Milestones in Chemistry

Boyle Began Modern Chemistry

By Ruth A. Sparrow

Early milestones in chemistry were described by Librarian Ruth A. Sparrow in the first part of Milestones in Chemistry which appeared in the last issue. This series describes the Museum's collection of first and rare editions of Milestones of Science.—Editor's Note.

The age of modern chemistry began with Robert Boyle (1627-1691), an Irish chemist. Boyle was born in the year Bacon died, and his place in the history of chemistry is that of the first true exponent of Bacon's method. The most important work of Boyle is *The Sceptical Chymist* (London, 1661). Of it Dr. Fulton says: ". . . . one of the greatest books in the history of scientific thought. It not only marks the transition from alchemy to modern chemistry but is a plea, couched in most modern terms, for the adoption of the experimental method." This first edition is so rare that it is literally unobtainable; there are only twenty-two copies recorded, and we are indeed fortunate in having such a fine copy in our collection. The second edition (1680) is also a rarity. It contains nearly twice as much material as the first. It formulates the corpuscular theory of the constitution of matter, which finally freed chemistry from the restrictions of the Greek concept of the four elements and was the forerunner of Dalton's atomic theory. Sir H. E. Roscoe writes of Boyle: "It was Boyle who first felt and taught that chemistry was not to be the handmaid of any art or profession, but that it formed an essential part of the great study of Nature, and who showed that from this independent point of view alone could the science attain to vigorous growth. He was, in fact, the first true scientific chemist, and with him we may date the commencement of a new era for our science, when the highest aim of chemical research was acknowledged to be what it is still upheld to be; viz, the simple advancement of natural knowledge."

Boyle's first work quickly established a wide reputation for him. His experiments on the air pump led to deductions of the highest scientific importance. He first proved that air had weight, and it was Linus's attack upon his deductions in his *Experiments Physico-Mechanicall* (1660) that brought forth (first appearing in our second edition, 1662) the first statement of Boyle's law — that the volume occupied by a gas is the reciprocal of its pressure.

A contemporary of Boyle was Robert Hooke (1635-1703), an English mathematician and natural philosopher, who made important observations on combustion. Hooke's only important work to be published during his lifetime was *Micrographia* (London, 1665). In this he expounds his discovery of the real nature of combustion, anticipating Mayow by thirteen years. He established the cellular structure of plants, and the optical discoveries he expounded in it greatly influenced Newton.

Our collection now takes a jump to the late eighteenth century when we find the phlogiston theory of Stahl firmly established. It was due to the investigations of Black and Scheele and others that the foundation of this theory was destroyed. Joseph Black's (1728-1799) university thesis on *Experiments Upon Magnesia Alba* (Edinburgh, 1754) announced the discovery of carbon dioxide. His experiments also showed the possibility of inducing compounds containing the elements magnesium and calcium to pass through a cycle of chemical transformations.

Henry Cavendish (1731-1810) was a coworker of Black. His most important work was the first experimental proof of the fact that when inflammable air (hydrogen) is burned in ordinary air, water is produced. This led to a bitter controversy, and Lavoisier did much to clear it up and advance chemical theory. *Experiments on Air* (London, 1784-5) was read before the Royal Society on January 15, 1784, and was a great contribution to the progress of chemistry.

Joseph Priestley's (1733 - 1804) chemical fame rests chiefly on his discovery and isolation of oxygen, which as a follower of the phlogistic doctrine he called "dephlogisticated air." Until his death he adhered to this theory of combustion, and *The Doctrine of Phlogiston Established* (Northumberland, 1800) is one of his most important and rarest works. It is interesting to note that this paper bears the imprint of Northumberland, Pennsylvania. Priestley was forced to flee England because of his politics and with difficulty escaped to the United States and made his home in Pennsylvania where he died.

It was left for Antoine Lavoisier (1743-1794), a French chemist, however, to interpret the experiments of these men correctly. Lavoisier sifted and collated the facts handed down to him by the phlogistons and gave correct explanations for many processes. While he made no independent experiments, he did however contribute several of the greatest treatises on chemistry. *Méthode de Nomenclature Chimique* (Paris, 1787) first propounded the principles of chemical nomenclature, and the reform of the language effected by him was an indispensable beginning to the reform of thought. This new terminology was used without change for over fifty years and has been the basis of modern nomenclature.

Lavoisier's greatest work is *Trâite Elementaire de Chimie* (Paris, 1789). This is an extremely rare book and is said to have done for chemistry what Newton's *Principia* did for physics. It is truly one of the great classics of chemical science and forms the foundation of modern chemistry. It is here that Lavoisier expounds his antiphlogistic theory and the principle of the indestructibility and conservation of matter—the basis of chemical science. It is also the first attempt made to enumerate a list of true chemical elements and their compounds. The year 1789, which marked the end of the phlogiston, also proved to be the downfall of Lavoisier. It was at the time of the French Revolution, and Lavoisier was unfortunately of the old regime; he was guillotined in 1794.

The death of Lavoisier was merely the death of a man; his work had been so revolutionary and wide that chemistry faced the future on a much stronger foundation. The phlogistic theory had been deposed by the oxygen theory.

So chemistry faced the nineteenth century, and in the early days of it appeared John Dalton (1766-1844), an Englishman. His *New System of Chemical Philosophy* (Manchester, 1808-1810, 1827) is one of the great classics of chemistry. It contains Dalton's exposition of the atomic theory for the first time. It laid the foundation of chemical notation by representing graphically the supposed collations of atoms in compound bodies. This system did not come into general use owing to the introduction of a simpler one sometime later. At this time there were thirty-seven elements known.

