HISTORY OF CHEMISTRY

SIR EDWARD THORPE

THE HISTORY OF SCIENCE SERIES
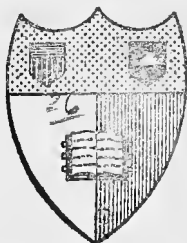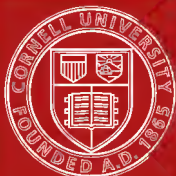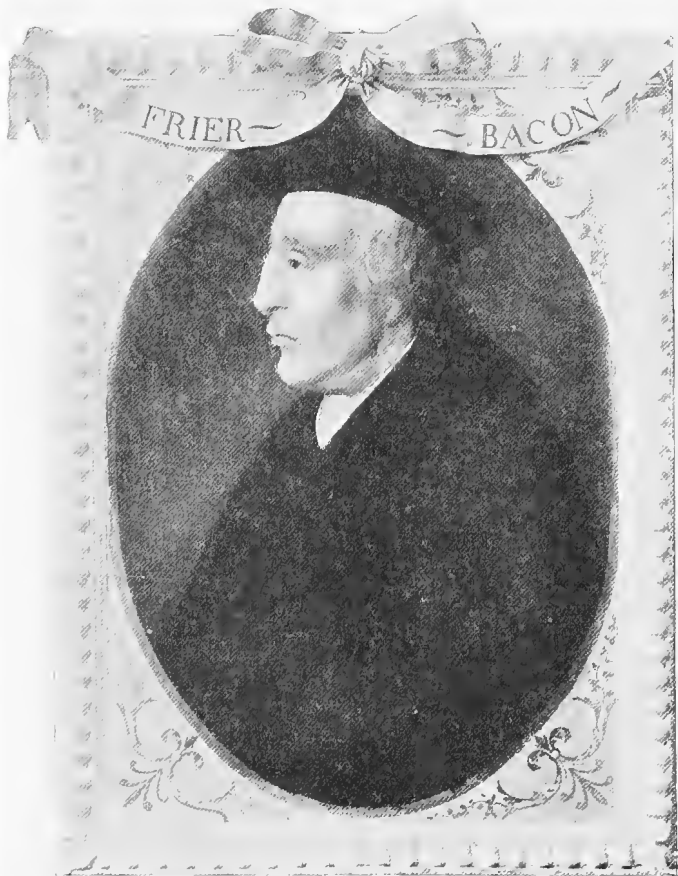
ROGER BACON.
From a painting in the possession of Lord Sackville at Knole.

HISTORY OF

CHEMISTRY

BY

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Nineteenth Century.

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Chapter I.

THE CHEMISTRY OF THE ANCIENTS

CHEMISTRY, as an art, was practised thousands of years before the Christian era; as a science, it dates no further back than the middle of the seventeenth century. The monumental records of Egypt and the accounts left us by Herodotus and other writers show that the ancient Egyptians, among the earliest nations of whom we have any records, had a considerable knowledge of processes essentially chemical in their nature. Their priests were adepts in certain chemical arts, and chemical laboratories were occasionally attached to their temples, as at Thebes, Memphis, and Heliopolis. It is to be supposed, too, that in a cultured class, as the priesthood undoubtedly was, there would be now and again curious and ingenious persons who would speculate on the nature and causes of the phenomena which they observed. But there is no certain evidence that the Egyptians ever pursued chemistry in the spirit of science, or even in the manner in which they and the Chaldeans followed, for example, astronomy or mathematics. The operations of chemistry as performed by them were of the nature of manufacturing processes, empirical in character and utilitarian in result. It was comparatively late in the world's history that men were found willing to occupy themselves in chemical pursuits in order to gain an insight

into the nature of chemical change, and to learn the causes and conditions of its action.

Although we have cited the ancient Egyptians as practising the chemical arts, there is no proof that these arts actually originated with them.   China, India, Chaldaea have each in turn been regarded as the birth-place of the various technical processes from which chemistry may be said to have taken its rise.   Neverthe-less, it is mainly from Egyptian records, or from writings avowedly based on information from Egyptian sources, that such knowledge as we possess of the earliest chemical processes is derived.   It is significant that the word "chemistry" has its origin in *chêmi*, "the black land," the ancient name for Egypt.   The art itself was constantly spoken of as the "Egyptian art."

"The word *chemistry*," says Boerhaave, in the Pro-legomena of his *New Method of Chemistry* (Shaw and Chambers's translation, London, 1727),

> in *Greek* should be wrote χημια, and in *Latin* and *English* *chemia* and *chemistry*; not as usual, *chymia* and *chymistry*.
>
> The first author in whom the word is found is *Plutarch*, who lived under the Emperors *Domitian*, *Nerva*, and *Trajan*. That philosopher, in his treatise of *Isis* and *Osiris*, takes occasion to observe that *Egypt*, *in the sacred dialect of the country*, *was called by the same name as the* black *of the eye*—viz., χημια—by which he seems to intimate that the word *chemia* in the *Egyptian* language signified black, and that the country, *Egypt*, might take its denomination from the *blackness* of the soil.
>
> But [continues Boerhaave] the etymology and gram-matical signification of the name is not so easily dis-patched.   The critics and antiquaries, among whom it has been a great subject of inquiry, will not let it pass without some further disquisition.   Instead of *black*, some will have it originally denote *secret*, or *occult*; and

hence derive it from the *Hebrew chaman*, or *haman*—a *mystery*, whose radix is *cham*. And, accordingly, *Plutarch* observes that *Egypt*, in the same sacred dialect, is sometimes wrote in *Greek* χαμια—*chamia ;* whence the word is easily deduced further from *Cham*, eldest son of *Noah*, by whom Egypt was first peopled after the deluge, and from whom, in the Scripture style, it is called the *land of Cham*, or *Chem*. Now, that *chaman*, or *haman*, properly signifies *secret* appears from the same *Plutarch*, who, mentioning an ancient author named *Menethes Sibonita*, who had asserted that *Ammon* and *Hammon* were used to denote the god of *Egypt*, *Plutarch* takes this occasion to observe that in the *Egyptian* language anything secret or occult was called by the same name, αμμον—*Hammon*....... Lastly, the learned *Bochart*, keeping to the same sense of the word, chooses to derive it from the *Arabic chema*, or *kema*—to *hide ;* adding that there is an *Arabic* book of secrets called by the same name *Kemi*.

From the whole of which Boerhaave gathers that chemistry was thus originally denominated because it was considered of old as " not fit to be divulged to the populace, but treasured up as a religious *secret*."

If we are to credit Zozimus the Panopolite, who is said to have lived about the beginning of the fifth century, there were sound reasons for thus treasuring up chemistry as a religious secret, since, as it sprang from the *pretium amoris*, its origin was not too reputable. " What the divine writings relate is that the angels, enflamed with the desire of women, instructed 'em in all the works and mysteries of nature. For which indiscretion they were excluded heaven, as having taught men things unfit for 'em to know." And Scaliger asserts that " Hermes testifies as much ; and all our learning, both open and occult, confirms the account." But who Hermes was, adds that author, is

hard to say, for none of his writings has survived to our age, "that lately published in Italy under the name of *Hermes Trismegistus* being a manifest forgery."

This legend of the "feministic" origin of chemistry is in reality much older than the fifth century of our era, and is but a variant of that which, according to Jewish writers, led to the expulsion of man from Paradise. A similar myth was current among the Phœnicians, Persians, Greeks, and Magi. We trace it in the legend of Sibylla, who demanded, as the price of her favour to Phœbus, not only length of years, but a knowledge of the divine *arcanum*. Some of the ecclesiastics who elaborated these myths are particular in their accounts of the mysteries thus imparted. They included the use of charms, a knowledge of gold and silver and precious stones, the art of dyeing, of painting the eyebrows, etc.—the kind of *arcana*, in fact, which women in all ages were presumably most keen to know. It is, however, significant that in all allusions to *chemia*, even after the translation of the seat of the Roman Empire to Constantinople, it is implied that a knowledge of it was a sacred mystery, to be known only to the priesthood, and jealously guarded by them. It was characteristic of writers who had affixed an eternal stigma on Eve to make the sex in general answerable for an illicit knowledge of "things unfit for men to know."

For, in reality, chemistry originated with men, and it was not so much in the love of women as of wine that it took its rise.

The manufacture of *alcohol* by processes of fermentation is probably the oldest of the chemical arts. The word *wine* means, in fact, a *product of fermentation*. Mosaic history relates that Noah, soon after he got to

dry land, "planted a vineyard and drank of the wine," with results that would appear to show that the potency of wine was not unfamiliar to him. Diodorus Siculus, who studied Egyptian antiquities when Egypt was a Roman province, states that the ancient Egyptians ascribed the origin of wine to Osiris. It was a sacrificial offering even in the earliest times, as was bread. Wine seems to have been prepared by the Chinese as far back as the time of the Emperor Yü, *circa* 2220 B.C. Beer was manufactured in Egypt in the time of Senwosret III. (Sesostris) B.C. 1880.

The Egyptians were skilled in dyeing and in the manufacture of leather, and in the production and working of metals and alloys. They were familiar with the methods of tempering iron. They made glass, artificial gems, and enamels. The oldest known enamel was found as an amulet on the Egyptian Queen Aahotep (1700 B.C.), and glass beads were made before the time of Thutmosis III. (1475 B.C.). The Jews knew of gold, silver, copper, iron, lead, and tin. Indeed, it is through them and the Phœnicians, who were among the earliest of traders, that Europe was gradually made acquainted with many technical products of Eastern origin.

The beginnings of the art of extracting and working of metals are lost in the mists of antiquity; the chemistry of metals, indeed, has been said to be almost coeval with mankind. Diodorus Siculus found traditions in Egypt as to the first inventor of metallurgical processes identical with that of the son of Lamech and Zillah, Tubal-cain or Tuval-cain of the Hebrews—the Vulcan of the Romans.

Gold was undoubtedly one of the earliest metals to be made use of by men, as it probably was one of the

first to be discovered. It occurs free in nature, and is met with in many rocks and in the sands of rivers. Its colour, lustre, and density would early attract attention to it ; and its malleability and ductility and the ease with which it could be fashioned, together with its unalterability, would render it valuable. Ethiopian and Nubian gold were known from the earliest times, and quartz crushing and gold washing were practised by the Egyptians. Representations of these processes have been found on Egyptian tombs dating from 2500 B.C. Gold-wire was used by the Egyptians for embroidery, and they practised plating, gilding, and inlaying as far back as 2000 B.C.

Silver also was employed by them, and appears, like gold, to have been coined into money. It was originally known as " white gold." Some of the oldest coins in existence are alloys of silver and gold, obtained probably by the fusion of naturally occurring argentiferous gold, such as the pale gold of the Pactolus. Such an alloy was termed *electrum*, from its resemblance in colour to amber.

Copper is also found to a limited extent in the metallic state, but probably the greater part of that used by the ancients was obtained from its ores, which are comparatively abundant and readily smelted. It was also used for coinage by the Egyptians, and was fashioned by them into a variety of utensils and implements. The older writers drew no clear distinction between copper, bronze, and brass, and the terms designating them— *æs* and χαλκός—are frequently employed, as by Pliny, indiscriminately. The statement in Deut. viii. 9—" Out of whose hills thou mayest dig brass "—obviously cannot mean an alloy of copper and zinc, since this does not occur naturally.

Pure copper is too soft a metal to be used for swords and cutting instruments, but copper ores frequently contain associated metals, as, for example, tin, which would confer upon the copper the necessary hardness to enable it to be fashioned into weapons. Such copper would be of the character of bronze, and it was known to the early workers that the nature of the metal was greatly modified by the selection of ores from particular localities. It was comparatively late in the metallurgical history of copper that bronze was produced by knowingly adding tin to the metal.

Copper was largely used by the Romans, who obtained it from Cyprus; it was known to them as *æs Cyprium*, and eventually *Cuprum*, whence we obtain the chemical symbol Cu. What the Romans called *æs* was found also at Chalkis, in Eubœa, whence χαλκός, the Greek word for copper.

Aurichalcum, or golden copper—that is, brass—was well known to the early workers in copper, and was made in Pliny's time by heating together copper, cadmia (calamine), and charcoal.

Bell metal was employed by the Assyrians, and bronze was cast by the Egyptians for the manufacture of mirrors, vases, shields, etc., as far back as 2000 B.C. Statuary bronze, largely used by the Romans, usually contained more or less lead.

Tin, which was also known to the early Egyptians, would appear to have been first obtained from the East Indies, and to have been known under the Sanskrit name of *Kastîra* (*Kâs*, to shine), whence we have the Arabic word for tin, *Kàsdir*, and the Greek κασσιτερος, used by Homer and Hesiod. Tin ores are found in Britain (Cornwall), and were brought thence by the Phœnicians. The group of islands, including the Scilly Islands and

the larger island to the east (Britain), was known to the Romans as the *Insulæ Cassiterides*.

Pliny states that the tin is found in grains in alluvial soil, from which it is obtained by washing; but he gives no description of the method of smelting. The Latin word for tin was *stannum;* it was also known as *plumbum album*, in contradistinction to lead, which was called *plumbum nigrum*. Tin was used by the Romans for covering the inside of copper vessels, and was also occasionally employed in the construction of mirrors.

Lead was well known to the Egyptians. In Pliny's time it was mainly procured from Spain and from Britain (Derbyshire). Leaden pipes were used by the Romans for the conveyance of water, and sheet lead was employed by them for roofing purposes. The Romans were also aware of alloys of lead and tin. *Argentarium* was composed of equal parts of lead and tin ; *tertiarium*, used as a solder, consisted of two parts of lead and one part of tin.

Iron, although now the most important of the common metals, was not in general use until long after the discovery of gold, silver, and copper. This was probably due to the fact that, although its ores are relatively abundant and widely distributed, its extraction as a metal demanded greater skill and more appliances than were possessed by the earlier races. Metallic iron was, however, well known to the Egyptians, who employed it in the manufacture of swords, knives, axes, and stone-chisels, both as malleable iron and as steel. Steel was also known to the Chinese as far back as 2220 B.C., and they were acquainted with the methods of tempering it. The good quality of Chinese steel caused it to be highly prized by Western nations. The earliest people to smelt iron are supposed to have been the

Chalybes, a nation inhabiting the neighbourhood of the Black Sea; it is from them that the ancient name for steel—*chalybs*—is derived, and also our word "chalybeate."

Mercury has long been known, but there is no evidence that the ancient Egyptians were aware of its existence, or it would probably have been mentioned by Herodotus. It was familiar to Aristotle, and its mode of manufacture from cinnabar is described by Theophrastus (320 B.C.), who terms it "liquid silver." Processes of amalgamation were known to Pliny, who notes the readiness with which mercury dissolves gold. Pliny appears to distinguish the native metal found in Spain, which he terms *argentum vivum* (quicksilver), from that obtained by sublimation or distillation from cinnabar, which he calls *hydrargyrum*, from which we get the chemical symbol for mercury Hg.

A considerable number of metallic compounds were known to the ancients, and were employed by them as medicines and as pigments. The oxides of copper, known as *flos æris*, and *scoria æris*, obtained by heating copper bars to redness and exposing them to air, were used as escharotics. Verdigris, or *ærugo*, was made by the same methods as now. Blue vitriol, or *chalcantum*, is described by Pliny, who says that the blue transparent crystals are formed on strings suspended in its solution.

Chrysocolla, malachite, or copper carbonate, was used as a green pigment. The blue κύανος of the Greeks, or *cæruleum* of the Romans, was obtained by fritting together alkali, sand, and oxide of copper. *Botryitis, placitis, onychitis, ostracitis*, were varieties of *cadmia* or oxide of zinc, obtained by calcining calamine, and were used in the treatment of ulcers, etc.

Molybdena, which was the Latin name for litharge, was employed externally as an astringent and in the manufacture of plaster.   The lead plaster employed by Roman surgeons was practically identical in character and mode of preparation with that in use to-day. *Cerussa*, or white lead, was made as now by exposing sheets of lead to the fumes of vinegar.   It was used in medicine, as a pigment, and in the preparation of cosmetics.   *Cerussa usta* was probably red lead.   Its present name of *minium* was originally applied to cinnabar, the red sulphide of mercury, which was frequently adulterated with red lead.

Cinnabar, formerly obtained from Africa, and, by the Romans, from Spain, was also used externally in medicine, and was a highly prized pigment, whose value was known to the Chinese from very early times. The black sulphide of antimony, the *stimmi* and *stibium* of Dioscorides and Pliny, was employed by women in Asia, Greece, and latterly in Western Europe, and is still so used in the East, for blackening their eyelashes. Preparations of antimony were used in medicine. *Realgar*, the scarlet sulphide of arsenic, the *sandarach* of Aristotle, and the *arrenichon* of Theophrastus, was employed as a pigment, and also in medicine, both internally and externally.   The yellow sulphide of arsenic, or *auri pigmentum* (orpiment), was also used for the same purposes.

A variety of yellow and red ochres, in addition to the pigments above mentioned, were used by painters, such as *rubrica*, an iron ochre of a dark red colour, and *sinopis*, or reddle, obtained from Egypt, Lemnos, and the Balearic Isles.   Oxides of manganese were used as brown pigments.   The white pigment, *paratonium*, was probably meerschaum.   *Melinum* was a variety of

chalk found in Samos. The ancients were well acquainted with indigo and madder, and with the mode of manufacturing lakes, which were employed by Grecian artists

The famous *purpurissum* was chalk or clay stained by immersion in a solution of Tyrian purple. *Atramentum* was lamp-black : ivory-black was used by Apelles, and was known as *elephantinum.* The ink of the ancients consisted of lamp-black suspended in a solution of gum or glue. The *atramentum indicum*, imported from the East, was identical with China ink.

The ancients were well skilled in the art of dyeing, and even of calico printing. The Tyrians produced their famous purple dye as far back as 1500 B.C. It was obtained from shell-fish, mainly species of Murex, inhabiting the Mediterranean. Tyrian purple has been shown to be dibrom-indigo, and to have been produced by the action of air and light upon the juices exuded from the shell-fish. The fine linen of the Old Testament was probably cotton, for the production of which Egypt was long celebrated. That the Egyptians were acquainted with the use of mordants seems evident from the following passage from Pliny, quoted by Thomson :—

There exists in Egypt a wonderful method of dyeing. The white cloth is stained in various places, not with dye stuffs, but with substances which have the property of absorbing colours ; these applications are not visible upon the cloth, but when they are dipped into a hot caldron of the dye they are drawn out an instant after dyed. The remarkable circumstance is that, though there be only one dye in the vat, yet different colours appear upon the cloth ; nor can the colour be afterwards removed.

This passage accurately describes the process of madder dyeing on cotton, whereby a variety of fast colours—reds, browns, and purples—can be obtained from the same vat by the employment of different mordants, such as alumina, oxide of iron, or oxide of tin, etc.

Glass has been known from very early times. Representations of glass-blowing were found on the monuments of Thebes and Beni Hassan, and large quantities of glass were exported to Greece and Rome from Egypt, mainly by Phœnicians. Aristophanes mentions it as *hyalos*, and speaks of it as the beautiful transparent stone used for kindling fire. The Egyptians made use of various metallic oxides in colouring glass. The *hæmatinon* of Pliny was a red glass coloured with cuprous oxide. Cupric oxide was used to colour glass green ; and ancient blue glass has been found to contain cobalt. The costly *vasa murrhina* of the Romans, obtained from Egypt, probably consisted of fluorspar, identical with the Blue John of the Derbyshire mines.

Stoneware has been made from time immemorial, and the Chinese have manufactured porcelain from very remote periods. Bricks and tiles were made by the Romans, and mortar and stucco were employed by the ancient Egyptians.

Soap *(sapo)* is mentioned by Pliny, but its detergent properties were apparently unknown to him. It appears to have been first made by the Gauls, who prepared it from the ashes of the beech and the fat of goats, and used it as a pomatum, as did the *jeunesse d'oreé* of Rome. Wood ashes, as well as natron, were, however, used by the ancients for their cleansing properties.

Starch, acetic acid, sulphur, alumen or crude sulphate of alumina, beeswax, camphor, bitumen, naphtha, asphalt, nitrum (carbonate of soda), common salt, and lime, were all well known to the Egyptians, and were used by them for many of the purposes in which they are employed to-day.

It will be evident from this brief survey that the ancients possessed a considerable acquaintance with many operations of technical chemistry; but, although they must necessarily have accumulated a large amount of knowledge, very little has come down to us concerning the mode in which their processes were conducted, or as to the precautions they employed to ensure uniform results. Their methods were probably jealously guarded and handed down by successive members of the crafts as precious secrets. The experienced masters of these crafts must have met with many strange and perplexing phenomena in the course of their operations, and a spirit of inquiry must thereby at times have been awakened. But, under the conditions in which their industries were prosecuted, the scientific spirit was not free to develop, for science depends essentially upon free inter-communication of facts and the spread of knowledge of natural pheno-mena. Moreover, the great intellects of antiquity, for the most part, had little sympathy with the operations of artisans, who, at least among the Greeks and Romans, were, for the most part, slaves. Philo-sophers taught that industrial work tended to lower the standard of thought. The priests, in most ages, have looked more or less askance at attempts, on the part of the laity, to inquire too closely into the causes of natural phenomena. The investigation of nature in early times was impossible for religious reasons.

There was an outcry in Athens when the thunder-bolts of Zeus were ascribed to the collision of clouds. Anaxagoras, Diogenes of Apollonia, Plato, Aristotle, Diagoras, and Protagoras were charged by the priests with blasphemy and driven into exile. Prodikos, who deified the natural forces, as did Empedokles the primal elements, was executed for impiety. Sacerdotalism in Athens had no more sympathy with science than had the Holy Congregation in Italy when it banned the writings of Copernicus, Kepler, and Galileo, and sent Giordano Bruno to the stake. The educated Greeks had no interest in observing or in explaining the pheno-mena of technical processes. However prone they might be to speculation, they had no inclination to experiment or to engage in the patient accumulation of the knowledge of physical facts. " You Greeks," says Plato in one of his Dialogues, " are ever children, having no knowledge of antiquity, nor antiquity of knowledge !" The influence of a spurious Aristotelian-ism, which lasted through many centuries and even beyond the time of Boyle, was wholly opposed to the true methods of science, and it was only when philo-sophy had shaken itself free from scholasticism that chemistry, as a science, was able to develop.

Chapter II.

THE CHEMICAL PHILOSOPHY OF THE ANCIENTS

Speculations as to the origin and nature of matter, and as to the conditions and forces which affect it, are to be found, more or less imperfectly developed, in the oldest systems of philosophy of which we have any record. These speculations are not based, in any real sense, upon the systematic observation of natural phenomena. Still, as they appealed to human reason, they must be held to be founded upon experience, or at least not to be consciously inconsistent with it. All the oldest cosmogonies regarded water as the fundamental principle of things : from Okeanos sprang the gods—themselves deified personifications of the " elements " or principles of which the world was made.

