HISTORY OF CHEMISTRY

VENABLE

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A SHORT
HISTORY OF CHEMISTRY

BY

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PREFACE.

This History has been written because of a conviction, from my own experience and experience with my students, that one of the best aids to an intelligent comprehension of the science of chemistry is the study of the long struggle, the failures, and the triumphs of the men who have made this science for us. The work is based upon a course of lectures delivered for several years past to my classes in the University of North Carolina. The effort has been to systematize and digest the material on hand so as to render it available for those desiring a general knowledge of the subject. Free use has been made of all the chief authorities; the historical works of Kopp, Berthelot, Hoefer, Thomson, Ernst v. Meyer, Ladenburg, Rodwell, Muir, Wurtz, Hartmann, Gmelin, Karmarsch, and Siebert, besides the original works of nearly all the chemists mentioned for the past century and a half, have been consulted. It has not been thought necessary, in so brief a work as this, to give references to such literature, so they have been omitted.

F. P. V.

Chapel Hill, N.C., *June*, 1894.

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A SHORT HISTORY OF CHEMISTRY.

PART FIRST.

THE GENESIS OF CHEMISTRY.

AMONG THE ANCIENTS.

In attempting to discover traces of a science in earliest historic times, one must first disabuse his mind of the idea that he will find it in anything like the elaborated modern form in which he knows it. These natural sciences are the result of a long process of evolution, and the primal form will probably prove a very much disguised one. In most cases it is idle to speak of systematic science as existing among the ancients. Unquestionably there was knowledge of isolated scientific facts, — here and there one may find a crude theory, more justly to be styled a philosopher's dream, — but of system there was none.

When one speaks, then, of the birth of chemistry, some such stage is meant as that of the ovum, which will lead through a series of metamorphoses up to the perfected insect. And yet it is most useful and entertaining to study these transformations. Rodwell aptly compares it to the study of the history of a nation. There is first the groping after causes, and then the struggle to frame laws. There are intellectual revolutions, bitter controversial conflicts, and the crash and wreck of fallen philosophies. As it is important to study the history of some people's growth, so we should follow the lines of march and onward progress of a great science. We know far too little of the struggles and warfare, the privations and sacrifices, the heroes and princes who have striven and wrought for us, and by whose labors our burdens are lightened, our comforts increased, and our minds enlarged.

Derivation of the Name. — The ovum from which chemistry has been slowly evolved seems to have been sorcery and magic. The name itself is most plausibly explained as pointing to this. The word *χημεία* occurs first in the writings of Suidas, a Greek lexicographer of the eleventh century. It is there defined as the "preparing of gold and silver." This is manifestly a Greek rendering of the name Chema or Chemi, which is of Egyptian origin, and all attempts at deriving it from χέω, to fuse, or χῦμα, a liquid, are without import. Plutarch tells us that Chemia was a name given Egypt on account of the black soil, and that this term further meant the black of the eye, symbolizing that which was obscure and hidden. The Coptic word *khems* or *chems* is closely related to this, and also signifies obscure, occult, and with this is connected the Arabic word *chema*, to hide. It is therefore the occult or hidden science, the black art. Zosimus, the Panopolite, says that the giants, sprung from the union of the angels and the daughters of men, were taught all that was supernatural and magical by their fathers, and this wonderful knowledge was recorded in a book called Chema.

Mysticism. — Two difficulties meet one in studying the early history of the science. One is just such mysticism as is seen in the quotation made from Zosimus, and the other is the custom among the early writers of ascribing their discoveries, books, etc., to fabulous names or ancient heroes and gods. This latter had two objects, the first being to shield the true author in time of persecution, and the second to gain a certain amount of credit and reputation for a discredited art by the use of the names of such celebrities as Moses, Solomon, Alexander, or Cleopatra. This tendency is especially noticeable among the writers of the Middle Ages, and also the early Greek authors, and is not peculiar to authors of alchemical treatises.

Manuscripts and Original Sources. — No original manuscript of the earliest writers on chemistry or alchemy has been discovered. Our knowledge must be gleaned from the pages of those writing upon other subjects, or must come from fragments handed down to us through several copyists. The earliest manuscripts that are known are preserved in the museum at Leyden, and were found at Thebes, probably in a tomb, enclosed in the wrappings of a mummy. They are of the greatest possible interest to chemists, and have been most carefully studied and commented upon by Berthelot. They are written partly in the Greek and partly in the Demotic character, though they are known as the Greek papyri. The earliest is somewhat fragmentary, the beginning and the end being lost. It was written apparently about the third century of the Christian era, and belonged to the class of books burned by Diocletian. These manuscripts are filled with magical formulas, recipes, and descriptions of chemical processes, together with drawings of various forms of apparatus. Rodwell states that there is said to be a Greek manuscript of the fifth century in the King's library at Paris, and others of a somewhat later date in the libraries of Munich, Milan, Venice, Hamburg, and Madrid; but he is inclined to doubt whether any of these were written before the ninth or tenth century. They are probably the work of monks living at Alexandria and Constantinople.

Destruction of Early Writings. — The reason generally assigned for this absence of early records is that Diocletian burned all writings of the Egyptians bearing upon alchemy, because, as he said, these taught the art of making gold and silver; and, by destroying them, he took away from the Egyptians the power of enriching themselves and rebelling against the Romans. Whether Diocletian actually ordered the books to be burned or not, it is certain that these books of a feared and prohibited art were subject to many another foray, as is evidenced by the scene recorded for us in the Acts of the Apostles: "Many of them also which used curious arts brought their books together and burned them before all men; and they counted the price of them, and found it fifty thousand pieces of silver." Such scenes were often repeated in the early part of the Christian era, and Diocletian had only to complete these iconoclastic ravages.

Chinese Sources. — No Chinese nor Japanese writings of early date on chemistry are known, with certainty, to exist. Some have been reported, but they appear untranslatable and their contents are unknown. Where the early literature is so imperfectly known, it is impossible to trace, on the part of these people, the growth of their knowledge of chemical substances and forms of combination. It is certain that the Chinese have had some knowledge of metals, alloys, colors, and salts for a long time, and that they manufactured gunpowder and porcelain before they were known in Europe.

Aryan Sources. — In the same way, with regard to the Aryan races of India, we can only say that their knowledge of the extraction of metals, the making of steel, the preparation of colors, and similar technical operations, dates back to the most remote antiquity. They also theorized as to the elements and their number. Their synonym for death was, "man returns to the five elements." Magic and mysticism find their natural home in India to the present day.

Egyptian Sources. — The almost universal tradition among alchemists is that their art was first cultivated among the Egyptians, and that Hermes Trismegistus, the Egyptian god of arts and sciences, was its founder. The finding of papyri of a chemical nature in the tombs, and many other facts, lead us to give credence to this tradition so far as the early cultivation of the art among the Egyptians is concerned. Clement of Alexandria tells us that the knowledge of this occult science was restricted to the priests, who were forbidden to communicate it to any save the heir-apparent to the throne, and to such among them as excelled in virtue or in wisdom. Plutarch also mentions the strict secrecy observed, and the cloaking of their knowledge under the guise of fables. The art was especially cultivated in the great temple at Memphis. Ptah-mer, the high priest of Memphis, whose statue is preserved in the Louvre, was so great an adept that he was said to know all things, and yet could conceal this knowledge from others as with a veil. The searching out of the books of the Egyptians and their burning by the Roman Emperor is another proof of the early and wide-spread practice of this art among them.

Further, there is a similarity easily detected between the hieroglyphics and the alchemical signs. The phraseology in the early treatises is similar to that in the priestly writings. Lastly, we must note the important part played by the number four with the alchemists as well as with the Egyptian priests. There are the four bases or elements, the tetrasomy of Zosimus; the four zones, four funeral deities, four cardinal points, four winds, four colors, etc.

