Ancient Indian Contribution to The Field of Astronomy, Chemistry and Metallurgy

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Abstract

Ancient India was a great country with one of the great ancient civilisations. When the entire world was in complete darkness India was shining as a golden sparrow in the horizon of knowledge. However, centuries of foreign invasion and political rule over the land the present generation have mostly lost contact of its rich heritage. The purpose of a series of articles being presented here is to remind and bring to the forefront the ancient glory of this vast nation. In a previous article we have covered ancient India's contribution to the field of Mathematics and Physics. Here in this article, we are presenting the same in the field of Astronomy, Chemistry and Metallurgy.

Astronomy

Ancient India's contributions to the field of astronomy are well known and quite well documented. Indian astronomy has a long history stretching from pre-historic Vedic period to modern times. Some of the earliest roots of Indian astronomy can even be dated to the period of Indus Valley civilization or earlier. Astronomy like Mathematics had an important part in its Vedic religious tradition to meet the requirement of appropriate spatio-temporal calculations based on astronomical observations for the correct performance of religious rites. Thus, the Shulva Sutras, the texts dedicated to altar construction; discusses advanced mathematics and basic astronomy. The oldest known text Vedanga Jyotisha, written by Lagadha (1400-1200 BCE) details several astronomical attributes generally applied for timing social and religious events. It includes details of astronomical calculation based on observation of the Sun, Moon and the Nakshyatras (constellations) according to the rules established for empirical observations. Rig Vedic rishis had the knowledge about the constellations (star-groups) called Nakshyatras which are 27 (or 28) in numbers and the moon gets conjoined with one each of these star-groups each night. The fact that the 28th nakshyatra 'Abhijit' is mentioned infrequently means that Vedic Rishis knew that the sidereal month was between 27 and 28 days. In other words, the approximate Solar year of 360 days was divided into 12 lunar months of 27 days (according to the Vedic text Taittiriya Samhita 4.4.10.1-3) or 28 days (according to Atharva Veda 19.7.1). Time was reckoned by the position marked off in the constellations on the ecliptic in which the Moon rises daily in the course of one lunation (the period from new Moon to new Moon) and the Sun rises in the course of one year. Each of these constellations (nakshyatras) measure an arc of 13°20′ of the ecliptic circle. The positions of the Moon were directly observable and those of the Sun inferred from Moon's position at full Moon, when the Sun is on the opposite side of the Moon. The position of the Sun at midnight was calculated from the nakshyatra that culminated on the meridian at that time, the Sun then being in opposition to that nakshyatra. Each solar year was also divided into twelve synodic months of 29 or 30 days. With the knowledge that a five-year yuga contained 1830 sidereal days, the resulting discrepancy was resolved by the intercalation of a leap month called Adhimasa to make the beginning of the Sun's ayanaansa fall in the correct months. According to Vedanga Jyotisha, the Sun and the Moon conjoined with Vashava (the nakshyatra presently known by the name Dhanistha) in the month of Magha proceed Northwards (uttarayana) and at the middle of Sarpa (Aslesa) in the month of Sravana, they proceed southwards (Dakshinayana). The beginning of a yuga is counted from the beginning of uttarayana in the shuklapakshya of Magha, when the Moon and the Sun are conjoined with the nakshyatra Dhanistha. Although the exact rule of intercalation for Adhimasa had not been made explicit in Vedanga Jyotisha, the relation of a yuga of 5 solar years to 62 synodic months and 1830 sidereal days was well known. Also, well known at that time about the twelve signs of the zodiac (rasi) along with the twenty-seven constellations (nakshyatras) and seven planets. The first important study and analysis of Indian Astronomy was done by Jean sylvain Bailly (1736-1793), who in his book **"Traits de Astronomic Indianne et Orientale"** published in 1787 had commented that the Indian Astronomical observations documented in their observational tables were based on quite accurate observations, some of which were made as early as 4300 BC. The great mathematician and astronomer Laplace who having discovered the inequality in the motion of Jupiter and Saturn, wrote in 1787: ***"I find by my theory, that at the Indian epoch of 3101 BC, the apparent and annual mean motion of Saturn was 12º 13 14 and the Indian tables make it 12º 13 14. In like manner, 1 find the annual and apparent mean motion of Jupiter at that epoch was 30° 20 42° precisely as in Indian astronomy."*** (As quoted in an article by J. Burgess under the title 'Notes on Hindu Astronomy and the History of our knowledge of it' in J. Royal Asiatic Society. 177-761,1893).