In the course of time this doctrine of the origin and essential nature of matter came to be more particularly associated with the name of Thales of Miletus, who lived six centuries before our era, and who, according to Tertullian, is to be regarded as the first of the race of the natural philosophers—that is, the first of those who made it their business to inquire after natural causes and phenomena. Thales is known to have passed some years of his life in Egypt, and to have been instructed in science by the priests of Thebes and Memphis ; and it is therefore possible that he may have been influenced

by the Egyptian teaching in the formulation of his cosmological theories.

It is significant of the tenacity with which the mind clings to dogma and reveres authority that the teaching of Thales should have survived through the space of twenty-four centuries. It can be shown to have affected the course of chemical inquiry down to the close of the eighteenth century. It influenced the experimental labours of philosophers so diverse in character as Van Helmont, Boyle, Boerhaave, Priestley, and Lavoisier—all of whom made attempts to prove or disprove its adequacy. Van Helmont, indeed, was one of the most strenuous supporters of the doctrine of Thales, and sought to establish it by observations which, in the absence of all knowledge of the true nature of air and water, seemed at the time irrefutable. Perhaps the one most frequently cited is his observation on the growth of a plant which apparently had no other form of sustenance than water. He describes how he planted a willow weighing 5 lbs. in 200 lbs. of earth previously dried in an oven. The plant was regularly watered, when at the end of five years it was found to weigh 169 lbs. 3oz., whereas the earth, after redrying, had lost only 2 oz. in weight. Hence, 164 lbs. of woody matter, leaves, roots, etc., had been produced seemingly from water alone. More than a century had to elapse before any clue to the true interpretation of Van Helmont's experiment was gained. It was first furnished by the observations of Ingenhousz and Priestley.

Although the idea of a primal " element " or common principle is to be found in every old-world philosophical system, the ancient philosophers were by no means in agreement as to its character. Anaximenes, who

lived *circa* 500 B.C., taught that it was air, Hera-
kleitos of Ephesus that it was fire, and Pherekides
that it was earth.   The supposition that a single
primordial principle could be made to account for
all forms of matter and all the phenomena and
manifestations of the material world had its difficulties.
Attempts to group qualities as principles, and to con-
struct from these principles the universe, were indeed
made even prior to the age of Thales.   It was a com-
paratively simple evolutionary step to regard these
principles or "elements" as mutually convertible.
Anaximenes' theory of the formation of rain was an
implicit admission of such convertibility.   This philo-
sopher taught that rain came by the condensation of
clouds, which in their turn were formed by the conden-
sation of air.   Everything comes from air, and everything
returns to air.   That water might be converted by fire
into air was surmised from the earliest times.   Such a
supposition naturally sprung from the circumstance
that water was everywhere recognised to disappear or
to pass into the air under the influence of fire or solar
heat.   The supposition had grown into a fixed belief in
the Middle Ages.   Even Priestley, as late as the end of
the eighteenth century, imagined for a time that he had
obtained proof of such a mutual conversion.   The possi-
bility of the transmutation of water into earth was a
belief current through twenty centuries, and was only
definitely and finally disproved by Lavoisier in 1770.
The conception of fire as the primal principle has its
germ in the fire- or sun-worship of the Chaldeans,
Scythians, Persians, Parsees, and Hindus ; and it is
not difficult to trace, therefore, how heat came to be
regarded either as antecedent to, or as associated with,
the other primal principles.   Empedokles, apparently,

was the first whose name has come down to us to reintroduce the definite conception of four primal elements—fire, air, water, and earth. These he regarded as distinct, and incapable of being transmuted, but as forming all varieties of matter by intermixture in various proportions. These principles he deified, Zeus being the personification of the element of fire, Here of air, Nestis of water, and Aidoneous of earth.

The doctrine of the four elements was also adopted by Plato and amplified by Aristotle, with whose name indeed it is commonly associated. Aristotle, the greatest scientific thinker among the Greeks, exercised an authority almost supreme in Europe during nearly twenty centuries. His influence is to be traced throughout the literature of chemistry long after the time of Boyle. It may be detected even now. Probably few who write chemical memoirs to-day, and who follow the time-honoured practice of prefacing their own contributions to knowledge by a statement of what is already known on the subject, are aware that in so doing they are obeying the injunctions of Aristotle. His theory of the nature of matter is contained in his treatise on *Generation and Destruction*. It mainly differed from that of Empedokles in regarding the four "elements" as mutually convertible. Each "element" or principle was regarded as being possessed of two qualities, one of which was shared by another element or principle.

Thus : Fire is hot and dry; air is hot and wet; water is cold and wet ; earth is cold and dry.

In each primal "element" one quality prevails. Fire is more hot than dry ; air is more wet than hot ; water is more cold than wet ; earth is more dry than cold. The relative proportion and mutual working of these

qualities determined the specific character of the
" element." Thus, if the dryness of fire is overcome by
the moisture of water, air is produced ; if the heat of
air is overcome by the coldness of earth, water is
formed ; if the moisture of water is overcome by the
dryness of fire, earth results. Ancient chemical litera-
ture contains many illustrations or diagrams symbolising
the convertibility or mutual relations of the four
" elements."

It has been frequently stated that the influence of
the Peripatetic philosophy has been inimical to the
development of science. But, in reality, the founder
of that school, a descendant of Esculapius, and un-
doubtedly one of the greatest and most enlightened
thinkers of antiquity, was an ideal man of science.
This is abundantly evident from such of his works as
can be proved to be genuine. Much of what is called
Aristotelianism is entirely foreign to the spirit of the
teaching of Aristotle. The Aristotelians of the Middle
Ages were mainly dialecticians, and almost wholly
concerned with the formulæ of syllogistic inference,
and without real sympathy with, or knowledge of, his
system. Much, too, that was attributed to him, and
which was venerated accordingly, is undoubtedly
spurious. The fame of the Master has consequently
suffered at the hands of those who, calling themselves
Peripatetics, were in no proper sense followers of his
method or interpreters of his dogma. Aristotle affirmed
that natural science can only be founded upon a know-
ledge of facts, and facts can only be ascertained through
observation and experiment. He illustrates this par-
ticularly by a reference to astronomy, "which," he
says, " is based on the observation of astronomical
phenomena, and it is the case with every branch of

science or art." It is erroneous and unjust, therefore, to suppose that Aristotle's philosophy, as he taught it, is opposed to the true methods of science.

A knowledge of Aristotle's works was transferred by Byzantine writers to Egypt; and, when that land was overrun by the Arabs in the seventh century, they adopted his system, spreading it abroad wherever their conquests extended. In the eighth century they carried it into Spain, where it flourished throughout their occupation of that country. From the ninth to the eleventh century the greater part of Europe was in a state of barbarism. The Moslem caliphate in Spain, under the beneficent rule of Jusuf and Jakūb, alone preserved science from extinction. Cordova, Seville, Grenada, and Toledo were the chief seats of learning in Western Europe; and it was mainly through "the perfect and most glorious physicist," the Moslem Ibn-Roshd—better known as Averroes—(1126–1198), that Christian scholiasts like Roger Bacon acquired their knowledge of the philosophical system of Aristotle, and mainly through the Moslems Geber and Avicenna that they gained acquaintance with the science of the East.

The conception that matter is made up of particles or *atoms*, and that these particles are in a state of ceaseless motion, is to be met with in Hindu and Phœnician philosophy. It was taught by Anaxagoras, Leukippos, and Demokritos to the Greeks, and by Lucretius to the Romans. Leukippos and Demokritos explained the creation of the world as due solely to physical agencies without the intervention of a creative intelligence. According to their theories, the atoms are variable not only in size, but in weight. The smallest atoms are also the lightest. Atoms are impenetrable; no two atoms can simultaneously occupy the same place. The

collision of the atoms gives them an oscillatory movement, which is communicated to adjacent atoms, and these, in their turn, transmit it to the most distant ones. Anaxagoras taught that every atom is a world in miniature, and that the living body is a congeries of atoms derived from the aliments which sustain it. Plants are living things, endowed like animals with respiratory functions, and, like them, atomically constituted.   This philosopher was so far in advance of his age that his countrymen accused him of sacrilege, and he only escaped death by flight.   Further, the assumption that these atoms exert mutual attractions and repulsions is probably as old as the fundamental conception itself.   At least, so far as can be traced, the conceptions of atoms and atomic motion are indissolubly connected.   This is not the place to develop the subsequent history of the doctrine of the atom, nor need we now concern ourselves with the old metaphysical quibble of its divisibility or indivisibility.   It may be, as Lucretius said, that the original atom is very far down.   It may be that the physical atom is something which *is* not divided, not something that *cannot* be divided.   This theory, dimly perceived in the mists of antiquity, has grown and strengthened with the ages, and in its modern application to the facts of chemistry has acquired a precision and harmony unimagined even by the poets and thinkers of old.   We shall see later how the whole course of the science has been controlled, illumined, and vivified by it.   It is not too much to say that the chemistry of to-day is one vast elaboration of this primeval doctrine.

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Chapter III.

ALCHEMY

Although the intellectual tendencies of the Hellenic mind were hardly calculated to favour the development of chemistry as a science, the speculations of the Greeks concerning the essential nature of matter and the mutual convertibility of the "elements" led incidentally to an extension of the art of operative chemistry. This extension resulted from attempts to realise what was the logical outcome of the teaching of their philosophers—viz., the possibility of the transmutation of metals. The idea of transmutation has its germ in the oldest systems of philosophy. It was a plausible doctrine, not wholly unsupported by the phenomena of the organic world ; and it naturally commended itself to men who were only too prone to adopt what their cupidity and love of wealth predisposed them to believe.

It has been assumed that alchemy at no time in its history had the slightest claim to a philosophical foundation, but that its professors and adepts, even at the outset, consciously traded on the credulity and greed of their dupes. Much may be urged against such a partial view. The supposition is not consistent with history or with evolutional tendencies. It may be, as Davy once said, that "analogy is the fruitful parent of error"; but the idea that metals could be modified —could even be changed one into the other—seemed to find support in innumerable chemical phenomena well known but imperfectly understood. The fact that

alchemy—that is, the profession of making gold from other metals—came to be practised by rogues is no proof that it never had, and never could have had, a philosophical basis.

The changes which substances experience under the influence of fire, air, and water, or as the result of their action on each other, are frequently so profound that even the most superficial of the early observers of chemical processes could not fail to be impressed by them. Many of these changes are, in fact, far more striking as regards alteration in outward characters— such as colour, lustre, density, etc.—than are the differences between individual metals; say, between lead and tin, or between tin and silver, or between brass and gold. That copper ores, by appropriate treatment with other ores, or that copper itself by the addition of another metal, could be made to furnish a metallic-looking substance having certain of the attributes of gold was known to the earliest workers in metals. What is thought to be the oldest chemical treatise in existence is a papyrus in the possession of the University of Leyden. It consists of a number of receipts for the working of metals and alloys, and describes methods of imitating and falsifying the noble metals. It explains how, by means of arsenic, a white colour may be given to certain metals, and how, by the addition of cadmia, copper acquires the colour of gold. The same papyrus describes a method of blackening metals by the use of preparations of sulphur. The limited knowledge of chemical phenomena and of chemical processes which these early workers necessarily possessed, so far from precluding a belief in the possibility of transmutation, actually encouraged it. As nothing was known of the true nature of brass,

or of its exact relation to copper, it was not unreasonable to suppose that, if this substance could be made to acquire *some* of the attributes of gold by a process essentially chemical, processes of a like nature might cause it to acquire, if not *all*, at least so many of them as to enable it to pass for gold of greater or less fineness. To them, as to us, perfection was, in technical practice, a question of degree: the very language of the metallurgists of old was in this respect nowise different from that of the metallurgists of to-day.

It is not necessary to suppose that these early attempts were deliberately and consciously fraudulent, like those of coiners who knowingly seek to make an alloy of lead and tin simulate silver. The first alchemists sought in good faith to make something which should be of the true nature and essence of gold as they conceived it to be. In fact, the idea of transmutation had a rational foundation in a theory of the intrinsic nature of metals which may be looked upon as a development of the ancient beliefs concerning the essential nature of all forms of matter.

Just as the Aristotelian "elements" were qualities which, according to their degree, determined the nature of substances, so, in like manner, the specific character of a metal depended upon the relative proportion of its "sulphur" and "mercury." These terms had no certain reference to what we to-day understand by sulphur and mercury. They denoted simply qualities. The essence or "element" of mercury conferred lustre, malleability, ductility, and fusibility, or, speaking generally, the properties which we connote as metallic; while to the essence or "element" of sulphur was to be attributed the combustibility or, speaking generally, the alterability of

the metal by fire. By modifying the relative proportion of these constituent elements, or by purifying them from extraneous substances by the operations of chemistry, it was conceived that the several metals could be changed one into the other. To effect this purification it was necessary to add various preparations known as "medicines," chief among which was the *Great Elixir*, or *Magisterium*, or the *Philosopher's Stone*, by which the final transformation into the noblest of the metals could alone be achieved.

The Arabic words *kímyá* and *iksír* were originally synonymous, and each was used to denote the agent by which the baser metals could be transmuted into silver and gold. Ultimately the former term became restricted to indicate the art of transmutation (alchemy), whereas *iksír*, or *al-iksír*, continued to denote the medium by which the transmutation was effected. By later writers the term was used to indicate a liquid preparation—the *quintessence of the philosophers*—whence we have the word *elixir*, which always means a liquid.

The alchemistic theory of the compound nature and mutual relations of the metals is usually ascribed to Geber ; but, although he adopted it, he distinctly states that it did not originate with him, but that he found it in the writings of his predecessors.

The idea of the *stone,* the *philosophical powder*, the *grand magisterium*, the *elixir*, the *tincture*, the *quintessence*—by all of which terms the transmuting medium is known in the literature of alchemy—is probably connected with another conception respecting the origin of metals which can be traced to very early times, and was prevalent throughout the Middle Ages. It was supposed of old that metals were *generated* within the earth, as animals and plants were generated on its

surface, and that something akin to a seed, or semen, was needed to initiate their formation. The great problem of alchemy was to discover this fecundating substance, as upon it depended the genesis of the perfect metal. This idea of the conception of metals runs through the literature of alchemy. It explains many allusions and much of the terminology of its writers. For example, the furnace in which the alchemist makes his projection is constantly spoken of as the *philosophical egg*.

It is impossible to say with certainty when and where the art of alchemy originated. There is no evidence that it has the antiquity which certain of its adepts claimed for it. Oleus Borrichius referred it to the time of Tubal-cain. The earliest writers on alchemy were probably Byzantine ecclesiastics, some of whom professed to ascribe the art to Egypt, and eventually to the mythological deity Hermes, whose association with chemistry in such terms as "the hermetic art," "hermetically sealed," etc., is thus explained.

This much is established—that at some period prior to the tenth century there arose a special class of operative chemists, for the most part more learned in the knowledge of chemical phenomena in general, and more skilled in chemical manipulation, than the craftsmen and artisans engaged in the manufacture of technical products. They devoted themselves to searching for methods whereby the common and baser metals might be converted into silver and gold. The first known definition of chemistry relates to the aim and operations of this special class. It occurs in the lexicon of Suidas, a Greek writer of the eleventh century, who defines chemistry, χημεια, as the preparation of silver and gold. Attempts at the artificial preparation of the

noble metals probably originated with the Arabians, who followed the Egyptians and the Greeks in the cultivation of chemical pursuits.

Neither Hesiod nor Homer makes mention of the art of producing gold from any other metal, or speaks of the universal medicine. Nor are they referred to by Aristotle or by his pupil Theophrastus. Pliny nowhere speaks of the philosopher's stone, although he tells the story of Caligula, who, tempted by his avarice, sought to make gold from orpiment (*auripigmentum*) by distillation. "The result was that he did indeed obtain gold, and of the finest kind; but in so small quantity, and with so much labour and apparatus, that, the profit not countervailing the expense, he desisted."

According to Boerhaave, the first author who mentions *al-chemia* is Julius Firmicus Maternus, who lived under Constantine the Great, and who, in his *Mathesis*, c. 15, speaking of the influences of the heavenly bodies, affirms "that, if the moon be in the house of Saturn when a child is born, he shall be skilled in alchemy."

The first writer who mentions the possibility of transmuting metals would appear to be a Greek divine called Æneas Garæus, who lived towards the close of the fifth century, and who wrote a commentary on Theophrastus. He was followed by Anastatius the Sinaite, Syncellus, Stephanus, Olimpiodorus; and, says Boerhaave, "a crowd of no less than fifty more, all Greeks, and most or all of them monks." "The art seemed now confined to the Greeks, and among them few wrote but the religious, who from their great laziness and solitary way of life were led into vain, enthusiastical speculations, to the great disservice and adulteration of the art.......They all wrote in the natural style of the Schoolmen, full of jargon, grimace, and obscurity."

Experimental alchemy, as distinguished from industrial chemistry, may, as already stated, be said to have originated with the Arabians. At first, alchemy was regarded as a branch of the art of healing, and its professors were invariably physicians who occupied themselves with the preparation of chemical medicines. In fact, in the beginning its true aim was regarded as that which Paracelsus and the school of iatro-chemists subsequently defined it to be. Under the rule of the Caliphs the study of chemistry made considerable progress, and its literature was greatly augmented. The most notable name in the history of chemistry during the eighth century was **Abu-Moussah-Dschabir-Al-Sufi**—otherwise **Geber**—(born 702, died 765), who is stated to have been either a native of Mesopotamia, or a Greek and a Christian, who afterwards embraced Mahometanism, went to Asia, and acquired a knowledge of Arabic. According to Leo Africanus, a Greek who wrote of the antiquity of the Arabs, Geber's book was originally written in Greek and translated thence into Arabic, and he was not known by the name Geber, which signifies a *great man* or a *prince*, till after this version. Latin translations of what purported to be his works were first published in the early part of the sixteenth century, and an English rendering appeared in 1678. According to this it would seem that Geber regarded all the metals as compounds of "sulphur" and "mercury," the differences between them depending upon the relative proportion and degree of purity of these constituents. He is said to have distinguished them by the astrological names of the planets : thus gold became *Sol*, silver *Luna*, copper *Venus*, iron *Mars*, tin *Jupiter*, and lead *Saturn*. That an occult connection of the metals with the stars existed was part of the creed of alchemy, and

the influence of that belief is still traceable in chemical, and especially in pharmaceutical, literature ; as, for example, in such terms as *Lunar caustic*, *Martian preparations*, *Saturnine solutions*, etc.

It has been held that the idea of a universal medicine had its origin with Geber. But this may be due to a misreading of his words, which in reality may have reference to the transmutation of metals. He tells of a medicine which cures all lepers. But this may be nothing but allegory. By *man* is probably meant gold, and by *lepers* the other metals ; and the medicine is the universal solvent or agent which transmutes. Alchemistic literature is full of allegories of this character. Berthelot has shown that in reality there were two Gebers—one who is generally considered to be of Arab origin, and another whose identity is not established, but who was probably a Western European who appears to have lived about the year 1300.[1]

Other notable names in the history of Arabian alchemy are **Rhazes,** or **Abû Bakr Mohammed ibn Zakariyâ el-Râzi,** who lived *circa* 925, and **Avicenna,** or in Arabic **Abû Ali el-Hosein ibn-Abdallah ibn-Sina,** born 980, died 1037. The former, a Persian, practised medicine at Baghdad as a follower of Galen and Hippocrates. The latter, one of the most eminent of Moslem physicians and a voluminous writer, was a native of Bokhara. He is mainly known in the history of science by his *Canon of Medicine*, in which he describes the composition and preparation of remedies.

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[1] There is very little doubt that the work of " Phileletha," which professed to be taken from an " Uhralten MS." preserved in the Vatican Library, entitled *Geberi des Königes der Araber*, and published by Hieron. Philipp. Nitschel, Frankfurth and Leipzig, in 1710, is spurious.

He wrote at least one treatise on alchemy, but others attributed to him are probably apocryphal. Of his *Philosophia Orientalis*, mentioned by Roger Bacon and Averroes, no trace remains.

Although it is reasonably certain that the alchemists of the time of Geber and of his successors had a considerable acquaintance with manipulative chemistry, there were so many impudent literary forgeries during the alchemical period that the precise extent of the knowledge possessed by the early chemists must always remain uncertain.

A number of the ordinary chemical processes, such as distillation, sublimation, calcination, filtration, appear to have been known to, and to have been commonly practised by, the Arabian chemists; and many saline substances, such as carbonate of soda, pearlash, sal-ammoniac, alum, copperas, borax, silver nitrate, cinnabar, and corrosive sublimate, were prepared by them. They seem to have known of certain of the mineral acids, and were familiar with the solvent properties of *aqua regia*.

An examination of the literature of alchemy serves to show how its principles and tenets developed. The philosopher's stone is first heard of in the twelfth century. Prior to that period the greater number of the Greek and Arabian writers contented themselves with affirming the fact of transmutation, without indicating how it might be accomplished. The universal medicine and the elixir of life were the products of a later age; no mention of them is known before the thirteenth century.

Alchemy flourished vigorously during the Middle Ages, and lingered on even until the early part of the nineteenth century. Its history is simply a long chapter

in the history of human credulity. For the most part
it is a record of self-deception, imposture, and fraud.
It produced an abundant literature, mainly the work
of ecclesiastics, between the seventh and fourteenth
centuries ; but as regards the artificial preparation of
the noble metals or the discovery of the universal medi-
cine or the elixir of life it was barren of result.

Although no clear line of demarcation is possible, it
may be convenient, in dealing with the personal history
of alchemy, to divide it into the two periods before
and after Paracelsus, since under his inspiration and
example alchemy underwent a great development as
regards its professed objects. These eventually became
so extravagant that, wide as are the limits of human
credulity, its pretensions gradually brought it into dis-
repute, and it fell by the weight of its own absurdities.

One of the most reputable of the early Western
alchemists was **Albert Groot,** or **Albertus Magnus,**
born at Lauingen in 1193. He was a Dominican monk,
who became Bishop of Regensburg, but, resigning his
bishopric, retired to a convent at Cologne, where he
devoted himself to science until his death in 1282. He
is credited with having written a number of chemical
tracts, for the most part in clear and intelligible
language, which is more than can be said of the greater
portion of alchemistical literature. He gives an account
of the origin and main properties of the chemical
substances known in his time, and describes the
apparatus and processes used by chemists, such as the
water-bath, alembics, aludels, and cupels. He speaks
of cream of tartar, alum and caustic alkali, red lead,
liver of sulphur and arsenic, green vitriol and iron
pyrites.