Chaldean Sources. — The Chaldeans, as masters of occult sciences, played an important part at Rome. In much earlier times, the Bible mentions them as the depositaries of all wisdom and science, the trusted advisers of the far Eastern kings. They were rivals of the Egyptians in knowledge, and were especially famous as astrologers. Many industrial arts were brought to as high perfection in Babylon as in Egypt; for instance, the processes of glass-making, of dyeing, and of working in metals. Those Chaldeans who settled in Rome in later years came from Syria and Mesopotamia. Tacitus makes mention of them. They were much sought after by the fashionable as the representatives of Eastern religions and mystic doctrines. Ostanes, the Mede, was one of the celebrated early alchemists. Several writers have recorded for us the existence of a book called "*The Book of the Divine Prescriptions*," which seems to have been the most famous writing of these Persian sages.

The belief in some wonderful connection between planets and metals is due to these Chaldeans. The signs of the heavenly bodies became the symbols for the metals. These planets influenced a supposed growth of the metals, and were esteemed all-powerful in regulating human life and fate. Many of these notions are to be attributed to the Alexandrian epoch. The idea of the macrocosm, or outer world, and the microcosm, or little inner world of a man's own nature, which is so often referred to and utilized in alchemical writings, originated also at Babylon.

Jewish Sources. — In many of the treatises on alchemy we meet with Jewish names, and some of these writings have been ascribed to Jewish authors. Though jealous guardians of the only pure religion, the Jews sought after other gods. They were often superstitious, and believers in magic and demons. They were very learned; and at Alexandria, where Greek culture came in contact with the culture of Egypt and of the Chaldeans, the Jews, for a while, just at the time of the birth of Christianity, were at the head of science and philosophy, and played a very important part in the fusion of Greek doctrines, scientific and religious, with those of the Orient.

The European nations first became interested in the occult science in times much later than those we have been referring to in connection with the Eastern nations.

Degree of Knowledge. — As to the degree of knowledge attained, apart from mysticism and magic, we find that the practical and useful came first before all theory. A somewhat detailed account of this knowledge will be given later. There is much to prove that, both at Babylon and in Egypt, the industrial arts were practised with a high degree of skill; but, of course, all was empirical, and hence very slow of development. There is little evidence of any attempt at finding out the causes of the changes observed or brought about.

ANCIENT ALCHEMISTS.

Hermes. — First among the names connected with alchemy before the Christian era is that of Hermes Trismegistus. He is by some supposed to be identical with Canaan, the son of Ham. The name is synonymous with Toth, the god of intellect, the patron of arts and sciences in ancient Egypt. The adepts in alchemy were unanimous in writing of him as the founder of their art. He was said to be the author of twenty thousand or thirty-six thousand five hundred books, which means probably that, as the god of letters, all books were dedicated to him and he was in one sense their author. Clement of Alexandria describes the solemn procession in which these books were borne in the great ceremonies. Tin and mercury were set apart as metals sacred to him. During the Middle Ages the science was often known under the name of the Hermetic Art.

Inscription of Hermes.—Albertus Magnus, in a treatise attributed to him, tells us that Alexander the Great found in the sepulchre of Hermes (or in the tomb of Sarah) certain emerald tables inscribed with the secrets of his wisdom. This famous inscription is constantly quoted in books on alchemy. It consisted of thirteen parts or sayings. They are sufficiently obscure to receive almost any interpretation. The most careful commentators agree that they refer to the universal medicine or the philosopher's stone. Two quotations will suffice to give an idea of the whole.

No. 7. Separate the whole earth from the fire, the subtle from the gross, acting prudently and with judgment.

No. 8. Ascend with the greatest sagacity from the earth to heaven, and then again descend to the earth, and unite together the powers of things superior and things inferior. Thus you will possess the glory of the whole world, and all obscurity will fly far from you.

To most this seems a meaningless forgery of the early alchemists. Still, this mystical personage had great influence and through many centuries. We find various axioms ascribed to Hermes, also a mystic hymn, and a so-called instrument or table of figures for predicting the outcome of disease, a life's fate, etc. Such tables were used in very ancient times in Egypt.

The Hermetic Philosophers.—The alchemists called themselves the Hermetic Philosophers, and followed the Hermetic Art or Hermetics. To close anything very securely, as, for instance, to seal it in a glass tube, is called to this day sealing it hermetically. In old times the symbol of Hermes was affixed to the article, and it was thus sealed with "Hermes, his seal."

Demokritos of Abdera.—The earliest historical personage connected with alchemy is Demokritos of Abdera, who lived

460–357 B.C. He was the founder of the atomistic school, extending and developing the theory of Leukippos. His definition of the atom is almost as absolute and precise as that found in modern treatises. His chief work was entitled "*Physica et Mystica.*" Aristotle frequently cites from the writings of Demokritos. Many works have been ascribed to him which were undoubtedly the productions of later centuries. As was customary for men of learning in early times, Demokritos visited Egypt, Chaldea, and various parts of the East, in the search of knowledge, and doubtless owes much to the wise men of those regions.

The works of Demokritos and his school formed a sort of encyclopædia of philosophy and science. These books are unfortunately lost, with the exception of a few fragments. Pliny tells us that Demokritos was instructed in magic by Ostanes the Mede. The name of Demokritos is found in the Leyden Papyrus, in the magic ritual there recorded. To him was attributed also a table called the Sphere of Demokritos, for foretelling death or recovery from a malady. This was similar to the table of Hermes mentioned above. It is impossible to tell how much of the magical and alchemical should justly be accredited to this Greek philosopher.

The Greeks and Natural Science. — The observation and experiments necessary for the pursuit of alchemy did not comport with the Greek idea of philosophy. This is shown by the saying of Socrates, that the nature of external objects could be discovered by thought without observation, and by the renunciation of all natural sciences by the Cynics. This came largely from the fact that they saw in the nature around them the mutable only. Plato separated logic, as the knowledge of the immutable, from physics, the knowledge of the mutable. That which was subject to indefinite change would not repay observing nor recording, therefore they could not conceive of astronomy and physics as serious objects of mental occupation. There was nothing to be learned from fields and trees and stones. One of the philosophers is said to have gone to the length of putting out his eyes, in order that his mind might not be influenced by external objects, but might wholly give itself to pure contemplation. The intellectual power and grasp of these philosophers were wonderful, but faulty and misleading, since the real and practical was left out.

The Mutability of Nature as viewed by the Ancients. — The Egyptians and other ancient peoples held the same idea of the mutability of all external objects, and the absence of law in their changes. They could see no regularity, no laws, governing their changes, and looked for none. With the observing faculty thus blunted, progress in science was necessarily slow. The investigation of nature was even considered impious. The phenomena of nature were brought about by the gods, and their actions should not be inquired into too closely by men. This manner of thinking is not yet extinct.

Theories of the Greek Philosophers. — The theories of the early Greek philosophers, then, were not based upon close observation and a multitude of facts experimentally learned, as all modern theories are. "The baseless fabric of a vision" more nearly describes them. Rodwell gives a most interesting *résumé* of the theories of these philosophers with regard to the formation of the world and the primal elements. These elements were not the chemical elements of the present day, but rather principles. They meant more the characteristic and essential properties of matter than matter itself. Thales of Miletus (sixth century B.C.), the "first of the natural philosophers," affirmed that water was the first principle of all things. This theory had its supporters even during the Middle Ages, philosophers who got water from air and solids by evaporating water, and carefully proved that plants would grow when fed with water only. The theory was not completely disproved until a little more than a century ago.

Anaximenes regarded air as the primal element; Herakleitos, fire; Pherekides, earth. According to Anaximenes, clouds are caused by the condensation of air, and rain by the condensation of clouds. Archelaus said that air, when rarefied, became fire; when condensed, water; and water, when boiled, became air.