Indian astronomy flowered in the 5th to 6th century CE, with Aryabhyatta (476-550 CE), whose treatise Aryabhattiya represented the pinnacle of astronomical knowledge at that time. Its contents were preserved to some extent in the works of Varahamihira (550 CE), Bhaskara I (129 CE) Brahmagupta (598-668 CE) and others. Aryabhatta explicitly mentioned in his work that Earth rotates about its own axis, thereby causing what appears to be an apparent westward motion of the stars. He suggested further that the Earth was spherical in shape with a circumference of 24835 miles (39,967 km) which works out to give the radius of earth as R = 6362 km. In fact, now it is well known from measurement by orbiting spacecraft that the earth is almost, but not quite, a perfect sphere having its equatorial radius as 6378 km and its polar radius is 6357 km, which are not far too different from Aryabhatta's estimate. Apart from his significant contributions to trigonometry, arithmetic and algebra that he developed for his accurate mathematical calculations of astronomical events like solar eclipse and lunar eclipse; he also mentioned that the cause behind the shining of the moon is the reflected sunlight. Following Aryabhatta's principles and methodologies, his followers mostly from South India carried forward his works to further heights. Some of these works are worth mentioning here as follows.

Brahmagupta (598-668 CE), well known for his contributions of mathematics and astronomy wrote Brahmasphuta Siddhanta in 628 CE, which had been translated into Arabic in 771 CE providing a major impact on Islamic mathematics and astronomy subsequently. Brahmagupta reinforced Aryabhatta's idea of a day to begin from the midnight of the previous day. He also calculated the instantaneous motion of planets to give the correct equation for parallax and also provided valuable information relating to the computation of eclipses. He also theorized that all bodies with mass are attracted towards earth. Varahamihir (505 CE), who studied Indian Astronomy along with several other contemporary knowledge systems, had mentioned and compiled in his 'Pancha-Siddhantika'; one of the most ancient Sanskrit treatises on Indian astronomy; Surya Siddhanta. Surya Siddhanta describes rules to calculate the motions of various planets and the Moon relative to various constellations and calculates the orbits of various astronomical bodies. The authorship of this ancient text is not known exactly. According to al-Biruni, the 11th century Persian Scholar, the second verse of the first chapter of Surya Siddhanta attributes the authorship to Mayasura, father of 'Mandodari' and father-in-law of Ravana around two million years ago at the end of the first golden age of Hindu mythology, the Satya Yuga. As per the legend, the contents were dictated to Mayasura through someone named 'Lata' an emissary of the Sun-God. However, the text is known from a 15th century palm-leaf manuscript and several newer manuscripts. It was recomposed or revised in 500 CE from an earlier text by this name. The text believed in the geocentric model with earth as the stationary globe around which the sun, moon along with other planets orbit. It calculates earths' diameter to be 8000 miles (compared to its modern value 7928 miles), the diameter of moon as 2400 miles (actual value 2160 miles) and the distance between the moon and the earth to be 258000 miles (now known to vary between 221,500 to 252,700 miles). Surya Siddhanta represented a functional system that made reasonably accurate predictions. The text was translated into Arabic and had its impact on medieval Islamic astronomy.

Bhaskara-I in 269 CE authored the astronomical texts like Mahabhaskariya, Laghubhaskariya and Aryabhattiyabhasya as a commentary on Aryabhatta's 'Aryabhattiya'. In these treatises, Bhaskara-I discussed the planetary longitudes, heliacal rising and setting of planets, conjunctions among planets and stars, solar and lunar eclipses and the phases of the moon.