Contemporaneously with him was **Roger Bacon,**

Doctor Mirabilis, one of the most erudite men of his age, who was born near Ilchester in Somerset in 1214, and, after studying at Oxford, became a friar, occupied himself in philosophical pursuits, and wrote numerous tracts on alchemy. He describes what was probably gunpowder, but there is no certain proof that he invented it. In his *De Secretis Artis et Naturæ,* written before 1249, he gives instructions for refining saltpetre, and in an anagram which Colonel Hime, in his *Gunpowder and Ammunition,* has interpreted, he states that a mixture " which will produce a thundering noise and a bright flash " may be made by taking " 7 parts of saltpetre, 5 of young hazelwood, and 5 of sulphur." He died in 1285.

Raymund Lully, a friend and scholar of Bacon, was born in Majorca in 1225 (others say 1235), and was buried there in 1315. A member of the Order of Minorites, he had a great reputation as an alchemist ; and a number of books on alchemy and chemical processes are ascribed to him. He described modes of obtaining nitric acid and aqua regia, and studied their action upon metals. He obtained alcohol by distillation, and knew how to dehydrate it by the aid of carbonate of potash, which he obtained by calcining cream of tartar. He prepared various tinctures and essential oils, and a number of metallic compounds, such as red and white precipitate. To him is usually ascribed the first idea of a universal medicine.

There is some difficulty in believing that all that is ascribed to Lully was actually the work of his age, for it would appear to have been a common practice with the disciples and followers of a notable scholar to usher in their performances under their master's name — a practice not unknown in later days. " So full are they of the

experiments and observations which occur in our later writers that either the books must be suppositious, or the ancient chemists must have been acquainted with a world of things which pass for the discoveries of modern practice " (Boerhaave). The story is that Lully plunged into the study of chemistry from the desire to cure a maiden of a cancered breast, and that he was stoned to death in Africa, whither he had journeyed as a missionary. It has been further alleged that at one period of his life he made gold in the Tower of London by the King's order, and that he offered Edward III. a supply of six millions to make war against the infidels. As Boerhaave drily remarks, " the history of this eminent adept is very much imbroiled."

Arnoldus Villanovanus, or **Arnaud de Ville-neuve,** a Frenchman, is said to have been born in 1240, and to have practised medicine in Barcelona, where he incurred the enmity of the Church by reason of his heretical opinions, and was obliged to leave Spain. He led a wandering life, eventually settling in Sicily, under the protection of Frederick II., and acquired a great reputation as a physician. Summoned thence by Clement V., who lay sick at Avignon, he lost his life by shipwreck in 1313.

Johannes de Rupecissa, or **Jean de Raquetaillade,** a Franciscan friar who lived from about the middle to the end of the fourteenth century, wrote a number of treatises on alchemy, and described methods of making calomel and corrosive sublimate. He was accused of the practice of magic, and, by order of Innocent VI., was thrown into prison, where he died. He was buried at Villefranche.

George Ripley, an Englishman, Canon of Bridlington, practised alchemy during the second half of

the fifteenth century. He spent some time in Italy in the service of Innocent VIII. On his return to England he became a Carmelite, and died in 1490. Like Bacon, he was charged with magic. According to Mundanus, he followed alchemy with such success that he was able to advance to the knights of St. John of Jerusalem large amounts of gold for the defence of the Isle of Rhodes against the Turks.

One of the most important names in connection with the history of alchemy is that of **Basil Valentine.** Of his personal history nothing is known. He was supposed to be a Benedictine monk who lived in Saxony during the latter half of the fifteenth century; but there are grounds for the belief that the numerous writings attributed to him are in reality the work of various hands. The attempt made by Maximilian I. to discover the identity of the author was unavailing, nor have subsequent inquiries had any better result. The collection of books bearing his name, first published in the beginning of the seventeenth century, reveals quite a remarkable number of chemical facts up to that time not generally known. The most important of these relate to antimony and its preparations, such as butter of antimony, powder of algaroth, oxide of antimony, etc. He seems to have known of arsenic, zinc, bismuth, and manganese. He describes a number of mercurial preparations, and many of the salts of lead were known to him. He mentions fulminating gold, and was aware that iron could be coated with copper by immersion in a solution of blue vitriol. He knew of green vitriol and the double chloride of iron and ammonium, and gave the modes of making a considerable number of other metallic salts, such as the *sal armoniacum*, which we now know as sal ammoniac. He

also appears to have prepared ether and the chloride and nitrate of ethyl.

There is reason to believe, as stated already, that many of the published works ascribed to these learned men are the work of obscure individuals who traded on their fame. What may with certainty be credited to them serves to show that their theoretical opinions had much in common. They all regarded the transmutation of metals and the existence of the philosopher's stone as facts which could not be controverted. They followed Geber in assuming that all the metals were essentially compound in their nature, and consisted of the essence or " element " of mercury, united with different proportions of the essence or " element " of sulphur.

The alchemists were the professional chemists of their time, and many of them were practising physicians. Indeed, professional chemistry may be said to have originated out of the practice of physic. As the number of chemical products increased and their value in therapeutics became more and more appreciated, there arose another school of alchemists, whose energies were devoted, not to the transmutation of metals—which, however plausible as a belief, seemed hopeless of achievement—but to the more immediate practical benefits which it was recognised must follow from the closer association of chemistry and medicine. This school came to be known as the iatro-chemists. As their doctrines exercised a great influence upon the development of chemistry, it will be desirable to treat of them and their professors in a special chapter.

THE PHILOSOPHER'S STONE

DURING the fourteenth, fifteenth, and sixteenth centuries the cult of alchemy attained to the dignity of a religion. Belief in transmutation and in the virtues and powers of the philosopher's stone, in the universal medicine, the alkahest, and the elixir of life, formed its articles of faith. The position it acquired was due to some extent to the attitude towards it of the Romish Church. Many reputable bishops and fathers were professed alchemists; and chemical laboratories, as in the Egyptian temples, were to be found in monasteries throughout Christendom. Pope John XXII., who had a laboratory in his palace at Avignon, is the reputed author of a work, *Ars Transmutatoria*, published in 1557. But to a still larger extent it was due to the fact that alchemy appealed to some of the strongest of human motives—the wish for health, the fear of death, and the love of wealth. It was a cunningly devised system, which exploited the foibles and frailties of human nature. The policy of the Church, however, it should be said, was not consistently and uniformly favourable to alchemy. Its practices occasionally came under the papal ban, although at times, to suit the exigencies of Christian princes, the interdict was removed. Theosophy and mysticism were first imported into alchemy, not by Arabs, but by Christian workers. The intimate association of religion with alchemy during the Middle Ages is obvious in the writings of Lully, Albertus

Magnus, Arnaud de Villeneuve, Basil Valentine, and other ecclesiastics. Invocations to divine authority are freely scattered over their pages. Even the lay alchemist professed to rule his life and conduct by the example and precepts of the good Bishop of Regensburg. He was directed to be patient, assiduous, and persevering; discreet and silent; to work alone; to shun the favour of princes and nobles, and to ask the divine blessing on each operation of trituration, sublimation, fixation, calcination, solution, distillation, and coagulation.

Although alchemy, at least in its decadent days, lived for the most part by its appeal to some of the lowest instincts of mankind, and is only worth notice as a transient phase in the history of science, a few details concerning the tenets and practices of its professors may be of interest to the curious reader. And first as regards the nature of the philosopher's stone—the grand magistery, the quintessence. Many alchemists professed to have seen and handled it. It is usually described as a red powder. Lully mentions it under the name of *Carbunculus*. Paracelsus says that it was like a ruby, transparent and brittle as glass; Berigard de Pisa that it was of the colour of a wild poppy, with the smell of heated sea salt; Van Helmont that it was like saffron, with the lustre of glass. Helvetius describes it as of the colour of sulphur. Lastly, an unknown writer, under the pseudonym of "Kalid," says that it may be of any colour—white, red, yellow, skyblue, or green. As the substance was wholly mythical, a certain latitude of description may reasonably be expected. Some of the alchemists were of opinion that the magistery was of two kinds—the first, the *grand* magistery, needed for the production of gold;

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the second, the *small* magistery, only capable of en-
nobling a metal as far as the stage of silver.   Then,
as to the amounts required to effect a transmutation,
accounts are equally discrepant.   Arnaud de Villeneuve
and Rupescissa assert that one part of the grand
magistery will convert a hundred parts of a base metal
into gold ; Roger Bacon, a hundred thousand parts ;
Isaac of Holland, a million.   Raymond Lully states
that the philosopher's stone is of such power that even
the gold produced by means of it will ennoble an
infinitely large amount of a base metal.

It is hardly necessary to state that a preparation of
such potency is capable of effecting anything or every-
thing ; and accordingly, as time went on, other attri-
butes than that of transmutation came to be associated
with it.   It may be, as Boerhaave surmises, that the
idea of a universal medicine had its origin in a too
literal interpretation of Geber's allegory of the six lepers.
Be this as it may, during the fourteenth and fifteenth
centuries the philosopher's stone was gravely prescribed
as a means of preserving health and prolonging life.
In case of illness one grain was directed to be dissolved
in a sufficient quantity of good white wine, contained
in a silver vessel, the draught to be taken after mid-
night.   Recovery would follow after an interval depend-
ing upon the severity and age of the complaint.   To
keep in good health, the dose was to be repeated at the
beginning of spring and autumn.   " By this means,"
says Daniel Zacharias, " one may enjoy perfect health
until the end of the days assigned to one."   Isaac of
Holland and Basil Valentine are equally explicit, but in
their case it is recommended that the dose should be
taken once a month : thus life would be prolonged
" until the supreme hour fixed by the king of heaven."

Other alchemists were not always so prudent in prophecy. Artephius gave the limit of human life thus prolonged as a thousand years; Gualdo, a Rosicrucian, was stated to have lived four hundred years. Raymond Lully and Salomon Trismosin, we are told, renewed their youth by means of it. The advanced age at which Noah begat children could only be due, says Vincent de Beauvais, to his use of the philosopher's stone. Dickinson wrote a learned book to prove that the great age of the patriarchs was owing to the same secret.

But not only were health and length of days the fortunate lot of him who possessed the philosopher's stone; increase of wisdom and virtue equally followed from its use. As it ennobled metals, so it freed the heart from evil. It made men as wise as Aristotle or Avicenna, sweetened adversity, banished vain-glory, ambition, and vicious desires. Adam received it at the hands of God, and it was given also to Solomon, although the commentators were rather exercised to know why, as he possessed the philosopher's stone, he should have sent to Ophir for gold.

It would serve no good purpose to attempt to describe the recipes given by various alchemists to prepare this precious substance. With an affectation at times of precision, they were purposely obscure, and always enigmatical. As Boyle said of them, they could scarcely keep themselves from being confuted except by keeping themselves from being clearly understood. One example of their recipes must suffice: "To fix quicksilver.—Of several things take 2, 3 and 3, 1; 1 to 3 is 4; 3, 2 and 1. Between 4 and 3 there is 1; 3 from 4 is 1; then 1 and 1, 3 and 4; 1 from 3 is 2. Between 2 and 3 there is 1, between 3 and 2 there is 1. 1, 1, 1, and

1, 2, 2 and 1, 1 and 1 to 2.   Then 1 is 1.   I have told
you all."   No wonder, after an equally luminous expli-
cation, a pupil of Arnaud de Villeneuve should have
exclaimed: "But, master, I do not understand."   Upon
which the master rejoined that he would be clearer
another time.

Nor is it necessary to dilate upon the other virtues
which were ascribed at various times to the philo-
sophical powder, as, for example, its power of making
pearls and precious stones, or of its use in preparing
the *alkahest*, or universal solvent, invented by Para-
celsus.   In their attempts to fathom the depths of
human credulity the alchemists at length over-reached
themselves.   The idea of a universal solvent carried
with it, as Kunkel pointed out, its own refutation : if
it dissolved everything, no vessel could contain it.   And
yet, says Boerhaave, a whole library could be filled with
writings by the school of Paracelsus on the alkahest.
From the latter end of the sixteenth century repeated
attempts were made to expose the pretensions and
demonstrate the absurdities of alchemy.   Among its
adversaries may be cited Thomas Erastius, Hermann
Conringius, and the Jesuit Kircher.   Many of their
dupes, potentates and princes who were powerful
enough to exercise it, occasionally visited with their
vengeance those who, unmindful of the injunctions of
Albert the Great, had traded too long upon their
credulity.   The Emperor Rudolph II., who earned the
title of "The Hermes of Germany," was a zealous culti-
vator of alchemy, and had a well-equipped laboratory
in his palace at Prague, to which every adept was
welcome.   Ferdinand III. and Leopold I. were also
patrons of the hermetic art, as were Frederick I. and
his successor, Frederick II., Kings of Prussia.   Indeed,

at one period nearly every Court in Europe had its alchemist, with the privileges of the Court fool or the poet laureate. The fraud and imposture to which the practice gave rise led occasionally to the promulgation of stringent laws against it, and at times the pursuit of operative chemistry became well-nigh impossible in some countries. In the fifth year of the reign of Henry IV. (1404) it was enacted that " None from henceforth shall use to multiply gold or silver, or use the craft of multi-plication ; and if the same do he shall incur the pain of felony." According to Watson, the true reason for passing this Act was not an apprehension that men should ruin their fortunes by endeavouring to make gold, but a jealousy lest Government should be above asking aid of the subject. At the same time, letters patent were granted to several persons, permitting them to investigate the universal medicine and perform the transmutation of metals.

Alphonse X., of Castille, the author of the *Key of Wisdom*, practised alchemy. Henry VI., of England, and Edward IV. had dealings with adepts. Even Elizabeth Tudor, who was a shrewd enough sovereign, had the notorious Dr. Dee in her pay. Charles VII. and Charles IX., of France, Christian IV., of Denmark, and Charles XII., of Sweden, sought to replenish their exhausted treasuries by the aid of the philosopher's stone. If princes eventually learned not to put their trust in alchemists, alchemists learned equally to their cost not to put their trust in princes. Duke Julius, of Brunswick, in 1575, burnt a female alchemist, Marie Ziglerin, who had failed in her promise to furnish him with a prescription for the making of gold. David Benther killed himself to escape the fury of the Elector Augustus, of Saxony. Bragadino was hanged at

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Munich in 1590 by the Elector of Bavaria. Leonard Thurneysser, who gained an evil notoriety in his day as one of the most unscrupulous of the followers of Paracelsus, and who amassed considerable wealth by the sale of cosmetics and nostrums, was deprived of his ill-gotten gains in 1584 by the Elector of Brandenburg, and died in misery in a convent. Borri, a Milanese adventurer, who had deceived Frederick III., of Denmark, was imprisoned for years by that monarch, and died in captivity in 1695. William de Krohnemann was hanged by the Margrave of Beyreuth, who, with grim irony, caused the inscription to be fixed to his gibbet : " I once knew how to fix mercury, and now I am myself fixed." Hector de Klettenberg was beheaded in 1720 by Augustus II., King of Poland.

All the followers of Hermes were not so wary or so candid as the artist who declined an invitation to visit the Court of Rudolph II., saying : " If I am an adept, I have no need of the Emperor ; if I am not, the Emperor has no need of me." Well might John Clytemius, Abbot of Wiezenberg, write : " *Vanitas, fraus, dolus, sophisticatio, cupiditas, falsitas, mendacium, stultitia, paupertas, desesperatio, fuga, proscriptio et mendicitas, perdisæque sunt chemiæ.*"

Despite the attacks of Kunkel, Boerhaave, the elder Geoffroy, Klaproth, and other chemists of influence and repute, alchemy died hard. It found believers in England until near the close of the eighteenth century, and was professed even by a Fellow of the Royal Society—Dr. James Price, of Guildford, who, in chagrin at the exposure of his pretensions, put an end to his existence in 1783. Hermetic societies existed in Westphalia, at Königsberg, and at Carlsruhe down to the first decade of the nineteenth century. M.

Chevreul, who lived well into that century, relates that he knew of several persons who were convinced of the truth of alchemy, among them "generals, doctors, magistrates, and ecclesiastics." The strange medley of alchemy, theosophy, thaumaturgy, and cabalisticism professed by Christian Rosenkreuz is not without its adherents, even in this twentieth century.

If the baser metals have not been made to furnish gold, truth at least has followed from the practice of error. This is the only transmutation which the art of Hermes has succeeded in effecting. To err is human. Although alchemy is not without its special interest as one of the most remarkable aberrations in the history of science, some of its practitioners, it must be admitted, deceived only themselves : if misguided, they were at least honest, and pursued their calling in a settled conviction of the soundness of their faith. Although they never reached their goal—the discovery of the Philosopher's Stone and the Elixir of Life—their labours were not wholly vain, for many new and unexpected facts came to light as the result of their assiduity.

" Credulity in arts and opinions," wrote Lord Bacon in *De Augmentis Scientiarum*,

> is likewise of two kinds—viz., when men give too much belief to arts themselves, or to certain authors in any art. The sciences that sway the imagination more than the reason are principally three—viz., astrology, natural magic, and alchemy.......Alchemy may be compared to the man who told his sons that he had left them gold, buried somewhere in his vineyard; while they by digging found no gold, but by turning up the mould about the roots of the vines procured a plentiful vintage. So the search and endeavours to make gold have brought many useful inventions to light.

IATRO-CHEMISTRY

The term "iatro-chemistry" denotes a particular phase in the history of medicine and of chemistry. The iatro-chemists were a school of physicians who sought to apply chemical principles to the elucidation of vital phenomena. According to them, human illnesses result from abnormal chemical processes within the body, and these could only be counteracted by appropriate chemical remedies. Although this idea did not originate with him, the chief exponent of this school is commonly said to be Paracelsus.

A man of violent passions, coarse, drunken, arrogant, and unscrupulous, **Philippus Aureolus Theophrastus Paracelsus Bombastus von Hohenheim**—to give him his full name—would seem to have possessed none of the attributes needed by the successful leader of an intellectual revolution.

Born at Etzel in Switzerland in 1493, the son of a physician, William Bombast von Hohenheim, who combined the practice of astrology with that of alchemy, Paracelsus, even as a youth, became a wanderer, passing from province to province and cloister to cloister, living by telling fortunes and practising sometimes as a quack and at other times as an army surgeon, and gaining, as he tells us, much curious information from old women, gipsies, conjurers, and chemists. If we may trust his own account of himself, he had, before he was thirty-three, wandered over the whole of Europe,

and even into Africa and Asia, everywhere performing miraculous cures and constantly getting into trouble. In 1526 he secured the appointment of Professor of Physic in the University of Basle, and signalised his occupancy of the chair by a course of lectures—a farrago of confused German and barbarous Latin—in which he assailed with extraordinary vigour and unexampled coarseness the medical system of the school of Galen. Scandalised as his professional brethren might be, Paracelsus expressed, intentionally or unintentionally, the feeling of impatience with which the laity viewed a system of therapeutics based only on tradition. In this revolt against authority he initiated a movement which, whatever might have been its influence on medicine, served eventually, under the guidance of worthier men, to emancipate chemistry from the thraldom of alchemy.

Paracelsus did little more than initiate. Although his many tracts show that he was familiar with nearly every chemical preparation of his time, many of which he used in his practice, he added no new substance to science. A man of great ability and extraordinary talent, he squandered his powers in dissipation. His intemperate conduct soon lost him his chair at Basle; and, after an ignoble quarrel with the magistracy, he fled the town, and, resuming his wandering life, died, under wretched circumstances, at Salzburg, in his forty-eighth year.

Space will not permit of any account of the philosophical opinions of Paracelsus—of his mysticism, his theosophy, his pantheism, his extraordinary doctrine of the Archæus and Tartarus, his association of astrology with medicine. His chief merit lies in his insistence that the true function of chemistry was not to make

gold artificially, but to prepare medicines and substances useful to the arts. He thereby made chemistry indispensable to medicine, and thenceforward chemistry began to be taught in the universities and in the schools as an essential part of a medical education.

Paracelsus is usually regarded as a typical alchemist —the kind of man made familiar to us by the paintings of Teniers, Van Ostade, and Stein—a boorish, maudlin knave, who divided his time between the pothouse and the kitchen in which he prepared his extracts, simples, tinctures, and the other nostrums which he palmed off upon a credulous world, as ignorant and superstitious as himself. There is much in the personal history of Paracelsus that serves to justify such a view of him. That he was in the main an impudent charlatan, ignorant, vain, and pretentious, there can be little doubt. He had an astonishing audacity and a boundless effrontery ; and it was largely by the exercise of these qualities that he secured such professional success as he enjoyed.

To judge from the number of the published works associated with his name, he was an active and industrious writer. Considering that during the greater part of his waking time he was more or less intoxicated, it is difficult to conceive what opportunity he had for composing them. Only one or two are known to be genuine. These, according to Operinus, his publisher, he dictated ; and from their incoherence and obscurity, their mystical jargon, and misuse of terms, they read like the ravings of one whom drunkenness had deprived of reason. Many of the tracts and larger works appeared after his death—some of them years after ; and there is no certain proof that he was the actual author. Even if we regard them as supposititious, the fact that they

should be published under his name is significant of the influence and notoriety which this extraordinary man succeeded in achieving during his short and chequered career.

The immediate followers of Paracelsus—among whom may be named Thurneysser, Dorn, Severinus, Duchesne —distinguished themselves only by the boldness with which they promulgated his doctrines, and the unscrupulous use which they made of his methods. They were all zealous anti-Galenists, who professed to believe that the sum and perfection of human knowledge was to be found in the Cabala, and that the secrets of magical medicine were contained in the Apocalypse. They adopted pantheism in all its grossness : everything that exists eats, drinks, and voids excrement ; even minerals and liquids assimilate food, and eliminate what they do not incorporate. Sylphs inhabit the air, nymphs the water, pigmies the earth, and salamanders the fire. Thus even the Aristotelian elements were animated. Mercury, sulphur, and salt were, according to Paracelsus, the primal principles which entered into the composition of all things, material and immaterial, visible and invisible. The following so-called "harmonies" were essential articles of faith with a Paracelsian :—

Soul	Spirit	Body
Mercury	Sulphur	Salt
Water	Air	Earth

The laws of the Cabala were held to explain the functions of the body. The sun rules the heart, the moon the brain, Jupiter the liver, Saturn the spleen, Mercury the lungs, Mars the bile, Venus the kidneys. Gold was a specific against diseases of the heart ; the liquor of Luna (solution of silver) cures diseases of the

brain. "The remedies," said Paracelsus, "are sub-
jected to the will of the stars, and directed by them.
You ought, therefore, to wait until heaven is favourable
before ordering a medicine."

The Paracelsian physicians, for the most part, were
a set of dangerous fanatics, who, in their contempt for
the principles of Hippocrates, Galen, and Avicenna, and
in their reckless use of powerful remedies, many of them
metallic poisons, wrought untold misery and mischief.
The inevitable reaction set in, and certain of the faculties,
particularly that of Paris, prohibited their licentiates,
under severe penalties, from using chemical remedies.
It is not to be supposed, however, that all iatro-chemists
were unscrupulous charlatans. Some of them clearly
perceived the significance and true value of the move-
ment which Paracelsus may be credited with having
originated.