Sir Humphry Davy (1778-1829), an Englishman, was among the first to investigate the question of the decomposition of water. He delivered a Bakerian Lecture before the Royal Society of London in 1806 at the age of twenty-seven, which established him as one of the greatest scientists of his day. The paper *On Some Chemical Agencies of Electricity* (London, 1807) exploded several fallacies in the theory of electrolysis. He outlined the electrical theory of mass action, with a description of the emergence of ions from the human body under electrical influence. He also suggested the use of electricity in atomic disintegration. Berzelius, his greatest rival, describes this lecture as "the most remarkable of all contributions to the theory of chemistry." And, although England was at war with France at the time, the Paris Institut awarded Davy a prize of three thousand francs for this outstanding contribution.

Joseph Louis Gay-Lussac (1778-1850), French chemist and physicist, discoverer of the law of volume, published *Memoires de Physique at de Chimie* (Paris, 1807). This appeared in the year previous to the announcement of the law and contains many of his important papers.

It was Amadeo Avogadro (1776-1856), an Italian physicist, who demonstrated the connection between Gay-Lussac's law of volumes and Dalton's atomic theory. In *Essai d'une Maniere de Determiner les Masses Relatives des Molecules Elementaires des Corps* (Paris, 1811), he announced the discovery that changes in volume which take place when gases combine are explained by assuming that the molecules of elementary gases may be composed of more than one atom. These conclusions had practically no effect at the time, and it was more than fifty years later that they were given due recognition.

Joseph Frauenhofer (1787-1826), a German physicist, announced the discovery of absorption lines in the solar spectrum in 1817. He also announced the generally accepted spectroscopic scale which eventually led to the discovery of spectroscopy: *Bestimmung des Brechungs-und Farbenzerstreunges-Vermögnes* (Munich, 1817).

One of the pioneers in organic chemistry was Frederich Wöhler (1800-1882), a German chemist. He announced, in *Ueber Kunstliche Bildung von Harnstoff* (1828), the discovery of synthesizing of urea from ammonium cyanate simply by heating. This was the first synthesis of an organic compound and is generally regarded as the beginning of scientific organic chemistry.

Justus von Liebig (1803-1873), a German chemist, is noted chiefly as the founder of agricultural chemistry. *Die Organische Chemie* (Braunschweig, 1840) is the first formal treatise on organic chemistry in its application to physiology and pathology. It also introduced the conception of metabolism.

Robert Bunsen (1811-1899), a German chemist, created the gas analysis methods of today. *Gasometry* (London, 1857) is a treatise on the physical and chemical properties of gases. Bunsen was also the inventor of the burner and the galvanic cell which bear his name. He was codiscoverer with Kirchoff of spectrum analysis.

Gustav Kirchoff (1824-1887), a German physical chemist, and Bunsen investigated the color and position of the bright spectral lines. They investigated the early work of Frauenhöfer (1817) and published this classical discovery in spectrum analysis, *Untersuchungen über das Sonnenspectrum und Derchemischen Elemente* (Berlin, 1861). This work was destined to play an important part in the determination of the constitution of terrestrial and celestial bodies.

New elements were being discovered with great rapidity. In the prehistory period there were four elements evident; up to the days of the alchemists only six had been added;

the alchemists added four new elements; and twenty-eight were added during the phlogiston era. The age of electrochemistry brought to light sixteen more elements, and with the introduction of spectroscopy four more were added. In 1869 sixty-two elements were known. That year Dmitri Mendeleef (1834-1907), a Russian chemist, published his first paper on the important principles of the Periodic Law — *Versuch Eines System Der Elemente Nach Ihnre Atomgewichten und Chemischen Functionen* (German edition, Leipzig, 1869). The Periodic Law claims the properties of elements to be the periodic functions of their atomic weight. Mendeleef discussed the relations of known elements and on this basis predicted the finding of further elements. In the eighteen years following this announcement fourteen new elements were found; in the next four, five were located.

Henry Becquerel discovered the principle of radioactivity which opened up an entire new field of elements. From 1898, when the Curies discovered polonium and radium, up to 1927, eleven new elements were added. It was generally accepted that there could be only ninety-two elements, with uranium as the heaviest, and until about two years ago all except two had been discovered. Since that time, with new methods and equipment, chemistry has made new discoveries. An atom-smasher has been perfected. This has made possible the building up of two new elements — numbers ninety-three and ninety-four. This has been possible by the bombardment of uranium by neutrons. Element number eighty-seven has also been discovered, leaving only one of the original ninety-two unfound.

The history of chemistry has been the history of civilization. Without its advance, life for the most part would be quite primitive. Chemistry has utilized all the resources of nature to contribute to the health and wealth of the world. Since the day in 1828 when Wöhler announced that organic compounds could be made outside living plants and animals, chemistry has put to use all its resources to make substitutes or new products. Indigo is no longer made from the indigo plant but from a combination of chemicals; vanilla is synthetically prepared; oil of wintergreen does not come from the plant but from methyl-salicylate. These are only a few of the thousands of uses to which chemistry has been applied. This branch of chemistry which has been able to build up artificially what in the past has been regarded as vital products is called synthetic chemistry.

Chemistry has also applied itself to the task of salvaging waste products and turning them into useful purposes. We find that the by-products of coal, cotton, ore, and countless other things are the basis for most of the common needs of life. Industrial chemistry has advanced so rapidly that the consumer is scarcely able to keep up with its pace. Chemistry had its origin from the knowledge of small mysteries. Chemistry of our times has practically eliminated any mystery that may be attached to it, and the ends to which it may attain are unpredictable.