Following the works of Aryabhatta, Brahmagupta, and Bhaskara-I; Lalla in 8th century CE authored 'Sisyadhivruddhida, consisting two parts Grahadhyaya and Goladhyaya. Grahadhyaya deals with planetary calculations, determination of the mean and true planets, rising and setting of planets, eclipses, planetary and astral conjunctions etc. Goladhyaya deals with graphical representation of planetary motion, astronomical instruments used and also emphasizes on corrections to and rejection as well of the flawed principles. His works were followed by later astronomers like Bhaskara-II (1114 CE) who was heading the astronomical observatory in Ujjain at that time. He authored 'Siddhanta Siromani' and reported on his observation of planetary positions, conjunctions, eclipses as well as the astronomical equipment used in his observation.

Notable amongst many other astronomers of the fifteenth century was Nilakantha Somyaji (1544 CE) of the Kerala School of astronomy and mathematics who is worth mentioning here. In his 'Tantrasangraha', he revised Aryabhatta's model for planets Mercury and Venus. His equation of the center for these planets remained the most accurate ones, until the time of Johannes Kepler in the 17th century. He also authored an Aryabhattiyabhasya, a commentary on Aryabhatta's Aryabhattiya, where he developed his own computational system based on a partially heliocentric planetary model in which Mercury, Venus, Mars, Jupiter and Saturn orbit the Sun and Sun along with these orbiting planets in turn orbits the Earth. This was similar to the model proposed by Tycho-Brahe in the late 16th century, Nilakantha's system, however, was mathematically more efficient than the Tychonic system due to its correct equation of the center and longitudinal motion of Mercury and Venus. Most astronomers of Kerala School of Astronomy who followed him accepted his planetary model. In this tradition, with a long chain of astronomers of India, Samanta Chandrasekhar (1835-1904) was the last link during a period spanning over a millennium and half. He was probably the last naked eye astronomer of Siddhantic tradition, popularly known as Pathani Samanta in Orissa. He worked in astronomy following traditional methods, completely unaware of the telescope, and using handy tools like bamboo poles and sticks, all fabricated by himself. He recorded his own study and observations in an invaluable classic treatise 'Siddhanta Darpana' in 1895. Siddhanta Darpan has been composed in fine metrical Sanskrit verses. It contains many original contributions in observation, calculation, instrumentation as well as theory and the models demonstrating appreciable improvement over the earlier classics like Surya Siddhanta and Siddhanta Siromani. The results of his observations are often comparable with modern data and his predictions in positional astronomy are in fair agreement with actual occurrence of astronomical events even today. (P.C. Nayak and L. Satpathy in, Bulletin of Astronomical Soc. India (1998), 26,33-49).

This discussion finally brings us to highlight some of the ancient Indian devices used for astronomical observations. One such common device was gnomon known as sanku, in which the shadow of a vertical rod on a horizontal plane was observed and measured to ascertain the cardinal direction, the latitude of the observation points and the observation time. This device finds mention in the works of Varahamihira, Aryabhatta, Bhaskara and Brahmagupta etc. Similarly, the Yasti-Yantra, a cross-staff, was used by the time of Bhaskara-II. This device could vary from a simple stick to V-shaped staffs designed specifically to determine angles with the help of calibrated scale. The gola-yantra, the Indian armillary sphere finds mention in the works of Aryabhatta. Gola-dipika, a detailed treatise composed by Paramesvara between 1380 and 1460 CE, deals with globes and armillary spheres. The Indian armillary spheres were based on equatorial coordinates whereas the Greek armillary spheres used elliptical coordinates. Indian armillary spheres also had an elliptical hoop. Bhaskara-II in the 12th Century invented the Phalaka-yantra to determine time from the Sun's altitude. This consisted of a rectangular board with a pin and an index arm. Kapala-yantra was an equatorial Sun-dial instrument used to determine Sun's azimuth. Padmanava invented a nocturnal polar rotation instrument consisting of a rectangular board with a slit and a set of pointers with concentric graduated circles. Time and other astronomical quantities could be calculated by adjusting the slit to the directions of Alpha and Beta Ursa Minor. Its backside was made as a quadrant with a plumb and an index arm. Thirty parallel lines were drawn inside the quadrant and trigonometrical calculations were done graphically after determining the Sun's altitude with the help of the plumb whereas time was calculated graphically with the help of the index arm.