Andreas Libavius, or Libau, originally a physician,
born in Halle, is best known by his *Alchymia*, published
in 1595, which contains an account of the main chemical
facts known in his time, and is written in clear and intel-
ligible language, in strong contrast to the mystery and
obscurity of his predecessors. He was the discoverer
of stannic chloride, still known as the fuming liquor of
Libavius, and described a method of preparing oil of
vitriol in principle identical with that now made use
of on a manufacturing scale. He died in 1616.

John Baptist van Helmont, a scion of a noble
Brabant family, was born in Brussels in 1577. After
studying philosophy and theology at the University of
Louvain, he directed his attention to medicine, and
made himself familiar, in turn, with every system from
Hippocrates to Paracelsus. Having spent some time in
travel, he settled on his estate at Vilvorde, and occupied

himself with laboratory pursuits until his death in 1644. Van Helmont was a scholarly, studious man, and a philosopher. A theosophist and prone to mysticism, he had many of the mental characteristics of Paracelsus, without his fanaticism and overweening egotism. He narrowed the number of Aristotle's elements down to one, and, like Thales, considered water to be the true principle of all things, supporting his theory by ingenious observations on the growth of plants (see p. 16). He first employed the term *gas,* and was aware of the existence of various aeriform substances, anticipating Hales, who has been styled the father of pneumatic chemistry, in the discovery of many gaseous phenomena. He gave an accurate description of carbonic acid gas, which he termed *gas sylvestre,* and showed that it is produced from limestone and potashes in the fermentation of wine and beer, and that it is formed in the body and in the earth. The doctrines of the iatro-chemists were further spread by Sylvius in Holland, and by Willis in England.

Francis de le Boë Sylvius, born at Hanau in 1614, became Professor of Medicine in the University of Leyden, where he exercised great influence as a teacher until his death in 1672. Medicine he treated simply as a branch of applied chemistry, and the vital processes of the animal body as purely chemical. He freed the theory of physic from much of the mystical absurdity introduced into it by Paracelsus and van Helmont, and by his practice brought chemical remedies once more into vogue. He was aware of the distinction between venous and arterial blood, and that the red colour of the latter was due to the influence of air. Combustion and respiration he regarded as analogous phenomena.

Thomas Willis was born in Wiltshire in 1621, and while a student at Christchurch bore arms in the Royalist army when Oxford was garrisoned for Charles I.   In 1660 he became Sedleian Professor of Natural Philosophy, and ultimately settled in London as a physician. He died in 1675, and was buried in Westminster Abbey.

Willis imagined that all vital actions were due to different kinds of fermentation, and that diseases were caused by abnormalities in the fermentative process. Although a Paracelsian as regards his theory of the constitution of matter, he followed Sylvius and his pupil Tachenius in banishing mysticism from medicine.   He was a skilful anatomist, and gave the first accurate description of the brain and nerves.

Other notable iatro-chemists were Angelus Sala, Daniel Sennert, Turquet de Mayerne (who became body physician to James I.), Oswald Croll, Adrian van Mynsicht, and Thomas Lieber.   Croll introduced the use of potassium sulphate and succinic acid into medicine, and Van Mynsicht that of tartar emetic.   Various antimonial preparations had previously been employed by chemical physicians since the time of Basil Valentine, despite the ban of the Parliament of Paris on their use.

The chief service of iatro-chemistry to science consisted in its influence in bringing chemistry within the range of professional study, whereby a great extension in its pursuit was effected, with the result that a largely increased number of substances was discovered.   Moreover, this wider experience of chemical processes familiarised workers with chemical phenomena in general, and thereby contributed to lay the foundations of a general theory of chemical action, which a succeeding age strove to complete.

During the period of iatro-chemistry, which may be

said to have extended from the first quarter of the sixteenth century to the latter half of the seventeenth, chemistry was advanced along practical lines by the labours of many men, chief of whom were Agricola the metallurgist, Palissy the potter, and Glauber the technologist. These men were primarily experimental chemists, who took little or no part in the fruitless polemics of the period, but followed their avocation in the true spirit of investigators, and thereby enriched science with many new and well-ascertained facts.

George Agricola, born at Glauchau in Saxony in 1494, was a contemporary of Paracelsus. After studying medicine at Leipzig, he devoted himself to metallurgy and mineralogy, first at Joachimsthal, and published a number of works which were long deservedly regarded as the leading treatises on these subjects.

In his *Libri XII. de re Metallica* he gives an account of what was known in his time respecting the extraction, preparation, and testing of ores. He describes the smelting of copper and the recovery of the silver which might be associated with it. He also describes methods of obtaining quicksilver, and of purifying it by treatment with salt and vinegar. He gives a full description of the method of obtaining gold by amalgamation, and of recovering the mercury by distillation. He gives accounts of the smelting of lead, tin, iron, bismuth, and antimony, and describes the manufacture of salt, nitre, alum, and green vitriol.

The whole work, which is of folio size, is illustrated by wood-cuts, which give a faithful idea of the nature of the several operations, and of the character of furnaces, trompes, bellows, and tools employed in them. It is by far the most important technical work of the sixteenth century, and it exercised great influence on the

art of metallurgy. The descriptions—at least as regards European processes—are evidently the result of personal observation. Agricola visited the mines, and faithfully noted the different methods of sorting and washing the ores, the characters of which he accurately describes. His accounts of the various smelting operations are so detailed that it is obvious they must have been put together after personal inquiry. The study of metallurgy, indeed, was the main object of his life ; and he devoted to its pursuit even the pension which had been settled on him by Maurice, Elector of Saxony. He became Mayor of Chemnitz, died there in 1555, and was buried at Zeitz.

Bernard Palissy lived throughout the greater portion of the sixteenth century. Although not a professed chemist, nor a follower of any particular school, he was an ardent self-taught experimentalist and a keen and accurate observer, who greatly enriched ceramic art by his discoveries.

Johann Rudolf Glauber was born at Karlstadt, in Bavaria, in 1604, and after a restless life died in Amsterdam in his sixty-fourth year. He published an encyclopædia of chemical processes, in which he describes the preparation of a great variety of substances of technical importance. The greater number of the pharmacopæias of the seventeenth century are indebted to him for their descriptions of the mode of manufacture of their official preparations. He discovered sodium sulphate—his *sal mirabile*, still frequently named after him—and introduced it into medicine.

During this period the common mineral acids—sulphuric, hydrochloric, and nitric—became ordinary articles of commerce, and were used in the manufacture

of a number of useful products, chiefly inorganic salts. A considerable number of metallic oxides were also in common use, and were applied to a variety of purposes in the arts. The knowledge of definite organic substances was much more limited. Acetic acid had long been known, but was first obtained in a concentrated form during this period by the distillation of verdigris. A number of other acetates were also known, as well as certain tartrates—as, for example, salt of sorrel, Rochelle or seignette salt, and tartar emetic. Succinic and benzoic acid were introduced into medicine, and Tachenius discovered one of the characteristic acids of fat and oil (stearic acid). Spirit of wine was, of course, largely made and used in the preparation of tinctures and essences. Ether, originally known as *oleum vitrioli dulce verum,* was first discovered by Valerius Cordus ; and a mixture of it with alcohol, long known as Hoffmann's drops, appears to have been employed as a medicine by Paracelsus.

"THE SCEPTICAL CHEMIST": THE DAWN OF SCIENTIFIC CHEMISTRY

THE latter half of the seventeenth century was a remarkable period in the history of the intellectual development of Europe. At that time nearly every department of human knowledge seemed to have become permeated by an eager spirit of scepticism, inquiry, and reform. The foundation of the Royal Society of London for Improving Natural Knowledge, the Accademia del Cimento of Florence, the Académie Royale at Paris, the Berlin Academy, all within a few years of each other, was significant of the times. Chemistry was no longer to be a sacred mystery, to be known only to priests, and its secrets jealously guarded by them. Science had chafed under the domination of the schoolmen; it was now contemptuous of the dialectics of the Spagyrists. Experimentarian philosophy became even fashionable; and the purely deductive methods of the Peripatetics gradually gave place to the only sound method of advancing natural knowledge. The supremacy of the old philosophy may be said to have been first distinctly challenged by Robert Boyle. The appearance in 1661 of his book, *The Sceptical Chemist*, marks a turning-point in the history of chemistry. The "Chemico-physical Doubts and Paradoxes" raised by Boyle "touching the experiments whereby vulgar Spagyrists are wont to endeavour to evince their Salt, Sulphur, and Mercury to be the true Principles of Things,"

eventually sealed the fate of the doctrine of the *tria prima*, and of the tenets of the school of Paracelsus.

In this treatise Boyle sets out to prove that the number of the peripatetic elements or principles hitherto assumed by chemists is, to say the least, doubtful. The words " element " and " principle " are used by him as equivalent terms, and signify those primitive and simple bodies of which compounds may be said to be composed, and into which these compounds are ultimately resolvable.   He considered that the matter of all bodies was originally divided into small particles of different shapes and sizes, and that these particles might unite into small " parcels," not easily separable again ; that a great variety of compounds may arise from a few ingredients ; that various substances are obtainable from bodies by fire ; that fire is not the true and genuine analyser of bodies, since it does not separate the principles of a body, but variously alters its nature ; and that some things obtained from a body by fire were not its proper or essential ingredients.   Three is not precisely and universally the number of the distinct substances or elements into which all compound bodies are resolvable by fire, inasmuch as some bodies afford more than three principles.   Earth and water are as much chemical principles as salt, sulphur, and mercury.   Even the limitation to five chemical principles is too narrow. Such is proved to be the case by the mode in which bodies, animal and vegetable, grow, and by the analysis of minerals and metals.   The chemical theory of " qualities " of the Spagyrists is narrow, defective, and uncertain; supposes things not proved ; is often superfluous, and frequently contradicts the phenomena of nature.   The " principles " found in bodies cannot be the cause of their qualities, since contrary qualities

are ascribed to the same body. He concludes, therefore, that the Paracelsian elements — their " salt," " sulphur," and " mercury "—are not the first and most simple principles of bodies ; but that these consist, at most, of concretions of corpuscles or particles more simple than they, and possessing the radical and universal properties of volume, shape, and motion.

Robert Boyle, fourteenth child and the seventh and youngest son of Richard the " Great " Earl of Cork, and Lord High Chancellor of Ireland, was born at Lismore in 1626. He was educated at Eton under Sir Henry Wotton, and, after spending some years on the Continent, settled at Stalbridge in Dorset, where he owned a manor. He became a member of what was known as the Invisible College, a small association of men interested in the new philosophy, who met at each other's houses in London, and occasionally at Gresham College, " to discourse and consider of philosophical inquiries and such as related thereunto." The meetings were subsequently held in Oxford, and Boyle took up his residence there in 1654. Here—in association with Wilkins ; John Wallis and Seth Ward, the two Savilian Professors of Geometry and Astronomy ; Thomas Willis, the physician, then student of Christ Church ; Christopher Wren, then Fellow of All Souls' College ; Goddard, Warden of Merton ; and Ralph Bathurst, Fellow of Trinity, and afterwards its President—they sought to cultivate the new philosophy, " being satisfied that there was no certain way of arriving at any competent knowledge unless they made a variety of experiments upon natural bodies. In order to discover what phenomena they would produce, they pursued that method by themselves with great industry, and then communicated their discoveries to each other." The

ROBERT BOYLE.
From a painting by F. Kerseboom in the possession of the Royal Society.

Invisible College eventually grew into the Royal Society, which received its charter in 1663. Boyle removed to London in 1668, and died there on December 31st, 1691, in the sixty-fifth year of his age.

A man of integrity, modest, simple, and unassuming, Boyle was an assiduous and true student of science, and practically the whole of his life was given to its pursuit. His social position, his example, the purity of his private life, and the fame of his discoveries made his personal influence very considerable, to the great advantage of science in this country. His experimental work was of a high order. He introduced the air-pump into England, and his "pneumatical engine" enabled him to discover many of the fundamental properties of a gas, notably the relation of its volume to pressure. He also discovered the dependence of the boiling point of a liquid upon atmospheric pressure, explained the action of the syphon, the effect of the air on the vibration of a pendulum and on the propagation of sound, and made experiments on the nature of flame, and on the relation of air to combustion and respiration. In his History of Fluidity he seeks to show that a body seems to be fluid by consisting of corpuscles touching one another only in some parts of their surfaces; whence, by reason of the numerous spaces between them, they easily glide along each other till they meet with some resisting body to whose internal surface they exquisitely accommodate themselves. He considers the requisites of fluidity to be chiefly these: The smallness of the component particles, their determinate figure, the vacant spaces between them, and the fact of their being agitated variously and apart by their own innate motion or by some thinner substance which tosses them about in its

passage through them.   His published works contain many well-authenticated chemical facts, which are commonly held to be the discovery of a later time.   He prepared acetone by the distillation of the acetates of lead and lime ; and he isolated methyl alcohol from the products of the destructive distillation of wood.   He was one of the earliest to insist on the necessity of studying the forms of crystals.   He saw in their formation proof that the internal motions, configuration, and position of the integral parts are all that is necessary to account for alterations and diversities in outward character.   Some of the stock illustrations of our lecture-rooms were of his contrivance.   Thus he illustrated the expansive power of freezing water by bursting a plugged gun-barrel filled with water by solidifying the water by means of a mixture of snow and salt—a freezing mixture which he first introduced.

Boyle was the first to formulate our present conception of an element in contradistinction to that of the Greeks and the schoolmen who influenced the theories of the iatro-chemists.   In the sense understood by him, the Aristotelian elements were not true elements, nor were the salt, sulphur, and mercury of the school of Paracelsus.   He was also the first to define the relation of an element to a compound, and to draw the distinction we still make between compounds and mixtures. He revived the atomic hypothesis, and explained chemical combination on the basis of affinity.   He contended that one of the main objects of the chemist was to ascertain the nature of compounds ; and thereby he stimulated the application of analysis to chemistry. Boyle discovered a number of qualitative reactions, and applied them to the detection of substances, either free or in combination.

But Boyle's greatest service to learning consisted in the new spirit he introduced into chemistry. Henceforward chemistry was no longer the mere helpmeet of medicine. She became an independent science, the principles of which were to be ascertained by experiment; a science to be studied with the object of discovering the laws regulating the phenomena with which it is concerned and hence elucidating truth for truth's sake. The old philosophy of the Greeks had, as we have seen, become merged into the doctrine of the iatro-chemists; and this was now to be purified from the theosophical mysticism with which Paracelsus and his followers had enshrouded it. "The dialectical subtleties of the schoolmen much more," says Boyle, "declare the wit of him that uses them than increase the knowledge or remove the doubts of sober lovers of truth.......For in such speculative inquiries where the naked knowledge of the truth is the thing principally aimed at, what does he teach me worth thanks, that does not, if he can, make his notion intelligible to me, but by mystical terms and ambiguous phrases darkens what he should clear up, and makes me add the trouble of guessing at the sense of what he equivocally expresses, to that of learning the truth of what he seems to deliver." The influence of the new spirit thus infused into the science by Boyle is seen in the general style of chemical literature at the end of the seventeenth century, when compared with that of the close of the sixteenth. The mysticism and obscurity of the alchemists were no longer tolerated.

Boyle was slender and tall, with a countenance pale and emaciated. His constitution was delicate and his body feeble, and it was only by strict attention to diet and regularity of exercise that he accomplished

what he did.   Although he suffered occasionally from an excessive lowness of spirits, there was nothing morose or ascetic in his nature.   He was never married, although, says his friend John Evelyn, " few men were more face- tious and agreeable in conversation with the ladies whenever he happened to be engaged among them."

Kindly, courteous, charitable ; unaffected, and tem- perate in his manner of life, Boyle enjoyed the respect and esteem of all his contemporaries.   It was said of him that he was never known to have offended any person in his whole life by any part of his deport- ment.   He allowed himself a great deal of decent cheer- fulness, and had about him all the tenderness of good nature, as well as all the softness of friendship.   These gave him a large share of other men's concerns, for he had a quick sense of the miseries of mankind.   Although a philosopher in the broadest sense of that term, his peculiar and favourite study was chemistry, " in which," says Bishop Burnet, " he engaged with none of those ravenous and ambitious designs that drew many into them.   His design was only to find out nature, to see into what principles things might be resolved, and of what they were compounded."

John Kunkel, born in 1630, was the son of an alchemist attached to the Court of the Duke of Holstein. After serving his father for some years, he obtained employment as chemist and pharmacist under the Dukes Charles and Henry, of Lauenburg.   He subsequently entered the laboratory at Dresden of John George II., Elector of Saxony, and, after teaching chemistry at the University of Wittenburg, then famous as a medical school, he accepted an invitation to take charge of the glass works and laboratory of the Elector of Branden- burg, at Berlin.   The laboratory was burnt down, and

then Charles XI. of Sweden called him to Stockholm and ennobled him as Baron von Lowenstiern. He died in Stockholm in 1702. Kunkel's chief work is his *Laboratorium Chymicum,* published after his death. It was written in German. In it Kunkel relates how he acquired possession of a knowledge of the manufacture of Baldwin's phosphorus, and of the phosphorus discovered by Brand—perhaps the most important, as it certainly was one of the most striking, of the chemical discoveries of the seventeenth century.

Kunkel did much to liberate chemical literature from the mysticism and obscurity of alchemy. He was scornful of the theories of the adepts, and contemptuous of their *tria prima*.

> I, old man that I am, who have been occupied with chemistry for sixty years, have never yet been able to discover their fixed sulphur, or how it enters into the composition of metals.......Moreover, they are not agreed among themselves respecting the kind of sulphur. The sulphur of one is not the sulphur of the other. To that one may reply that each is at liberty to baptise his child as he likes. I agree : you may even, if you are so disposed, call an ass a cow ; but you will never make anyone believe that your cow is an ass.

As to the alkahest he says :—

> There has been much discussion concerning this grand natural solvent. Some derive it from the Latin—*alkali est;* others from the two German words *all geist* (all gas); lastly, others say it is from *alles est* (that's all). As to myself, I do not believe in Van Helmont's universal solvent. I call it by its true name—*alles Lügen heist*, or *alles Lügen ist* (it is all a lie).

Kunkel discovered the secret of the manufacture of aventurine glass and of ruby glass by means of the purple of Cassius—a product from gold first obtained

by a doctor of medicine of that name in Hamburg. He made observations on fermentation and putrefaction—recognised that alum was a double salt (*sal duplicatum*); described the present method of preparing pure silver, and of parting gold and silver by means of sulphuric acid. He also described the mode of preparing a number of essential oils, detected the presence of stearopten in oils, and discovered nitrous ether.

John Joachim Becher, the son of a Lutheran minister, was born at Speyer in 1635. Owing to the death of his father and the devastation of the family property during the Thirty Years' War, Becher had a hard struggle with poverty during his youth, and led a restless, wandering life. In 1666 he was Professor of Medicine in the University of Mayence. Subsequently he went to Munich as head of the finest laboratory in Europe, but, quarrelling with the Chancellor of the Bavarian Court, betook himself to Vienna. After a short stay there, he quitted Austria for Holland, and established himself in Haarlem. Here he proposed to the States-General to extract gold from the sand-dunes ; but, the project failing, he left for England and visited the Cornish mines. On the invitation of the Duke of Mecklenburg-Güstrow, he returned to Germany. Shortly afterwards (in 1682) he died, in the forty-seventh year of his age. Becher's name is remembered mainly in connection with his theory of combustion, which, as we shall see, was subsequently developed by Stahl into the theory of Phlogiston—a generalisation which dominated chemistry until near the close of the eighteenth century.

John Mayow, born in Cornwall in 1645, was a practising physician, whose name chiefly lives by virtue of his clear recognition of the substance or principle in the air which is concerned in combustion, the calcination of

metals, respiration, and the conversion of venous into arterial blood.   This substance, which he found to be contained in saltpetre, he called *spiritus igno-aëreus* or *nitro aëreus*.   Mayow died at the age of thirty-four. Had he been able to follow up his observations, he might have influenced very materially the development of theoretical chemistry.   As it was, he was practically overlooked by his contemporaries, and the real significance of his work was not appreciated until long afterwards.

Nicolas Lemery, also born in 1645, wrote a *Cours de Chimie*, one of the best text-books of the time, which passed through as many as thirteen editions, and was translated into English, German, Latin, Italian, and Spanish.

In this book he strove, as he says, to express himself clearly, and to avoid the obscurities which were to be found in the authors who had preceded him.

> The fine imaginations of other philosophers concerning their physical principles may elevate the spirit by their grand ideas, but they prove nothing demonstratively. And, as chemistry is a science of observation, it can only be based on what is palpable and demonstrative.

Nicolas Lemery, who is not to be confounded with his son Louis, also a chemist, made a considerable number of contributions to pharmaceutical chemistry ; and his *Pharmacopée Universelle*, *Dictionnaire Universel des Drogues Simples*, and *Traité de l'Antimoine* were standard works in their day.

Lemery was at one time a Protestant, and on the revocation of the Edict of Nantes fled to England ; but, embracing Catholicism, he returned to Paris, re-established his pharmacy, and was elected into the Academy in 1699.   He died in 1715.

William Homberg, born in Batavia in 1652, was originally intended for the profession of law, but, becoming attached to science, studied botany and medicine in Padua, chemistry at Bologna and in London, mechanics and optics at Rome, and anatomy at Leyden. In the course of his travels he visited the mines of Germany, Hungary, Bohemia, and Sweden. In 1682 he was invited to Paris by Colbert, and in 1691 was made a member of the Academy and was placed by the Duke of Orleans in charge of his laboratory— then one of the finest in Europe. Homberg married the daughter of Dodart, the physician. She became an expert *préparateur*, and was of great assistance to him in his experimental inquiries. He first made known the existence of phosphorus in France, discovered by Brand, of Hamburg, and he described the phosphorescent salt associated with his name. He made important observations on the saturation of alkalis by acids, and was aware that they combined in different proportions. He was an industrious worker, and, with the exception of Cassini, was the most active member of the Academy. He died on September 24th, 1715.

Next to Boyle, perhaps the most active agent in emancipating chemistry from the yoke of alchemy was Boerhaave, who, by his teaching as Professor of Physic, raised the University of Leyden to the summit of its fame.

Hermann Boerhaave, the son of a minister, was born near Leyden, in 1668. He occupied himself in turn with theology, classics, mathematics, chemistry, and botany, when he turned to physic, and, after a course of study at the University of Harderwyk, in Gelderland, began to practise. In 1702 he was appointed to a lectureship, and eventually to the Chair of Medicine,

HERMANNUS BOERHAAVE
Medicinae, Botanices, Chemiae
Collegii practici in ACAD. LUGD. BAT.
PROFESSOR ORDINARIUS

After a painting by T. Wandelaar.

in the University of Leyden, of which he became Rector in 1714. His reputation as a teacher spread throughout Europe, and steadily increased until his death.

