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CHEMISTRY IN ANCIENT AND MEDIEVAL INDIA

THE beginnings of the science of chemistry in India can be traced to ancient times. Chemical processes were first utilized in practical arts such as the manufacture of decorated earthenware and porcelain, burnt bricks, glass beads, alloys, and medicines. The craftsmanship in these industries was of a high order suggesting that the artisans had a good working knowledge of the chemical processes involved. But it is doubtful if the understanding of theoretical chemical principles had developed to a great extent. Nevertheless, philosophical speculations about the cosmogenesis and nature of matter by ancient Indian thinkers led to the formulation of the concepts of the atom and chemical combination, which were not, however, supported by experimental data.

The origin and development of chemistry in ancient and medieval India may be studied with reference to the following periods: (i) pre-Harappan, Harappan, and post-Harappan; (ii) Vedic; (iii) post-Vedic; and (iv) Medieval.[1]

PRE-HARAPPAN, HARAPPAN, AND POST-HARAPPAN PERIODS

Copper articles and specimens of burnt clay which have been unearthed in Baluchistan and the neighbouring areas of Sind[2] show that the people who settled there around the fourth and third millennia B.C. laid the foundation of chemistry in India. Excavations at Mohenjo-daro in Sind and at Harappa in the Punjab[3] have shown that the people of the Indus valley civilization (*c.* 2500-1800 B.C.) were skilled in employing a wide range of chemical processes. Bricks, water-pots, vessels, jars, earthenware, faience, terracotta, jewellery, metal implements, seals, painted polychrome and glazed pottery, and other items have been found. The glaze was made of a fusible silicate (sodium silicate made from fusing soda with sand) mixed with colouring matter like ferric oxide and some types of copper ore. Quartz with clay was used for the body material. According to Mackay, the glazed pottery found at Mohenjo-daro represents the earliest specimens yet discovered, thus suggesting the possibility that glazed pottery is of Indian origin.[4] But there is evidence that the people of the Indus valley civilization had communications with those of the Sumerian culture in Mesopotamia and the Nile valley civilization in Egypt. Seals found in the

[1] *History of Chemistry in Ancient and Medieval India* incorporating the *History of Hindu Chemistry* by Acharya Prafulla Chandra Ray, ed. P. Ray (Indian Chemical Society, Calcutta, 1956), pp. i-ii.

[2] *Ibid.*, pp. 1-7.

[3] *Ibid.*, pp. 9-33; cf. P. Neogi, 'Copper in Ancient India', *Bulletin of the Indian Association for the Cultivation of Science* (Calcutta, 1918).

[4] Ray, *op. cit.*, p. 17.

excavations had glazes made of a fused mixture of powdered cornelian and soda. Oxides of manganese, copper, and iron were used for making coloured faience. Brown glazed pottery articles, both slip-glazed and paint-glazed, were the common varieties. The Indus valley people used lime, gypsum, and sand as constituents of mortar. They employed gypsum cement as plaster for houses.

In metal-working, the Indus valley people applied the processes of casting and forging. Among the metals used, copper and bronze were utilized for making tools, weapons, domestic utensils, statuettes, bangles, finger-rings, ear-rings, amulets, wires, and rods. Bronze was made from the smelting of mixed ores of copper and tin. Crude copper, first smelted in clay-lined pits in which charcoal was used as fuel, was later refined in clay crucibles. Crude copper, copper-arsenic alloy, and copper-arsenic-lead alloy were used for making cast objects, and refined copper for vessels and sound casting. A copper-tin alloy or bronze was preferred for sharp-edged tools. Gold was used for jewellery, and silver for jewellery and ornamental vessels. A gold-silver alloy, electrum, was found at Mohenjo-daro. Silver was extracted from an argentiferous lead ore.

A large variety of minerals and ores was known to the Indus valley people. These include lapis lazuli, turquoise, rock crystal, limestone, soapstone, alabaster, haematite, amethyst, slate, agate, jasper, chalcedony, onyx, bitumen, steatite, sodalite, jade, lollingite, arsenical pyrites, and several others. Most of these were found in the forms of ornamental beads, pendents, and other kinds of jewellery. Some like steatite were often coated with a glaze. Lollingite and leucopyrites were utilized for the preparation of arsenious oxide and arsenic. Cerrusite and cinnabar found at Mohenjo-daro were probably used for cosmetics and medicinal purposes. White lead was possibly utilized for plasters, eye-salves, and hair-washes. Galena was employed for the preparation of eye-salves and paints. The art of dyeing cotton with the red colouring matter of the madder root was also known. Excavations in southern Baluchistan have unearthed specimens of iron implements belonging to the post-Harappan period (*c.* 1800-1500 B.C.), indicating the knowledge of the use of iron in India even before the advent of the Aryans.[5]

VEDIC PERIOD

In the *Ṛg-Veda* there is mention of gold, silver, copper, and bronze. Golp was used for ornaments like anklets and rings. Metal vessels, tools, and armour were made mainly of bronze. All this affords evidence of the knowledge of metal-working. We also find reference to the tanning of hides for making slings, head-strings, reins, and whips. The dyeing of garments

[5]*Ibid.*, pp. 31-33; N. G. Majumdar, 'Exploration in Sind', *Memoirs of the Archaeological Survey of India*, No. 48.

with certain natural vegetable colouring materials and the preparation of fermented drinks from *soma* juice, barley grain, and milk (curd) are also mentioned in the same text. The *Yajur-Veda* speaks of lead and tin among other metals. Gold, according to the *Atharva-Veda* (XIX.26), was regarded as an effective agent for the prolongation of life. Lead was looked upon as an antidote to the spell of sorcery. Thus it may be inferred that several chemical processes were utilized during the Vedic period (*c.* 1500-600 B.C.).