Empedokles introduced the idea of four distinct elements, — earth, air, fire, and water, — which were not interchangeable, but formed all things by mixing. Anaxagoras of Klazomene (500 B.C.) seems to have been the first of the Greeks to formulate a theory approaching the atomic. This was more clearly expressed by Leukippos and extended by Demokritos. Long before the time of any of these, however, the idea seems to have been conceived in India.

Aristotle. — Aristotle was the most prolific writer on science among the ancients. His books have come down to us, and have exerted a wonderful influence over all fields of knowledge. Yet there was nothing bearing directly upon chemistry in his writings, nor do we find a single one among the learned men of ancient Greece who can be looked upon as aiding directly in the advancement of chemistry, except Demokritos. The views of Aristotle on science, metaphysics, and ethics were almost universally accepted during the Middle Ages, and held undisputed sway for nearly twenty centuries. He introduced into the science many new ideas, as, for instance, a fifth element, the *quinta essentia*, which he called ether more subtle and divine than the other elements. From this comes the word quintessence, so much used by the alchemists, and used in a different sense now. We have to assume the existence of a rarefied ether in the theories of the present day.

The Four-element Theory. — Aristotle added much to the theory of the four elements, assigning properties to each, and elaborating the changes caused by their mingling, and also dwelling on their inter-convertibility. This was often cited as justifying the idea of the transmutation of the metals. The four elements — earth, air, fire, and water — became known as the Aristotelian elements, and from them various names were derived in the early chemical books. Thus there were earths, alkaline earths, rare earths, etc.; fixed airs, inflammable airs, dephlogisticated air, and others; and a number of different waters, — aqua fortis, aqua regia, aqua ammonia, etc.

Greek Contributions to the Science. — The absence of actual experiment, the philosophical sophistries, and the decrying of all observation of nature as useless speculation, render the intellectual work of the Greeks of small value in science. Yet they had more or less definite notions as to matter and force. The four-element theory, the atomic theory, the idea of an ethereal medium, of the transmutation of metals, of changing one form of matter into another by some active energy or principles — these are mostly distinct gains in scientific thought. The motive principle causing combination and change was, in the philosophy of Anaxagoras. the νοῦς; in that of Demokritos, ἀνάγκη; of Herakleitos, fire; of Aristotle, the moving ether. In our day we call it affinity, but we are still a long way off from solving the mystery of its nature.

ALCHEMISTS IN THE EARLY PART OF THE CHRISTIAN ERA.

In the period from the dawn of Christianity to the fifth century we have the Greek school predominating. For the first time we come across historic personages from whom authentic writings have been transmitted to us. These were genuine alchemists. In this period alchemy attained considerable notoriety, and was of sufficient interest and importance to be celebrated by the poets. Bishops, embassadors, physicians, philosophers, were engaged in the pursuit of the science, and have left us fragments of their works.

Zosimus, the Panopolite. — First among these is Zosimus, the Panopolite. He is the most ancient of the alchemists whose works we possess. He lived in the third century of the Christian era; and Suidas, the Greek lexicographer, tells us that he wrote twenty-eight books on alchemy entitled "*Manipulations.*" Most of these books are lost. Still, many of his treatises have been collected from the Greek papyri; and, though often obscure, they give us a good idea of the learning of the man and of his times. They contain descriptions of apparatus, of furnaces, studies of minerals, of alloys, of glass-making, of mineral waters, and much that is mystical, besides a good deal referring to the transmutation of metals. How much of these fragments is properly to be ascribed to him it is impossible to say. He is cited as the author of the saying that like begets like, and is often quoted by the alchemists of later times, being always spoken of with deep respect as a great and learned master of the science.

Africanus, the Syrian. — Africanus, another of these alchemists, was a Syrian of the time of Heliogabalus. He is said to have written on medical, agricultural, and chemical subjects. Certain geographical and military works are also attributed to him.

Synesius. — Synesius is an important name in the history of the fourth century. He was named Bishop of Ptolemais, and was an astronomer, physician, agriculturist, and embassador. His works were published in 1631 in Paris. They are mostly philosophical and commentaries on Zosimus.

Olympiodorus. — Olympiodorus is more noted as a historian. He was a native of Thebes, and wrote a history of his times. He was not so obscure in his language as Zosimus. He reproduced the early Greek philosophy of Thales and Anaximenes. He seems to have been the first to divide matter into the fixed and the volatile, a distinction depending upon the combustibility.

These few names serve to give some idea of the character of the Greek alchemists. It is impossible to speak of the progress made by, or the learning of, each one.

Breaking up of the Alexandrian School. — Alexandria had been, during this period, the centre of science and philosophy. Under Roman rule and depredations it gradually declined, until by the fourth century no buildings of importance were left in it except the Temple of Serapis. This was the great bulwark of Greek culture and of medical and alchemical study. Under an order to destroy all heathen temples, this also was destroyed in the reign of Theodosius, and most of the books in the magnificent library suffered the same fate. The Serapeum of Memphis and the Temple of Ptah, where the medical laboratories and the workshops of the alchemists were probably to be found, were destroyed at the same time. And thus the learned men of Greece and Egypt were dispersed, suffering a political and a religious persecution.

Transference of Learning to Arabia. — The light of science was transferred to Constantinople, communicated in the sixth and seventh centuries to the Arabians, and by them in turn to their brothers of Mesopotamia and Spain. The name alchemy, al-embic, al-cohol, etc., are of Greek origin, with the Arabic article prefixed; and they point to the source of the knowledge possessed by the Arabians when Europe was in darkness. This darkness which came over Europe is to be accounted for by the many political changes which took place in the Western Empire. Revolutions and invasions were frequent, and the capital had to be moved from place to place. There was a general breaking up of the loosely jointed empire, and a foundation of strong priestly orders hostile to all independence of thought.

THE CHEMICAL KNOWLEDGE POSSESSED BY THE ANCIENTS.

Although chemistry as a science was unknown to the ancients, they possessed some knowledge of chemical substances, and were by no means ignorant of various manufactures and industries based on chemical processes; and hence they had a sort of practical or technical chemistry. In certain branches of metallurgy, in glass-making, dyeing, and tanning, they attained decided proficiency.

Apparatus.—First, as to the apparatus used in the workshops, we derive some information from the Greek papyri. These contain many drawings of alembics and other forms of apparatus, which may of course have been the discovery of later workers if the great age of these papyri is denied. The processes used were those requiring the aid of fire; crucibles, furnaces, etc., therefore abound. Mention has already been made of the treatise of Zosimus, "*On Instruments and Furnaces*," in which he claims to describe the various appliances he saw in the temple at Memphis. These different forms of apparatus were made of gold or bronze or clay-ware. The alembic was a crude form of distilling apparatus, and comes from the Alexandrian period. The water-bath, or *bain-marie* as it is still called by the French, was said to have been invented by Mary the Jewess at a very early period. The blow-pipe and bellows are both figured among these drawings, as well as on very early Egyptian and other monuments.

Metallurgy. — Six metals were well known, — gold, silver, tin, iron, copper, and lead. Homer mentions these six, and the Bible does also; so they seem to have been in use from a very early antiquity. Mercury was afterwards added to the list. The derivation of the word metal is from the Greek word μεταλλάω, "to search after," and the noun first meant or referred to mines. The ancients, especially the Egyptians, were very skilful workers in metals. They made gold wire and leaf, and fine inlaid work, and very beautiful ornaments. Gold was the first known of the metals apparently. Its color, lustre, and malleability attracted the attention of the early peoples. Its occurrence free in nature and in a bright pure state would doubtless account for its being utilized first of the metals. Early vessels were made of it; and it was used for coating, or plating, over wood and other materials.

Silver seems to have been known at very nearly the same time as gold. It also occurs free, and was easily prepared ready for use. Then follow copper, iron, tin, and lead. The Egyptians attributed the discovery of these metals to their sovereigns; the Phœnicians and other nations, to their divinities.

