchanges the knowledge created in India percolated to Greece, Rome, and Persia, and ideas from knowledge-centres like Baghdad, Athens and Alexandria reached India and became integrated into its body of knowledge. We know that the Greek philosopher Eratosthenes of Alexandria (276-194 BC) measured the diameter of the Earth by observing the shadows of vertical sticks in two different places. We see the mention of exactly the same method in *Siddhanta-Jyotisha*. The motions of the planets as seen from the Earth are not uniform. Sometimes they are fast, sometimes slow, and sometimes they even move in the reverse direction. To explain such peculiar motion, the Greek astronomer Ptolemy (90-168 AD) had proposed that these do not move around the Earth in circles, rather there are circles over circles — called epicycles (see the 2nd instalment on this essay). In Aryabhata we see a similar explanation of planetary motion, based on two epicycles.

It is however remarkable that Aryabhata was the first to talk about the spin of the Earth about its own axis. This means he was the first to guess that the sun is not really moving around the Earth; rather we see it moving because the Earth itself is spinning about its own axis. But this idea was not accepted by other eminent scholars like Brahmagupta and Varahamihira, who criticised Aryabhata for infusing fanciful

**Series Article**

**The Bakhshali manuscript**



The Bakhshali Manuscript is a mathematical text written on birch bark which was found near the village of Bakhshali in Pakistan in 1881. Only about 70 pages have survived, and are now kept in the University of Oxford.

The manuscript is written in an earlier form of *Sarada* script which was mainly in use from the 8th to the 12th century AD. It is a handbook of rules and illustrative examples together with their solutions. It is devoted mainly to arithmetic and algebra, with just a few problems on geometry and mensuration.

ideas into astronomy. Even though Aryabhata talked about the diurnal motion of the Earth, he did not reach the same conclusion as Copernicus, as he described planetary motion in the same way as Ptolemy. He, however, gave the correct scientific explanation for the solar and lunar eclipses.

In his book *Aryabhatiya* written in 499 AD, we see many contributions in mathematics, including square root and cube roots of numbers, arithmetic progression, solution of simultaneous equations, etc. We also see treatments of infinite series including formulae like

$$1^2 + 2^2 + \cdots + n^2 = \frac{n(n+1)(2n+1)}{6}$$

After Aryabhata, the cultivation of astronomy and mathematics gained momentum, and continued unhindered for many centuries. In this period it was enriched in different directions by eminent scholars like Varahamihira (6th century), Brahmagupta (7th century), Mahavira (9th century), Munjal (9th century), Sripati (10th century), Sridhara (11th century) and Bhaskara (12th century). But before going into this glorious phase of Indian science, we have to understand the greatest contribution of India in the world of knowledge — the discovery of zero and the invention of the place-value system of writing numbers.

Writing of numbers requires a basis. In different parts of the world, different bases were used to write numbers. The Babylonians used base 60, the Mayans used base 20. In India, Arabia, and in many other parts of the world, the number system had base 10 since antiquity. This means that there were 10 number-symbols (1 to 10) to write numbers up to 19 (19 = 10+9). Another symbol representing 20 would be required for writing numbers from 20 to 29, and then it would require another symbol, so on and so forth. Thus, such a number system would require a large number of symbols to write big numbers. This was the problem with the Brahmi and Kharosthi numbers found in stone tablets of Ashoka's time. The same was the problem of the Roman number system. If you try to write a number like 3905 in Roman script, you would realize the difficulty.

