THE BIRTH OF CHEMISTRY

X.

The Theory of Phlogiston—Comparison with Hooke's Theory of Combustion.—Early Ideas regarding Calcination.—Stephen Hales—His Pneumatic Experiments.—Boerhaave.—Conclusion.

ABOUT the year 1669 we find the first dawnings of a theory which was proposed in order to connect together various chemical phenomena, and notably for the explanation of combustion, the common and most obvious of all chemical actions. This theory, known as the "Theory of Phlogiston," powerfully influenced chemistry for a century; indeed upon its ruins the structure of modern chemistry was raised by the labours of Lavoisier, Priestley, and Scheele. The proposers of this theory —John Joachim Becher (b. 1625, d. 1682) and George Ernest Stahl (b. 1660, d. 1734) endeavoured to trace the cause of various phenomena of chemical change to the assimilation or rejection of what they called "*materia aut principium ignis, non ipse ignis*"—not actual fire, but the principle of fire; a something not much unlike the pure, elemental, celestial fire which a few ancient and many Middle Age writers had feigned to exist. Stahl believed this *materia ignis* to be a very subtle, invisible, substance, which neither burns nor glows; its particles penetrate the most dense substances, and are agitated by a very rapid motion. When a body is burned it loses phlogiston; when a body is un-burned, if we may use such an expression, or de-oxidised, it assimilates phlogiston (φλογιστός, burnt). Thus if lead is heated for some length of time it is converted into a powdery substance which they called *calx of lead*, and we, *lead oxide;* the lead has lost Phlogiston, said Stahl. On the other hand, if this same calx of lead is heated with red-hot charcoal, it is deoxidised and becomes lead again. It has now assimilated the Phlogiston, which it had before lost.

But here arose a difficulty. A metal was found to be heavier after calcination than before; thus loss of Phlogiston lead to gain of weight, which was altogether anomalous, and apparently incapable of explanation. But the Phlogistians were equal to the occasion; the supporters of a pet theory will create any number of the most vague and impossible hypotheses, rather than yield up their darling to destruction: so, said they, Phlogiston is a principle of levity; it confers negative weight; it makes bodies lighter, just as bladders attached to a swimmer lighten him.

The theory was applied as generally as possible:—thus sulphuric acid is produced by burning sulphur under certain conditions of oxidation; the sulphur loses Phlogiston, and becomes heavier like the metallic calx; hence sulphuric acid is sulphur *minus* Phlogiston, while sulphur is consequently sulphuric acid *plus* Phlogiston. In fact *loss of phlogiston* was synonymous with what we call *oxidation*; and *gain of phlogiston* with *deoxidation.* The existence of Phlogiston was so utterly unsupported by experimental proof that the theory could scarcely exist without many opponents. The endurance of the most false chimerical theory is often really wonderful. The Phlogistians were attacked first in one direction, then in another, yet the theory continued to find supporters. At last, as a last resource, hydrogen gas—recently investigated by Cavendish—was said to be Phlogiston, but this was so entirely different from the Phlogiston of Stahl that the theory was now seen on all sides to be fast giving way. At length Lavoisier, a century ago, conclusively disproved the theory by means which cannot be discussed here, because they belong to the more advanced history of the science.

How the crude, unscientific, illogical theory of Phlogiston could have arisen in the face of Hooke's admirable theory of combustion, and Mayow's experiments in support of it, must always remain a mystery. It is probable that if Mayow had not died a young man, or if Hooke had found leisure to prosecute his views, the theory of Phlogiston would never have been propounded. The theory has been much over-praised. The only service which it rendered to the science was that it introduced a certain amount of order and system, which was hitherto wanting. It led to the grouping together of certain classes of facts, and, to a slight extent, to the application of similar modes of reasoning to similar chemical phenomena. And although that reasoning was altogether wrong, it seemed to indicate the means by which, with a more perfect and advanced system, chemistry might become an exact science subject to definite modes of treatment.

We have more than once spoken of calcination, which was indeed one of the most prominent operations of old chemistry. Since the examination of the process led to the proposal of just ideas concerning the materiality of the air—most often denied by ancient and middle-age writers—it may be well to glance at the early ideas regarding calcination. Here then was the dominant experiment in this direction: I take a bright lustrous metal, tin or lead, melt it, keep it in a molten state for awhile, and it is converted into powder, which weighs more than the original metal. Again I heat this same powder with charcoal, and it becomes metal again; yet nothing that can be seen has been added to the metal, or taken away from its calx. Geber defines calcination as "the pulverisation of a thing by fire, by depriving it of the humidity which consolidates its parts." He observed that the metal increases in weight during the operation, although "deprived of its humidity." Cardanus asserted that the increase of weight in the case of lead amounted to one-thirteenth the weight of the metal calcined; and he accounted for it on the supposition that all things possess a certain kind of life, a *celestial heat*, which is destroyed during calcination; hence they become heavier for the same reason that animals are heavier after death, for the celestial heat tends upwards. This idea was almost similar to that of the Phlogistians, although published more than a century before Becher wrote his *Physica Subterranea.* In 1629 Jean Rey, a physician of Bergerac, attempted to discover the cause of increase, and attributed it to the absorption of "thickened air" (*l'air espessi*) by the metal during calcination. Lemery, as we have seen, attributed the gain to the absorption of *corpuscules de feu.* Afterwards came the nitre-air of Mayow, then a century later the increase was proved to be due to the union of the body with a constituent of the air which Lavoisier named oxygen gas; and this gas was first discovered by heating one of the calces (calx of mercury), about which so much speculation had been wasted, and so little experiment bestowed, by earlier writers.