The purification of gold and silver by the cupellation process was known before the Christian era, but there was no means of separating gold from silver. The alloy of the two metals, as they are often found together in nature, was regarded as a peculiar metal itself, and was called *electrum.* The oldest coins we have are made of this electron, or pale gold. This alloy was made artificially out of three parts of gold and one of silver.

Copper was in use before iron, and was called χαλκός by Homer. From this we get the word chalcopyrite and others. The Romans got it first from the Island of Cyprus, and called it *aes cyprium;* and from this it became *cuprum*, and in English copper. It was used mainly in alloys. *Aurichalcum*, or golden copper, they called the alloy made from copper and an ore of zinc; and this is known now as brass. They were ignorant of the metal zinc in the free state. Bronze was an alloy of copper and tin, and was known also before metallic tin. This was very strong, and much easier to work into shape than iron, and hence was a substitute for it. Weapons and many utensils were made from it. Iron was known in very early times; Lepsius maintaining that the Egyptians used it five thousand years ago in the preparation of the harder instruments which they required for much of their work, as in building the pyramids, and engraving precious stones. Iron was coined by the Greeks, and in the time of Homer they used it for axes and ploughshares. As it rusts so easily very few early implements have come down to us. The early Egyptians understood how to harden or temper iron. Steel was made in India at a very early period. The difficulty of reducing iron from its ores, and the fact that it does not occur free, would account for its not being used more largely and at an earlier time.

Tin was obtained from India and Spain and afterwards from Britain. It was one of the articles of commerce used in trade by the Phœnicians. Mirrors were made of it, and copper vessels were coated over with it. Lead and tin seem to have been regarded as varieties of the same metal, and were called *plumbum nigrum* and *plumbum candidum*. Pliny speaks of conveying water in leaden pipes, and Homer makes much earlier mention of the metal. It came mainly from Britain and Spain; and from this latter country mercury was also gotten, and was used, as now, in extracting gold from its ores. The first mention of it was in 300 B.C. Native mercury was called *argentum vivum* (quicksilver), and mercury distilled from cinnabar was known as *hydrargyrum* (ὕδωρ, ἄργυρος). Various compounds of these metals were known and used.

Minerals and Salts. — The two oxides of copper were used in glass-making; verdigris was manufactured and put to several uses; white lead was used as a cosmetic by the Athenian ladies, and found further use as a medicine; red lead was used as a paint; *stibium*, or native antimony sulphide, was used as a paint for the eyelashes, and is still used for that purpose in the East under the name of *kohl*; black oxide of manganese was used in glass-making, especially for clearing up darkened masses, and so got its name of pyrolusite; the native carbonate of zinc was also known and used; the sulphides of arsenic, orpiment and realgar, were well-known pigments. According to Sir Humphry Davy, the ancient Greeks and Romans had almost the same colors as those employed by the great Italian masters at the period of the revival of arts in Italy.

Soda and potash were both used in washing and whitening clothes, in glass-making, and in saponifying the fats for soap and unguents. Lime was burned and mortar made from it, though the earliest cementing material was bitumen. Bitumen and asphalt were also used for torches and embalming.

Glass-making and Pottery. — The art of glass-making is exceedingly old, and apparently originated with the Egyptians. They reached a high degree of proficiency in its preparation, knowing how to color it, and also how to prepare imitation precious stones from it. Clear, transparent, colorless glass was not known by them, however.

They were also skilful in the production of clay-wares and pottery. The Egyptians decorated these wares with colored enamels. The Etruscans showed great skill in the ceramic art. From the earliest ruins have been unearthed specimens of pottery. The Chinese, alone of early nations, knew how to make porcelain.

Dyeing and Tanning. — Dyeing was carried to great perfection. Many vegetable and animal coloring matters were known. Mordants were used, and the effects produced were very beautiful. Paints were also prepared, and applied with brushes. The following mineral colors were known at the time of Pliny: white lead, cinnabar, litharge, smalt, verdigris, ochre, lampblack, realgar, orpiment, and stibnite.

Leather was tanned, at first by means of oil, and later with bark, very much after the manner in use now. The hair was removed by means of lime, as is still done. Some leather, said to have been tanned at the time of Solomon, has been found in modern times fairly well preserved.

Soaps, Medicaments, etc. — Soap was made by mixing wood ashes with animal fats, thus saponifying them. It was used as a kind of pomatum; unguents, oils, etc., were rubbed upon the body in the place of soap as used in modern times. Both hard and soft soap were known. Burnt lime was often added in the manufacture.

Many substances were used as medicaments; some of these might be called chemical preparations, showing an early union between chemistry and pharmacy. Lead plasters were made from litharge and oil, iron rust was used, also alum, soda, and bluestone. The use of sulphur as a disinfectant is mentioned in the well-known passage in Homer, in which he speaks of its being burnt to drive away the evil spirits from a home. It was also used for bleaching purposes. The only acid known was acetic acid, or vinegar; and its solvent power seems to have been greatly over-estimated.

PART SECOND.

THE ALCHEMISTS.

THE ARABIANS.

Science in the East. — Greek learning, with its rudimentary science, had been transferred to Arabia and Persia. The decline and fall of the Roman Empire had left Europe in intellectual darkness; on the other hand, universities, libraries, museums, and observatories were founded and maintained by the Arabians. About the middle of the eighth century the caliph Al-Mansour (754–775) founded the city of Bagdad. He was all-powerful, his land was blessed with peace, and he began to cultivate the arts and sciences. He founded an academy or university at Bagdad, which became very celebrated. Pupils and professors flocked to it from all quarters, and they numbered at one time as many as six thousand. Hospitals and laboratories were erected, and experimental science began to be properly recognized. The names of several caliphs are connected with this university as its fostering patrons, for the successors of Al-Mansour continued his work. Ancient books were collected, and every scrap that could add to their store of learning was eagerly saved. For several centuries this great institution of learning flourished.

Science in Spain. — This love for learning extended to the western possessions of the Arabs. At Fez and Morocco academies were founded, but Spain was still more favored.

The caliphate of Cordova was probably the most prosperous and splendid of the Moorish possessions, and the University of Cordova became the most celebrated in the world. It was attended by Christian students from all Western Europe, as well as by Moors. Its library contained two hundred and eighty thousand volumes, the catalogue filling forty-four volumes. The university produced one hundred and fifty authors. Other universities and libraries were scattered through Spain during this, its golden age.

Progress made by the Arabians. — Yet with all their zeal for learning, and for hoarding old books, and their much writing of new ones, the Arabs made little progress in science. Centuries passed with but slight additions to what was already known. The greatest obstacle to the progress of science lay in their religion, though fortunately chemistry was the branch of science least obnoxious to their prejudices. Islamism prohibited magic and all arts of divination, and also all dissection of the human body after death. In the hands of the Arabians, therefore, alchemy was chiefly applied to the preparation of medicines. During this period there were two especially famous authors and workers, Geber and Avicenna.

Geber. — Geber (eighth century) was a Sabean of Mesopotamia, of Greek parentage, but a convert to Islam. His name in full was Abou-Moussah-Dschafer-al-Sofi. Very little is known of his early history, though he may be looked upon as the founder of experimental chemistry, and was called the Father of Chemistry. Berthelot has shown that the existence of Geber is open to question, and his writings may be attributed to a later date.

His Writings. — Several manuscripts are to be found in the libraries of Europe, purporting to contain his writings. From what source he derived his knowledge we do not know, as he makes no mention of earlier writers except in a general way, speaking of the "ancients." Some think that he obtained his knowledge from Egyptian sources. His works were translated into Latin in 1529, and into English in 1678. There are four treatises: 1. "*Of the Search for Perfection;*" 2. "*Of the Sum of Perfection;*" 3. "*Of the Invention of Verity;*" 4. "*Of Furnaces.*"

He makes no distinction in these between the knowledge gotten from others and that learned by his own experiments. His language is plain enough for one to understand most of the operations indicated and the substances named.