POST-VEDIC PERIOD

The post-Vedic period (*c.* 600 B.C.-A.D. 800) forms the most flourishing and fruitful age as far as it concerns the development of the science of chemistry in ancient India. Chemistry was then closely associated with medicine. Moreover, these two subjects were dominated by the abstract philosophical theories and systems of the Upaniṣads. The physical and chemical theories of cosmic evolution as well as the methodology of science, for instance, were influenced by them.

Theory of Five Elements:[6] The Sāṁkhya-Pātañjala system of philosophy dealing with the process of cosmic evolution gives an account of the origin of the five elements (*bhūtas*)—earth (*kṣiti*), water (*ap*), fire (*tejas*), air (*vāyu*), and space or ether (*ākāśa*). This concept of five elements as the basis of the material universe is, however, much older. It occurs in the Āraṇyakas and the Upaniṣads (*c.* eighth century B.C.), and thus antedates the Greek theory of four elements—earth, water, air, and fire—formulated by Empedocles (*c.* fifth century B.C.).

These five elements postulated in the Sāṁkhya-Pātañjala system represent five abstract principles, or rather a classification of substances on the basis of their properties and states of aggregation. For instance, earth, water, and air may be viewed as comprising all the elements or compounds of chemistry in the solid, liquid, and gaseous states respectively. According to Sāṁkhya, these elementary substances consist of ultimate units called *aṇus* (atoms) which are made up of infra-atomic particles known as *tanmātras*. It admits that the properties of each of the *pañcabhūtas* vary with the grouping of *tanmātras* in the atoms of each.

In the Sāṁkhya-Pātañjala view, *ākāśa* functions in two different aspects: non-atomic and atomic.[7] In the non-atomic form it might be said to correspond to the hypothetical ether—an all-pervasive, ubiquitous medium—of nineteenth-century physics. Atomic *ākāśa* (*kāryākāśa*) is a derivative of non-atomic *ākāśa* (*kāraṇākāśa*). The former is charged with vibration potential, and the latter

[6] Vyāsa, *Yoga-bhāṣya*, II.19; IV.14; also Vijñānabhikṣu, *Sāṁkhyapravacana-bhāṣya*, I.62 and *Yoga-vārttika*, III.40.

[7] Vijñānabhikṣu, *Yoga-vārttika*, III.40.

behaves as a universal medium identified with space (*avakāśa*). The *ākāśa* atom, however, serves as the starting-point for the building up of the atoms of the other four elements. A similar view about the two different aspects of *ākāśa* is found in the Vedānta philosophy where they are distinguished as *purāṇaṁ kham* and *vāyuraṁ kham*. The former represents the *kāraṇākāśa*, the motionless, ubiquitous, primordial matter-stuff or matter-rudiment (known as *bhūtādi* in Sāṁkhya). The latter represents the *kāryākāśa*, a materialization from non-atomic *ākāśa*.[8]

The twofold aspect of *ākāśa*, non-atomic and atomic, related to each other as cause and effect with the atomic *ākāśa* serving as the basis of all other material atoms, may be regarded as a very significant concept of ancient Indian philosophy—a concept which seems to have some resemblance to modern ideas of continuous generation of matter in space and of space being filled with radiation as the starting-point of material creation.

Atomic Theory of Kaṇāda: Kaṇāda, founder of the Vaiśeṣika system of philosophy, primarily concerned himself with the concepts of atoms and molecules and their characteristic properties. He postulated four kinds of elementary atoms: *kṣiti*, *ap*, *tejas*, and *vāyu*. Regarded as material, these four elements are of two types, eternal and non-eternal. In his view, *ākāśa*, which is non-material, is one and all-pervasive, has no atomic structure, and serves merely as an inert and ubiquitous substratum of sound without taking any part in material evolution. An identical view is echoed in the Nyāya system. The Nyāya-Vaiśeṣika system, too, elaborately discusses atoms and their properties.