Boerhaave was one of the most learned men of his age, and singularly well cultured, not only in science, but in history, poetry, and polite literature. He conversed in English, French, and German, and read Italian and Spanish with facility. "The Latin he spoke extempore in lectures or conversation was so clear that, with his action, method, and the aptness of his similes, he could level the most abstruse points to the meanest capacities."[1] He was fond of music, and a good performer on several instruments, particularly the lute. He delighted to welcome musicians to his house. His profession as a physician brought him wealth, much of which he spent in horticulture; and the garden of his country seat, nearly eight acres in extent, was enriched with all the exotic trees he could procure and induce to flourish in the climate of Holland.

Boerhaave was of a robust frame and healthy constitution, early inured to constant exercise and the inclemencies of weather. His stature was rather tall, and his habit corpulent. "He had a large head, short neck, florid complexion, light brown curled hair (for he did not wear a wig), an open countenance, and resembled Socrates in the flatness of his nose and his natural urbanity."[2] He died at Leyden on September 23rd, 1738, in the seventieth year of his age.

As a chemist Boerhaave is chiefly known by his *Elementa Chemia*, published in 1732—the most complete and most luminous chemical treatise of its time, translations of which appeared in the chief European languages.

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[1] Burton, *Life of Boerhaave*, p. 58 *et seq.*   [2] *Ibid.*

The work is divided into three main parts. The first is concerned with the origin and progress of the art, and with the personal history of its most distinguished cultivators. The second and largest part deals with the attempt to form a system of chemistry based on such observational matter as seemed well established. The third consists of a collection of chemical processes relating to the analysis or decomposition of bodies, grouped under the heads of "vegetables," "animals," and "fossils"—the beginnings, in fact, of a sub-division of the science into organic and inorganic chemistry.

As regards his belief in alchemy, Boerhaave was an agnostic: he neither affirmed nor denied the possibility of transmutation. In this respect he resembled Newton and Boyle. Boyle, indeed, was singularly cautious and reticent in his references to alchemistic matters. As was said of him by Shaw, he was too wise to set any bounds to nature : he was not prone to say that every strange thing must needs be impossible, for he saw strange things every day, and was well aware that there are powerful forces in the world of whose laws and modes of action he knew nothing. With that wariness which was habitual to him, he was wont to say that "those who had seen them might better believe them than those who had not"; and he was modest enough to suppose that Paracelsus or Helmont might conceivably know of agents of which he was ignorant.

Boerhaave unquestionably spent much time in the study of alchemical works, particularly those of Paracelsus and Helmont, which he repeatedly read. The *Philosophical Transactions* of the Royal Society contain the results of a laborious but fruitless investigation by him on quicksilver, which he undertook in the hope of discovering the seminal or engendering matter which,

on the old theory of the generation of metals, was supposed to be contained in mercury. But although, as he relates, he tortured it by "conquassation, trituration, digestion, and by distillation, either alone or amalgamated with lead, tin, or gold, repeating this operation to 511 or even to 877 distillations," the mercury appeared only "rather more bright and liquid, without any other variation in its form or virtues, and acquired very little, if any, increase of its specific gravity."

Stephen Hales (1677–1761), an ingenious divine—he held the perpetual curacy of Teddington, and lived practically the greater part of his life there—distinguished as a physiologist and inventor, occupied himself in chemical pursuits, and made a number of observations on the production of gaseous substances. His results were communicated to the Royal Society and subsequently republished, in a collected form, under the title of *Statical Essays*. In these experiments he used methods very similar in principle to those subsequently employed by Priestley. It is evident from his description of his experiments that he must have prepared a considerable number of gaseous substances —hydrogen, carbonic acid, carbonic oxide, sulphur dioxide, marsh gas, etc.—but he seems to have made no systematic attempt to study their properties, as he considered that they were simply air, modified or "tinctured" by the presence of substances which he regarded as more or less fortuitous. Prior to the time of Black all forms of gaseous substance were regarded as substantially identical—in fact, as being *air*, as understood by the Ancients—a simple elementary substance. It was Black's study of carbonic acid which first clearly established that there were essentially distinct varieties of gaseous matter.

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Chapter VII.

PHLOGISTONISM

Even before the appearance of *The Sceptical Chemist* there was a growing conviction that the old hypotheses as to the essential nature of matter were inadequate and misleading. We have seen how the four " elements " of the Peripatetics had become merged into the *tria prima*—the " salt," " sulphur," and " mercury "—of the Paracelsians. As the phenomena of chemical action became better known, the later iatro-chemists —or, rather, that section of them which recognised that chemistry had wider aims than to minister merely to medicine—felt that the conception of the *tria prima*, as understood by Paracelsus and his followers, was incapable of being generalised into a theory of chemistry. Becher, while clinging to the conception of three primordial substances as making up all forms of matter, changed the qualities hitherto associated with them. According to the new theory, all matter was composed of a mercurial, a vitreous, and a combustible substance or principle, in varying proportions, depending upon the nature of the particular form of matter. When a body was burnt or a metal calcined, the combustible substance—the *terra pinguis* of Becher—escaped.

This attempt to connect the phenomena of combustion and calcination with the general phenomena of chemistry was still further developed by Stahl, and was eventually extended into a comprehensive theory of chemistry, which was fairly satisfactory so long as

no effort was made to test its sufficiency by an appeal to the balance.

George Ernest Stahl, who developed Becher's notion into the theory of *phlogiston* (ὁλόγιστος—burnt), and thereby created a generalisation which first made chemistry a science, was born at Anspach in 1660, became Professor of Medicine and Chemistry at Halle in 1693, physician to the King of Prussia in 1716, and died in Berlin in 1734.

Stahl contributed little or nothing to practical chemistry; and no new fact or discovery is associated with his name. His service to science consists in the temporary success he achieved in grouping chemical phenomena, and in explaining them consistently by a comprehensive hypothesis.

The theory of phlogiston was originally broached as a theory of combustion. According to this theory, bodies such as coal, charcoal, wood, oil, fat, etc., burn because they contain a combustible principle, which was assumed to be a material substance and uniform in character. This substance was known as phlogiston. All combustible bodies were to be regarded, therefore, as compounds, one of their constituents being phlogiston: their different natures depended partly upon the proportion of phlogiston they contain, and partly upon the nature and amount of their other constituents. A body, when burning, was parting with its phlogiston; and all the phenomena of combustion—the flame, heat, and light—were caused by the violence of the expulsion of that substance. Certain metals—as, for example, zinc—could be caused to burn, and thereby to yield earthy substances, sometimes white in colour, at other times variously coloured. These earthy substances were called *calces*, from their general resemblance to lime.

Other metals, like lead and mercury, did not appear to burn ; but on heating them they gradually lost their metallic appearance, and became converted into calces. This operation was known as calcination. In the act of burning or of calcination phlogiston was expelled. Hence metals were essentially compound : they consisted of phlogiston and a calx, the nature of which determined the character of the metal. By adding phlogiston to a calx the metal was regenerated. Thus, on heating the calx of zinc or of lead with coal, or charcoal, or wood, metallic zinc or lead was again formed. When a candle burns, its phlogiston is transferred to the air; if burned in a limited supply of air, combustion ceases, because the air becomes saturated with phlogiston.

Respiration is a kind of combustion whereby the temperature of the body is maintained. It consists simply in the transference of the phlogiston of the body to the air. If we attempt to breathe in a confined space, the air becomes eventually saturated with the phlogiston, and respiration stops. The various manifestations of chemical action, in like manner, were attributed to this passing to and fro of phlogiston. The colour of a substance is connected with the amount of phlogiston it contains. Thus, when lead is heated, it yields a yellow substance (litharge) ; when still further heated, it yields a red substance (red lead). These differences in colour were supposed to depend upon the varying amount of phlogiston expelled.

The doctrine of phlogiston was embraced by nearly all Stahl's German contemporaries, notably by Marggraf, Neumann, Eller, and Pott. It spread into Sweden, and was accepted by Bergman and Scheele ; into France, where it was taught by Duhamel, Rouelle, and Macquer ; and into Great Britain, where its most

influential supporters were Priestley and Cavendish. It continued to be the orthodox faith until the last quarter of the eighteenth century, when, after the discovery of oxygen, it was overturned by Lavoisier.

During the sway of phlogiston chemistry made many notable advances—not by its aid, but rather in spite of it. At a matter of fact, until the time of Lavoisier few if any investigations were made with the express intention of testing it, or of establishing its sufficiency. When new phenomena were observed the attempt was no doubt made to explain them by its aid, frequently with no satisfactory result. Indeed, even in the time of Stahl facts were known which it was difficult or impossible to reconcile with his doctrine; but these were either ignored, or their true import explained away. Although, therefore, these advances were in no way connected with phlogiston, it will be convenient to deal with the more important of them now, inasmuch as they were made during the phlogistic period.

With the exception of Marggraf, Stahl's German contemporaries contributed few facts of first-rate importance to chemistry. **Pott,** who was born at Halberstadt in 1692 and became Professor of Chemistry in Berlin in 1737, is chiefly remembered by his work on porcelain, the chemical nature and mode of origin of which he first elucidated. **Marggraf,** born in Berlin in 1709, was one of the best analysts of his age. He first clearly distinguished between lime and alumina, and was one of the earliest to point out that the vegetable alkali (potash) differed from the mineral alkali (soda). He also showed that gypsum, heavy spar, and potassium sulphate were analogous in composition. He clearly indicated the relation of phosphoric acid to phosphorus, described a number of methods of preparing that acid,

and explained the origin of the phosphoric acid in urine.

Of the Swedish chemists of that period, the most notable was Scheele.

CARL WILHELM SCHEELE.
From the statue by Börjeson at Stockholm.

Carl Wilhelm Scheele was born in 1742 at Stralsund. When fourteen years of age he was apprenticed to an apothecary at Gothenburg, and began the study of experimental chemistry, which he continued to prosecute

as an apothecary at Malmö, Stockholm, Upsala, and eventually at Köping on Lake Malar, where he died in 1786, in the forty-third year of his age. During the comparatively short period of his scientific activity Scheele made himself the greatest chemical discoverer of his time.

He first isolated chlorine, and determined the individuality of manganese and baryta. He was an independent discoverer of oxygen, ammonia, and hydrogen chloride. He discovered also hydrofluoric, nitro-sulphonic, molybdic, tungstic, and arsenic, among the inorganic acids; and lactic, gallic, pyrogallic, oxalic, citric, tartaric, malic, mucic, and uric acids among the organic acids. He isolated glycerine and milk-sugar; determined the nature of microcosmic salt, borax, and Prussian blue, and prepared hydrocyanic acid. He demonstrated that graphite is a form of carbon. He discovered the chemical nature of sulphuretted hydrogen, arsenuretted hydrogen, and the green arsenical pigment known by his name. He invented new processes for preparing ether, powder of algaroth, phosphorus, calomel, and *magnesia alba*. He first prepared ferrous ammonium sulphate; showed how iron may be analytically separated from manganese; and described the method of breaking up mineral silicates by fusion with alkaline carbonates. Scheele's contributions to chemical theory were slight and unimportant, but as a discoverer he stands pre-eminent.

Of the French phlogistians we have space only to mention Duhamel and Macquer.

Henry Louis Duhamel du Monceau was born at Paris in 1700. He was one of the earliest to make experiments on ossification, and one of the first to detect the difference between potash and soda.

Peter Joseph Macquer was born in 1718 at Paris. He investigated the nature of Prussian blue (discovered by Diesbach, of Berlin, in 1710), worked on platinum, wrote one of the best text-books of his time, published a dictionary of chemistry, and was an authority on the chemistry of dyeing.

In addition to those already mentioned, the most notable names as workers in chemistry in Great Britain during the eighteenth century are Black, Priestley, and Cavendish.

Joseph Black was born in 1728 at Bordeaux, where his father was engaged in the wine trade. A student of the University of Glasgow, he became its Professor of Chemistry in 1756. In 1766 he was transferred to the Chemical Chair of the University of Edinburgh, and died in 1799. Black published only three papers, the most important of which is entitled *Experiments upon Magnesia Alba, Quicklime, and Other Alkaline Substances.* He proved that magnesia is a peculiar earth differing in properties from lime. Lime is a pure earth, while limestone is carbonate of lime. He showed that magnesia will also combine with carbonic acid, and he explained that the difference between the mild and caustic alkalis is that the former contain carbonic acid, whereas the latter do not. He also explained how lime is able to convert the mild alkalis into caustic alkalis. Simple and well known as these facts are to-day, their discovery in 1755 excited great interest, and marked an epoch in the history of chemistry. Black's name is associated with the discovery of latent and specific heat, and he made the first determinations of the amount of heat required to convert ice into water.

Joseph Priestley, the son of a clothdresser, was born in 1733 at Fieldhead, near Leeds. When seven years

JOSEPH PRIESTLEY.
From a mezzotint after Fuseli in the possession of the Royal Society.

of age, on the death of his mother, he was taken charge
of by his aunt, and was educated for the Nonconformist
ministry, eventually becoming a Unitarian. He was
first attracted to science by the study of electricity, of
which he compiled a history. At Leeds, where he had
charge of the Mill Hill congregation, he turned his
attention to chemistry, mainly from the circumstance
that he lived near a brewery and had the opportunity of
procuring large quantities of carbonic acid, the proper-
ties of which he carefully studied. He abandoned the
ministry for a time to become librarian and literary
companion to Lord Shelburne, with whom he remained
seven years. During this time he industriously pursued
chemical inquiry, and discovered a large number of
æriform bodies—viz., nitric oxide, hydrogen chloride,
sulphur dioxide, silicon fluoride, ammonia, nitrous
oxide, and, most important of all from the point of
view of chemical theory, oxygen gas. Priestley's work
gave a remarkable impetus to the study of pneumatic
chemistry. It exercised great influence on the exten-
sion of chemical science, and—in other hands than his
—on the development of chemical theory. The most
important of his contributions to science are contained
in his *Experiments and Observations on Different Kinds of
Air*. This work not only gives an account of the methods
by which he isolated the gases he discovered, but
describes a great number of incidental observations,
such as the action of vegetation on respired air,
showing that the green parts of plants are able
in sunlight to decompose carbonic acid and to restore
oxygen to the atmosphere. He was, in fact, one of
the earliest to trace the specific action of animals
and plants on atmospheric air, and to show how these
specific actions maintained its purity and constancy of

composition. He initiated the art of eudiometry (gas analysis), and was the first to establish that the air is not a simple substance, as imagined by the ancients. Priestley is to be credited with the invention of *soda-water*, which he prepared as a remedy for scurvy ; and his name is connected with the so-called *pneumatic trough*—a simple enough piece of apparatus, but one which proved to be of the greatest service to him in his inquiries.

After leaving Lord Shelburne, Priestley removed to Birmingham and resumed his ministry. His religious and political opinions made him obnoxious to the Church and State party ; and during the riots of 1791 his house was wrecked, his books and apparatus destroyed, and his life endangered. Eventually he emigrated to America, and settled at Northumberland, where he died on February 6th, 1804, in the seventy-first year of his age.

Henry Cavendish was born at Nice in 1731, and died in London in 1810. He was a natural philosopher in the widest sense of that term, and occupied himself in turn with nearly every branch of physical science. He was a capable astronomer and an excellent mathematician, and he was one of the earliest to work on the subject of specific heat, and to improve the thermometer and the methods of making thermometric observations. He also determined the mean density of the earth. He made accurate observations on the properties of carbonic acid and hydrogen, greatly improved the methods of eudiometry, and first established the practical uniformity of the composition of atmospheric air. His greatest discovery, however, was his determination of *the composition of water*. He was the first to prove that water is not a simple or elementary substance, as supposed

H. Cavendish

From a drawing by Alexander in the Print Room of the British Museum.

by the ancients, but is a compound of hydrogen and oxygen. In certain of his trials he found that the water formed by the union of oxygen and hydrogen was acid to the taste ; and the search for the cause of this acidity led him to the discovery of the *composition of nitric acid*. He was the first to make a fairly accurate analysis of a natural water, and to explain what is known as the *hardness of water.*

Phlogistonism may be said to have dominated chemistry during three-fourths of the eighteenth century. Although radically false as a conception and of little use in the true interpretation of chemical phenomena, it cannot be said to have actually retarded the pursuit of chemistry. Men went on working and accumulating chemical facts uninspired and, for the most part, uninfluenced by it. Even Priestley, perhaps one of the most conservative of the followers of Stahl, regarded his dogma with a complacent tolerance ; and as its inconsistencies became apparent he was more than once on the point of renouncing it. Of one thing he was quite convinced, and that was that Stahl had greatly erred in his conception of the real nature of phlogiston. Perhaps the most signal disservice which phlogiston did to chemistry was to delay the general recognition of Boyle's views of the nature of the elements. The alchemists, it will be remembered, regarded the metals as essentially compound. Boyle was disposed to believe that they were simple. Becher and Stahl and their followers, until the last quarter of the eighteenth century, also regarded them as compounds, phlogiston being one of their constituents. On the other hand, what we now know to be compounds —such as the calces, the acids, and water itself—were held by the phlogistians to be simple substances.

The discovery, in 1774, of oxygen—the dephlogisti-
cated air of Priestley—and the recognition of the part
it plays in the phenomena which phlogiston was invoked
to explain, mark the termination of one era in chemical
history and the beginning of another.   Before entering
upon an account of the new era it is desirable to take
stock of the actual condition of chemical knowledge at
the end of the phlogistic period, and to show what
advances had been made in pure and applied chemistry
during that time.

During the eighteenth century greater insight was
gained into the operations of the form of energy with
which chemistry is mainly concerned, and views con-
cerning chemical affinity and its causes began to assume
more definite shape, chiefly owing to the labours of
Boerhaave, Bergman, Geoffroy, and Rouelle.   It was
clearly recognised that the large group of substances
comprised under the term " salts " were compound, and
made up of two contrasted and, in a sense, antagonistic
constituents, classed generically as acids and bases.

On the practical side chemistry made considerable
progress.   Analysis—a term originally applied by Boyle
—greatly advanced.   It was, of course, mainly qualita-
tive ; but, thanks to the labours of Boyle, Hoffmann,
Marggraf, Scheele, Bergman, Gahn, and Cronstedt,
certain reactions and reagents came to be systemati-
cally applied to the recognition of chemical substances,
and the precision with which these reagents were used
led to the detection of hitherto unknown elements.
The beginnings of a quantitative analysis were made
even before the time of Boyle, but its principles were
greatly developed by him, and were further extended
by Homberg, Marggraf, and Bergman.   Marggraf
accurately determined the amount of silver chloride

formed by adding common salt to a solution of a known weight of silver, and Bergman first pointed out that estimations of substances might be conveniently made by weighing them in the form of suitably prepared compounds, which, it was implicitly assumed, were of uniform and constant composition. The foundations of an accurate system of gaseous analysis were made by Cavendish ; and various forms of physical apparatus were applied to the service of chemistry.

To the elements which were known prior to Boyle's time, although not recognised as such, there were added phosphorus (Brand, 1669), nitrogen (Rutherford), chlorine (Scheele, 1774), manganese (Gahn, 1774), cobalt (Brandt, 1742), nickel (Cronstedt, 1750), and platinum (Watson, 1750). Baryta was discovered by Scheele, and strontia by Crawford. Phosphoric acid was discovered by Boyle, and its true nature determined by Marggraf ; Cavendish first made known the composition of nitric acid. As already stated, Scheele first isolated molybidic and tungstic acids and determined the existence of a number of the organic acids (p. 75). Other discoveries—such as the true nature of limestone and *magnesia alba* and their relations respectively to lime and magnesia by Black, the many gaseous substances by Priestley, and the compound nature of water by Cavendish—have already been referred to.

Technical chemistry also greatly developed during the eighteenth century, thanks to the efforts of Gahn, Marggraf, Duhamel, Reaumur, Macquer, Kunkel, and Hellot ; and many important industrial processes—such as the manufacture of sulphuric acid by Ward of Richmond, and subsequently by Roebuck at Birmingham, and the Leblanc process of conversion of common salt into alkali—had their origin during this period.

Chapter VIII.

LAVOISIER AND LA RÉVOLUTION CHIMIQUE

WE have seen how chemistry made a new departure during the political upheaval which occurred in this country about the middle of the seventeenth century. It acquired a new impetus and took a fresh course during the political cataclysm which overwhelmed France and alarmed Europe towards the close of the eighteenth century. The instigator and leader of this second revolution in chemistry was Lavoisier, one of the most distinguished men of his age, and himself a victim of the political fury of his own people.

Antoine-Laurent Lavoisier was born in Paris in 1743. At the Jardin du Roi he came under the influence of Rouelle, one of the best teachers of his time, who eventually shaped his career as a chemist. In 1765 he sent to the Academy his first paper on gypsum, which is noteworthy as giving for the first time the true explanation of the " setting " of plaster of Paris, and the reason why overburnt gypsum will not rehydrate. Three years later he became a member of the *Ferme-général*—a company of financiers to whom the State conceded, for a fixed annual sum, the right of collecting the indirect taxes of the country. It was this connection that brought Lavoisier to the scaffold during the revolution of 1794. Like Stahl, Lavoisier discovered no new substance ; but, also like Stahl, he created a new epoch by destroying the philosophical system which Stahl had established.

It is commonly stated that the exception is a proof of the rule. The history of science can show many instances whereby the rule has been demolished by the exception. Little facts have killed big theories, even as a pebble has slain a giant. During the reign of phlogiston a few of such facts were not unknown—at least to some of the better informed of Stahl's followers.

Some of the alchemists had discovered that a metal gained, not lost, weight by calcination. This was known as far back as the sixteenth century. It had been pointed out by Cardan and by Libavius. Sulzbach showed that such was the case with mercury. Boyle proved it in the case of tin, and Rey in that of lead. Moreover, as knowledge increased it became certain that Stahl's original conception of the principle of combustion as a ponderable substance—he imagined, with Becher, that it was of the nature of an earth—was not tenable. The later phlogistians were disposed to regard it as probably identical with hydrogen. But even hydrogen has weight, and facts seemed to require that phlogiston, if it existed at all, should be devoid of weight.

