EVOLUTION OF CHEMISTRY—Part 1

P. N. Thankachan*

THE EARLIEST applications of chemical processes were concerned with the extraction and working of metals and manufacture of pottery. These arts were carried without any theoretical knowledge, but often with considerable skill. A survey of the industrial activities of the ancient nations shows that the technical arts of the classical period in Greece and Rome are really decadent forms of crafts practised by Bronze Age cultures. The copper tools and utensils had been extensively used by Sumerians and Indians.

Classical Concept of Materials

Like other branches of knowledge, the knowledge in chemistry also underwent an evolutionary process. This was from the primitive materialistic stage, through the mystic, and finally to the scientific stage. For example, in Greece, the Ionian philosophers like Thales and Heraclitus expounded a materialistic outlook of nature. They thought water and air were the basic forms of matter, from which everything evolves. Heraclitus conceived a dynamic, ever changing material world. Empedocles suggested the 'four elements' theory whereby all forms of matter has air, water, fire and earth as their basic constituents. It was Aristotle who attributed the hierarchical order for the four elements. Fire with highest priority followed by air, water and earth. He linked the four elements to the social hierarchy of different classes. In India, five elements: earth, water, fire, air and ether, were supposed to be the basic elements.

Alchemy

The dawn of Western alchemy is sometimes associated with that of metallurgy, extending back to 3500 BC. Many writings were lost when the emperor Diocletian ordered the burning of alchemical books after suppressing a revolt in Alexandria (292 AD). Few original Egyptian documents on alchemy have survived, most notable among them are the Stockholm papyrus and the Leyden papyrus X. Dating from AD 300 to 500; they contained recipes for dyeing, making artificial gemstones, cleaning and fabricating pearls and the manufacture of imitation gold and silver. These writings lack the mystical, philosophical elements of alchemy. They contain the works of Bolus of Mendes which aligned these recipes with astrology and the Classical element. Between the time of Bolus (fourth century BC) and Zosimos of Panopolis of fourth century AD, the change took place that transformed this metallurgy into a Hermetic art.

Alexandria acted as a melting pot for philosophies of Pythagoreanism, Platonism, Stoicism and Gnosticism which shaped the character of alchemy. An important example of alchemy's roots in Greek philosophy originated by Empedocles and developed by Aristotle, was that everything in the uni-

*The author is a member of the Kerala state chapter of *Breakthrough Science Society* . He is currently working as Associate Professor, Dept. of Electronics and Communication, Rajiv Gandhi Institute of Technology, Kottayam.

verse was supposed to be formed from only four elements: earth, air, water, and fire. According to Aristotle, each element had a sphere to which it belonged and to which it would return if left undisturbed. The four elements of the Greek were mostly qualitative aspects of matter, not quantitative, as our modern elements are. Though Greeks were much ahead in cultivating philosophy, the actual knowledge in chemistry matured somewhere else, in Alexandria, after its invasion by Alexander. Alchemy developed further with the Arabs. Since all matter was thought to be made from the primary matter hule and to be composed of the four elements combined in varying proportions, the Alexandrian chemists concluded that all substances are convertible and transmutable one into another, by adjusting the relative proportions of the four elements. Their attempts to effect what their theory predicted failed; and so they made further supposition, namely, that a special substance, which later came to be known as the 'Philosopher's stone', was necessary to achieve transmutation. When water is boiled and evaporated, some earthy matter was left; and it seemed that water was convertible to earth. When a steel knife was dipped in a 'blue stone' or copper sulphate solution, copper coating is produced on the knife. The inference was that iron could be transmuted to copper. This resulted in a natural quest: Why cannot all substances be transmuted into gold by a suitable chemical process? People attempted to do that in various ways, which has a long history. Though chemistry did not grow much through these attempts, some progress was made in the methods, and the use and design of apparatuses.