According to Kaṇāda, atoms are eternal, ultimate, indivisible, and infinitesimal. They possess certain characteristic properties and potentials of sense stimuli. *Kṣiti* has fourteen qualities, namely, colour, taste, smell, touch, numerical unit, mass, weight, conjunction, disjunction, distance, proximity, gravity, fluidity, and faculty; among them its unique quality is smell. *Ap* has the qualities of *kṣiti* with the exception of smell, instead of which viscidity is added; its special quality is taste. Excepting smell, taste, and weight, all the other eleven qualities of *kṣiti* are in *tejas*, its distinguishing quality being colour. Touch is the special quality of *vāyu*, which has the qualities of *kṣiti* excepting smell, taste, and colour.[9]

Kaṇāda's conception of atoms bears many points in common with that of the Greek philosopher Democritus (*c.* 470-360 B.C.). But the atomisms of Kaṇāda and Democritus failed to make any tangible contribution to the growth of science in India and Greece, because they were, by and large, mere speculations, though based on rational, systematic, and logical thought re-

[8] B. Seal, *The Positive Sciences of the Ancient Hindus* (Motilal Banarsidass, Delhi, 1958), p. 121.
[9] *The Vaiśeṣika Aphorisms of Kaṇāda*, trans. A. E. Gough (Oriental Books, New Delhi, 1975), p. 138.

garding the nature of matter and the structure of the universe, as also on the observation of some natural processes by the unaided senses.

Combination of Atoms: According to the Nyāya system, atoms possess a spherical shape (*parimaṇḍalīya*). Vācaspati Miśra (*c.* A.D. 840) indicates the position of one atom in space with reference to another by a geometrical analysis of the conception of three-dimensional space. He holds that in the original physical arrangement of atoms each spherical atom is surrounded by six others. Variations of this arrangement in the collocation of atoms and molecules give rise to the variety of mono- and poly-*bhautika* compounds. A conception of the arrangement of atoms in space constitutes an essential part of Kaṇāda's theory that chemical combination occurs under the influence of heat corpuscles. In the Nyāya-Vaiśeṣika view, atoms, though eternal in themselves, are non-eternal as aggregates which may be organic or inorganic.

According to the Vaiśeṣika system, atoms possess an intrinsic vibratory or rotatory motion (*parispanda*). By its original tendency, an atom combines with another atom to form a binary molecule (*dvyaṇuka*). The binary molecules thus formed by the combination of the atoms of the same element in pairs will possess the homogeneous qualities corresponding to the original qualities of the atoms only if there is no chemical transformation under the action of heat corpuscles. Combining among themselves by threes, fours, fives, etc., these binary molecules produce larger aggregates resulting in a variety of elementary substances. Another view in the Vaiśeṣika system maintains that the combination of atoms, which takes place either directly or by the successive addition of one atom to each preceding aggregate, may be in pairs, triads, tetrads, etc. to form accordingly a binary (*dvyaṇuka*), ternary (*tryaṇuka*), quarternary (*caturaṇuka*), and so on. A variety of substances results from the same element due to the differences in the molecular composition and configuration, particularly in the grouping (*vyūha*) or collocation (*avayavasanniveśa*). The elementary substances thus formed by the primary molecular combination may undergo qualitative changes and be decomposed into the original homogeneous atoms under the impact of heat corpuscles, which transform the character of the atoms and make them reunite in different groups or arrangements with different characteristic properties.

Two or more substances belonging to the same *bhūta* or to different *bhūtas* may also combine to form mono-*bhautika* or hetero-*bhautika* (simple and quasi) compounds. Homogeneous atoms of different substances of the same *bhūta* may unite to form mono-*bhautika* compounds, while bi- or poly-*bhautika* (hetero) compounds may be produced by the combination of heterogeneous atoms of substances belonging to different *bhūtas*.

Buddhist View of Atoms: The Vaibhāṣika and Sautrāntika schools belonging to the Hīnayāna sect of Buddhism accept the atomic view of matter. They consider gross matter as a conglomeration of atoms that are impenetrable, indivisible, intangible, and unanalysable. These atoms, either simple or compound, are dynamic forces and undergo a continuous phase-change. The four types of elements—*vāyu*, *tejas*, *ap*, and *kṣiti*—formed by aggregation from their corresponding atoms with characteristic properties are known as fundamental atoms, while the four sensible qualities—touch, colour, taste, and smell—are secondary atoms. These elements combining with each other give rise to aggregates that are inorganic and organic substances.

Atomic Theory of the Jains: Matter, called *pudgala* in Jaina philosophy, acts as the vehicle of energy in the form of motion. It can exist in two forms: atomic (*aṇu*) and aggregate (*skandha*), the latter being formed from the former. *Aṇu*, an infinitesimal, eternal, and subtle particle having no parts, is both cause and effect. A *skandha*, being an aggregate of atoms, is not considered to be absolute and beginningless. A variety of *skandhas* from a *dvyaṇuka skandha* or *dvipradeśa* (binary aggregate) to an *anantāṇuka* (infinite aggregate) is formed by either the decomposition of large *skandhas* or the successive addition of an *aṇu* to the previous *skandha*. A *skandha* may, therefore, be made up of (i) a definitely large number of *aṇus* that may be counted (*saṁkhyeya*), (ii) an indefinitely large number of *aṇus* (*asaṁkhyeya*), (iii) an infinitely large number of *aṇus* of the first order (*ananta*), (iv) an infinitely large number of *aṇus* of the second order (*anantānanta*), and so on.