Towards the latter half of the eighteenth century clearer views began to be held concerning the relations of atmospheric air to the phenomena of combustion and of calcination ; many half-forgotten facts relating to these phenomena were recalled, and the inconsistencies and insufficiency of phlogiston as a dogma became gradually manifest. Three cardinal facts conspired to bring about its overthrow—the isolation of oxygen by Priestley ; the recognition by him of the nature of atmospheric air, and of the fact that one of its constituents is oxygen ; and, lastly, the discovery by Cavendish that water is a compound, and that its constituents are

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oxygen and hydrogen. The significance of these facts was first clearly grasped by Lavoisier, and to him is due the credit of their true interpretation. By reasoning and experiment he proved conclusively that all ordinary phenomena of burning are so many instances of the combination of the oxygen of the air with the combustible substance ; that calcination is a process of combination of the oxygen in the air with the metal, which thereby increases in weight by the amount of oxygen combined. Water—no longer a simple substance—is formed by the union, weight for weight, of oxygen and hydrogen. Lavoisier's reasoning was so sound and his experimental evidence so complete that his views gradually gained acceptance in France. The phlogiston myth was thus exploded. Inspired by Lavoisier, a small band of French chemists—Berthollet, Fourcroy, Guyton de Morveau—thereupon set to work to remodel the system of chemistry and to recast its nomenclature so as to eliminate all reference to phlogiston. The very names "oxygen," "hydrogen," "nitrogen," corresponding respectively to the "dephlogisticated air," "phlogiston," and "phlogisticated air" of Priestley, were coined by the new French school. For a time *le principe oxygine* was regarded by this school in much the same relation as phlogiston was regarded by Stahl and his followers. The one fetich was exchanged for the other. The combustible principle —phlogiston—was renounced for the acidifying principle —oxygen. The new chemistry for a time centred itself round oxygen, just as the old chemistry had centred itself round phlogiston. The views of the French school met with no immediate acceptance in Germany, the home of phlogistonism, or in Sweden or England, possibly owing, to some extent, to national prejudices. The

spirit of revolution, even although it might be an intellectual revolution, had not extended to these countries. Priestley, Cavendish, and Scheele could not be induced to accept the new doctrine. It was, however, accepted by Black, and its principles taught by him in Edinburgh; and before the end of the century it had practically supplanted phlogistonism in this country. Some of those who, like Kirwan, had energetically opposed the new theory ended by enthusiastically embracing it. Its introduction into Germany was mainly due to the influence of Klaproth.

We further owe to Lavoisier the recognition of the principle which lies at the basis of chemical science— the principle of the conservation of matter. Lavoisier was not the first to introduce the use of the balance into chemistry: quantitative chemistry did not actually originate with him. Boyle, Black, and Cavendish, as a matter of fact, preceded him in recognising the importance of studying the quantitative relations of substances. Nevertheless, no one before him so clearly foreshadowed the doctrine of the indestructibility of matter, and it was mainly through his teaching that the balance came to be recognised as indispensable to the pursuit of chemistry. Before his untimely death he had succeeded in impressing upon the science the main features which at present characterise it.

Lavoisier was one of the most distinguished men of his age, and his merits as a philosopher were recognised throughout Europe. Indeed, it is not too much to say that at the time of his death he was the dominant figure in the chemical world of the eighteenth century. In addition to his position as a member of the *Ferme-général*, he was made by Turgot a commissioner of the *Régie des Poudres;* and in this capacity he effected

improvements in the manufacture and refining of salt-
petre, and greatly increased the ballistic properties of
gunpowder. He became Secretary of the Committee
of Agriculture, and drew up reports on the cultivation
of flax, of the potato, and on the liming of wheat ; he
prepared a scheme for the establishment of experimental
farms, and for the collection and distribution of agri-
cultural implements. He introduced the cultivation of
the beetroot in the Blesois, and improved the breed of
sheep by the importation of rams and ewes from Spain.
He was successively member of the Assembly of the
Orléanais, *Député suppléant* of the States-General, and
of the Commune of Paris. In 1791 he was named
Secretary and Treasurer of the famous Commission of
Weights and Measures, out of which grew the inter-
national system, based theoretically on a natural unit,
known as the metric system, and now adopted by most
civilised countries in the world. He was not only the
administrative officer of the Commission : he contributed
to the nomenclature of the system, and directed the
determination of the physical constants on which the
measurements rested, and especially the determination
of the weight of the unit volume of water on which the
value of the standard of mass was based. Lastly, he
was Treasurer of the French Academy until its suppres-
sion in 1793 by the Convention, which shortly afterwards
ordered the arrest of Lavoisier and others of the
Fermiers-généraux—twenty-eight in all. They were
sentenced to be executed within twenty-four hours, and
their property confiscated. Coffinhal, who pronounced
their doom, declared : *"La republique n'a pas besoin de
savants."* Thus, in the fifty-first year of his age,
perished the creator of modern chemistry—a victim to
the senseless, sanguinary fury of the " Friends of the

LAVOISIER AND BERTHOLLET
in the Laboratory of the Sorbonne, Paris.

People." His rectitude, his public services, the purity of his private life, the splendour of his scientific achievements—all were unheeded. As Lagrange said to Delambre : "It required but a moment to strike off this head ; a hundred years may not suffice to reproduce such another."

Of the men who were associated with Lavoisier in the creation of what was known at the period as the antiphlogistic chemistry, the most eminent was Berthollet.

Claude-Louis Berthollet was born in Savoy in 1748, and, after a medical education, became physician to the Duke of Orleans. Devoting himself to chemistry, in 1781 he was made a member of the Academy, and he became Government Commissary and Director of the Gobelins, the chief tinctorial establishment of France. Although in the main in agreement with Lavoisier, he never wholly subscribed to the idea that all acids contained oxygen. He discovered the bleaching power of chlorine, prepared potassium chlorate, and investigated prussic acid and fulminating silver.

In his *Statique Chimique*, published in 1803, he combated the partial and imperfect views of Bergman and Geoffroy with regard to the operation of chemical affinity, and showed that the direction of a chemical change is modified by the relative proportion of the reacting substances and the physical conditions—temperature, pressure, etc.—under which the change is effected. He was one of the first to draw attention to a class of phenomena known as reversible reactions, and gave a number of instances of their occurrence. Berthollet pushed his conclusions so far that he was led to doubt that chemical combination took place in fixed and definite proportions ; and his views

gave rise to a memorable controversy between him and Proust, in which the latter eventually triumphed.

Berthollet enjoyed a great reputation in his time, and played a considerable part in the political history of his country. It was largely to his zeal, sagacity, and skill in developing her internal resources at a critical period when she was hemmed round by foreign troops and her ports blockaded by British ships, that France was saved from conquest. His life was more than once in jeopardy when France was governed by a Committee of Public Safety ; but his honesty, sincerity, and courage even impressed Robespierre, and he escaped the perils of the Great Terror. He was an intimate friend of Napoleon, and accompanied him to Egypt as a member of the Institute. He died at Arcueil in 1822.

Davy, who visited him at his country house in 1813, says of him :—

> Berthollet was a most amiable man ; when the friend of Napoleon, even, always good, conciliatory, and modest, frank and candid. He had no airs, and many graces. In every way below La Place in intellectual powers, he appeared superior to him in moral qualities. Berthollet had no appearance of a man of genius ; but one could not look on La Place's physiognomy without being convinced that he was a very extraordinary man.

Other notable men of this period were Fourcroy, Vauquelin, Klaproth, and Proust.

Antoine-Francois Fourcroy, the son of a pharmacist, was born at Paris in 1755, and started his career as a dramatic author. On the advice of Vicq-d'Azir, the anatomist, he turned to medicine, and in 1784, by the influence of Buffon, obtained the chair of Chemistry at the Jardin du Roi, in succession to Macquer. He was an excellent teacher—clear, orderly,

and methodical. He had, indeed, a talent for oratory. This he assiduously cultivated, and became one of the most popular lecturers of his time in France. Ambitious and time-serving, he became embroiled in the turbulent politics of the period, and, after a chequered career, died, embittered and disappointed, in the fifty-fourth year of his age. His chief services to science consisted in his works, *Système des Connaissances Chimiques* and *Philosophie Chimique*. These, no less than his public lectures, did much to popularise the doctrines of Lavoisier among his countrymen.

Louis Nicolas Vauquelin, the son of a Norman peasant, was born in 1763, and while a boy became assistant to an apothecary in Rouen. In 1780 he came to Paris, and entered Fourcroy's laboratory. Much of the experimental work published in Fourcroy's name was actually done by Vauquelin. He became a member of the Academy in 1791, Professor of Chemistry at the Mining School, Assayer to the Mint, and subsequently Professor of Chemistry at the Jardin des Plantes. On Fourcroy's death he was made Professor of Chemistry of the Medical Faculty of Paris. Vauquelin was no theorist; he was, however, an excellent practical chemist, and one of the best analysts of the period. He made a large number of mineral analyses, more particularly for Hauy, the crystallographer. He discovered the element *chromium* in the so-called red-lead ore (lead chromate) from Siberia. He also first made known the existence of *glucinum* in beryl. He described a method of separating the platinum metals, and worked upon *iridium* and *osmium*. He investigated the *hyposulphites, cyanates*, and *malates*. He discovered the presence of *benzoic acid* in the urine of animals ; with Robiquet, he first isolated *asparagin ;* with Buniva,

allantoic acid; and with Bouillon de la Grange, *camphoric acid*.

Vauquelin lived wholly for science, and had no other interests than in his laboratory.   He was pensioned in 1822, and died at his birthplace—St. André d'Héberlot —in the sixty-sixth year of his age.

Martin Heinrich Klaproth, born in 1743 at Wernigerode, in the Hartz, began life, like Vauquelin, as an apothecary's apprentice at Quedlinburg.   Thence he went to Hanover, and ultimately to Berlin, where he studied under Pott and Marggraf and entered the pharmacy of Valentine Rose, father of Heinrich Rose, the distinguished chemist, and Gustav Rose, the mineralogist.   In 1788 he became a member of the Berlin Academy, and, on the creation of the Berlin University in 1809, was made Professor of Chemistry. As already stated, he was the first chemist of eminence in Germany to adopt the antiphlogistic theory.   He was distinguished as an analyst.   He discovered *tellurium*, analysed *pitchblende* and *uranit*, and first made known the existence of *uranium, zirconium*, and *cerium,* which he termed " ochroita."   He analysed *corundum*, and was an independent discoverer of *titanium* and *glucinum*, termed by him *beryllium*.   He made a large number of analyses of minerals, such as leucite, chrysoberyl, hyacinth, granite, olivin, wolfram, malachite, pyromorphite, etc.   He continued actively at work until his death, in the seventy-fourth year of his age.

Analytical chemistry is under great obligations to Klaproth.   He established a standard of accuracy never before approached ; and much of his analytical work, both as regards processes and results, is of permanent value.

Joseph Louis Proust, the son of a pharmacist, was

born at Angers in 1761. He received his early training in chemistry from his father, and, after studying under Rouelle in Paris, obtained an appointment at the Salpetrière. Proust has the credit of being the first chemist to make a balloon ascent in a Montgolfier balloon with Pilâtre de Rozier On the invitation of the King of Spain, he went to that country to superintend certain chemical manufacturing processes. He became Professor of Chemistry at the University of Salamanca, and subsequently went to Madrid, where he was installed in a well-equipped laboratory to enable him to examine the mineral riches of Spain. On the breaking out of war his work was interrupted, and he was obliged to leave Madrid. His laboratory was completely destroyed, and his valuable collection of apparatus and specimens dissipated. Through the good offices of Berthollet, Proust was offered a considerable sum of money by Napoleon in order to induce him to turn his discovery of grape sugar to practical account. Proust was, however, too broken in health to undertake the work of a factory manager, and he retired to Mayence. On the restoration of the Monarchy he was made a member of the French Academy, his honorarium as an Academician being augmented by a pension from Louis XVIII. He died in 1826, while on a visit to Angers, his native place.

Proust is the discoverer of what is now styled " the law of constant proportion," which states that the same body is invariably composed of the same elements, united in the same proportion. He was a skilful analyst, and made numerous analyses of minerals ; and he was one of the earliest to undertake a systematic study of metallic salts of organic acids.

Chapter IX.

THE ATOMIC THEORY

The opening years of the nineteenth century were made memorable by the promulgation of the atomic theory by John Dalton. The enunciation of this theory, which affords a simple and adequate explanation of the fundamental laws of chemical combination, marks an epoch in the history of chemistry.

It may be desirable to trace, as briefly as possible, the successive steps which led up to the generalisation which more than any other has served to stamp chemistry as an exact science. That matter was *discrete*—that is, that it was not continuous, but was composed of ultimate particles—was, as already stated, imagined by the ancients, and was part of the philosophy of Leukippus, Demokritus, and Leucretius. But this supposition, although favoured by Newton and other thinkers, had little or no scientific basis prior to the middle of the eighteenth century. From that time onward a variety of chemical facts gradually accumulated, many of which at the time of their discovery had no obvious connection with pre-existing facts. It was reserved for Dalton to point out how an extension and more precise definition of the old doctrine would suffice to connect and explain them.

The first germ of an atomic theory based on chemical fact may be traced in the observation of **Tobern Bergmann** (b. 1735, d. 1784), Professor of Chemistry at Upsala, that neutral solutions of certain metals in

contact with other metals gave a precipitate without the
neutrality of the solution being disturbed, and without
gas being evolved. One metal had simply replaced the
other in solution. Bergman thus incidentally discovered
the fact of the chemical equivalence of metals. He was
of opinion, however, that the phenomenon meant a trans-
ference of phlogiston from one metal to another, and
that the process might be made a mode of determining
the relative amount of phlogiston in various metals.
Lavoisier extended Bergman's observations, and sought
to show, in effect, that the process afforded a means of
determining the amounts of the several metals which
combined with one and the same quantity of oxygen.
But neither Bergman nor Lavoisier really grasped the
idea of equivalence as we understand it to-day. It
began to be appreciated as the result of the work of
Jeremiah Benjamin Richter (b. 1762, d. 1807) and of
G. E. Fischer on the mutual action of salts in solu-
tions, and on the determinations of the amounts of
acids and bases which respectively combine with one
another. Methods of measurement of the proportions
in which substances combine were grouped by Richter
under the term *Stöchiometry*.

However desirable it may be in the interests of his-
tory to indicate the sequence of the surmises and facts
which preceded the formulation of the atomic theory,
it is very doubtful whether Dalton was, to any material
extent, influenced by them. A self-educated man of
lowly origin, sturdily independent and highly original,
he was accustomed to rely upon his own faculty of
observation and experiment for his facts, and upon
his own intellectual powers and mental energy for
their interpretation.

John Dalton, the son of a Quaker hand-loom weaver,

was born at Eaglesfield, in Cumberland, in 1766. While still a boy he took to school-teaching, and acquired, in his leisure and by his own exertions, a competent knowledge of mathematics and physical science. In 1793 he was called to give instruction in mathematics, natural philosophy, and chemistry at the Manchester New College, the Nonconformist academy —now moved from Warrington—in which Priestley had formerly lectured. Here he remained six years, leaving the college to take up an independent position as a private tutor, so as to enable him the more freely to pursue his scientific inquiries. In 1800 he became Secretary of the Philosophical Society of Manchester, and remained connected, as an official, with that institution until his death in 1844. The greater number of his scientific communications were published by that society. In the outset of his scientific career he was attracted to meteorology; and it was probably its problems which led him in the first place to experiment, and to speculate on the physical constitution of gases. In the course of these observations he was led to the discovery of the law of thermal expansion of gases, with which his name is now generally associated. His speculations concerning the physical constitution of gaseous substances, arising from the contemplation of gaseous phenomena, led him to the conception that a gas is composed of particles that repel one another with a force decreasing as the distance of their centres from each other ; and it is probable that in this manner he familiarised himself with the idea of the existence of atoms. His first insight into the laws of the chemical combination of these atoms seems to have originated from his discovery that, when two substances unite in different proportions, these proportions may be expressed in simple

JOHN DALTON.
From a painting by B. R. Faulkner in the possession of the Royal Society

multiples of whole numbers. Thus he found, on examining the composition of marsh gas and of ethylene, both hydrocarbons, that for the same weight of hydrogen there was twice the amount of carbon in ethylene that there was in marsh gas. He then examined the oxides of nitrogen, and found a similar regularity to hold good in these compounds. Some time prior to the autumn of 1803 Dalton was led to the supposition that these regularities could be satisfactorily explained by the assumption that matter is composed of atoms having sizes and weights differing with each substance, but of identical weight and size for any particular substance, and that chemical combination consists in the approximation of these atoms. This simple hypothesis explained all the facts then known. It explained the constancy in the chemical composition of substances, which may be said to have been established by Proust, and which is now formulated as the Law of Constant Proportion— that the same body is invariably composed of the same elements, united in the same proportion. It explained also the fact discovered by Dalton that, when an element unites with another in different proportions, the higher proportions are multiples of the lowest—now formulated as the Law of Multiple Proportion. It further explained the fact, which may be said to have been foreshadowed by Richter, that when two bodies, A and B, separately combine with a third body, C, the proportions of A and B which unite with C are measures or multiples of the proportions in which A and B combine together. This is known as the Law of Reciprocal Proportion.

Dalton's theory was first made generally known by Thomas Thomson, in the third edition of his *System of Chemistry*, published in 1807, and was employed by

ELEMENTS

Simple
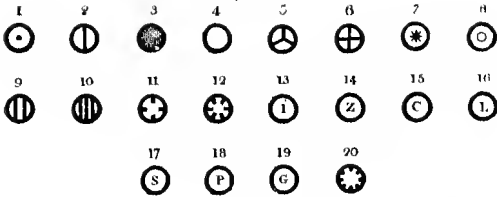
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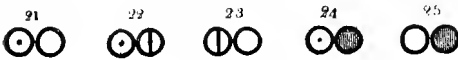
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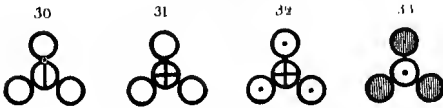
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Septenary
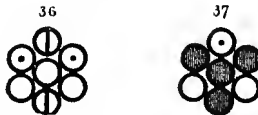
The illustration on the preceding page contains the arbitrary marks or signs chosen to represent the several chemical elements or ultimate particles.

Thomson in his paper on "The Oxalates of Strontium," published the same year in the *Philosophical Transactions.* The first printed account by Dalton himself is contained in Part I. of his *New System of Chemical Philosophy,* published in 1808, the substance of which had been previously given in a course of lectures at the Royal Institution, London, and subsequently repeated in Edinburgh and Glasgow.

The statement of his theory is contained in chapter iii. of this work, under the heading "Of Chemical Synthesis," and is accompanied by a plate and explanation, of which a facsimile is given on pp. 100–1.

The facts upon which Dalton based his theory are incontrovertible ; but Dalton's explanation of them was not universally accepted at the time he gave it. Davy, who, of course, was familiar with the conception of atoms as part of the Newtonian philosophy, objected to the term "atomic weight" introduced by Dalton, and suggested the expression "combining proportion"; and Wollaston, for similar reasons, proposed the term "equivalent," as denoting the constant quantity with which bodies went in and out of combination. There is no doubt that the use of these terms retarded the general acceptance of Dalton's doctrine, and, moreover, brought into the science a confusion which was not finally dispelled, as we shall see, until during the second half of the century.

Dalton's estimations of the relative weights of the atoms, or, to use Davy's phrase, the values of their combining proportions, were, as might be expected, very rough approximations to the truth. This arose partly from inadequate experimental data, and partly from uncertainty as to the relative number of the constituent atoms which made up a compound. Neither

Dalton nor his immediate successors had any rational or consistent method of determining the latter point. The view taken of the composition of the compound decided what particular multiples or sub-multiples of the values of the atomic weights of its constituents were to be adopted. As Dalton, in many cases, had no real criterion to guide him, he made the simplest possible assumptions ; but these might or might not be valid ; and subsequent experience showed that in some cases they were erroneous.

It was, however, generally recognised that these atomic weights, combining proportions, or equivalents, as they were for a time indifferently termed, were chemical constants of the highest importance, both to the scientific chemist, who, apart from their theoretic interest, had need of them in the course of quantitative analysis, and to the manufacturing chemist, who required them for the intelligent exercise of his operations ; and accordingly a number of chemists, very shortly after the promulgation of Dalton's theory, attempted to determine their values with all possible precision. Chief among these was the Swedish chemist Berzelius, to whom science was indebted for a series of estimations of atomic weights, which were long regarded as models of quantitative accuracy, and stamped their author as the greatest master of determinative chemistry of his age.

Jöns Jakob Berzelius, the son of a schoolmaster, was born near Linköping, in East Gothland, Sweden, in 1779. Entering Upsala with a view to the profession of medicine, he was attracted, under the influence of Afzelius—or, rather, in spite of it—to the study of chemistry, and, later, of voltaic electricity, then in its infancy. While holding a number of minor appointments

as a teacher of medicine, pharmacy, physics, and chemistry, he was elected, in 1808, a member of the Swedish Academy of Sciences, of which he became President in 1810. In 1818 he was made permanent Secretary of the Academy, and, by means of a yearly subsidy, was enabled to devote himself wholly to experimental science. He was ennobled in 1818, and on the occasion of his marriage, in 1835, was created a baron of the Scandinavian kingdom. He died in 1848.

Berzelius occupies a pre-eminent position in the history of chemistry, and during a considerable portion of his lifetime exercised an almost unassailable authority as a chemical philosopher. He is distinguished as an experimenter, as a discoverer, as a critic and interpreter, and as a lawgiver. His contributions to chemical knowledge range over every department of the science. He shares with Davy the honour of having established the fundamental laws of electro-chemistry. His experimental work on the atomic weights of the elements—the great work of his life— was of supreme importance at this particular period of the development of chemistry : it served not only to give precision to, and enhance the significance and value of, Dalton's generalisation, but it furnished chemists, for the first time, with a set of constants, ascertained with the highest exactitude of which operative chemistry was then capable, thereby contributing to the expansion of quantitative analysis, and to a more exact knowledge of the composition of substances. Berzelius, indeed, was an analyst of the first rank—conscientious, patient, and painstaking ; an ingenious and skilful manipulator ; inventive and resourceful. What determinative chemistry owes to his labours, and not less to his example, is obvious from even the most superficial

JÖNS JAKOB BERZELIUS.
From a painting by J. G. Sandberg.

examination of its literature during the first third of the last century.

As a discoverer, Berzelius first made known the existence of *cerium* (1803), of *selenium* (1818), and of *thorium* (1828); and he prepared and investigated a large number of their combinations. He isolated *silicon* (1823), *zirconium* (1824), *tantalum* (1824), and studied the compounds of *vanadium*, discovered by his countryman Sefström. He largely extended our knowledge of groups of substances in which sulphur replaces oxygen; investigated compounds of fluorine (1824), platinum (1828), and tellurium (1831–33), and made many analyses of minerals, meteorites, and mineral-waters. He discovered *racemic acid* and investigated the ferrocyanides. It was his investigation of racemic acid—which has the same percentage composition as tartaric acid—that first enabled him to grasp the conception of *isomerism*, a term which we owe to him, and of *metamerism* and *polymerism*. He was the first to study the phenomena of contact-actions, which he comprehended under the term *catalysis*.

As an author his literary activity was astonishing. His new system of mineralogy marks an epoch in the history of that branch of science. His text-book on chemistry was long the leading manual, and went through many editions, being constantly revised by him. His annual reports on the progress of physics and chemistry extended to twenty-seven volumes, and constitute a monument to his industry, thoroughness, perspicacity, and critical ability.

