INDIAN SCIENCE

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Overview Although not typically associated with rigorous scientific enquiry, India has a long tradition of exploring the natural world. As in the West, traditional Indian scientists made generalisations, tested them and adjusted their theories according to the results. One distinguishing feature of Indian science, however, is that it relied on a single set of 'proofs' (*pramana*), unlike western science which used different proofs for different scientific fields. Although Indian proofs were secular, they were influenced by underlying cultural concepts, just as western science was influenced by Christian metaphysics. The primary fields of traditional Indian science are linguistics, astronomy, astrology, mathematics and medicine. While India is not considered the world's technology laboratory, it did also contribute to computer science.

Prehistory

There is no evidence of scientific activity in prehistory India.

Indus Valley Civilisation

An early example of scientific activity was system of measurement for length and mass used in the Indus Valley civilisation (c. 3000-1500 BCE). An ivory scale found at the port of Lothal contains divisions of 1.704 mm, the smallest ever discovered on a Bronze Age artefact anywhere in the world. A similarly precise measurement system was employed for weights. At Harappa, six differently sized cubes have been found that conform to the binary weight system used in all excavated settlements. The smallest weight is less than 1 gram and the most common weight is approximately 13.7 grams, which is in the 16th ratio. In the heavier weights, there is a decimal increase, so that the largest is100 times the weight of the 16th ratio in the binary system. Brick sizes, using the decimal system, were made in a perfect ratio of 4:2:1.

Indo-Aryan Period

Ayurveda Ayurveda ('knowledge of health'), the oldest of three Indian medical traditions, is based on Sanskrit texts dating back to about 1000 BCE. Ayurvedic medicine emphasises balance between physiological states (*dosha*s)

known as 'humours' in traditional European terminology. While Greek medicine has four humours, Ayurveda recognises three such elements: fire (*pitta*), wind (*vatta*) and water (*kapha*). Diagnosis and treatment are holistic, and the physician gives equal attention to physical, emotional and psychological states. Treatments often involve herbal as well as synthetic medicines. Surgery is also used, the techniques of which were well known to Indian doctors long before contact with Islam or the West.

Classical Period

Linguistics India excelled in the rigorous study and description of language, establishing many of the concepts of modern linguistics. This is hardly surprising, given the special attention to language, both spoken and written, in Indian culture generally. As early as the 5th c. BCE, Panini composed a treatise (*Ashtadhyayi*) of 4000 aphorisms to describe the Sanskrit of his day and its evolution from earlier Vedic Sanskrit. About 300 years later, Patanjali composed another text (*Mahabhyasa*), which commented on Panini's and introduced rules for phonology and morphology. These early Indian linguists contributed to the modern study of language in three key ways. First, their description of Sanskrit helped Europeans unravel the history of Indo-European languages. Second, their understanding of phonetics helped Europeans to progress in this area. And, lastly, Panini's description of sentence structure laid the basis for modern morphology. Alongside this Sanskrit tradition, Tamil had its own independent study of language. The first Tamil grammar *(Tolkappiyam*), dated between 300 BCE and 200 CE, contains sophisticated descriptions of phonology, semantics and morphology.

Astrology Although astrology studies the same heavenly phenomena as astronomy, it uses that information to forecast events on earth and in people's lives. A Sanskrit text dated to the 2nd c. BCE *(Vedanga Jyotisha*) is often thought to be the basis for Indian astrology, but it is only concerned with fixing dates for rituals and contains no observations on planets. The order of the planets was fixed in the seven-day week with the transmission of Greek astrology to India, as evidenced in the Sanskrit text *Yavanajataka* ('Sayings of the

Greeks', c. 200 BCE), which included instructions for casting astrological predictions according to the 12 zodiac signs. Indian astrology, however, developed a very different system to that of the Greeks. First, Indian astrology uses adjustments for the progression of the vernal equinox (the sidereal zodiac as opposed to the Greek tropical zodiac). Second, Indian astrology invented a system of lunar mansions to make more subtle interpretations. Further refinements were made by later scientists, such as Aryabhata (c. 6th c. CE), and soon five distinct schools of astrology were in practice.

Metallurgy Indian metallurgy was sophisticated enough in the second millennium BCE to have discovered smelting. From 200 CE, high-quality steel was produced, and by 500 CE, Indian blacksmiths made a pillar that still stands today, rust free. The 24-foot high pillar was made by forge welding pieces of wrought iron. A protective film on the surface was made from slag, unreduced iron oxides, phosphorous and a manufacturing process of alternate wetting and drying stages.