Every atom possesses an infra-sensible or potential taste, smell, and colour, and two infra-sensible tactile qualities—roughness or smoothness, dryness or moistness, hardness or softness, heaviness or lightness, heat or cold. A *skandha*, however, possesses in addition the following physical characteristics: sound, atomic linking, dimension, shape and configuration, divisibility, opacity, and radiant heat and light.

A very significant feature of the Jaina atomism relates to the mechanism of chemical combination and atomic linking. For the occurrence of chemical combination a mere juxtaposition of two atoms is not sufficient. They will combine under the following conditions: (i) when the atoms are endowed with opposite qualities such as roughness (*rukṣatva*) and smoothness (*snigdhatva*), provided the opposite qualities are not very feeble; or (ii) when atoms of similar character differ widely in the strength or intensity of their qualities. The properties of the atoms undergo change as the result of their chemical combination.

A detailed presentation of the atomic theory and chemical combination found in Umāsvāmin's (*c.* A.D. 40) *Tattvārthādhigama-sūtra* (V.26) may remind one of Empedocles's idea of four elements. It is also interesting to note that the Jaina theory of chemical combination bears some crude resemblance to the 'dualistic hypothesis' of Berzelius propounded in the early part of the nineteenth century.

Chemical Action and Heat: Many ancient Indian philosophical works, particularly of the Nyāya-Vaiśeṣika system, have noted the close association of chemical change with heat. According to Vātsyāyana (*c.* fourth century A.D.), chemical change may occur either by the application of external heat or due to the effect of internal heat. It was believed that the heat generated by the combustion of fuel existed in the fuel before in a latent form. In his *Kiraṇāvali*, Udayana (*c.* tenth-eleventh century A.D.) considered solar heat to be the ultimate source of all heat required for chemical change occurring on the earth. He thought that this solar heat was responsible for the change of colour in the grass; for the ripening of mangoes bringing about changes in their colour, smell, and taste; for the rusting of metals (combustion due to solar heat—*sūryapāka*); and for the conversion of food into blood. All these are instances of chemical transformation by heat.

Many early philosophers conceived of heat and light rays as consisting of infinitely small particles radiating in straight lines in all directions with inconceivably high velocity and with a sort of conical dispersion. These, on striking atoms, may break up their groupings, transform their physico-chemical character, and bring about chemical changes.

Indian and Greek Atomisms: In both ancient India and Greece, philosophical and scientific concepts were developed independently on parallel lines with distinctive features of their own. The Indian conception of the nature of matter and the structure of the universe, like that of the contemporaneous Greeks, followed a double tradition, viz. materialistic and religious. These two traditions were, however, often blended together, particularly in the case of the Indians.

The conception of *ākāśa* as both non-atomic and atomic is a distinctive feature of the atomic theory of ancient Indians. In both the Vaiśeṣika and Greek views, atoms are indivisible. In the Sāṁkhya-Pātañjala system, however, atoms are not indivisible in the strict sense of the term since they are made up of *tanmātras* in different proportions for each type of element. The atomism of the Nyāya-Vaiśeṣika school differs in conception as well as configuration from the Greek atomism. The Greek idea that atoms are real, of various dimensions, and in eternal motion is not found in the Nyāya-Vaiśeṣika atomism. According to the Indian theory, atoms have qualitative differences, but in the Greek view they differ quantitatively. A sort of mechanical concept of the universe postulated in Greek atomism is not at all mentioned in the Indian system. Furthermore, the soul, which is regarded as a composition of atoms in Greek atomism, is non-material, having no atoms, in the Indian view. However, the atomism of Kaṇāda as well as of Democritus, which anticipated the formulation of Dalton's atomic theory by several centuries, receded to the background for reasons already stated.

Kauṭilya, Caraka, and Suśruta: Literary and technical compositions of the post-Vedic period contain considerable information regarding chemistry, metallurgy, and medicine. The treatises of Kauṭilya, Caraka, and Suśruta are extremely rich in this respect.

Kauṭilya's *Arthaśāstra* (*c.* fourth century B.C.), although mainly a work on polity, is also a source-book of many branches of science in ancient India. This work describes the ores of gold, silver, copper, lead, tin, mercury (probably imported), and iron; the processes of extraction of their metals; and the preparation of their alloys. It explains the procedure of gold and silver working, and a process of silver purification in which silver and lead are heated in a skull—a technique somewhat resembling the modern cupellation process. It also describes a variety of gems like diamond, coral, sapphire, ruby, emerald, opal, and pearl. The composition of a variety of liquors is also discussed.

A definite progress in the chemical knowledge of the ancient Indian is found in the two well-known medical treatises, the *Caraka-saṁhitā* and the *Suśruta-saṁhitā*, believed to have been originally composed in about the first century A.D. but revised in subsequent recensions. Minerals like sulphate of copper, sulphate of iron, realgar, orpiment, rust of iron, sulphur, and pyrites have been mentioned in the *Caraka-saṁhitā*. The text also describes the use of coral, lapis lazuli, ashes of conch-shell, calces of iron and copper (oxides), and sulphide of antimony (as an ingredient of collyrium). The roasting of metals like iron and copper with sulphur is described as the 'killing' of these metals, meaning the formation of their sulphides. The preparation of various kinds of fermented liquors and of almost anhydrous alcohol by distillation has also been described.