Although holding no university appointment, and with a laboratory of the most modest dimensions and character, Berzelius exercised great influence as a teacher. Some of the most notable chemists of the

last century, such as Heinrich and Gustav Rose, Dulong, Mitscherlich, Wöhler, Chr. Gmelin, and Mosander, were among his pupils ; and many of them have testified to his stimulating power as an investigator of nature, and to his merits as a worthy, genial man.

The reasonableness of Dalton's conjecture received further support from the discovery by Gay Lussac in 1808, that gases always combine in simple proportions by volume, and that the volume of the gaseous product formed, when measured under comparable conditions of temperature and pressure, stands in a simple relation to the volumes of the constituents. The law of pressure discovered by Boyle, that of thermal expansion by Dalton, and of volumes by Gay Lussac (which, it ought to be stated, was previously and independently made by Dalton), are explained on the assumption that equal numbers of the particles—either as simple particles or as compound particles—are present in the same volume of the gas. This method of explanation was first clearly stated by the Italian physicist **Avogadro** in 1811, but its significance, as will be seen subsequently, was not appreciated until half a century later.

As the values for the atomic weights gradually became more exact, speculations arose as to the significance of the numerical relations which were observed to exist among them. In 1815 **William Prout** threw out the supposition that the atomic weights of the gaseous elements are multiples by whole numbers of that of hydrogen. Extended into a generalisation, this might be held to indicate that all kinds of matter are so many forms of a primordial substance. Subsequent inquiry showed that Prout's " Law," as it is sometimes called, was not tenable in its original form. Certain elements,

it was conclusively proved, had atomic weights which were not whole numbers. Dumas subsequently modified the law, after a redetermination of a large number of atomic weights, by assuming that the substance common to the so-called elements had a lower atomic weight than unity. Although there are a considerable number of elements whose atomic weights, based upon the most accurate determinations, are remarkably close to whole numbers, the investigations of Stas and others afford no valid reason for believing that Prout's hypothesis, and the underlying supposition to which it has been held to point, are justified by experimental evidence.

Chapter X.

THE BEGINNINGS OF ELECTRO-CHEMISTRY

THE first year of the nineteenth century is further memorable on account of the invention of the voltaic pile, and by reason of its application by **William Nicholson** and **Sir Anthony Carlisle** to the electrolytic decomposition of water. This mode of resolving water into its constituents made a great sensation at the time, mainly because of the extraordinary method by which it was effected. It afforded an independent and unlooked-for proof of the compound nature of water by a method altogether differing in principle from that by which its composition had been previously ascertained. The formation of water by the combustion of hydrogen brought no conviction of its real nature to a confirmed phlogistian like Priestley; and it is even doubtful whether Cavendish ever fully realised the true significance of his great discovery. But the fact that the quantitative results of the analysis thus effected were identical with those of its synthesis, as made by Cavendish and Lavoisier, admitted of only one interpretation. This cardinal discovery may be said to have completed the downfall of phlogiston.

The value of the voltaic pile as an analytical agent was nowhere more quickly appreciated than in England. In the hands of Humphry Davy its application to the analysis of the alkalis and alkaline earths led to discoveries of the greatest magnitude.

Humphry Davy was born in Penzance in 1778. In

the course of his studies for the profession of medicine
he was attracted to chemistry; and he became
chemical assistant to Dr. Beddoes, a former teacher of
chemistry at Oxford, but then living at Clifton, near
Bristol. While in the capacity of assistant and operator
in Beddoes's Pneumatical Institute, Davy discovered
the intoxicating properties of *nitrous oxide* (so called
laughing gas), which brought him into prominence
and led to his engagement by the managers of the
newly-created Royal Institution in London as lecturer
in chemistry in succession to Garnett. He early began
to experiment on galvanism, and soon succeeded in
developing the fundamental laws of electro-chemistry;
and in 1807 he effected the *decomposition of potash and
soda* by the application of voltaic electricity—thereby
establishing, what indeed had been surmised previously,
that the alkalis are compound substances. He subse-
quently proved that this was also the case with the
alkaline earths. Davy thus added some five or six
metallic elements to those already known.

These discoveries, perhaps the most brilliant of their
time, afforded additional evidence of the invalidity of
Lavoisier's assumption that oxygen, as the name
implies, was the "principle of acidity." The surmise,
in fact, was already disproved by the case of water—a
neutral substance and devoid of all the recognised attri-
butes of an acid. It was still further disproved by the
cases of potash and soda—strongly alkaline compounds.

Additional evidence was adduced by Davy in demon-
strating, in 1810, that the so-called *oxymuriatic acid*,
the *dephlogisticated marine acid* discovered by Scheele,
contained no oxygen, but was a simple, indivisible sub-
stance. For the old designation, which connoted a com-
pound body, he substituted the name *chlorine*, in allusion

SIR HUMPHRY DAVY.
From a painting by Lawrence in the possession of the Royal Society.

to the characteristic colour of the element. In the course of his investigation on this substance he discovered the *penta- and trichloride of phosphorus, chlorophosphamide*, and *chlorine peroxide*. He was also the discoverer of *telluretted hydrogen* and an independent discoverer of *nitrosulphonic acid*.

He worked on *iodine* and the *iodates*, on the *diamond*, on the so-called *fuming liquor of Cadet*, on *nitrogen chloride*, and on the *pigments of the ancients*. Lastly, he invented the *miner's safety lamp*, with which his name will always be associated, effecting thereby what was practically a revolution in coal-mining. He became President of the Royal Society in 1820, and died at Geneva on May 29th, 1829, in the fifty-first year of his age. Davy was a singularly gifted man, of great mental vigour and imaginative power; quick, lively, and ingenious; an eloquent teacher and a daring and brilliant experimenter.

Another noteworthy name in the chemical history of this period is Wollaston. **William Hyde Wollaston,** born at East Dereham, in Norfolk, in 1766, was educated at Cambridge with a view to the profession of medicine, but, failing to secure a practice, he devoted himself to the pursuit of science, and especially to optics and chemistry. He devised a method of *working platinum*, and was the first to make known the existence of *palladium* and *rhodium*. He was one of the most ingenious and acute analysts of his time, and possessed remarkable inventive powers. He investigated the nature of *urinary calculi* and *chalk stones*. His paper on the *oxalates of potash* was of great service at the time as a demonstration of the law of multiple proportions. He first drew attention to the existence in the solar spectrum of what were subsequently termed

WILLIAM HYDE WOLLASTON.
From a painting by J. Jackson, R.A., in the possession of the Royal Society.

the *Fraunhofer lines*; and he invented the *reflecting goniometer* and the *camera lucida*, and a *slide rule* for chemical calculations. He resembled Cavendish in temperament and mental habitudes, and, like him, was distinguished for the range and exactitude of his scientific knowledge, his habitual caution, and his cold and reserved disposition. He died in 1828.

Almost immediately after the publication of Volta's discovery attempts were made—notably by Berzelius in Sweden and by Davy in England—to prove that electrical and chemical phenomena are correlated and mutually dependent. This assumption was more fully worked out by Berzelius in 1812, and it served as the basis of a chemical system which exercised considerable influence on chemical doctrine during the first half of the nineteenth century.

Berzelius assumed that electric polarity was an attribute of all atoms—that these were bipolar, in fact, but that in them either positive or negative electricity predominated. Hence the elements were capable of being divided into two classes—that is, positive or negative, depending upon the excess of either charge. Which of the electricities predominated might be ascertained by determining the particular pole at which the element was separated on electrolysis. Combinations of dissimilar elements—or, in other words, chemical compounds—were also endowed with polarity. The chemical affinities of elements and compounds were related to the excess of either kind of electricity resident in them; and chemical combination resulted from, and was a consequence of, the more or less perfect neutralisation of the two kinds. From a study of the electrical deportment of the elements Berzelius sought to arrange them in series, starting with oxygen as the most electro-

negative member. These conceptions were employed by him as the basis of a method of classification. The attempt is historically interesting as being the first systematic endeavour to gain an insight into the constitution of chemical compounds—that is, to determine the manner in which the constituent atoms are grouped or arranged with respect to one another, or, in other words, to distinguish between the empirical and the rational composition of substances, which is the ultimate aim of modern chemistry.

A necessary consequence of these views was that every compound was to be considered as made up of two parts in electrically different states. Thus baryta consisted of a combination of the electro-positive barium, combined with the electro-negative oxygen ; it combined with sulphuric oxide because the preponderating positive electricity it contained met with the negative electricity which prevailed in the sulphuric oxide. Generalising, it may be said that the basic oxides are invariably the positive constituents of salts, whereas the acid oxides are the negative constituents, as proved by the mode in which the two kinds of oxides separated at the poles on electrolysis. Barium sulphate, then, was to be regarded as made up of two entities—BaO and SO_3—and hence was to be called sulphate of baryta. Berzelius extended this conception in order to explain the formation of double salts—such, for example, as potash alum, which he regarded as a binary compound of positive potassium sulphate and negative aluminium sulphate, each of which, in its turn, could be resolved into an acidic and a basic oxide of opposite electricities.

The dualistic notions of Berzelius led him to the construction of a system of chemical nomenclature and notation which, in its main features, has persisted to

this day, and is universally current, with certain modi-
fications, in modern chemical literature.   We owe to
him the grouping of the elements into metals and metal-
loids, and also our present system of symbolic notation,
whereby even complicated chemical reactions may be
expressed in a concise and intelligible manner.   Chemical
symbols were used by the alchemists; but Berzelius first
suggested that a chemical symbol should not only
represent the element to which it refers, but also its
relative atomic weight.   Chemical equations became
quantitative as well as qualitative expressions of the
facts they denote.   Such equations implicitly assumed
that, to use Davy's words, chemistry had passed under
the dominion of the mathematical sciences.   Professed
mathematicians were, however, slow to recognise that
the phenomena of chemical action were capable of formal
mathematical treatment.   Davy relates that on speaking
to Laplace of the atomic theory in chemistry, and expres-
sing his belief that the science would ultimately be
referred to mathematical laws similar to those he had
so profoundly and successfully established with respect
to the mechanical properties of matter, the idea was
treated in a tone bordering on contempt.

Berzelius's electro-chemical system, and the dualistic
ideas associated with it, were of considerable service
when applied to the inorganic branch of the science ;
but attempts to fit them to the facts of organic
chemistry, which began to accumulate rapidly after the
first quarter of the century, failed.   Its inadequacy as
a comprehensive generalisation became more and more
manifest, and it eventually fell.   In fact, it may be said
to have received its death-blow by Davy's discovery of
the elementary nature of chlorine, and by the recog-
nition of the fact that the acids do not necessarily

contain oxygen. Davy and, later, Dulong made it obvious that, if any one element was to be regarded as the acidifying principle, it was hydrogen, and not oxygen ; and, in a sense, this view ultimately prevailed in the recognition of the acids as salts of hydrogen.

In France the study of electro-chemistry was undertaken by Gay Lussac and Thénard, largely owing to the action of the Emperor Napoleon, who furnished the funds for the construction of a powerful galvanic battery. The results were published, in 1811, under the title, *Recherches Physico-Chimiques, faites sur la Pile*, etc. Gay Lussac, whose name has already been mentioned as one of the discoverers of the Law of Combination of Gases, played a considerable part in the history of chemistry at this period. He was one of the earliest to appreciate the importance of Dalton's generalisation, and to point out the significance of his own discovery in strengthening it. He was probably led, in the first instance, to the recognition of the law of gaseous combination by Berthollet's work on the volumetric composition of ammonia gas, and by his own discovery —made in 1805, in conjunction with Humboldt, in the course of their analysis of atmospheric air—that one volume of oxygen combined with exactly two volumes of hydrogen to form water. The regularities thus indicated he found to be general : all gases which are capable of chemical union combine in simple proportions by volume, and the volume of the product, if a gas, always stands in some simple relation to the volumes of the constituents.

Joseph Louis Gay Lussac was born in 1778, at Saint Leonard, studied chemistry in Paris, and was associated in chemical inquiry with Berthollet. As Eleve-Ingenieur in the Ecole Nationale des Ponts et des

Chaussées he began the experimental work in physics and chemistry upon which his fame rests. In 1804 he undertook, with Biot, a series of balloon ascents for the purpose of investigating the physics and chemistry of the upper regions of the atmosphere. In 1806 he became Professor of Chemistry at the École Polytechnique, and in 1832 Professor at the Jardin des Plantes. He was one of the chief assayers of the French Mint, and, as member of many commissions, exerted considerable influence in official circles. He died in 1850.

Gay Lussac and Thénard were the first to devise a method of obtaining potassium and sodium by a purely chemical process, whereby these metals could be procured in far larger quantities than was at that time possible by electrolytic means. They were thus enabled to make use of the strong deoxidising power of these metals to effect a number of reductions, notably that of boric oxide to *boron*. Gay Lussac and Thénard were also the first to make known the existence of *boron fluoride*. We further owe to Gay Lussac the discovery of *cyanogen*, the first of the so-called compound radicals. He first prepared ethyl iodide, investigated sulphovinic acid and grape sugar, studied etherification and fermentation, etc. We are also indebted to him for a method of determining vapour densities which proved of great service in ascertaining the molecular weights of substances. He worked on iodine and its compounds, discovered, with Welter, *thiosulphuric acid*, and investigated fulminic acid in collaboration with Liebig.

Among his services to analytical chemistry were his method for the analysis of gunpowder, his volumetric estimation of silver (wet silver assay), chlorometric analysis, alkalimetry, etc. He devised the system still

in use in France for the estimation of alcohol in spirits of wine.

Louis Jacques Thénard was born in 1777 at Nogent-Sur-Seine, and was a pupil of Vauquelin and of Berthollet. In 1797 he became *répétiteur* at the Polytechnic School of Paris, and eventually its professor. He subsequently occupied the chair of chemistry at the Collège de France, and of the Faculty of Science of the University of Paris. He was ennobled by Charles X. in 1824, and died at Paris in the eightieth year of his age.

In addition to his work with Gay Lussac already mentioned, we owe to Thénard the discovery of *hydrogen peroxide* and *hydrogen persulphide*. Together with Dulong he studied the catalytic action of platinum on mixtures of oxygen and hydrogen. He investigated the fatty acids, and worked on fermentation and on ether-formation ; and he was the first to isolate citric and malic acids. He also occupied himself with the chemistry of bile, perspiration, albumen, the acids of urine and milk, and with the theory of mordants.

In 1834 Faraday made known the important fact that on passing the same galvanic current through a number of electrolytes—water, hydrochloric acid, solutions of metallic chloride—these were decomposed in such manner that definite amounts of hydrogen or metal were separated at the negative pole, and corresponding amounts of oxygen or chlorine were evolved at the positive pole. These observations were comprehended by Faraday under his "law of definite electrolytic action." The electro-chemical equivalents thus obtained were in some cases identical with the atomic weights deduced by Berzelius ; in others they were not ; but, nevertheless, when they differed, they stood in some simple relation to the assumed atomic weight. The

significance of Faraday's observation was not lost sight of, although his anticipation that the determination of electro-chemical equivalents would be of use in fixing atomic weights was not immediately appreciated. A clear distinction between the *equivalent*, the *atom*, and the *molecule* was not then apprehended. As will be subsequently shown, it was only during the latter half of the nineteenth century that the discrepancies and inconsistencies thus revealed were definitely reconciled and cleared up.

CHAPTER XI.

THE FOUNDATIONS OF ORGANIC CHEMISTRY

As the horizon of chemistry widened and its operations extended, it became necessary to treat its subject-matter methodically. Accordingly attempts were made in the various systematic treatises which began to appear in the seventeenth century to group its facts into an orderly and rational arrangement. One of the earliest of such systematic treatises was the *Cours de Chimie* of Nicolas Lemery, published in 1675. Although this work was styled by Boerhaave "a tumultuary mass of pharmaceutical processes, without any certain design or coherence," it is noteworthy as being the first of its kind to divide the science into its present main branches of inorganic and organic chemistry.

It may be desirable to indicate, as briefly as possible, the general state of knowledge respecting the chemistry of organic substances down to the early years of the last century. As already mentioned, such substances as acetic acid, turpentine, starch, sugar, certain dye stuffs, and oils, had long been known; and such processes as saponification and fermentation had been practised from very early times. The alchemists had prepared a variety of essential oils, aliphatic ethers, and esters; and the iatro-chemists had obtained benzoic and succinic acids, and acetic acid from wood. Milk sugar was first prepared by Fabrizio Bartoletti in 1619. Grape

sugar was first mentioned as occurring in honey by Glauber in 1660. Boyle first detected the presence of a spirit among the products of the destructive distillation of wood. Few of the followers of Stahl occupied themselves with organic products ; and it was only towards the end of the phlogistic period that attention was once more directed to products of animal and vegetable origin. Scheele isolated glycerin in 1784, and obtained *ethyl chloride* by the distillation of a mixture of common salt, pyrolusite, oil of vitriol, and alcohol. *Ethyl acetate* was first prepared by Lauraquais in 1759. Arvidson obtained *ethyl formate* in 1777. *Oxalic ether* was first made by Savary in 1773. What was long known as *oil of wine* appears to have been first mentioned by Libavius, but its true nature was discovered by Hennel in 1826. The formation of *aldehyde* was first recognised by Scheele in 1774, and it was in turn investigated by Fourcroy and Vauquelin, Döbereiner, and Gay Lussac; but it was first definitely isolated in 1835 by Liebig, who gave it its name.

The first organic acid known was vinegar (acetic acid), and for a long time all naturally occurring organic acids having a sour taste were regarded as identical with or as forms of vinegar. It was only during the second half of the eighteenth century that it was clearly ascertained that a variety of organic acids exist, perfectly distinct from acetic acid. *Glacial acetic acid* was first obtained by Löwiz in 1789. Acetic acid, as a product of the destructive distillation of wood, was first obtained by Göttling in 1779. The acetic fermentation has been studied from very early times. Surmises as to the mode in which wine was converted into vinegar are to be met with in the works of Basil Valentine, Becher (1669), Lemery (1675), and Stahl (1667). Priestley, for a time,

held the opinion that vinegar contained a vegetable acid air, but he subsequently discovered and corrected his error. The direct conversion of spirit of wine (ethyl alcohol) into acetic acid was studied by Lavoisier and Berthollet, who first clearly recognised that it was a process of oxidation. The quantitative composition of acetic acid was first established by Berzelius in 1814. Many of the acetates have been known from early times. *Verdigris* is mentioned by Theophrastus, Dioscorides, and Pliny. *Zinc acetate* was known to Geber, and *potassium acetate* to Pliny, who mentions its use in medicine. *Ammonium acetate* was also used in medicine as far back as the beginning of the seventeenth century, and was particularly recommended by the physician, Raymond Minderer. *Sodium acetate* was prepared by Duhamel in 1736. *Lead acetate* was known in the fifteenth century, and was styled by Libavius *saccharum plumbi quintessentiale*, in allusion to its sweet taste. What was called by the alchemists *lac virginis* was a turbid solution of basic lead acetate, and it was frequently used in medicine, more particularly by Goulard in 1760. What we now call *acetone* was first observed by Libavius, in 1595, and subsequently by Boyle, during the destructive distillation of lead acetate : its formation from other acetates was noticed by Trommsdorff, Derosne, and Chenevix, by whom it was termed pyroacetic spirit. Its true nature and composition were first ascertained by Liebig in 1831.

The formation of tartar in the manufacture of wine has been known from the earliest times. It was regarded as, and originally styled, the *faex vini*. The word "Tartarus" is first met with in alchemistic literature in the eleventh century, and is the Latinised form of an Arabic word. Marggraf, in 1764, recognised that

the tartar of wine contained potash ; but tartaric acid itself was first isolated by Scheele in 1769.

The *double tartrate of potash and soda* was first prepared in 1672 by Peter Seignette, an apothecary of Rochelle, and was used by him in medicine.   *Tartar emetic* was discovered by Adrian von Mynsicht in 1631, and its true nature explained by Bergmann in 1773. *Racemic acid* was first mentioned by a wine manufacturer named Kestner, and was recognised as an acid in 1819. Its relation to tartaric acid, with which it is isomeric, was first explained by Berzelius, who gave it its name.

The naturally occurring oxalates were long considered as identical with tartar.   *Oxalic acid* was obtained by Scheele in 1776 by means of the action of nitric acid upon sugar.   This acid was further investigated by Bergmann, who observed its decomposition by heat with the formation of a gas burning with a blue flame.   The identity of the naturally occurring oxalic acid with that prepared from sugar was established by Scheele in 1784.   The quantitative composition of oxalic acid was first ascertained by Dulong in 1815.   *Mucic acid* was discovered by Scheele in 1780, and was studied by Fourcroy, who gave it the name it now bears.   *Pyromucic acid* was also known to Scheele, and was observed by Hermbstädt and Houton-Labillardière.   *Camphoric acid* was first recognised by Bouillon-Lagrange and Vauquelin. *Suberic acid* was discovered by Brugnatelli in 1787.

That gum benzoin yielded a product (*benzoic acid*) by sublimation was known in the sixteenth century.   It was introduced into medicine by Turquet de Mayerne as *flowers of benzoin*.   Scheele showed how this acid might be obtained by wet methods from gum-benzoin. It was detected in Peru-balsam by Lehmann in 1709. Rouelle found it in the urine of the cow and the camel.

Liebig, in 1829, detected the difference between *hippuric acid* and benzoic acid. The characteristic acid in amber *(succinic acid)* was first detected by Pott in 1753.

Formic acid was first isolated by Wray in 1676. *Lactic acid* was discovered by Scheele in sour milk in 1780. For a time it was regarded as impure acetic acid, until it was detected in muscle juice by Berzelius, and its individuality established. Its true composition was ascertained by Mitscherlich and by Liebig in 1832. *Citric acid* has been known since the thirteenth century, but it was first definitely isolated by Scheele in 1784. Apple juice was used in medicine in the sixteenth century, and the soda salt of its characteristic acid *(malic acid)* was prepared by Donald Monro in 1767.

It was known to the ancients that extract of gall nuts acquired a black colour when mixed with a solution of iron vitriol; and Boyle and Bergmann ascribed this phenomenon to the presence of a peculiar acid. *Gallic acid* was first isolated by Scheele in 1785, and its composition established by Berzelius in 1814. *Tannic acid* was definitely recognised as distinct from gallic acid by Seguin in 1795.

Mellite, or honey-stone, is mentioned in mineralogical treatises in the sixteenth century. That it consisted of the alumina salt of a special acid *(mellic acid)* was shown by Klaproth in 1799.

Prussian blue was accidentally discovered in 1710 by a dyer named Diesbach. Its mode of manufacture was first made known by Woodward in 1724. The peculiar reaction by which it was obtained was made the subject of investigation by many chemists of the period without any decisive result. Scheele observed that, when the salt which occasioned the blue colour with vitriol was distilled with sulphuric acid, a volatile acid, inflammable

and soluble in water, was obtained. This acid received from Bergmann the name of *acidum cærulei berolinensis*, or " Berlin-blue acid," subsequently shortened by Guyton de Morveau to *prussic acid*. Scheele also prepared the cyanides of silver and ammonium. That prussic acid was free from oxygen was established by Berthollet. Anhydrous prussic acid was first obtained by Von Ittner, who first established its highly poisonous nature. Bolim, in 1802, had previously observed the presence of prussic acid in oil of bitter almonds, the poisonous character of which was known to Dioscorides. Porret first definitely isolated *potassium ferrocyanide*, and subsequently discovered the *thiocyanates,* the quantitative composition of which was ascertained by Berzelius in 1820. That prussic acid was a compound of hydrogen and cyanogen was established by Gay Lussac in 1815.