There are several such instruments still surviving in this epoch at the observatories built by Maharaja of Jaipur, Sawal Jai Singh (1688-1743 CE) in the beginning eighteenth century. Except for the observatory in Mathura; rest of them in Delhi, Jaipur, Ujjain and Banaras are still extant today. Notable amongst all these instruments based on Indian and Islamic astronomy is the Samrat-yantra which is a huge Sundial consisting of a triangular gnomon wall and a pair of quadrants towards the east and west of the gnomon wall. The quadrants had been graduated to record time.

Chemistry & Metallurgy

Development in Chemical Science in ancient India was not limited to an abstract level like Physics, but found in a variety of practical activities. Chemical techniques developed in ancient India can be traced back all the way to Indus Valley or Harappan civilization (3rd millennium BCE). According to Acharya Prafulla Chandra Ray (1861-1944), the eminent Indian Chemist and a historian of Chemistry, development of chemical techniques can be recognized to have taken place in five stages (i) the pre-Vedic period up to 1500 BCE (ii) the Vedic and Ayurvedic period up to 700 CE (iii) transitional period from 700 CE to 100 CE (iv) the Tantric period from 700 CE to 1300 CE and finally (v) the Iatro chemical period from 1300 CE to 1600 CE. However, we would focus our attention more on the chemical techniques of the pre-Vedic and Vedic period only.

Pre-Vedic Indians were acquainted with the art of baked and burnt clay pottery and dyeing them with two or more colours. This needed the construction of open and closed kilns. These potteries consisted of mainly wheel made wares in various shapes, sizes and colour out of the well-levigated alluvium of Indus. The colour and other characteristics of the potteries depended upon the composition of the clay and techniques of firing under either oxidizing or reducing conditions. The Harppan Indians also experimented with various mortars and cements made of burnt limestone, gypsum and mica among other things. Finely crushed quartz when burnt produced faience, a synthetic material which when coated with silica (Perhaps fused with Soda) with addition of copper oxide; it produced a shiny turquoise glaze. Faience was then shaped into various ornaments and figurines. Addition of iron oxide or manganese oxide etc. resulted in different colours. The Harappan artisans must have had the knowledge of processing and the proportions of several naturally occurring chemical substances as mentioned above. The craftsmen of that period were also highly skilled in the art of shaping and polishing precious and semi-precious stones in preparing ornamental beads.

During the period earlier than 1500 BCE, as has been mentioned in Rig Veda, ancient Indians knew the process of fermentation to prepare various fermented drinks. Soma juice from the stems of soma plant was highly extolled and was considered as a divine drink. Madhu and Suraa brewed from barley grain also find mention in Rig Veda. Curd, the fermented milk was an important food item. Woolen cloths and garments were often dyed red, purple or brown with certain natural vegetable colouring matters. Vedic period is also associated with a type of pottery now known as 'Painted grey ware'. This ceramic is a thin gray deluxe ware, mostly wheel-made, well burnt, glossy and richly painted. In the eastern part of Gangetic planes earthen black polished wares were also found along with plenty of iron objects. Glass beads dating back to the 10th century BC have been discovered. Evidences for notable feat of excellence of flourishing glass industry at that epoch had been found by archaeologists at more than 30 sites which include Taxila in present Pakistan, Hastinapur and Kopia in Uttar Pradesh, Nalanda in Bihar, Ujjain in Madhya Pradesh, Brahmagiri in Karnataka etc. The glass objects include coloured beads, glass vessels in green and blue colours, bangles, ear-reels, eye-beads etc. The glass makers of this period were no doubt very skilful in controlling the temperature of fusion, moulding, annealing, blotching and gold foiling. The chemical composition of a typical glass specimen from Kopia site in Uttar Pradesh was found as follows. It had silica 66.6%, alumina 7%, alkalis (Na_2O) 21.7%, ferric Oxide 1.6%, lime 2.4%, manganese oxide 0.07% and traces of titania and magnesia. Koutilya's Artha