An elaborate description of the preparation and properties of alkali carbonates and caustic alkali as well as of the neutralization of the alkali by an acid is given in the *Suśruta-saṁhitā*. This description is so perfect in detail that it could almost be transferred bodily to a modern textbook of chemistry. Caustic alkali was made by boiling a weak variety of alkali carbonate with a solution of lime.

Suśruta recommended as drugs the oxides (calces) of tin, lead, copper, silver, iron, and gold, which were prepared by roasting the metals with minerals like alum earth and red ochre. The poisonous property of the compounds of arsenic such as white arsenic and orpiment was known to him. Suśruta described a crude method known as *ayaskṛti* (action affecting the metals) of preparing metallic oxides or oxy-salts by roasting the metals with common salt, saltpetre, and sulphate of magnesia. It seems that mercury was not well known in Suśruta's time inasmuch as he only vaguely refers to it once or twice.

In the writings of the medical schools of ancient India originating from Caraka and Suśruta, references are often found to chemical composition and decomposition by more or less crude processes of calcination, distillation, sublimation, steaming, fixation, etc. On the basis of Sāṁkhya philosophy Caraka developed theories of chemical combination and the formation of compounds, and distinguished between chemical compounds and mechanical mixtures. Suśruta followed Caraka in this matter.

Caraka and Suśruta classified organic substances into two groups: vegetable and animal. Caraka made reference to vegetable as well as animal oil. Viscous (oily) substances were grouped under four heads: butter, oil, fat, and marrow. Salts were divided into mineral and vegetable types. Suśruta arranged poisons into two classes: vegetable and animal; but several poisons expressly termed as mineral poisons were included under the first category.

The chemistry of digestion has been elaborately discussed in the *Caraka-saṁhitā*, but a more detailed discussion is found in a medical treatise of a much later date, the *Aṣṭāṅgahṛdaya-saṁhitā* by Vāgbhaṭa (seventh-eighth century). The latter describes many preparations of gold, silver, copper, iron, tin, and lead.

Glass and Pottery: The process of melting, refining, and colouring glass was known in India as early as the sixth century B.C. This is borne out by the discovery of the earliest specimen of true glass in India (*c.* fifth century B.C.) which was unearthed at Taxila in the Bhir mound. Further evidence is provided by the find of the site of an ancient glass factory, believed to be of about the fifth century B.C., at Kopia in the Terai region of Uttar Pradesh. Samples of glass beads, fragments of earthen crucibles with glass sticking to the inner side, and lumps of glass of different colours in various stages of formation were recovered from that site. Excavations at Piprahwa near Kopia also unearthed glass beads in a Buddhist *stūpa*.[10] According to Pliny, the art of making glass and of colouring it with the help of metallic salts or oxides was well known to the ancient Indian. This is evident from the results of analysis of certain porcelain-like fragments found at Taxila. Reference may be made to an observation by Pliny about the Indian glass as being superior to all others.[11] Green and blue glass bangles, generally opaque but occasionally transparent, belonging to the Śaka-Parthian and Kuṣāṇa periods (*c.* 300 B.C., A.D. 100), have also been recovered at Taxila.[12] Similar bangles of the Andhra culture (*c.* first century A.D.) have been found at Brahmagiri and Chandravalli in the Chitaldurg district of Mysore and at Sisupalgarh near Bhuvaneswar in Orissa.

[10] Ray, *op. cit.*, pp. 73-76; M. M. Nagar, *U. P. Information* (15 August 1949), p. 79.
[11] Pliny, *Natural History*, XXXVI, p. 66.
[12] Ray, *op. cit.*, p. 78.

Specimens belonging to the second century A.D. which were unearthed at Taxila reveal that the art of making painted, decorated, and glazed pottery was fairly well developed during the post-Vedic period. Excavations at Ahicchatra and Bhita in Uttar Pradesh and at Bangarh in Bengal have yielded specimens of similar pottery ware belonging to *c.* 300 B.C. - A.D. 1100. Most of these are wheel-made with a fair percentage of mould-made pots. Terracotta objects, beads, plaques, moulds, figurines, toys, large rings for the construction of wells, and other items belonging to the Śuṅga, Kuṣāṇa, and Gupta periods have also been recovered at Bangarh. In addition, lime and powdered bricks of the Gupta period which were used as mortar for making rammed concrete on the floor of buildings, as well as decorative bricks of the Pāla period, have been found there. Specimens of ancient pottery, mostly local, have been discovered during excavations at Arikamedu in Tamil Nadu. The local pottery recovered there is to a great extent wheel-turned, excepting large troughs, storage jars, and a type of portable oven. The imported pottery, mainly from Italy and many Mediterranean ports, found at Arikamedu belongs to the early Christian era. Both black-and-red and black-and-grey wares resulting from firing under oxidizing and reducing conditions respectively have been discovered. They are slip- and salt-glazed, giving rise to very picturesque effects. Beads of semi-precious stones, faience, and various coloured glass were manufactured on a large-scale at Arikamedu in those days.