The Nature of his Work. — The object of his work seems to have been the discovery of the philosopher's stone, by which he may have meant some great medicine or remedial agent. This interpretation is a matter of question, however. He was especially interested in finding out the properties of substances, and experimenting upon the possibility of putting them to use as medicines. In his works we find various additions, made by himself or others, to the chemical knowledge already described as possessed by the ancients.

He considered all metals as compounds of mercury and sulphur in varying proportions, an opinion which he says he derived from the ancients, and which was handed down with many variations through the Middle Ages. Gold and silver were the perfect metals, the others imperfect. He frequently made use of sulphur, and knew many of its properties. Geber writes thus of sulphur: —

His Views as to Sulphur and Arsenic. — "Sulphur is a substance, homogeneous, and of a very strong composition. Although it is a fatty substance, it is not possible to distil its oil from it. It is lost on calcining. It is volatile, like a spirit. Every metal calcined with sulphur augments its weight in a palpable manner. All the metals can be combined with this body except gold, which combines with it with difficulty. Mercury produces with sulphur, by way of sublimation, Uzufur or cinnabar. Sulphur generally blackens the metals. It does not change mercury into gold nor into silver, as has been imagined by some philosophers."

As to arsenic, he says: "Arsenic is composed of a subtile matter, and of a nature analogous to that of sulphur. It is fixed by the metals as sulphur; and one prepares it, like the last, by the calcination of minerals."

Views as to Transmutation. — His description of the metals is fairly accurate. As a proof of the possibility of transmutation, he gives an example of copper being changed into gold. "In copper mines we see a certain water which flows out and carries with it thin scales of copper, which (by a continued and long-continued course) it washes and cleanses. But after such water ceases to flow, we find these thin scales with the dry sand, in three years' time to be digested with the heat of the sun; and among these scales the purest gold is found; therefore we judge those scales were cleansed by the benefit of the water, but were equally digested by the heat of the sun, in the dryness of the sand, and so brought to equality." Very plausible reasoning from defective premises, as Thomson observes.

Apparatus, etc. — In the treatise on furnaces he describes a furnace for calcining metals, and also gives a description of a furnace for distilling. In this there is a detailed account of the glass or stone ware or metallic aludel and alembic used in the process. He describes the distillation of many bodies, and uses the term spirit for volatile bodies in general; thus mercury was a spirit. He made use of crucibles and cupels, and gives a full account of the purification of gold and silver by cupellation. He understood the purification of bodies by crystallization, solution, and filtration, calling the latter process distillation through a filter. The majority of the chemical processes in use up to the eighteenth century were known to Geber.

New Substances known to Him. — The alkaline carbonates were known to him, and he prepared caustic soda. He knew also saltpetre and sal ammoniac, and evidently made use of the mineral acids, nitric, sulphuric, and aqua regia. He made use of these as solvents, and thus the wet processes of modern chemistry began to substitute the furnaces of the old. Various vitriols or sulphates were spoken of by him, and also borax and purified common salt. Certain compounds of mercury were prepared by him; among others, the chloride or corrosive sublimate and the red oxide. As an illustration of these processes we may take his method of preparing silver nitrate, which he discovered.

"Dissolve silver calcined in solutive water (nitric acid), as before; which being done, coct it in a phial with a long neck, the orifice of which must be left unstopped, for one day only, until a third part of the water be consumed. This being effected, set it with its vessel in a cold place, and then it is converted into small fusible stones, like crystal."

His philosophy was not very advanced, as he ascribed the various phenomena he observed to occult causes. His writings along this line are obscure and often unintelligible.

Avicenna (978–1036). — Avicenna was the next great Arabian scientist, exerting the same influence over medicine that Geber did over chemistry. He was called the Prince of Physicians, and as an authority ranked next to Aristotle and Galen. He was very precocious as a youth, repeating the Koran by heart at the age of ten. At sixteen he was a physician of eminence, and from that time on his career was one of great success, and yet marked by great dissipation. He was the author of the "*Canones Medicinæ*," a work which was translated into many languages, and was the standard medical authority for several centuries.

Writings. — Many manuscripts bear his name, but there is doubt as to their genuineness. He divided minerals (chemical compounds) into: 1. Infusible minerals; 2. Fusible and malleable (metals); 3. Sulphurous minerals; 4. Salts.

There was little that was original in the canons of Avicenna, the matter coming mainly from the works of Galen and Aristotle, but there was a clear and orderly arrangement, which gave the chief value to the work.

Other Arabic Chemists. — Avenzoar (eleventh century), a Spanish physician, is quoted as making some additions to the knowledge of medicinal preparations. In the beginning of the twelfth century Averrhoes attained prominence as a physician and chemist. The Arabian alchemists of the eleventh, twelfth, and thirteenth centuries, who devoted themselves to attempts at gold-making, were numerous, but of little prominence. Their works are, in the main, unintelligible, and where the meaning can be puzzled out, contain nothing new

THE ARABISTS.

Characteristics of the Age. — From the thirteenth to the fifteenth centuries may best be called the period of the Arabists. The decadence of the Moorish power in Europe was very rapid. The greater caliphates were broken up into smaller dynasties. The Arabs, after a severe struggle, were driven from Spain, and Bagdad was conquered by the Mongols. There was a decline, and then almost complete cessation from literary work. Still, for some centuries the influence of Arabic thought was very great. Their writings were translated into Latin and other languages, and formed the chief treasures of medical and scientific men. Their modes of thought and work were often imitated by their monkish successors. The centre of learning began to shift westward and northward. Schools and universities were established at Montpelier, Paris, Salamanca, Naples, Padua, and Toulouse.

During the previous centuries of intellectual sterility, the monks had been the only conservators of books and scientific works, a dead treasure in their hands. These orders began to awaken to intellectual life. The Benedictine order especially labored for the spread of knowledge. A medical school was founded at Salermo in 1100. During this period also the monks preached and led crusades; and, though these did little directly for the increase of knowledge, indirectly they greatly aided in the spread of Eastern learning and art.

Many industries were founded by the returned crusaders. Alchemy, or the gold-making craze, especially infected them, as the nobles were impoverished by wars and the crusades, and the urgent necessity was laid upon them of in some way replenishing their treasuries. Though the religious orders began to show signs of seeking the spread of knowledge, they were determined to retain control of the onward march, and to allow the progress to go only so far as they saw fit. The characteristics of the age were a shameful mental imprisonment and caging of the human reason. Free striving for higher light, or criticism of accepted authorities, was looked upon as high treason to the Holy Church, and punished by the Inquisition. Those who dared to think clearly for themselves, wrote mysteriously for their fellows as a measure of safety. Several well-known names fall in this period, amid a great number of lesser lights, distinguished by their chosen names as monks and the name of the country to which they were accredited. Such a one is Richard of England, who is mainly noted for having prepared a medicine from gold which was warranted to rejuvenate the old, strengthen the weak, drive out all sickness, and fend off poison from the heart.

Albertus Magnus (1193–1280). — Albertus Magnus, or Albert of Bollstädt, was the first eminent German chemist. He was a Dominican friar and became Bishop of Regensburg. He studied at Padua, Cologne, and at Paris, and mastered all of the sciences of his day. He was a theologian, physician, astronomer, alchemist, and dipped into magic and necromancy. He was an eloquent and successful teacher. Many wonderful feats of magic were recorded of him. He and his pupil, Thomas Aquinas, are said to have constructed a brazen statue which he animated with his *elixir vitæ.* It was capable of walking, talking, etc., like a living being, and was very useful as a servant. It was unfortunately very talkative and noisy. It one day so enraged Thomas Aquinas, by constantly interrupting him while he was deeply engaged with mathematical problems, that he took a hammer and broke it in pieces. Of course this is a fanciful account of a noisily creaking automaton, made by these two, who were very fond of mechanics, and then, in a fit of dissatisfaction, destroyed by one of them. Albertus Magnus lectured in Cologne, and great numbers of students flocked to hear him. He skilfully managed to escape the persecution which befell so many of his brother monks who dabbled in the occult art, and was high in the odor of sanctity.