Shastra of 3rd or 4th century BC, has a lot of information on prevailing chemical practices. Apart from mines and minerals, one can find detailed discussions on precious stones like pearl, ruby, beryl etc. as well as of the preparation methods for the fermented juices (sugarcane, jaggery, honey, jambo, jackfruit, mango etc.) and oil extractions. Varahamihira's Brihat Samhita of 6th century CE mentions detailed information on the preparation of various perfumes and cosmetics along with the recipes for preparation of a glutinous material to be applied on the roofs and walls of buildings. Charaka Samhita and Sushruta Samhita give account of several minerals, metals, metallic compounds, salts and fermented beverages. There are also discussions on preparation of various alkalis (khara) in three different forms such as mild (mridu), caustic (teekshna and average (madhyama). They were prepared from 25 different plants described there. Hot alkaline solutions were used to treat thin metal sheets like iron, gold or silver before incorporating them into drugs. Caustic alkalis were also used for treating surgical instruments. Will Durant has written in his 'The story of civilization our 'Oriental Heritage' referring to India - ***"as the most skilled of the nations in such chemical industries as dyeing, tanning, soap making, glass and cement.... By the sixth century the Hindus were far ahead of Europe in industrial chemistry. They were masters of calcinations, distillation, sublimation, steaming, fixation, the production of light without heat, the mixing of anesthetic and soporitic powders, preparation of metallic salts, compounds and alloys….".***

Metallurgy was intimately linked with the developments in chemistry and industrial chemistry in India. The commonly used metals in antiquity include gold, silver, copper, tin, lead, zinc, mercury and iron. Early gold and silver ornaments from the Indian subcontinent have been found from the Indus valley sites of Mohenjodaro dating to a period of 3000 BC, which are on display in the National Museum; New Delhi. India had the deepest ancient gold mines in the Maski region of Karnataka during the 1st millennium BC. Besides this antiquity, gold was usually collected by panning alluvial sands from placer deposits. According to the Greek tales of Herodotus, gold-digging-ants in India (referring to marmots, a type of rodent found in Afghanistan) used to dig up river sand which were then panned for gold by the nearby inhabitants. In fact, such a tale can be corroborated by literary evidence in the mention of ant's gold in epic Mahabharata. The interesting technique of granulation of gold (using surface tension of melted gold filings, tiny spherical granules of gold could be produced) in making jewellery was developed in several parts of the world around 600 BC. However, this technique was in practice in India in the late 1st millennium BC to the early Christian era. In fact, the mining and extensive use of gold, silver and copper was undertaken in the Indus valley in the third century BC. In the Vedic period extensive use was made of copper, bronze and brass for household utensils, weapons and images of worship. The image of Nataraja the God of Dance is made of five metals (Pancha-Dhatu). This technology of mixing two or more metals and producing superior alloys was well known to ancient Indians. Patanjali's Lohasastra of second century B.C. gives elaborate description of many chemical and metallurgical processes especially the preparation of metallic salts, alloys, amalgams and the extraction and purification and assaying of metals. The discovery of aqua-regia (a mixture of nitric and hydrochloric acid to dissolve gold and platinum) is ascribed to Patanjali. Numerous specimens of weapons made of iron have been excavated, probably belonging to the 4th century BC. Iron clamps, iron stags found at Bodhagaya temple point to the knowledge of processing and manufacturing iron as early as the third century B.C. It was especially well established in the South Indian megalithic cultures of this period.