Excavations at Brahmagiri and Chandravalli have uncovered specimens of painted slip- and salt-glazed, hand-made pottery of the Stone Age. These bear no resemblance to the Indus valley ceramics. Slow-wheeled pottery of the Iron Age (*c.* 200 B.C.-A.D. 50) and fast-wheeled varieties of the Andhra culture have also been unearthed in Brahmagiri. Wheel-turned, plain, and polished pottery belonging to *c.* A.D. 50 has been found by excavations at Sisupalgarh.

Copper Working and Casting: The craftsmanship and remarkable achievements in copper metallurgy of the ancient Indians are confirmed by both extant monuments and archaeological evidence. In the Rampurwa Aśoka pillar near the frontiers of Nepal, a solid bolt of pure metallic copper (*c.* third century B.C.) has been found, which measures 24½ inches in length with a circumference of 14 inches at the ends. A seven-foot high pure copper statue of Buddha weighing about one ton and belonging to the fifth century A.D. was found at Sultanganj in Bihar and later removed to the Birmingham Museum. This statue is provided with an outer garment sufficiently transparent to make the body visible. The figure seems to have been cast in two layers, the outer layer having been cast over the inner one presumably by the *cire perdue* process. The casting of the inner body was effected on an earthen mould in segments held together by iron bands. Lumps of copper ore and other small copper figures found in the vicinity suggest that the smelting and casting operations were conducted at the site.[13]

The Chinese traveller Hiuen Tsang describes a colossal 80-foot copper statue of Buddha which stood near the famous Nālandā university in Bihar. It is believed to have been constructed during the reign of a king Pūrṇavarman. This figure of remarkable metallurgical skill must have disappeared very shortly afterwards as no further mention of it is found in later chronicles.

There is archaeological and other evidence that punch-marked and stamped or cast copper coins were issued by the Maurya, Śuṅga, Kuṣāṇa, and Gupta kings. Large copper plates have been in use in India from very early times, particularly during ceremonies associated with land grants. The Sohgaura plate (*c.* third century B.C.) discovered in Uttar Pradesh bears testimony to this. Silver and gold jewellery with granulation and filigree work which was made on copper and bronze moulds or dies has been found at Taxila (*c.* third century B.C.). Copper utensils were commonly used in religious ceremonies in ancient India.

Smelting of copper on an extensive scale about two thousand years ago is corroborated by geological evidence found in Chotanagpur in Bihar. Deposits of copper slags have been found in abundance on the hills all around the area. Many extinct copper mines are found in Rajasthan from which the metal was evidently obtained in ancient times. Copper mines were worked and copper smelting done in Madhya Pradesh, Uttar Pradesh, and Madras. Nepal was an important source of copper in ancient India.

Among copper alloys, bronze and brass were extensively used in ancient India for making utensils, water-vessels, coins, ornamental articles, images of deities, and other items. Brass was manufactured by heating copper with calamine and carbonaceous matter or by smelting mixed ores of copper and zinc. From the records of Hiuen Tsang, it seems that there was an unfinished brass temple of Buddha near Nālandā (*c.* seventh century A.D.).

Iron and Steel: Although the preparation and use of steel were known in ancient India, wrought iron was mostly produced. This is because the heat resulting from the charcoal fuel which was used in a crude form of blast furnace was insufficient to melt the iron resulting from the reduction of the ore and thus to absorb carbon to form pig iron.

Specimens of many iron implements and a large variety of weapons believed to have been produced in the fourth century B.C. were discovered by the excavation of numerous burial grounds in the gravelly mounds at Tinnevelly in Tamil Nadu. Iron slag and clamps belonging to the third century B.C. have been found at the Bodh Gaya temple. Archaeological excavations carried

[13] P. Neogi, *Copper in Ancient India* (The Indian Association for the Cultivation of Science, 1918) pp. 20-21.

out in the forties in many sites in the Doab, e.g. Ahicchatra, Hastināpura, Rupar, Panipat, Atrañjikhora, and Alamgirpur, led to the discovery of painted grey ware with which iron was associated. Radio-carbon dating of these objects, which include arrow-heads, spear-heads, and axes of different shapes, places them between 1025 and 537 B.C. Iron implements found in many megalithic burials in South India at Tekwada, Brahmagiri, Piklihal, Maski, and other places also date from the eleventh and twelfth centuries B.C.

Excavations at Bangarh and Taxila have led to the discovery of a large number of objects made of iron belonging to the Śuṅga, Kuṣāṇa, and Gupta periods. The famous wrought iron pillar near Qutb Minar in Delhi, a noteworthy testimony to the skill and special technical abilities of the early Indian metallurgists, has withstood for centuries the onslaught of weather without any sign of corrosion. This twenty-four-foot high pillar with a diameter of 16·4 inches at the bottom and 12 inches at the top and a weight of more than six tonnes is supposed to have been constructed in the early fourth century A.D. The extensive use of iron clamps and beams in the temple at Bhuvaneswar (*c.* A.D. 640) provides another instance of large-scale production and working of wrought iron in early India.