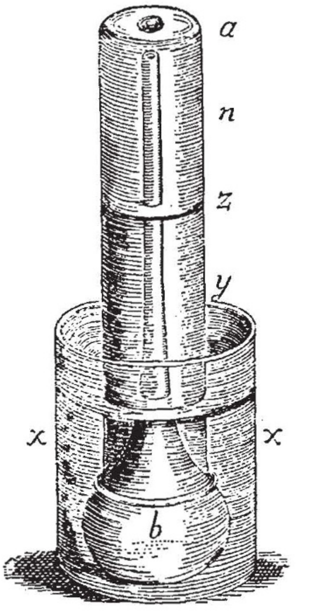

FIG. 21.

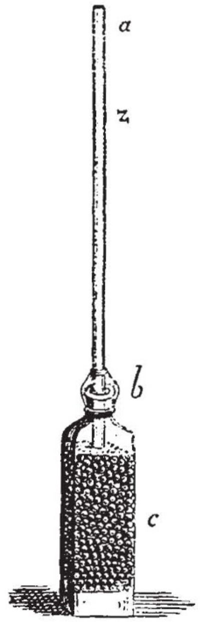

FIG. 22.

FIG. 21.—Hales' method of measuring a gas. FIG 22.—Measurement of the elastic force of the gas produced by fermenting peas.

We are drawing towards the end of our subject, but we think any account of the earlier history of chemistry would be very incomplete without a notice of the work of Dr. Stephen Hales (born 1677, died 1761). In a number of papers communicated to the Royal Society, and afterwards published in a work entitled *Statical Essays*, we find a variety of experiments by Hales, chiefly relating to pneumatic chemistry. Herein we find an account of "a specimen of an attempt to analyse the air by a great variety of chymico-statical experiments, which show in how great a proportion air is wrought into the composition of animal, vegetable, and mineral substances, and withal how readily it resumes its former elastick state, when in the dissolution of those substances it is disengaged from them." In order to determine the quantity of air disengaged from any substance during distillation or fusion, Hales placed the substance in a retort, and luted the retort to a large receiver with a small hole, at the bottom; water was caused to occupy a known space in the receiver, and the amount of air expelled was estimated by noting the amount of water remaining in the receiver at the conclusion of the experiment, after cooling. Hales employed the following apparatus (Fig. 21) to measure the volume of air generated by any kind of fermentation, also by the reaction of one body upon another.

The substances undergoing fermentation were placed in b, and over the whole a vessel, $a\ y$, was inverted, closed below by the vessel $x\ x$, and containing above a certain amount of air, to the level y. If air were generated, the water in a sank (say to y); while if air were absorbed by the bodies in b, the water rose (say to n). Sometimes he placed different substances on pedestals in a jar of air, and ignited them, as Mayow had done, by a burning-glass, and noted the alteration in the bulk of air. He did this with phosphorus, brown paper dipped in nitre, sulphur, and other substances. If he required to act upon substances by means of a strong acid, he would place the substance in a suitable vessel on a pedestal in a known volume of air, standing over water, and would suspend over it a phial which could be emptied by pulling a string. These devices were closely copied by Priestley and Lavoisier in their experiments upon gaseous bodies. If a substance required to be heated violently, it was placed in a bent gun-barrel, $r\ r$ (Fig. 23), one end of which was placed in a furnace, while the other was placed under a bell jar, $a\ b$, full of water, inserted in the pail of water $x\ x$. He distilled a number of substances, apparently taken at random, and determined the amount of gas evolved, but he appears to have been at no pains to determine the nature of the gas, assuming it to be ordinary atmospheric air. Thus he distilled 1 cubic inch of lard, and collected thirty-three cubic inches of gas as the products of decomposition. Tallow, horn, sal ammoniac, oyster shells, peas, amber, camphire, and many other substances, were similarly treated.