In India the Samkhya system of philosophy, ascribed to Kapila (550 BC?) describes five elements: ether, air, fire, water, and earth. Each natural element was supposed to contain varying proportions of all these five elements. A form of atomic theory was introduced in the Vaisesika system, attributed to Kanada. Indian Alchemy (Rasasidddhi, "knowledge of mercury") dates from 5th century AD. In India chemistry was very much associated with medicine. Old Indian medical works are the Bower Manuscript (4th century AD) and the treatises attributed to Caraka (AD 100) and Susrtha (AD 200). India produced good iron, the famous Delhi Pillar, weighing 6.5 tons, of forged (not cast) iron, was made in AD 415.

Paracelsus (11 Nov. 1493 – 24 Sept. 1541)

Chemistry in the middle ages

The stagnation and the static view persisted through the middle ages not only in chemistry, but in all fields of knowledge. The biblical concepts interpreted by the famous clergyman Thomas Aquinas were the last word in all matters. Thomas Aquinas related the heavenly life to the human being and nature. This worldview, though static, was comprehensive. The conception of universe with earth as the centre and the heavenly bodies revolving round it was developed. The stars remain static in the universe. Different angels were believed to control the universe. They also had hierarchical positions. The lowest one residing on Mars controls the bottom level, the earthly matters. Everything was supposed to be composed of the four elements, with fire at the helm, followed by air, water and earth.

Roger Bacon was the foremost among the later middle age philosophers to throw some light on the dark picture. The wave of renaissance started in Italy in the 16th century. Copernicus and Bruno questioned the geocentric model of universe. In chemistry Paracelsus' name figures in the 16th century. He burned the books of the doctor Galen in public and tried to link theory and practice in Medicine. He added three principles: sulphur, mercury and salt, to the four elements. He made chemistry a part of medicine (Iatrochemistry) but ultimately he himself fell to more mystic propositions with different souls in the human body.

Though Galileo was put under house arrest, and had to submit to the church, the 'Two New Sciences' published in 1642 in Leiden and his other works attracted the attention of the scholars of Europe. Newton was born in the same year Galileo died. New wind was blowing in Europe. The law of gravitational was suggested in 1666. Robert Hooke also postulated the inverse square law. In every field of knowledge, new wave of thought started evolving. It was Luther in Germany to start a new stream in prose. It was Raphael and Leonardo in Painting. Robert Boyle did it in chemistry.

Robert Boyle (January 25, 1627 – December 30, 1691)

The birth of modern chemistry

In the 17th century, the scientific endeavours took a definite turn. Instead of following Aristotle or the Holy Scriptures blindly, scientists started enquiring about the phenomena around them with their own sense organs. Many of the truths revealed were contradictory to the old concepts. They discovered and proved the findings through experiments. Analogy had been drawn between metals of Alchemy and astronomical bodies. Hence the fall of Alchemy was imminent due to the victory of the Copernican model over the geocentric model of the universe.

Robert Boyle was a contemporary of Isaac Newton. Instead of simply following the four element theory, he ventured to do experiments, especially on the gases. He later published the book, "Sceptical Chemist." Boyle launched a criticism of the current beliefs in the theories of the four elements and the three principles. He especially attacked and refuted the underlying assumptions of these theories by facts drawn

Robert Hooke (28 July 1635 – 3 March 1703)

from well known observations in chemistry. Boyle urged the chemists to examine facts closely and to fit their theory to facts. To clear the way, he defined the chemical elements as "an element is a substance that cannot be decomposed into anything simpler ···"

Robert Hooke was an assistant to Boyle. He was known as the best experimental scientist before Michael Faraday. He constructed most of the experimental setups of Boyle. Another name that figures in the same period was John Mayow. Boyle, Hooke and Mayow were called the Oxford Scientists. The last and lethal blow was given by Toricelli, a student of Galileo, by inventing vacuum. But in chemistry the wind blew in another direction.

Phlogiston Theory

Following Paracelsus' inclusion of sulphur, mercury and salt in the list of 'elements', Johann Joachim Becher and Earnst Stall put forward a new theory of combustion—the phlogiston theory. They said that all combustible bodies contain an entity called phlogiston. The more the content of Phlogiston, the better it burns. When the body burns, the Phlogiston comes out. Subsequently it was found that when calx (oxides of metals) was formed by heating metals, the weight was increased. This contradicted the phlogiston theory that something is given out when burning process happens. To answer this, phlogiston was supposed to be a levitating (negative gravity) material. We now know that it is oxidation taking place during combustion. But Joseph Priestly, who discovered oxygen, was a believer of Phlogiston theory. This prevented him from seeing that it was an element. The Phlogiston theory delayed the growth of chemistry by almost one century.