Steel of a fairly high quality used to be prepared in ancient India by a technique very similar to the modern cementation process. It was deemed to be very precious. The reported presentation of a piece of steel weighing about 30 lb. to Alexander the Great by the Indian ruler Porus corroborates this.[14] The use of fine steel implements is suggested by the nicely and precisely carved stone inscriptions of Aśoka. Descriptions given in the *Suśruta-saṁhitā* indicate that steel surgical instruments were also used. The steel produced in Hyderabad, Mysore, and Salem was exported to western countries as early as the beginning of the Christian era and was used for the preparation of the famous Damascus blades. The art of tempering steel was also known to the ancient Indians[15] from whom the Persians and, through them, the Arabs learnt the operation.

Dyes, Paints, Cosmetics, and Cement: The use of dyes like indigo, lac, turmeric, madder, resin, and red ochre was known to the ancient Indians. Varāhamihira (*c.* A.D. 550) in his *Bṛhat-saṁhitā* refers to mordants like alum and sulphate of iron for the fixing of dyes on textile fabrics. Relics of the fourth to the second century B.C. excavated at Taxila and Andher as well as the inscriptions in Kharoṣṭhī (*c.* first century A.D.) from Khotan bear evidence of the use of carbon or black ink.[16] The Ajantā cave paintings (*c.* fifth century A.D.) testify to the use of colouring materials.

[14]See *Journal of the Royal Asiatic Society*, Vol. V (1839), p. 395.

[15]See Varāhamihira, *Bṛhat-saṁhitā*, XLIX.23-26.

[16]*Report of the Archaeological Survey of India*, 1929-30, p. 209; cf. P. K. Gode, *History of Ink Manufacture in Ancient India*, Vol. III (Prachyavani, 1946), pp. 1 and 10-11.

The *Bṛhat-saṁhitā* (LXXVI) alludes to cosmetics, scented hair dyes, frankincense, delicately blended perfumes, etc. It also contains information on various cement preparations which may be classified under two heads: rock cement (*vajra-lepa*) and metal cement (*vajra-saṁghaṭa*). These varieties of cement were applied primarily to the walls and roofs of temples and other buildings.

CHEMISTRY IN MEDIEVAL INDIA

Chemistry in medieval India was closely associated with alchemy which was an integral part of the Tāntric cult. Although the origin of alchemy in India may be traced to a date as far back as that of the *Atharva-Veda*, or even that of the *Ṛg-Veda*, practical alchemy reached its acme only during the Tāntric period. Alchemy, as is well known, has a twofold objective: (i) the preparation of an elixir of life and (ii) the production of the philosophers' stone for the transmutation of base metals into gold. Tāntric treatises, both Brāhmaṇic and Buddhistic, abound in recipes for such transmutation of base metals, particularly of mercury into gold. The *Rasa-ratnākara*, attributed to the famous Buddhist alchemist Nāgārjuna (*c.* eighth century A.D.), contains descriptions of alchemical processes and preparations of many mercurial compounds. It gives an account of many chemical processes like the extraction of zinc, mercury, and copper, and the preparation of crystalline red sulphide of mercury (*svarṇasindūra* or *makaradhvaja*). This medicament is still used as a panacea for many ailments by physicians in India following the indigenous system of medicine. The treatise also describes more than two dozen varieties of apparatuses (*yantras*) for carrying out various physico-chemical processes like distillation, sublimation, extraction, calcination, digestion, evaporation, filtration, fumigation, fusion, pulverization, heating by steam and by sand, and the preparation of many metallic compounds.

The *Rasārṇava* or *Devī-śāstra* (twelfth century), a Tantra of the Śaiva cult dealing with alchemy and chemistry, gives a description of the colours imparted to flames by various metallic compounds like those of copper, tin, lead, and iron. A variety of minerals and ores, the extraction of copper from pyrites and zinc from calamine, the distillation of alum (possibly giving rise to sulphuric acid), and the purification of mercury by distillation are described in this Tāntric text.

The alchemical ideas and treatises of India found their way to China and Tibet. The *Dhātuvāda* (*c.* eighth-ninth century), a Tāntric text in Sanskrit, found translated in the Tanjur division of Tibetan literature, gives an account of the deposition of copper on iron from a copper salt solution and the preparations of amalgams of copper and of white lead. The *Sarveśvara-rasāyana*, another Tāntric text in Sanskrit of the same time which is also translated in the Tanjur, explains the process of making cuprous sulphide. The preparation of antimony by heating a mixture of stibnite and iron is mentioned in the *Rasendra-cūḍāmaṇi* (thirteenth century). This shows that the process was known in India much earlier than its discovery in Europe by Basil Valentine (1604). The preparations of calomel and of oil of vitriol (sulphuric acid) from alum, the use of alum as a mordant for dyes, and the extraction of zinc from calamine are described in the *Rasaprakāśa-sudhākara* (*c.* thirteenth century).