But today we write arbitrarily big numbers with ease, with only 10 number symbols. This has been possible due to two major discoveries that happened in India. The first was the realization that the absence of something, or zero, is also a number. The second was the invention of the place value system. In the modern decimal system of writing numbers when we write 3905, we actually construct it as

$$3 \times 10^3 + 9 \times 10^2 + 0 \times 10^1 + 5 \times 10^0$$

Here a digit assumes a "value", a power of 10, depending on the position where the digit is written. This system of writing numbers was developed in India. The literature of that time shows that this way of writing numbers was started sometime between the 1st and 3rd centuries AD. Zero may have been discovered a century or two before that, because the place value system is not possible without the use of zero. We see the use of the place value system in Aryabhata and the later mathematicians like Brahmagupta and Varahamihira. Their writings were translated into Arabic, through which the Arabs came to know of this system. The Arab world was very fast in adopting it. Through them, it reached Europe. That is why the English numerals are still called the "Arabic" numbers, even though the system was invented in India.

With the introduction of a new number system, society faced a new problem. None of the old methods of adding, subtracting, multiplying and dividing numbers would be applicable to the new number system. So one had to freshly develop the methods of arithmetic suitable for this new number system. At that time many techniques were invented, some of which have come to be adopted universally — the ones that students learn in school today.

In mathematics another area in which India made big contribution is algebra. The contribution of the ancient Greeks in mathematics is restricted to geometry. They could not advance much in arithmetic and algebra because they could not invent zero and the place value system. In contrast, the Indian mathematicians did not have this handicap, and so could progress significantly in these directions. The unknown quantity ($x$ in modern algebra) used to be written in Devnagri script using the alphabet "ya", or if two unknown quantities were involved, using the first letters of Sanskrit words for different colours. They used to write equations using these notations, and proceeded to solve many of these equations. Much of the Indian contribution to algebra concerns linear and quadratic equations. Brahmagupta (628 A.D.) gave the first explicit solution of the quadratic equations. Later it was systematized by Sridhar Acharya in the eleventh century.

Another important contribution was in the field of indeterminate equations. When an equation has two unknowns, it is not possible to obtain the values of the unknown quantities. But Brahmagupta, Sripati and Bhaskara showed that in particular situations, such as when the quantities to be found are whole numbers, it is possible to find solutions. Brahmagupta gave a general solution to the linear Diophantine equation $ax + by = c$, where $a, b$, and $c$ are integers. The solution of second order indeterminate equations of the form

$$x^2 - Ny^2 = 1$$

(called Pell's equation) using whole numbers is considered one of the greatest contributions in number theory. Bhaskara developed an algorithm called *Chakravala* for solving indeterminate equations like the Pell's equation in a systematic way.

However, the Indian contribution in geometry is meagre, mostly confined to mensuration. We see rules of finding the areas of rectangles and triangles in the writings of Aryabhata and Brahmagupta. Brahmagupta also gave a formula for the area

**The spread of the Indian numeral system**

It is worth quoting from a speech delivered by the Nobel Prize winning Pakistani physicist Dr. Abdus Salam [5]:

"Almost twelve hundred years ago, Abdullah Al Mansur, the second Abbasid Caliph, celebrated the founding of his new Capital, Baghdad, by inaugurating an international scientific conference. To this conference were invited Greek, Nestorian, Byzantine, Jewish, as well as Hindu scholars. From this conference, the first international conference in an Arab country, dates the systematic renaissance of science associated with Islam. The theme of the conference was observational astronomy. Al Mansur was interested in more accurate astronomical tables than available then. He wanted, and he ordered at the conference, a better determination of the circumference of the Earth. No one realized it then, but there was read at the conference a paper destined to change the whole course of mathematical thinking. This was a paper read by the Hindu astronomer, Kankah, on Hindu numerals, then unknown to anyone outside India."

of a cyclic quadrilateral (whose diagonals are perpendicular to each other). Even though the value of $\pi$ is stated as $\sqrt{10}$ in some *Siddhanta Jyotisha* manuscripts, people like Aryabhata succeeded in obtaining it in much greater accuracy (3.1416).