Early Postclassical Period

Astronomy Astronomy, or the study of heavenly objects and phenomena, was a second important Indian science during the classical period. As with many cultures, rituals were observed in coordination with the movements of the sun, moon and planets. By the early centuries of the Christian era, Greek influences are evident in Sanskrit astronomical texts. The great trio of scientists (Aryabhata, Bhaskara and Brahmagupta, all 6th-7th centuries CE) agreed that the motion of the planets was elliptical and not circular. These scholars also mention the use of a sun-dial (the gnomon, or *sanku*), which indicated directions, latitude and time of observation. Other instruments were later used to determine time from the height of the sun.

Mathematics Since astronomy depended on accurate mathematics, two of these astronomers also made major contributions to mathematics. Aryabhata developed new rules for solving quadratic equations and established the study of trigonometry. He also created the place value (or positional) system for numbers, which is used around the world today. Earlier inscriptions did include marks for the numbers 1 through 9, 10, 90 and 100, in which the zero was represented by a dot. But Aryabhata developed the fully positional system and dispensed with the previous system that used letters of the alphabet to represent numbers. Born approximately a century later, Brahmagupta wrote four significant treatises. His most important achievement was laying down clear rules for arithmetic, particularly for the multiplication of positive, negative and zero values.

Bakhshali manuscript The oldest extant mathematical manuscript from India is made of birch bark and written in Buddhist hybrid Sanskrit in the Śāradā script, which was used in the northwest region of the Indian subcontinent between the 8th and 12th centuries CE. The authors of this Bakhshali manuscript cover a wide variety of topics in three areas: arithmetic (fractions, square roots, profit and loss, simple interest, the rule of three, and regula falsi); algebra (simultaneous linear equations and quadratic equations); and arithmetic progressions. In addition, the manuscript describes several complex geometric problems, such as how to measure the volume of irregular solids.

Medicine A second medical tradition, which evolved in south India, is Siddha ('excellence' or 'perfection'). Although the early history of Siddha, like that of Ayurvedic medicine, is obscure, there are textual references in the 7th and 8th centuries CE and a transmission of manuscripts leading back several centuries earlier. Siddha practitioners carried out extensive research on plants to discover treatments that would cure patients. Siddha is deeply influenced by Ayurveda and shares its theory of the three humours (or *dosa*s, 'faults')—air, fire and water—which holds that illness is caused by an imbalance between them. However, its recipe for equilibrium is different, which is 4:2:1, respectively. Siddha also developed its own medical theory of the 'six pulses': three are read on the right hand, and three on the left hand. Each pulse indicates the state of one of the three humours, in either its right or left manifestation. Another Siddha belief is that the body and mind are composed of seven elements: plasma, blood, muscle, fatty tissue, bone, bone marrow and semen.

Late Postclassical Period

Mathematics Indian mathematics was taken to new levels of complexity by Bhaskaracharya (1114–1185 CE). The son of a Brahmin priest, he became head of a famous astronomical observatory at Ujjain, in western India. Of his six works, three concentrated on mathematics: *Lilavati* ('The Beautiful'); *Bijaganita* ('Seed Counting or Root Extraction'); and *Siddhantasiromani*. He made significant progress in describing a variety of problems, especially the squaring of numbers and arithmetical progression. For example, here is a problem he gave to his readers:

> ‘On an expedition to seize his enemy's elephants, a king marched two yojanas the first day. Now tell me, intelligent calculator, with what increasing rate of daily march did he proceed, since he reached his foe's city, a distance of eighty yojanas, in a week?’

The answer, the author reveals, is that each day the king must travel $^{22}/_{7}$ yojanas further than the previous day to reach the city in 7 days.

Medicine The third tradition of Indian medicine is Unani, lit. ‘Ionian’ or ‘Greek’ because Muslim physicians borrowed heavily from Greek and Roman medicine. Indian Muslim medicine, which itself derived from Persian and Arabic (as well as Greek) traditions, developed during the Sultanate period, although it also received court patronage under the Mughals. Like both Ayurveda and Siddha, Unani is based on balancing the body’s elements and upon holistic diagnosis and treatment, but it recognises a different set of humours (*akhlat*): blood, yellow bile, black bile and phlegm. Unani also recognises six other factors in diagnosis: *ada* (organs), *arwa* (life force), *uwa* (energy), *arkan* (elements), *mizaj* (temperament) and *afal* (functions).

Early Modern Period

Astronomy Even today, visitors to India can see massive sun-dials or observatories constructed during the early 18th century in several cities, including New Delhi. These outdoor instruments represent a synthesis of Indian and Islamic astronomical knowledge that emerged in the late Mughal Empire. Even before this, however, a unique instrument had been invented by a Kashmiri Muslim in the 16th century. This seamless celestial globe represented an unprecedented technological achievement, since it was thought that a metal sphere without seams was impossible.