The ideas of the alchemists about the possibility of transmuting base metals into gold gradually lost their charm because of repeated failure of experiments. But the numerous preparations of mercury, iron, copper, and other metals obtained in the process came to be used in medicine. As a result, the compilation of a number of medical treatises dealing with the use of metallic preparations followed. One such work, the Buddhist treatise *Rasaratna-samuccaya*, contains a vast mass of the then existing chemical information but very little that is new and of intrinsic value. It treats of mercury, minerals, metals, gems, liquefaction, incineration, construction of apparatuses, purification of metals, and extraction of essences (active principles). A beautiful description of the location, construction, and equipment of a chemical laboratory is recorded in this treatise. A method of preparing mineral acids, particularly *aqua regia* (*śaṅkha-dravarasa*), by distillation has been given in the *Rasa-pradīpa* (*c.* 1535).

Unlike what happened in Europe, alchemy in India failed to develop into rational, scientific chemistry. As a result, it gradually became extinct.

Practical Arts: There is plenty of evidence of the application of chemical knowledge and processes in the medieval period, particularly relating to metallurgy and metal-working, gunpowder, saltpetre, mineral acids, alum, paper, ink, soap, and cosmetics. Heavy guns and cannons made of copper, bronze, and brass were used by the Mogul emperors. Instances of working with wrought iron on a large scale by means of forging and hammering are provided by the following: the iron pillar at Dhar (fourteenth century); the pillar on Mount Abu (fourteenth century); the large iron beams at Konarak and in the temples of Puri (*c.* twelfth century); and the big iron guns and cannons of the Mogul period as found at Bijapur, Hyderabad, and Murshidabad. Records of the preparation of steel swords at various places in India are found in the *Yuktikalpataru* (*c.* eleventh century) and *Śārṅgadhara-paddhati* (*c.* fourteenth century).

The tinning of copper vessels gained currency in India from the Middle Ages, possibly after the arrival of the Muslims. An alloy made of copper, lead, and tin, or of copper, lead, and zinc known as *bidery* (from Bider, a town in Andhra Pradesh), produced during this period, was used to make vases, basins, cups, etc. which were then inlaid with gold and silver. These products were made largely in Hyderabad, Bengal, and North-West India. Enamelling on gold and silver ornaments in different colours with metallic oxides mixed with soda-lead glass was known all over India. From the beginning of the seventeenth century, or possibly even earlier, a method of recovering gold remaining as waste of gold working was in vogue. In this process the waste materials were boiled in an aqueous solution of a mixture of nitre, common salt, and alum. This solution evidently contained *aqua regia*. Gunpowder was introduced in India about the time of Babur (*c*. 1483-1530). Formulas for the manufacture of fireworks are found in the *Kautuka-cintāmaṇi* and the *Ākāśa-bhairava-kalpa* of the fifteenth century.[17] The preparation of mineral acids (dilute *aqua regia*) is described in several medical works composed in the sixteenth and seventeenth centuries.

Paper-making was introduced in India from China through Nepal in about A.D. 1000 and became a flourishing industry during the Mogul and Peshwa periods. The raw materials used were mainly worn-out clothes, old tents, barks of certain shrubs and trees, and similar substances. These were beaten into a pulp in a lime-lined water reservoir and then made into paper sheets with the help of moulds. Soap, made in India for the first time during the Mogul period, was prepared from trona or natron, common salt, sesamum oil, and goat's suet. The preparation of black ink in solid and liquid forms from lamp-black, gum, and the infusion of gallnut in water has been described in the *Rasa-ratnākara* of Nityanātha (thirteenth century). The preparation of cosmetics and perfumes was known from the sixth century A.D. A detailed description of several aromatic ingredients for the preparation of cosmetics and perfumes, and the technical processes and recipes for the preparation of different perfumed products are given in the *Gandhasāra* and the *Gandhavāda*, which were composed around A.D. 1000 on the basis of earlier texts dating from A.D. 500 to 1000.[18]

CONCLUSION

Chemistry in India was developed empirically and occupied itself, more or less, with the collection of accidentally discovered facts associated with various practical arts like ceramics, metallurgy, metal-working, and medicinal preparations without any recognition of the chemical principles or nature of the chemical changes involved in their pursuit. The result was that the thoughts and ideas could not germinate into scientific laws and theories based on experimental observations and verifications. Likewise, the mechanical skill displayed in the pursuit of practical arts could not develop into technology in the absence of guidance and suggestions from scientific knowledge. Chemistry was dominated more by seeing and believing than by thinking and knowing. After

[17] See P. K. Gode, 'The History of Fireworks in India', *Transactions of the Indian Institute of World Culture*, No. 17 (Bangalore, 1953), pp. 1-26.

[18] See P. K. Gode, 'History of Indian Cosmetics and Perfumery', *Studies in Indian Cultural History*, Vol. I, pp. 297-308; Vol. III, pp. 1-12.

the age of Nāgārjuna, Indian treatises provide very little new chemical information, though quite a large number of commentaries and compilations were composed till the end of the sixteenth century. Nevertheless, India's achievements in the use of minerals, metallurgical techniques, processing of chemicals of everyday use, extraction of metals from their ores, and craftsmanship in the manufacture of certain metal products, which required mastery of some chemical processes, were quite remarkable. Some of the technical skills exhibited by ancient Indian chemists and metallurgists were indeed noteworthy.