The revolution in gas dynamics

With the growth of mining, scientists became interested in the gases in mines. The gases causing explosion in mines, the dan-

J. J. Becher (1635-1682)

gerous gases in the marshy lands, the poisonous gases formed during distillation—the causes of these phenomena were unknown. Van Helmond called these gases 'ghosts' for the first time. Stephen Hales showed that these gases could be collected over water. Priestly and Cavendish demonstrated that these could be collected over mercury in a better way. The next step was to understand that these were not merely air but there was qualitative difference between them.

Joseph Black and fixed air

Quantitative experiments are the indispensable part in the development of any field of science. For the evolution of clear and comprehensive theories, the evidences from quantitative experiments are needed. It was Joseph Black, a doctor from Scotland, who made the first steps in this direction. Black collected carbon dioxide (which he called "fixed air") and weighed it. He could even collect the fixed air and thereby proves that the gas could be part of a solid and that there was nothing mystic about it.

Joseph Priestly and oxygen

The discovery of oxygen by Joseph Priestly in 1774 was another blow to the 'four element' theory. He showed that this air is not like ordinary air. Things burned easily in the presence of this gas and he called it dephlogisticated air. This showed that air, which was considered to be one of the four 'elements', is not a single thing. It contains constituent components like 'fixed air' and 'dephlogisticated air' which have their own individual characteristics. By this time, Henry Cavendish announced the discovery of hydrogen (inflammable air).

Joseph Priestley (13 March 1733 – 6 February 1804)

Lavoisier and modern chemistry

Lavoisier did not discover any new elements. He did not discover any new method for producing any new compounds. His merit is that he arrived at correct conclusions from the experiments conducted by other scientists, sometimes repeating the same in a better quantifiable manner. It has been well said that Lavoisier, though a great architect in science, laboured little in the quarry. His materials were chiefly shaped to his hand, and his skill was displayed in their arrangement and combination. Lavoisier completed the works of Priestly, Black and Cavendish and gave a correct explanation of their experiments. He conducted many quantitative experiments. He used the balance extensively. In the experiments of Joseph Black and Cavendish, the Law of Conservation of Mass was vivid. Lomnosov had already given hints in that direction. But it was Lavoisier

General Article

Antoine Lavoisier (26 August 1743 – 8 May 1794)

who categorically placed the Law of Conservation of Mass:

> "Nothing is created in the operations either of art or of Nature, and it can be taken as axiom that in every operation an equal quantity of matter exists both before and after the operation."

Another revolutionary contribution of Lavoisier was the new nomenclature in chemistry. In the eighteenth century, many substances retained the names given to them in classical antiquity, or names coined from their appearance or properties, or from the place of their discovery or occurrence, or from some superficial resemblance to a familiar substance. Instead of that the name given by Lavoisier to a substance was designed to indicate its chemical composition. The names oxygen, hydrogen, etc. were given by Lavoisier.

Through carefully conducted experiments on combustion, Lavoisier came to the conclusions that a body could burn only in pure air (oxygen) and thereby made the Phlogiston theory unnecessary.

He defined the elements as "the final condition a chemical analysis can reach." This was basically Boyle's definition. But the discovery of oxygen, hydrogen, and carbon dioxide clearly showed the new elements. With the repetition of the Cavendish's experiment on the synthesis of water from oxygen and hydrogen, the position of water as element was questioned. Lavoisier, continuing the experiments of Black, Priestley and Cavendish, conclusively proved that at least two elements of Alchemy—the air and water, had the component elements and were actually mixtures or compounds. Hence Alchemy could not survive after Lavoisier. He made Phlogiston theory unnecessary in Chemistry. Lavoisier defined the Law of Conservation of Energy. With the introduction of the new style of nomenclature, modern chemistry grew as a system of knowledge after Lavoisier. □