Writings. — His principal writings were the following: "*De Rebus Metallicis et Mineralibus*;" "*De Alchymia*;" "*Secretorum Tractatus*;" "*Breve Compendium de Ortu Metallorum*;" "*Concordantia*;" "*Philosophorum de Lapide.*"

Work and Theories. — He was the first to use the term "*affinitas*" to designate the cause of the combination of the metals with sulphur and other elements. The term "vitriol" was also first used by him. He regarded the transmutation of the metals as an assured possibility. He did not regard the metals as distinctly differing substances, but varieties of the same species.

"The metals are all essentially identical; they differ only in form. Now, the form brings out accidental causes, which the experimenter must try to discover and remove, as far as possible. Accidental causes impede the regular union of sulphur and mercury; for every metal is a combination of sulphur and mercury. A diseased womb may give birth to a weakly, leprous child, although the seed was good; the same is true of the metals which are generated in the bowels of the earth, which is a womb for them; any cause whatever, or local trouble, may produce an imperfect metal. When pure sulphur comes in contact with pure mercury, after more or less time, and by the permanent action of nature, gold is produced."

His views are in the main those of Geber, though he adds water to mercury and sulphur as one of the constituents of the metals. He seems to have combined some of the ideas of Aristotle with those of the Arabian school. He was a diligent and successful worker, and added many chemical facts to those known by Geber, as, for instance, the purification of gold, the preparation of arsenic, etc.

Thomas Aquinas (1225–1274). — Thomas Aquinas was also a Dominican friar. He was a favorite pupil of Albertus Magnus, and was known as the Angelic Doctor, occupying a high place in the church. He was devoted to mathematics and at the same time was a great alchemist. He taught at Bologna, Rome, and Naples, and wrote several books on alchemy, all of which are obscure and unintelligible. His chief treatise was the "*Most Secret Treasure of Alchemy.*" He wrote on the making of artificial gems, and, according to some, was the first to make use of the term *amalgam* for alloys containing mercury.

Roger Bacon (1214–1294). — Roger Bacon was one of the most remarkable men of this period. He was born in Somerset, England, and belonged to the Franciscan order. His vast store of knowledge won for him the title "Doctor Mirabilis." He was a linguist, astronomer, theologian, and mathematician. He first drew attention to the error in the Julian Calendar. He was a skilled optician and mechanic, and made several automata. His success in this line brought with it the reputation of being in league with the devil, and he was severely persecuted while at Oxford. He did not in this have the good fortune of Albertus Magnus, or lacked his skill and tact. He replied to his accusers by a strong tract, "*De Nullitate Magiæ*," in which he showed that no such thing as magic could exist, and that what his accusers thought were the work of spirits were but ordinary operations of nature. Still, in spite of his arguments, he was imprisoned ten years.

Writings and Work. — His chief writings were: —

1. "*Opus Majus.*" In this his high appreciation is shown of the experimental method and the inductive philosophy, afterwards advocated by his namesake, Francis Bacon.
2. "*Speculum Alchymiæ.*"
3. "*Breve Breviarium de Dono Dei.*"

Yet other transcripts are in the British Museum. He collected the facts known to the alchemists before his time, and followed Geber closely in many things. He knew of gunpowder, but speaks of it obscurely. According to some he mentions saltpetre and sulphur by name as two constituents, and the third constituent under the anagram *luru mone cap ubre,* which is convertible into *carbonum pulvere.* He probably got this knowledge from some Arabic source. He wrote thus obscurely and in riddles because of the example of others, he said, and because of the dangers of plain speaking. No one could appreciate these dangers better than himself. Gunpowder was first used by the English at the battle of Crecy, more than fifty years after the death of Bacon.

His Discoveries. — Roger Bacon was far in advance of his age in all branches of science. He is reputed to be the inventor of the telescope, camera obscura, and burning lenses. He subjected organic substances to dry distillation, and noticed that inflammable gases were produced; and he showed that air was necessary for the burning of a lamp. He was an ardent supporter of the belief in the transmutation of the metals, and related some very wonderful things as to the power of the philosopher's stone. His beliefs on these points he drew direct from Albertus Magnus and the Arabians.

Views as to Transmutation. — The following quotation from his treatise "*Speculum Secretorum*" will serve to give his ideas as to the transmutation of the metals: "To wish to transform one kind into the other, as to make silver out of lead, or gold out of copper, is as absurd as to pretend to create anything out of nothing. The true alchemists never held such a pretence. What is the real problem? The problem is, first, by means of art, to remove from a rough, earthy mineral a bright metallic substance, like lead, tin, or copper. But that is only the first step towards perfection; and the chemist's work must not stop there, for, besides that, he must look for some means of getting the other metals, which are always present in the bowels of the earth in an adulterated condition. For example, the most perfect is gold, which one always finds in the native state. Gold is perfect, because in it nature finished her work. It is necessary, then, to imitate nature; but here a grave difficulty presents itself. Nature does not count the cycles which she takes for her work, to which the term of life of a man is but as an hour. It is, then, important to find some means which will permit one to do in a little time that which nature does in a very much longer time. It is this means which the alchemists call, indifferently, the elixir, the philosopher's stone, etc."

Arnold Villanovanus (1235–1312). — Arnold Bachuone, or Villanovanus, born either in Provence or Catalonia, was a student and later a professor in the University of Barcelona. He was an astrologer, among other things; and proving too good a prophet in his prediction of the death of the King of Spain, he was driven as an exile from that country. He predicted the end of the world for 1335, and came under the persecution of the church, flying to Paris. From Paris he was driven as a gold-maker in league with the devil; and finding no resting-place in Italy, he finally sought refuge and protection in Sicily. He was shipwrecked and drowned in 1312, while on a voyage to Rome to heal the Pope, who lay sick there.

Work and Writings. — He was an adherent of the Arabian school, believing in the composite nature of the metals and their transmutation. He was also a believer in the wonderful curative powers of the gold medicine. Under this name went many yellow liquids which contained no gold. The *aqua auri* of Villanovanus seems to have been alcohol sweetened with sugar and colored yellow with herbs. Yet another of these golden drinks was wine in which a glowing plate of gold had been cooled. Arnold's chief service was in connection with the medicinal use of chemical preparations. He made external application of various mercurial compounds, distilled certain essential oils, and understood some of the properties of alcohol. His knowledge of poisons was extensive. He was the first to point out the poisonous nature of decaying flesh. His writings are numerous. The principal treatises are "*Rosarius Philosophorum*," "*De Vinis*," "*De Venenis*," "*Antidotarium*."

Raymond Lulli (1235–1315). — Raymond Lulli was born on the Island of Majorca, and was said to be the pupil of Arnold and Bacon. He was one of the most eccentric men of his times. He belonged to the order of the Minorites, and was a most voluminous writer upon alchemical subjects.

Character of his Work. — Some of his experiments and observed facts he describes clearly; but for the most part his writings are obscure and involved, yet with a fantastic and picturesque style which led many afterwards to think that wonderful facts lay concealed in his treatises. They were studied and commented upon, and had great influence. Their tendency was toward a sort of combination of religious cant with the pursuit of alchemy. For instance, he maintained that he only could succeed in preparing the philosopher's stone who approached the work with faith and purity. This pious or canting tone was greatly affected by alchemists for a long time afterwards. The followers of Lulli were called the Lullists, and many of their writings were attributed to Raymond. He was credited with some four thousand books in all, about twenty of which seem to be genuine. He was conversant with Geber's works, and often refers to him as the Pagan Philosopher. His works are quite unimportant, and contained little that was new.