In trigonometry also we see significant advancement. Aryabhata introduced a number of trigonometric functions. Varahamihira gave a table of the sines and cosines (he called jya and kojya) in his book *Panchasiddahntika*. From his writings we see that many trigonometric relations taught at school today were known in his time. Bhaskara obtained the sines and cosines of even smaller angles, for example he gives $\sin 1^\circ = 10/573$, $\cos 1^\circ = 6565/6569$. Note, however, that the Greek astronomer Hipparchus (2nd century BC) was the first to prepare a sine table and to use it for astronomical calculations.

Bhaskara's astronomical work of the 12th century covers topics such as latitudes and longitudes of planets, lunar and solar eclipses, the moon's crescent, conjunction of the planets with each other, conjunction of the planets with fixed stars, etc.

The Kerala school of mathematics and astronomy (14th to 16th century) made significant advances in astronomy and especially mathematics, including fields such as trigonometry and analysis. They made important contributions to the field of infinite series and provided the first example of power series. Rudiments of calculus are also present in their works, but they did not formulate a systematic theory of differentiation and integration.

## The centres of learning

In the Vedic age the way of imparting education was personal. A learned person or sage would teach a handful students in his own home. The students lived for a few years with the teacher, gave service in the teacher's home and field, looked after the cattle, and in return got an education. But in the Buddhist period, the Stupas and Mutts started emerging as centres of learning, where a large number of monks and bhikkhus lived together and exchanged knowledge.

This model slowly caught on, and a number of specialized centres of learning emerged where a large number of teachers and students lived in a compound, and the teachers could teach a larger number of students. The oldest of these is situated in Takshashila, the capital of Gandhara (present Kandahar province in East Afghanistan) which started developing from a time slightly before Buddha, but reached glory during the Buddhist period. Later, in the 5th century AD, another centre of learning was established in Nalanda with the patronage of the Magadh kings. Even though these two were the most famous, many more relatively smaller centres of learning have been found, like Pushpagiri in Odisha, Odantapuri and Vikramshila in Bihar, Jagaddal in Bengal, Balavi in Gujarat, etc. Some of these were so famous that students came from far-away places like China.

In these centres of learning, education was imparted in an organized manner somewhat like the Buddhist monasteries. However, the form and content of education were personal in nature. The residential facilities and class-rooms in these centres of learning enabled a teacher to teach 20-30 students at a time depending on one's ability and fame, and facilitated exchange of ideas among many scholars. These centres of learning were undoubtedly great initiatives in ancient India that helped knowledge to be consolidated and expanded.

## The decline of science in India

In spite of such a rich tradition in the cultivation of science and technology, after the 9th-10th century it subsided, and then was completely extinguished. Bhaskara can be said to be the last spark of light before it became dark. After him for more than 800 years, there was practically no contribution to science coming from India.

What was the reason behind the decline and fall of Indian science? The famous 19th century chemist Acharya Prafulla Chandra Ray investigated this issue in his book "The History of Hindu Chemistry". According to him, three factors were responsible for this decline in the cultivation of science.

The first was the introduction of the caste system in a rigid form. According to him, the interaction and exchange of ideas between the doers and the thinkers is an essential precondition of the cultivation of science, and casteism blocked this process. "The arts being thus relegated to the low castes and the professions made hereditary, a certain degree of fineness, delicacy and deftness in manipulation was no doubt secured, but this was done at a terrible cost. The intellectual portion of the community being thus withdrawn from active participation in the arts, the how and why of phenomena—the coordination of cause and effect—were lost sight of—the spirit of enquiry gradually died out among a nation naturally prone to speculation and metaphysical subtleties and India for once bade adieu to experimental and inductive sciences. Her soil was rendered mortally unfit for the birth of a Boyle, a DesCartes or a Newton and her very name was all but expunged from the map of the scientific world."