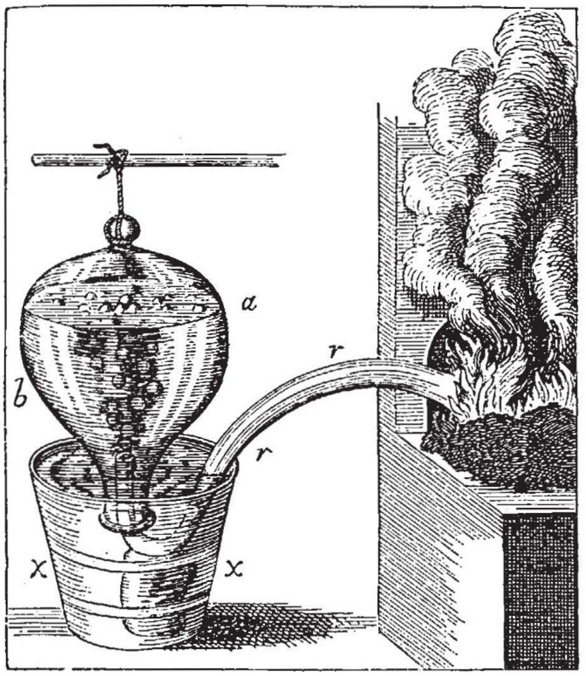

FIG. 23.—Hales' pneumatic experiments.

Two grains of phosphorus ignited in a closed vessel of air, were found to absorb 28 cubic inches of air. 211 grains of nitre mixed with bone-ash yielded 90 cubic inches of gas; 54 cubic inches of water on boiling yielded 1 cubic inch of air. In order to measure the elastic force of the gas produced by fermenting peas, Hales filled a small, strong bottle, c (Fig. 22) with peas, filling up the interstices with water; mercury to a depth of half an inch was then poured in, and of course remained at the bottom of the vessel c. A long tube, $a\ z$, the lower end of which dipped beneath the mercury, was securely fastened into the mouth of the bottle b, and fixed air-tight. In a few days' time the peas were in a state of fermentation, and the generated gas had forced the mercury to ascend in the tube $a\ z$ to a height of 80 inches, hence the gas in c was existing under a pressure of about 35 lbs. on the square inch.

Hales also produced gases by various reactions. Thus he poured a cubic inch of sulphuric acid on half a cubic inch of iron filings: no effect took place until he had diluted the acid with water, when forty-three cubic inches of *air* (as he calls it—in reality hydrogen gas) came off. Iron filings mixed with nitric acid, or with ammonia, or sulphur, were found to absorb air. A cubic inch of chalk treated with dilute sulphuric acid produced thirty-one cubic inches of *air* (in reality carbonic anhydride gas). If space permitted, we could say much more of Hales' works. His experiments on respiration, and on various principles of vegetation, are exceedingly ingenious, and often accurate. It has often been said that Lavoisier created modern chemistry by the introduction of the balance into chemical experiments, but here we find Hales weighing his substances, and measuring his gases, years before Lavoisier was born. Hales did not sufficiently investigate the nature of the various gases which he produced in the course of his experiments, but he assuredly paved the way for many of the after discoveries of Priestley, Cavendish, and Lavoisier.

Dr. Hermann Boerhaave, of Leyden (b. 1668, d. 1738), was a contemporary of Hales. He was the author of the first comprehensive system of chemistry:—a bulky quarto in two volumes, entitled *Elementa Chemiæ*, which appeared in 1732, and which for many years was the chemical text-book of Europe. In it he defines chemistry as "an art which teaches the manner of performing certain physical operations, whereby bodies cognizable to the senses, or capable of being rendered cognizable, and of being contained in vessels, are so changed by means of proper instruments, as to produce certain determinate effects, and at the same time discover the causes thereof for the service of various arts."

But hold! our task was to give some account of the *birth* of chemistry, while a science with such a ponderous definition as the above, is no longer infantile. The babe has grown up about us until it has assumed a tremendous individuality. The great discoveries of the fathers of modern chemistry, Lavoisier, Scheele, Priestley, Cavendish, Davy, need not be told here; they belong to the later history of chemistry. We have traced the science from its commencement in the crude metallurgical and other operations of the ancients, to the time when a comprehensive system of the science appeared. And when we think of the vast dimensions of the science of to-day, the numberless text-books in every language, the great laboratories springing up in every country, the immense amount of original research, we are carried back in spirit to those mistaken—but often grandly energetic men—who said to the disciples of their art:—

Ora!
Lege, Lege, Lege, Relege, Labora!
Et Invenies.

G. F. RODWELL

SCIENTIFIC SERIALS

Bulletin Mensuel de la Société d'Acclimatation de Paris. The April number contains much interesting information as to the work done by the Society, which besides gratuitously distributing specimens of various useful animals or plants wherever they are likely to thrive, also lends or lets to those persons, whose tastes or knowledge fit them for the charge, some of the rarer species of animal or vegetable life, thus sowing the seeds of miniature *jardins d'acclimatation* throughout the country. During the last 12 months 3 monkeys have been born at the Paris Gardens, one of them in March last. In that month 75 mammalia and 1,669 birds of various sorts were received, while the Society was able to distribute 62 mammalia and 1,731 birds. The Society aims at encouraging the reproduction of all sorts of useful animals, not merely confining its efforts to the maintenance of a stock for exhibition. An interesting account is given of an oyster breeding establishment and aquarium at Biarritz, and of the cultivation of silkworms in France generally. Our French neighbours have set us the example of cultivating