Growth in this Period. — As to the growth of chemical knowledge during this period, we do not find many important additions made. Ammonia was discovered, and also alcohol, or spirit of wine as it was called. Gunpowder first came to the knowledge of the Western nations. Metallurgy and the industrial arts, such as pottery, glazing, and glass-making, began to improve, and factories to multiply. Apothecaries also began as a class to be distinguished from physicians. The general tendency of the age was toward magic, sorcery, and gold-making. With the exception of a few prominent men, there was little attempt at the pursuit of chemistry in a scientific spirit or for a truly useful end.

THE SCHOLIASTS.

In this period the art of printing was invented, and book-making as well as book-owning became easier. In the realm of science light became clearer, the desire for knowledge and for conquest over nature became greater. Columbus made his famous voyage over the unknown ocean, and a new world was discovered. Constantinople was taken by the Turks, and the learned men gathered there were driven westward with their manuscripts and stores of learning. The learning of the ancients became a mine of treasure to be zealously worked over by monkish students. Scholarly men arose, and great discussions were held. The Greek philosophers, especially Aristotle, ruled the thought of the day. Still there was much to hamper progress. The work of these scholiasts was almost exclusively commenting upon and elucidating the earlier writers, with as little idea of adding to their writings or their knowledge as to the Holy Scriptures. What was called the "Unholy Quest of Alchemy" had greatly increased in extent. It pervaded all ranks, and caused great misery, deceit, and loss. In the Roman provinces, in England, and elsewhere, it was most rigidly forbidden by law; but these laws were evaded.

Several English names occur in this period, as George Ridley, Canon of Bridlington, who wrote a poem on alchemy, and was reputed to have been successful in the search for the wonder-working stone. Thomas Norton was another English writer on alchemy.

Basil Valentine (1394–). — Above all others stands the name of Basil Valentine. So much doubt has been thrown around the personality of this alchemist, that some have even denied his existence. He seems to have lived in Erfurt, however, and to have been a monk of the Benedictine order. In his writings he shows some similarity to Lully. He had largely the same ideas as to the healing power of the philosopher's stone and the peculiar spirit in which the search for the same should be made. He maintained that its discovery was to be a reward of piety. There was an identification of the spiritual with the material, of life with chemical processes. He was a strange mixture of a cool observer and a maudlin dreamer. In general, however, he had a clearer view and made a plainer path in alchemy and in medicine than his predecessors.

Work and Theories. — He showed especial skill in connecting experiments, following up some distinct line of thought. He made much progress in observing the action of medicines, and this at a time when there was very great abuse of medicines and poisons by physicians. He added salt to Geber's list of constituents of the metals. His knowledge of the metals was great. For the first time arsenic, bismuth, and zinc are distinctly mentioned and classed with the metals, though arsenic was discovered earlier. But his greatest discoveries were in connection with antimony and its compounds. In his book, entitled the "*Triumphal Car of Antimony*," these discoveries are described. Antimony was prepared by the ancients; but it was confused with the other metals, and was practically unknown to them. Basil Valentine first tells of its preparation and makes use of the name. The metal was used in purifying gold, and the compounds were applied medicinally. Through his use of these he wrought many cures and acquired great reputation. Hydrochloric acid was first prepared by him by heating together copperas and salt. He made use of precipitation as a method of experimenting, either discovering it or first largely applying it. Also the first attempts at qualitative analysis are due to him. He proved that iron was present in certain hard tins, copper in

Hungarian iron, silver in Mansfield copper, and gold in Hungarian silver. The spirit lamp was used by him in his work, a great step forward and a marked improvement upon the cumbrous furnace.

Writings. — His chief writings are: "*Currus triumphalis Antimonii*;" "*De magno Lapide Antiquorum Sapientum*;" "*Apocalypsis chemica*;" "*Testamentum ultimum*;" and "*Conclusiones*."

An example of his method of experimentation may be gotten from his "Marriage of Mars and Venus." This operation consisted in dissolving filings of iron and copper in oil of vitriol, mixing the two solutions, and allowing them to crystallize. The vitriol produced contained both iron and copper. This vitriol subjected to calcination gave a scarlet powder (mixture of red oxide of iron and oxide of copper). It was this powder which should furnish the mercury and sulphur of the alchemists. "Take this powder in a distilling vessel well luted and heat gradually. There is first obtained a colorless spirit which is the Mercurius Philosophorum, then a red spirit which is the Sulphur Philosophorum." Again in another place he says, "Antimony is the bastard of lead; bismuth or marcasite is the bastard of tin."

THE ALCHEMISTS PROPER.

The alchemists characterize this age. We find among them the genuine enthusiast, who labored unceasingly with the firm belief in the ultimate success of his search, if only he could hit upon the right way. There was something of the fascination of a lottery in it, along with the nobler feeling of earning success by work. Any one experiment might result in the wished for discovery, and bring with it untold wealth and freedom from pain, and even, it might be, a victory over death itself. The devotees to the search were led on and on, until fortune and life sometimes were sacrificed in the quest.

Growth of the Belief in Transmutation. — The belief in the transmutation of the metals was a natural outcome from the Greek theories as to the elementary principles. The Greek doctrines, as represented by Aristotle, were taught in all the great academies, and could easily be construed into meaning that gold and silver could be produced from the baser metals. It seems strange that truly learned men, as Geber, Villanovanus, Bacon, and Valentine should have believed in the existence of a philosopher's stone, a substance so powerful that a bit of its dust thrown upon melted base metals could transmute them into gold and silver.

Confirmation of the Belief. — We must remember, however, that there were many remarkable phenomena known to them for which this theory offered the simplest explanation; everyday phenomena they are to us, and their explanation seems very simple in the light of our wider knowledge.

Thus, we have certain changes of color in metals produced by the addition of other bodies. Geber knew that when red copper was melted with tutty (an impure oxide of zinc) golden yellow brass was produced, and certain other minerals (which we now know contained arsenic) gave this same metal, copper, a silvery white color. Of course it was known that these were not gold and silver, but the possibility of some sort of transmutation seemed proven. Again, iron dipped into water containing bluestone was changed into copper. Geber believed that when mercury was added to lead, tin was produced, the solid amalgam having very much the appearance of that metal.

The metallurgical operations of those days were very imperfect, and not at all understood; so that the fact that a bead of silver was gotten from certain galenas, and gold from copper ores and from pyrite, was looked upon as a proof of the changes of the base metals into the noble by some of the operations during the treatment. It was not until many analyses had been made in later years that this was given up as a proof of transmutation. These experimental proofs were further supported by much historic evidence.

Traditions as to Gold-making. — Traditions and stories of wonderful character and most circumstantially related, all combined to confirm this belief. One such story may be given as copied by Thomson from Mangetus.

"A stranger, meanly dressed, went to Mr. Boyle, and, after conversing for some time about chemical processes, requested him to furnish him with antimony, and some other common metallic substances, which then fortunately happened to be in Mr. Boyle's laboratory. These were put into a crucible, which was then placed in a melting-furnace. As soon as these metals were fused, the stranger showed a powder to the attendants, which he projected into the crucible, and instantly went out, directing the servants to allow the crucible to remain in the furnace till the fire went out of its own accord, and promising at the same time to return in a few hours. But as he never fulfilled his promise, Boyle ordered the cover to be taken off the crucible, and found that it contained a yellow-colored metal, possessing all the properties of pure gold, and only a little lighter than the weight of the materials originally put into the crucible."

Theories as to the Origin of the Metals. — There were many attempts at explaining the origin of the metals. Thus we have Geber's sulphur and mercury theory, elaborated and added to by later alchemists. It is noteworthy that these constituents were volatile. Basil Valentine speaks of them as "condensations of a mere vapor into a certain water." Some said that the sun acting upon and within the earth formed the metals, and that gold was merely its beams condensed to a solid. The belief that metals grew as vegetables was very common, and dated back to prehistoric times. It was customary in the Middle Ages to close a mine from time to time, and thus give the metals opportunity for growth.