South India was a region that was renowned for metallurgy and metal works in the old days. Fine steel wires for the use as strings in musical instruments were being produced in Karnataka when the western world was using animal gut for the same purpose. Kerala was well known for its large iron smelting furnaces as well as for the specialty in making metal mirrors of Aranmula. High quality steel from Tamilnadu has been exported to all over the world since Roman times. The Konasamudram region in Andhra Pradesh was famous for producing the world renowned Wootz Steel. Wootz is the English substitute for 'Ukku' in Kannada and Telugu, meaning steel. Studies on Wootz indicate that it was an ultra-high carbon steel with about 1-2% carbon and was believed to have been used to fashion the Damascus sword with blades having watery patterns whose wavy streaks always glisten like a pond on whose surface wind is gliding. These swords were the best swords in the ancient world, the strongest and sharpest, sharper even than the Japanese Katans. Romans, Greeks, Arabs, Persians, Turks and Chinese imported it. Wootz steel is also known as Damascus steel which is derived from the Arabic 'Damas' meaning water, because of the watery designs on the blade. Ktesias at the court of Persia in 5th century BC mentions two swords made of Indian steel which the Persian King presented him.

Since iron has a high melting point of around 1550°C, it was commonly produced in the olden days by reducing the one to metal in solid state to produce bloomery iron which was then wrought to give low carbon (0.1% to 0.2% carbon) wrought iron. However, Wootz steel was produced in India in a clever way in lowering the melting point of iron. The lower the melting point, the more carbon got absorbed and high carbon steel was produced. This was done by carburizing chips of wrought iron in a closed crucible process. Wrought iron, wood and carbonaceous matter were placed in a crucible and heated in a current of hot air till the iron became red hot and plastic. It was then allowed to cool very slowly (in about 24 hrs.) until it absorbed a fixed amount (generally 1.2 to 1.8 percent) of carbon. When it is forged into a blade, the carbides in the steel form the visible pattern on the surface. In the early 1800 CE, Europeans tried their hand at reproducing Wootz on an industrial scale. Michael Faraday, the great experimenter and himself the son of a blacksmith, tried to duplicate the steel by alloying iron with a variety of metallic additions including Noble metals but failed. His failure marked the beginning of alloy steel making in the world. Wootz had been a prime motivating force in the development of metallurgical science and study of micro structures. Although iron and steel had been used for thousands of years; the role of carbon in steel as the dominant element was understood only in 1774 by Tobern Bergman in unravelling the mysteries of Wootz. The textured Damascus steel was one of the earliest materials to be examined by electron microscope in 2006, to show that it contains large amounts of carbon nanotubes. Referring to this the Nobel laureate Robert F. Curl said that carbon nanotechnology was much older than carbon nanoscience and hence nanotechnology is not new to India, when it is of raging interest to scientists world over now. But Indians had used nano materials long since unwittingly in making Damascus steel swords which were stronger and sharper.

Traditional Indian iron and steel are known to have some very special properties such as resistance to corrosion. This is substantiated by the 1600 yr old twenty-four feet high iron pillar next to the Qutub Minar in Delhi. This iron pillar belonging to the fourth fifth century CE believed to have been erected during Chandragupta Maurya's reign, is a metallurgical wonder. This huge wrought iron pillar, 24 feet in height, 16.4 inches in diameter at the bottom, and 6 1⁄2 tons in weight has stood exposed to tropical Sun and rain for more than fifteen hundred years without showing any sign of rusting or corrosion. Evidence shows that this pillar was once a Garuda Stambha from a Vishnu temple which was plundered by Islamic invaders securing the pillar as a trophy in the Quwwat al-Islam mosque in Delhi. Made of pure iron, which even today can be produced only in small quantities by electrolysis. The pillar is believed to have been made by forging together a series of disc-shaped iron blooms. Apart from its dimensions; absence of corrosion must have its link to the high purity of wrought iron and its composition with phosphorus content and the distribution of slag. Even with today's advances, only few foundries in the world could make this piece with none able to keep it rust free. The pillar stands today as a mute testimony to the highly advanced scientific knowledge and skill that was known and mastered by ancient Indian ironsmiths. According to Percy Brown, this pillar is a remarkable tribute to the genius and manipulative dexterity of Indian workers. The huge iron girders used in roofing the porch of temples at Puri and Konark, the ornamental gates of Somanath and the 24 feet wrought iron gun at Nurvar are also such monuments bearing eloquent testimony to the marvellous metallurgical skill attained by the ancient Indians.