The second reason was the introduction of the "shastras" or moral code books that specified what can and cannot be done. "The drift of Manu and of the later *Puranas* is in the direction of glorifying the priestly class, which set up most arrogant and outrageous pretensions. According to Susruta, the dissection of dead bodies is a sine qua non to the student of surgery and his high authority lays particular stress on knowledge gained from experiment and observation. But *Manu* would have none of it. The very touch of a corpse, according to *Manu*, is enough to bring contamination to the sacred person of a Brahmin. Thus we find that shortly after the time of *Vagbhata*, the handling of a lancet was discouraged and Anatomy and Surgery fell into disuse and became to all intents and purposes lost sciences to the Hindus."

The third reason was the influence of the Vedanta philosophy, which taught people to see the material world as maya or illusion, on the learned section of the people. "The *Vadanta* philosophy, as modified and expanded by Samkara, which teaches the unreality of the material world, is also to a large extent responsible for bringing the study of physical science into disrepute. Samkara is unsparing in his strictures on Kanada and his system. One or two extracts from Samkara's commentary on the *Vedanta Sutras*, will make the point clear." Thus, according to Acharya P. C. Ray, a scientist's queries are directed at the material world, its processes, phenomena and events. If one sees the material world as *maya* or illusion, one cannot do any science. The spread and intellectual dominance of the Vedanta philosophy as propagated by its powerful exponent Samkara (8th century AD), was responsible for the elimination of the materialistic philosophies like *Lokayata*, and for the death of science in India.

## The unscientific claims

In recent times various claims are being made—mainly by the Hindutva protagonists—by mixing science with mysticism, and history with mythology, in order to create an imaginary picture of India's past glory based on religious chauvinism. It is not possible to go into an in-depth analysis of such claims in this article. But I shall briefly deal with some of them, to enable the reader judge for themselves the veracity of the claims.

### Claim 1: Indus Valley civilization was a part of the Vedic era

On this issue, we need to understand why, soon after the discovery of the Harappan sites, historians and archaeologists had come to the conclusion that this was a pre-Vedic civilization. They had found four important clues.

1. The Harappan people knew how to make bricks, but the Vedic people did not. Not a single brick has been found in the one thousand year span of the Vedic age. After the Indus Valley civilization, the first brick-built building was found in the Buddhist period, during the reign of the Maurya dynasty.

2. The horse is the main animal in the Vedic literature. But no horse bone has been found in any of the Indus Valley cities. The main animal depicted in the Indus Valley art, sculpture and seals, is the bull. Not a single picture of a horse has been found. This implies that this animal—the horse—was not known to the Harappan people, but was very common in the Vedic age.

3. The Harappan people had a written language, though scientists have not succeeded in deciphering the script because it has no resemblance with any of the modern languages. In contrast, the Vedic people did not have a written language in the early part of the Vedic age. That is why the *Rigveda* was communicated through *sruti* (to listen) and *smriti* (to memorize), and was written up much later.

4. No description of the Harappan cities are found anywhere in the literature of the Vedic age. There are no references to structures built on platforms, or the grid pattern of streets and the careful construction of drainage systems, to granaries, warehouses and areas of intensive craft production, to seals and their function, etc. "If the two societies were identical" writes the eminent Historian Romila Thapar, "the two systems would at least have to be similar."

There have been attempts by the Hindutva protagonists to contradict these pointers. In the year 2000 a book titled "The Deciphered Indus Script" was published by N. S. Rajaram and N. Jha which claimed that the scripts are actually worship of river Saraswati, in Sanskrit. They also claimed to have found the image of a horse in a Harappan seal. The claims were soon debunked by archaeologists who showed that the translation was a complete piece of imagination. There are linguistic rules that have to be observed in any decipherment, which make it necessary for a claim to stand the test of linguistic analyses. No such scientific process was followed in the claim of Rajaram and Jha. Moreover, the broken seal was photographed by shining light from one side so that the shadow looks like the image of a horse. For details see the article by the Harvard Indologist Michael Witzel and historian Steve Farmer in Frontline (September 30, 2000).