Cyanic acid was discovered by Wöhler in 1822, in which year also L. Gmelin discovered the *ferricyanides*.

Fulminating mercury was first prepared by Howard in 1800, and *fulminating silver* by Brugnatelli in 1802. These were recognised by Liebig, in 1822, to contain a peculiar acid, which he termed *fulminic acid*, and which he showed to have the same composition as the cyanic acid discovered by Wöhler. *Uric acid*, so named by Fourcroy, was discovered in gall stones by Scheele in 1776. *Urea* was first definitely isolated by Fourcroy and Vauquelin in 1799, and was synthetically prepared by Wöhler in 1828.

The bitter principles of plants and their medicinal virtues early attracted attention ; but the first attempt to isolate them was made by Fourcroy and Vauquelin in the case of the Peruvian bark, long known for its power as a febrifuge. In 1806 Vauquelin obtained *quinic acid*. *Cinchonine* was first isolated by Gomes in 1811.

The chemical nature of opium was the subject of numerous inquiries in the early years of the nineteenth century. In 1805 Sertürner detected the existence of *meconic acid,* and in 1817 that of *morphine,* which he recognised as an alkaloid. *Narcotine* was discovered by Robiquet in 1835. The investigation of other bitter substances was undertaken by Pelletier and Caventou, who in 1818 discovered *strychnine, brucine* (1819), and *veratrine* (1820).

The contemporaries and immediate followers of Lavoisier were the first to make a systematic attempt to elucidate the chemical nature of organic products of animal origin. To this period belongs the work of Fourcroy and Vauquelin on animal chemistry. Chevreul, a pupil of Fourcroy, worked on urine, adipocire, and the animal fats in the first decade of the last century. Kirchhoff, in 1811, discovered the method of converting starch into sugar ; and Döbereiner, in 1822, described a method of preparing formic acid artificially. Dumas and Boullay, in 1827–1828, prepared a number of new derivatives of ethyl alcohol ; and in 1834 Dumas and Peligot studied in like manner the chemistry of methyl alcohol, and pointed out many analogies which their compounds possessed, not only among themselves, but also to inorganic substances.

Although a considerable amount of information as to the existence, modes of occurrence, and properties of bodies found in the animal and vegetable kingdoms had been accumulated by the end of the first quarter of the nineteenth century, no serious attempt was made to study them systematically until after that period. In fact, they were not even regarded as coming within the operations of laws found to be applicable to the products of the inorganic world, by the investigation

of which products, indeed, those laws had been discovered.

Down to 1828 it was considered that inorganic and organic substances were sharply differentiated by the circumstance that, whereas the former might be prepared by artificial means, and even built up from their elements by synthetic processes in the laboratory, the latter could only be formed in the bodies of animals and plants as the result of vital force. In that year Wöhler showed that urea, pre-eminently a product of animal metabolism, could be prepared synthetically from inorganic materials. Other instances of a similar kind were discovered in rapid succession; and the idea that organic substances could alone be formed by vital processes was proved to be invalid. Moreover, large numbers of substances of a character analogous to those produced by physiological action, but not known to occur in the animal or vegetable kingdom, were prepared. There is, therefore, no absolute distinction to be drawn between the chemistry of the inorganic and organic worlds.

At the present day we mean by "organic compounds" simply the compounds of carbon. These are so numerous, and frequently so complex, that it is convenient to group them together, and study them as a special section of the science. At the outset it was supposed that only very few elements entered into the composition of organic substances. This, indeed, was held to be a point of fundamental distinction between organic and inorganic compounds. Lavoisier was of opinion that all organic bodies were combinations of carbon, hydrogen, and oxygen. Berthollet first discovered the presence of nitrogen in a product of animal origin. Sulphur and phosphorus were detected later.

There is apparently no *à priori* reason why any element should not be associated with carbon, and enter into the composition of an organic compound.

Lavoisier was one of the first to devise methods for ascertaining the composition of organic (carbon) compounds, and to indicate the general principles by which the proportion of the elements met with in these substances can be ascertained. So imperfectly, however, were these methods worked out that it was not established until the close of the first decade of the nineteenth century that organic compounds even obeyed the law of multiple proportions. Thanks to the efforts of Berzelius, Gay Lussac, and Thénard, and especially of Liebig, in 1830, methods of organic analysis were so far perfected that it became possible to ascertain the empirical composition of these compounds with certainty. This point reached, the development of this section of chemistry proceeded with unexampled rapidity. Not only was the composition of numbers of products, such as sugar, starch, the vegetable acids, certain alkaloids, etc., established, but altogether unlooked-for facts became manifest. One of the most surprising of these was that of *isomerism*.

Up to the close of the first quarter of the nineteenth century it seemed self-evident that substances of the same percentage composition are necessarily identical. In 1823 Liebig showed that the silver cyanate of Wöhler had the same composition as silver fulminate. Faraday, in 1825, found a hydrocarbon in oil gas, which had the same composition as olefiant gas, but was otherwise different from it ; and in 1828 Wöhler discovered that urea and ammonium cyanate—perfectly dissimilar substances—were identical in elementary composition. Lastly, Berzelius found this to be true of tartaric and

racemic acids; and he thereupon proposed the term *isomerism* to denote the general fact. He further pointed out that the phenomenon could only be explained by supposing that the relative positions of the atoms in isomeric compounds are different.

But the influence of molecular or atomic grouping in determining the specific character of a substance is not confined to compounds. The same phenomenon is observed to occur among the elements. It was conclusively established by Lavoisier that the diamond and charcoal are chemically the same thing—both forms of carbon. Scheele showed that graphite was a third form of carbon. Phosphorus, sulphur, and oxygen were subsequently shown to be each capable of existence in various modifications. Instances of this character were grouped together in 1841 by Berzelius under the term *allotropy*.

The recognition of the fact of isomerism exerted a great influence on the development of organic chemistry. It ultimately led to the assumption that particular groups of elements or atomic complexes, so-called *radicals*, were to be found in organic compounds—a conception based originally on Gay Lussac's discovery of *cyanogen*, a combination of carbon and nitrogen, which was found to behave like a simple substance, such as chlorine, and to give rise to compounds analogous to the corresponding chlorides. This idea of the existence of compound radicals was greatly strengthened by a memorable investigation by Liebig and Wöhler, in 1832, on oil of bitter almonds and its derivatives, in which they showed that these substances might be represented as containing a special group or radical, termed *benzoyl*, which behaved like an element. The idea of groups of elements going in and out of

combination like a simple substance was not new to chemists : there was not only the case of cyanogen, discovered by Gay Lussac in 1815. The attempt had been made by Dumas and Boullay in 1828 to classify the derivatives of alcohol and ether as compounds containing a common radical *etherin*. Gay Lussac had pointed out that the vapour density of ethyl alcohol seemed to show that it consisted of equal volumes of ethylene and water. Robiquet had also shown that ethyl chloride might be assumed to be a compound of hydrochloric acid and ethylene ; and Döbereiner had regarded anhydrous oxalic acid as a combination of carbonic acid with carbonic oxide.

But the investigation of Liebig and Wöhler served to give precision to the conception. It thereby exercised a profound influence on the development of organic chemistry by demonstrating, in effect, that this branch of the science might be regarded as the chemistry of the compound radicals, in contradistinction to inorganic chemistry—the chemistry of the simple radicals. Additional support for this view was afforded by the remarkable research by Bunsen on the so-called *alkarsin*, the " fuming liquor of Cadet "—an evil-smelling substance long known as being formed when an acetate is heated with arsenious oxide. Bunsen showed that this liquid contained a compound radical having arsenic as a constituent ; and he prepared a series of derivatives, all of which might be formulated as combinations of this radical, which he termed *cacodyl*. The study of the electrolytic decomposition of the acetates by Kolbe and the discovery of *zinc-ethyl* by Frankland afforded powerful support to the doctrine of combined radicals.

Although there can be no doubt that this doctrine greatly stimulated the pursuit of organic chemistry, it

was gradually perceived that to regard inorganic and organic chemistry as the chemistry respectively of the simple and of the compound radicals was an imperfect and misleading conception of the true relations of the two main divisions of the science. Facts showed that the properties of a substance depend more on the arrangement of its atoms than on their nature. The doctrine of compound radicals was implicitly an attempt to extend the dualistic conceptions of Berzelius to the facts of organic chemistry ; and as such it was welcomed by the great Swedish chemist. But dualism was found to have its limitations, even in inorganic chemistry; and these were still more apparent when it was sought to apply it in the other main branch of the science. Attempts were therefore made—notably by the French chemists Laurent, Dumas, and Gerhardt—to formulate organic substances by methods in which the electro-chemical and dualistic conceptions of Berzelius and his followers had no part. How these attempts developed, and how they subsequently grew into the organic chemistry of to-day, will be shown in the second part of this work.

It will be convenient also to delay any account of the personal history of the creators of the science of organic chemistry—Liebig, Wöhler, Dumas—until we are in a position to give a fuller statement of their labours, and of the results which flowed from them. Although the foundations of organic chemistry may be said to have been laid during the closing years of the first half of the nineteenth century, the superstructure was not erected until the second half.

Chapter XII.

THE RISE OF PHYSICAL CHEMISTRY

PHYSICS and Chemistry are twin sisters—daughters of Natural Philosophy; like Juno's swans, coupled and inseparable. Physics is concerned with the forms of energy which affect matter; chemistry with the study of matter so affected. Each, then, is complementary to the other. Philosophers of old drew no practical distinction between them, at least as regards their own studies. Men like Boyle, Black, Cavendish, Lavoisier, Dalton, Faraday, Graham, Bunsen, were pioneers "on a very broad gauge," pushing their inquiries into territories common to the two branches, as their genius or inclinations directed them. Accordingly, it has happened that many so-called physical laws have been discovered by men who were professed chemists. It has also happened that men who began their scientific career as chemists, like Dalton, Regnault, and Magnus, eventually gave the whole of their energies to physical measurements; or, like Black, Faraday, and Graham, devoted themselves to the elucidation of physical problems. As certain of these physical laws and problems have greatly influenced the progress of chemistry, it becomes necessary, in any historical treatment of the subject, to give some account of their origin, and to show how they affected the development of chemical theory.

The relations of heat to chemical phenomena are so obvious and so intimate that the study of their connection

necessarily attracted attention in very early times. But it was only when this study became quantitative that any important generalisations became possible. Most quantitative estimations of heat depend eventually upon the thermometer ; and thermometry is indebted to Englishmen in the first instance for attempts to render the instrument trustworthy.

In this connection may be mentioned the names of Newton and Shuckburgh.   Brooke Taylor, in 1723, made a special study of the mercurial thermometer as a measurer of temperature.   In other words, he sought to discover whether equal differences of expansion or contraction of mercury corresponded to equal additions or abstractions of heat.   The results showed that the principle of the mercurial thermometer is valid within at least the limits of temperature between the boiling and freezing-points of water.   These experiments were subsequently repeated and confirmed by Cavendish, and, independently, by Black.

The discovery of the phenomenon of *latent heat* by Black some time prior to 1760 marks an epoch in the history of science.   It was then for the first time clearly recognised that the state of aggregation of a substance is associated with a definite thermal quantity, and that, in order to effect a change, a definite amount of energy, in the form of heat, must be employed.   The quantitative connection that exists between work and energy was thus foreshadowed.

The doctrine of *specific heat* was taught by Black in his lectures at Glasgow between 1760 and 1765.   The subject was subsequently investigated experimentally by Irvine between 1765 and 1770, and by Crawford in 1779.   A series of determinations was published in 1781 by Wilcke, in the *Transactions* of the Swedish

Academy. In these the term *specific caloric,* since changed to *specific heat*, was first used. About this time the determination of the amount of heat required to raise substances through a definite interval of temperature was made the subject of experiment by many observers, notably by Lavoisier and Laplace, who greatly improved the calorimetric arrangements. The values they obtained long remained the most trustworthy estimations of the specific heats of substances. Their joint research had a further influence on the development of thermo-chemistry by indicating the general experimental conditions which were needed to ensure accuracy in such determinations. Lavoisier and Laplace also measured, in 1782–1783, the heat disengaged by the combustion of substances, and that evolved during respiration. In 1819 Dulong and Petit pointed out that the specific heats of a number of substances, more particularly the metals, were inversely proportional to their atomic weights ; or, in other words, the product of the specific heat into the atomic weight was a constant. The nature of the relation will be seen from the following table of certain of the results obtained by Dulong and Petit :—

Element.		At. wt.		Spec. heat.		Atomic heat.
Bismuth	...	208	...	0.0288	...	6.0
Lead ...	...	207	...	0.0293	...	6.0
Gold ...	...	197	...	0.0298	...	5.8
Platinum	...	195	...	0.0314	...	6.1
Silver ...	...	108	...	0.0570	...	6.1
Copper	...	63	...	0.0952	...	6.0
Iron ...	...	56	...	0.1138	...	6.4

It will be seen that these various elements have an uniform, or nearly uniform, atomic heat—approximately 6.2 on the average.

This would appear to prove that, as Dulong and Petit expressed it, "the atoms of simple substances

have equal capacities for heat." The variations from a
constant value are due partly to errors of observation,
but more particularly to the circumstance that the sub-
stances compared are not all in a strictly comparable
condition — e.g., they are not all equally remote from their
melting points. It was shown, moreover, that the
amount of heat needed to raise a substance through
a definite interval of temperature increased with the
temperature. The range of temperature through which
a determination was made in a particular instance
affected, therefore, the value of the specific heat. The
most noteworthy departures from a uniform value
were observed to occur among the metalloids —
e.g., carbon, the various modifications of which had
different specific heats — and generally among elements
of low atomic weight, in which the variation of specific
heat with temperature was particularly rapid.

Nevertheless, the significance of the generalisation
discovered by Dulong and Petit, in spite of its limita-
tions, was quickly appreciated, as it was perceived
that a knowledge of the specific heat of an element
might be of great value in determining its atomic
weight. The immediate effect was that a certain
number of the atomic weights fixed by Berzelius mainly
on chemical considerations were required to be halved.
Although subsequent experience has proved that the
law of Dulong and Petit is not capable of the simple
mathematical expression they gave it, it has shown
itself to be of great value in fixing doubtful atomic
weights.

Pierre Louis Dulong was born in 1785 at Rouen,
and, after studying chemistry and physics at the Poly-
technic School at Paris, became its Professor of Chem-
istry and subsequently its Professor of Physics. In 1830

he was made its Director of Studies; and in 1832 he became permanent Secretary of the Academy of Sciences. As a young man he worked with Berzelius, with whom he made the first approximately accurate determination of the gravimetric composition of water.   In 1811 he discovered the highly explosive *nitrogen chloride,* in the investigation of which he was severely injured, losing an eye and several fingers.   He died in 1838.   His collaborator, **Alexis Therese Petit,** was born in 1791 at Vesoul, and died, when holding the position of Professor of Physics at the Lycée Bonaparte, in 1820.

The attempt made by Neumann to extend Dulong and Petit's "law" to compound substances was only partially successful.   Nor has any important generalisation followed from our knowledge of the specific heat of liquids.   Almost simultaneously with the publication of Dulong and Petit's "law," Mitscherlich made known the fact that similarity in chemical constitution is frequently accompanied by identity of crystalline form.   Boyle, as far back as the middle of the seventeenth century, had insisted upon the importance of the forms of crystals in throwing light upon the internal structure of bodies.   Romé de l'Isle and Hauy had remarked that many different substances had the same crystalline form.   It had been observed that a crystal of potash alum would continue to grow and preserve its shape in a solution of ammonia alum ; and similar observations had been shown to occur in the case of vitriols.   The invention of the reflecting gonimeter by Wollaston greatly facilitated the investigation of such phenomena. Mitscherlich showed that the phosphates and arseniates of analogous composition had the same crystalline shape, or, in other words, were isomorphous.   The same fact was observed to occur in the case of the analogously

constituted sulphates and selenates, and in that of the oxides of magnesium and zinc, etc.   The value of isomorphous relations in determining the group-relationships of the elements and in deducing the composition of salts was at once recognised by Berzelius, who styled the discovery of isomorphism by his pupil Mitscherlich as "the most important since the establishment of the doctrine of chemical proportions."   The quantities of the isomorphously replacing elements in a compound were regarded by him as a measure of their atomic weights ; and the principle was subsequently constantly employed by him, whenever possible, as a criterion in fixing their values.   Other investigators have followed his example in this respect ; and isomorphism is still regarded as an important consideration in establishing the genetic relations of an element.

Eilhard Mitscherlich, the son of a minister, was born in 1794 at Neu Ende, near Jever, in Oldenburg, and, after studying philology and oriental languages at Heidelberg, went to Paris, and thence to Göttingen, where he occupied himself with natural science.   In 1818 he repaired to Berlin and commenced to work on the arseniates and phosphates, the similarity in the crystal-forms of which he was the first to detect.   His friend Gustav Rose, the mineralogist, thereupon instructed him in the methods of crystallography, to enable him to verify his discovery and to establish it by goniometric measurements.   In 1821 he joined Berzelius at Stockholm, where he pursued his inquiries on the connection between crystal-form and chemical composition.   It was at the suggestion of Berzelius that he adopted the term "isomorphy" to express this connection—the mechanical consequence of identity of atomic constitution.   In the same year

he was appointed Klaproth's successor in Berlin, where he died in 1863.

Mitscherlich also worked on the manganates and permanganates, on selenic acid, on benzene and its derivatives, and on the artificial production of minerals.

The study of the physical phenomena of gases, initiated in 1660 by Boyle's discovery of the law of gaseous pressure, has greatly contributed to our knowledge of their intrinsic nature. Boyle himself only proved his law in the case of atmospheric air ; but the observation was subsequently (1676) generalised by Marriotte. Charles, Dalton, and Gay Lussac independently showed that gases have the same rate of thermal expansion.

That gases are made up of particles possessing an internal movement was surmised by the Greeks ; but experimental evidence for such a view of their constitution was first presented by Thomas Graham in 1829–1831, when he discovered that gases move, or are diffused, at rates inversely proportional to the square roots of their densities. Observations of a like character, which found their explanation in Graham's discovery, had previously been made by Priestley, Döbereiner, and Saussure. This interchange in the position of their particles is a property inherent in gases. Inequality of density is not essential to diffusion. Graham proved this by connecting together two vessels, one containing nitrogen and the other carbonic oxide, which have the same density. After the expiration of a certain time both gases were found to be uniformly diffused through the vessels.

How these laws were found to be interdependent and mutually connected, and how they led up to a molecular theory of gases which serves to explain them, as well as certain other gaseous phenomena to be

subsequently noted, will be shown in the second part of this work.

By the end of the period with which we are concerned —that is, the middle of the nineteenth century—a considerable body of information had been accumulated as to the conditions which determine the different states of aggregation of matter—that is, the conditions which allow of the passage of the gaseous state into that of the liquid, and of the liquid into that of the solid.   That the same substance was capable of existence in the three states of gas, liquid, and solid was of course evident from the case of water.   Even the most primitive races must have realised that steam, dew, rain, snow, hail, and ice were only modifications of one and the same substance.   As knowledge increased, other substances came to be known which resembled water in their capacity for existence in various physical states. It was but natural to assume that this was a general attribute, and that all substances would, sooner or later, be found capable of existence in each of the different conditions of aggregation.

Attempts were made during the first quarter of the last century to prove that all the æriform bodies then known were simply vapours more or less remote from their point of liquefaction, and still further removed from their point of congelation.   Monge and Clouet condensed sulphur dioxide some time before 1800 ; and Northmore, in 1805, liquefied chlorine.   But these observations attracted little attention until Faraday, in 1823, independently effected the liquefaction of chlorine, and Davy that of hydrochloric acid.   Faraday almost immediately afterwards liquefied sulphur dioxide, sulphuretted hydrogen, carbon dioxide, euchlorine, nitrous oxide, cyanogen, and ammonia.

Other experimenters, among whom may be mentioned Thilorier and Natterer, greatly improved the mechanical appliances for liquefying these gases; liquid carbonic acid and nitrous oxide were obtained in considerable quantities, and employed in the production of cold. Certain of the gases—hydrogen, oxygen, nitrogen, nitric oxide, carbonic oxide, etc.—resisted all attempts to liquefy them ; and hence gaseous substances came to be classified as *permanent* and *non-permanent*, depending upon whether they could or could not be liquefied. The division was felt to be irrational even at the time it was made. There seemed no *à priori* reason why carbon dioxide and nitrous oxide should be liquefiable, while carbonic oxide and nitric oxide should resist all attempts to coerce them into changing their state. The real clue to the conditions required to effect the liquefaction of a gas was not discovered until nearly half a century later, when, as will be shown subsequently, the arbitrary division of gases into permanent and non-permanent was swept away.

The discovery of the law of gaseous combination by Gay Lussac, and the recognition by Ampère and Avogadro of the relation between the density of a gas or a vapour and its atomic weight, early led to improvements in the methods of determining the absolute weights of gases and vapours, especially by French chemists. Both Gay Lussac and Dumas devised processes for determining vapour densities which were in use until late in the century, and which, although now superseded by more convenient and more rapid modifications, afforded valuable information concerning the molecular weights of substances and the phenomena of gaseous dissociation.

During the first decade of the nineteenth century

Dalton and Henry discovered the simple law which connects pressure with the solubility of a gas in any solvent upon which it exerts no specific action. Dalton further developed the law so as to include the absorption by a solvent of the several constituents of a gaseous mixture.

Attempts were made by Schröder, Kopp, and others, to discover relations between the weights of unit volumes of liquids and solids and their chemical nature; but such attempts were only partially successful, owing to the difficulty of finding valid conditions of comparison. By comparing the specific gravities of liquids at their boiling-points Kopp succeeded in detecting a number of regularities among their specific volumes which seem to indicate that a comprehensive generalisation connecting them may yet be discovered. Kopp has also shown that regularities exist among the boiling-points of correlated substances, and that there is an interdependence between the temperature of their ebullition and the chemical characters of compounds.

This short summary will suffice to show that attempts to discover relations between the physical attributes of substances and their chemical nature were made more or less sporadically from the time that chemistry was pursued in the spirit of science. But it is only in recent times that any great accession to knowledge has resulted from such efforts. The science of physical chemistry is practically a creation of our own period. Its systematic study may be said to date only from the last quarter of the nineteenth century, since which time it has made extraordinary progress. Its broad features will be dealt with in the second volume of this work.

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