Artillery A major advancement in manufacturing metal cylinders used in artillery was made by scientists working for Hyder Ali, the ruler of Mysore, at the tail end of the 18th century. Previously, the container of combustion powder had been made of paper and had a low threshold for breaking. Hyder Ali’s scientists developed cylinders made of hammered soft iron, which was crude but nevertheless permitted higher internal pressure and thus a longer trajectory to a fired rocket. With this new technology, a rocket could fly for up to three-quarters of a mile, and while the accuracy of a single rocket was not high, the firing of many rockets in a mass attack was effective.

19th Century

Chemistry Prafulla Chandra Ray (1861-1944) was **e**ducated in the UK but came back to India at the end of the century and made substantial contributions to the field of chemistry. In particular, his work advanced scientific knowledge of nitrites and hyponitrites of various metals. Toward the end of his life he wrote a series of influential papers on compounds of gold and platinum. Perhaps his most lasting legacy, however, was the establishment of the Department of Chemistry at Calcutta University.

Radio Another notable scientist, and another Bengali, in the second half of the nineteenth century was Jagadish Chandra Bose (1858-1937). Bose was a polymath, who studied everything from biology to archaeology, even finding time to write science fiction. Like Ray, he was educated in the UK, where he made breakthrough discoveries in the field of radio and microwave optics. He progressed the understanding of remote wireless signalling and was a pioneer in the use of semiconductors to detect radio signals. Back in Calcutta, he concentrated on plant science and invented an instrument for measuring plant growth. His experimental work on optics earned him a permanent place in the history of science, since a crater on the moon was named after him.

20th Century

Astrology Astrology continues today as a major science in modern India. Many Hindus (and some Muslims and Christians) consult an astrologer before making a major decision, such as starting a business, going on a journey or buying a house. For most Hindus, determining and studying the astrological charts of proposed marriage partners is essential to ensuring success. Astrology is taught as a science in many Indian universities, receiving support from the Supreme Court of India, which upheld that status in 2004.

Mathematics Perhaps the most remarkable scientist of modern India was a mathematician. The story of Srinivasa Ramanujan (1887-1920) is truly remarkable (and the subject of a major feature film in 2016).

Lacking any formal training in mathematics, he nevertheless discovered theorems that revolutionised number theory and other fields of mathematics. While still in India, he wrote papers that contained solutions to supposedly unsolvable problems. When no one in India took him seriously, he sent the papers to G.H. Hardy, professor of mathematics at Cambridge. Hardy quickly realised the untutored genius and brought him to Cambridge, where he worked to make Ramanujan's work more rigorous, in order to gain approvable from the scientific establishment. The young Indian thinker, however, continued to favour an instinctive and imaginative approach. He could produce a formula that solved some previously unsolved number problem. But when asked to provide the background statistics that would validate his idea, he confessed that he had none. Although his ideas again met with scepticism, eventually his ideas and theories were proved correct. He died early, but left behind a notebook with many more ideas and notes, many of which are still being used to advance number theory.

Quantum Mechanics Satyendra Nath Bose (1894-1974) made a significant contribution to the field of quantum mechanics, even improving on work by Einstein. His work in the 1920s and 1930s laid the platform for a new theory of statistics ('Bose-Einstein statistics') and of condensates ('Bose-Einstein condensate'). Bose's research also resulted in the discovery of a new subatomic particle, which was then named after him as a 'boson.'

Computer Technology India entered the digital age in 1955, when an early computer (designed in the UK with Indian input) arrived in Calcutta. India-based computer science took off in the 1960s, when Tata partnered with Burroughs. Since then, Indian computer experts have made significant innovations in computer programming and communication protocols. These discoveries can be attributed, at least in part, to the science of language description, in which Indians have excelled, starting with Panini and his grammar in about 500 BCE. In 1999, scientists at the Indian Institute of Science, in Bangalore, designed an open hardware and handheld computer. Since then Indian specialists abroad have led the way in many IT fields, such as Krishna Bharat at Google.

Discussion/questions

1. Modern Indian science is a synthesis of traditional and Western principles and practices. This exchange was most intense during the period from 1600-1900, when European astronomers, botanists, linguists, anthropologists, cartographers, geologists and zoologists poured over India in search of knowledge. By the early 20th century, a considerable number of Indians were receiving training in Western sciences. Although much of Indian knowledge was dismissed as 'superstition', some concepts found their way into colonial science and medicine. A good example is the cases of smallpox vaccinations.

2. Science, inevitably, became enmeshed in twentieth century politics. Jawaharlal Nehru, India's first Prime Ministers, favoured Western science and technology over Indian tradition, while Gandhi promoted his own brand of indigenous methods. To what extent is current scientific and medical practice in India influenced by this debate between modernity and tradition?

3. Greek influence is evident in traditional Indian astronomy, astrology and Unani medicine (as well as early Indian sculpture, philosophy and literature). Compiling and studying a full list of these cultural influences, including a map of trade routes, is a prerequisite to understanding pre-modern Indian culture.

Reading

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