**Claim 2: Vedic Aryans were original residents of India**

Today Hindutva theorists are claiming that the Aryans did not come from outside the land. Some of them change the antiquity of the Vedic culture — some say it is 10000 years old, some say 50000 years. That is why it is necessary to understand on what basis the scientists have come to the conclusion about the antiquity of the Vedic age.

1. The first evidence is linguistic: It has been found that the languages spoken in Europe and in India have a common root. These languages are classified under a group, called the Indo-European family of languages. That is why it is believed that this language group has radiated along with human migrations, starting from a common birthplace. Linguistic evidence suggests that the Indo-Aryans split off from the Indo-Iranians around 1800-1500 BC.
2. The second evidence is zoological: The horse is the prime animal in all Vedic literature, but this animal is not native to the Indian subcontinent. There is no wild horse in any of the Indian forests. Wild horses are found in Asia Minor. Signs of the existence of horses in large numbers are found in India only after a certain time. That is why scientists have come to the conclusion that the horse-riding Aryans entered India around that time.

Nowadays there are attempts to disprove this theory by showing that there were horse fossils in Harappan sites, but the claims have not gone beyond newspaper articles as professional archaeologists did not find scientific merit in such claims. There are also attempts to show that the genetic make-up of Indians has not changed in millennia; hence the Aryan migration did not happen. This is sheer nonsense as many invading populations like Kushans, Huns, Mongols, Pathans, Portuguese, and English have settled in India and their genes have become integral part of the Indian gene pool. But the most important point is that, out of the various classifications on the basis of physical characteristics, "Aryan" was never identified as a "race". The idea of an "Aryan race" was originated by the German fascists, which has been debunked long since. Scientifically it is a language group, and those who spoke that group of languages are called Aryans.

**Claim 3: Vedic Mathematics**

Nowadays we see attempts to introduce certain calculation techniques into school curriculum in the name of "Vedic Mathematics". It should be clear from the above discussion that the discovery of zero happened much after the Vedic age, in the

Buddhist period. The techniques in these Vedic Mathematics books include the use of modern decimal number system, and hence these cannot be Vedic in origin. The proponents are basically counting on the fact that he average Indian considers anything written in Sanskrit as "vedic".

The way Latin was the common language of academic discourse all over Europe before the advent of modern languages like English, German, etc., in a similar way Sanskrit was the common link language of the educated people of India from antiquity all the way up to the medieval period. That is why, anything written in Sanskrit is not "Vedic".

But the most worrisome aspect of these "Vedic Mathematics" books is that most of their content is not obtained from ancient literature at all and are creations of people in the modern times, written in Sanskrit. Sometimes text written in modern times are inserted into ancient literature (Prof. Narlikar calls these as *prakshipta* or inserted [5]), and then the whole *shloka* is cited as pointer to certain calculation technique invented by the vedic people. Sometimes the text in the *shlokas* are just cryptic phrases from which any meaning can be extracted. The techniques given in the Vedic mathematics books are at best some shortcuts for number crunching that do not help the young minds to grasp the beauty of mathematical logic at all.

## Conclusion

Thus we see that there was significant cultivation of science in India in the ancient time, but a lion's share of it was done in the period from 6th century BC to about 10th century AD. The contribution of India to the world of knowledge in this period is truly something to be proud of. But this period is not the Vedic period, and the impact of the Lokayata and Buddhist philosophies was principally responsible for the development of science in this period. We also have to keep in mind that the glorious tradition of cultivation of science was halted and finally terminated in India, due to the imposition of a rigid caste system, and due to the *sastras* that dictate what to do and what not to do, and due to the revival of the *Vedanta* philosophy.

The preposterous claims about the science in ancient India — like the claims of aircraft that flew from one planet to another, of surgery to place an elephant's head on a human body, of in-vitro fertilization for giving birth to Karna — will only make Indian science a laughing stock before the rest of the world, and will undermine the actual contributions of India to the world of knowledge. Any right-minded person should defend the actual history and be proud of it, and should debunk the ludicrous claims. □

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