Besides the production of wootz steel and corrosion free iron; another metallurgical marvel of ancient India is the extraction of Zinc. Zinc is better known as a constituent of brass than a metal in its own right. Brass having 10 percent zinc glitters like gold. The earliest brass objects in India have been found from the excavation sites at Taxila (44 BC). These brass objects had more than 35 percent zinc; this high content of zinc, according to expert metallurgists, could be put in only by direct fusion of metallic zinc and copper. Zinc smelting compared to other metals used in antiquity is very difficult, since at normal pressure it boils and volatilizes at 913°C, while to extract zinc from its oxide ore, it must be heated to about 1200°C in a furnace. As a result, it would form as a vapor in the furnace which would immediately get reoxidised and hence lost. Hence metallic zinc is seldom reported in antiquity elsewhere in the world. However, in India there is unique evidence for extensive and semi-industrial production of metallic zinc at Zawar area of Rajasthan. The Zawar process consisted of heating zinc oxide ore in an atmosphere of carbon monoxide in clay retorts arranged upside down to collect zinc vapor in a cooler chamber placed vertically beneath the retort. Such an ingenious downward distillation method was devised where the zinc vapor was formed after smelting zinc ore using specifically designed retorts with condensers and furnaces, so that the smelted zinc vapor could be drastically cooled down to get a melt that could solidify to zinc metal. This process has been described in Rasaratnakara, the alchemical text written by Nagarjuna in the medieval period. In Europe, the production of metallic zinc was virtually unknown and as late as 1735, professional chemists in Europe believed that zinc could not be reduced to metal except in the presence of copper. William champion first established commercial zinc smelting in Bristol in 1740. Interestingly enough it has been pointed out that Champion's process of downward distillation bears a strong resemblance to the Zawar process, which would have been known to the British during the forays of the East India Company.

Mercury is also a volatile metal which is easily produced by heating Cinnabar followed by downward distillation of mercury vapor. The earliest literary references to the use of mercury distillation comes from Artha Shastra of Kautilya from the late 1st millennium BC onwards. In India; Vermillion or Cinnabar which is mercuric sulphide has had great ritual significance in making red bindi or dot on the forehead of married Hindu ladies. There is fairly extensive evidence for ancient mining of copper ores from Khetni regions of Rajasthan in north western India dating to about the 3rd to 2nd millennium BC along with smelting furnaces from Harappan civilization. Early copper artifacts of about the sixth millennium BC are also reported from the pre-Indus Valley sites of Baluchistan. Bronze is an alloy of copper and Tin. Some of the most beautiful and well executed bronze-castings in the world are icons from the Chola period in the Thanjavur area of south India in 10th century A.D. Investigations by some metallurgists have shown that the earliest and continuing use of artifacts of rapidly quenched high-tin bronzes are from the Indian subcontinent. The well-executed statue of a dancing girl from Mohenjo-Daro from the Indus Valley was an example of the earliest bronze castings in the world.

The above facts indicate that the ancient Indian metallurgists have also made significant contributions to the world to deserve their place along with other great civilizations. As clearly seen in case of high carbon steel, corrosion free iron castings and metallic zinc extraction, ancient India contributed significantly to their modern metallurgical advances.

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