Legal Prosecution of the Gold-makers. — Sometimes the aid of the law was invoked to suppress the pursuit of alchemy, in many cases because the government feared the possession of any such potent secret on the part of a subject; in others because it was impious or contrary to the interests of the church. In 1404, by an Act of Parliament, it was forbidden to make gold or silver. Patents were granted later by Henry IV. to certain persons who claimed to have discovered the philosopher's stone, and a commission of ten learned men was afterwards appointed to determine if this transmutation of base metals into gold were possible or not.

Mystical Language. — Legal prosecution, and the desire to keep their wisdom in a form intelligible only to adepts, as well as a desire to appear to be wise where no wisdom really was led to the adoption of a secret mystical language, variously interpreted from one generation to another, and unintelligible to chemists of the present day. The obscurity was much increased by the multiplication of symbols. These were often drawn from astrology and other sciences. Rodwell records one Italian MS. of the early part of the seventeenth century, in which mercury is represented by twenty-two distinct symbols and thirty-three names, many of which are of distinctly Arabic origin, such as Chaibach, Azach, Jhumech, Caiban, etc.

Sharpers and Charlatans. — Of course many sharpers and charlatans sprang up, pretending to possess great knowledge, to hold the wonderful secret of alchemy, and to be able to make gold without limit. Pieces of gold said to have been made by these adepts are still preserved in several of the museums of Europe. In some cases the frauds were discovered. Crucibles with double bottoms, nails hollowed out and filled with powdered gold, mercury or lead containing gold, and similar devices, are recorded. The delusion has proved a lasting one. Alchemists have deceived themselves and others in this century, and even in the last quarter of it some have come within the grasp of the law.

Adepts. — Among the genuine alchemists there was a secret and mystical language in use, intended for the initiated and adepts only. They had the same mottoes in their workshops. The old Greek idea of the impelling force of the universe was exemplified by the ἀνάγκη written on their walls. On another side, or over the furnaces, would appear the Latin exhortation, *Spira, Spera,* or *Ora, Labora.*

The Universal Medicine. — The making of gold was their first great aim, but not their only one. They sought also the universal medicine which should cure all diseases, and the *elixir vitæ,* which would fend off the encroachment of old age. This belief in a universal medicine is more difficult to trace than that in the transmutation of the metals. It may have been a mistake arising from the Oriental imagery of the early Arabian writers. These did not seem to hold the peculiar doctrines of the *elixir vitæ.* They called the base metals diseased, and spoke of healing their diseases. Thus Geber says, "Bring me six lepers that I may heal them;" that is, transmute the six base metals into gold. The discovery of remedial agents among the salts, or so-called minerals, strengthened greatly the belief in the healing powers of the philosopher's stone.

Other Aims. — Other objects of search were the universal solvent, and the lamp that would burn forever. All such fancies seem to us very childish, but in all ages the wonders of science have seemed very marvellous, and have been attributed to magic; and then, too, half-knowledge is generally very credulous. The average newspaper of to-day will count among the possible achievements of the near future things as impossible as the dreams of the old alchemists. And again, what dreams or wildest fancies of theirs could have exceeded what science really has accomplished with its steam and electricity and light. The chemist of the present dreams of all metals being but varying forms of the same matter or matters, and gropes his way backward to some primal element.

PART THIRD.

QUALITATIVE CHEMISTRY.

PARACELSISTS.

Paracelsus and his followers formed a sort of transition from the alchemists of the Arabic school to the iatrochemists. This, the sixteenth century, was characterized by restless adventure and discovery. The wilds of America were being explored, the sea route to India was discovered. There was a breaking loose from the authority of the church and of the Grecian philosophers. The Reformation of Luther, the discoveries of Copernicus, fall in this age. The great universities were beginning to make their influence felt: Oxford had been founded in 1300, Heidelberg in 1346; and these began to be centres of light and learning. There was a tendency to unite chemistry and medicine. Life processes and changes in the body were accounted for on chemical grounds. Medicine was, in a measure, a branch of applied chemistry, and then it began to be looked upon as the true end of chemistry. The consequence was that researches were more carefully made, and new compounds were discovered. A new object and zest were given to the study, and chemistry became the pursuit of cultivated men.

The dominant chemical theory determines the character of the work done in any period. Alchemy was a natural deduction from Geber's theory of the nature of metals. Now elements began to be regarded as distinct bodies, capable of preparation and examination; and the Aristotelian idea of their being the unmakable causes of certain peculiar properties or characteristics was gradually given up.

Paracelsus (1493–1541). — Philippus Aureolus Theophrastus Paracelsus Bombastus von Hohenheim was born at the little Swiss town of Marie-Einsiedeln. His father was a physician of good family. All Europe was stirring with the revolt against hitherto accepted authorities in church and state. Luther and Calvin were fighting their great battle against error and superstition. Copernicus was remodelling astronomy on a new system. Paracelsus was also a noteworthy reformer, and has been called the Luther of medicine. His early youth was spent under the tutelage of his father. At sixteen he entered the University of Basel as a student; and he also studied under the well-known alchemist, Frithemius, from whom he acquired his bent for occultism. He made prolonged journeys through most of the known countries of the world, going beyond India. He was taken prisoner by the Tartars, and remained with them a number of years. Wherever he went, he sought to glean every scrap of knowledge obtainable from those with whom he came in contact. In his thirty-fifth year he was chosen professor of medicine in the University of Basel. His striking originality and freedom of thought brought him many enemies, especially among his colleagues. The writings of Galen, Avicenna, Hippokrates, and others, so much revered by the great mass of physicians and scholars, were gathered by him and publicly burned. This and his freedom of thought in religious matters led to a persecution by his enemies, which drove him from the university, and forced him to take up once more a wandering existence. He is reported to have met a violent death in the town of Salzburg at the hands of assassins employed by his opponents.

The Character of his Work. — He was constantly active as teacher, physician, and author, and is said to have written over one hundred books. He has been accused of drunkenness, impiety, roughness, and trickery in performing his cures; but much of this can be set down to the malice of his enemies. He not only abjured the authority of the ancient philosophers and physicians, but also chose German, the language of the people among whom he lived, as the vehicle of his thoughts, giving up the monkish Latin. His opponents said this was because he knew no Latin. His works, printed and in manuscript, cover many subjects — medicine, chemistry, botany, philosophy, physics, astronomy, astrology, and magic. Many of these seem to have been dictated to his pupils, or to have been notes taken on his lectures. He was not fond of ambiguity of expression, but was for the most part short, concise, and clear in his style; and his writings are marked by energy and enthusiasm.

As a Physician. — He was most skilful and successful as a physician, introducing a new theory and system. All diseases, according to the prevalent idea, came from excess in either bile, phlegm, or blood. Paracelsus maintained that each disease had its own definite existence, with definite cause and sequences, and must be antagonized by specific remedies. This was the inaguration of the modern method of combating disease. No progress was possible until this view of its nature was adopted. He was the first to apply the magnet in disease, and anticipated Mesmer in his discovery of animal magnetism, or mesmerism. He believed in one universal principle, life, and that all organic functions were caused by it. He could not wholly separate himself from the belief of his times, so that much that is foolish and incomprehensible is mixed with his science. Much of his mystic philosophy he brought back from India and the East, and some of his writings resemble a good deal the Theosophism of to-day.

As a Chemist. — Paracelsus was by far the most approved chemist of his times. All that was then known of analytical methods he had made his own, and he added much to them that was important. To him the first discovery of hydrogen is accredited, though of course it could not be called a discovery in the sense of preparing and identifying the gas. The foundation for a classification of the metals which lasted for many generations was laid by him. He was largely instrumental in turning chemistry from wasteful aims to became an adjunct of medicine.

Contributions to Pharmacy. — Pharmacy as a distinct profession and object of study was largely founded by him. It is astonishing how many new and valuable remedies were introduced by him. Mercurial preparations, lead compounds, iron salts, arsenic for skin diseases, milk of sulphur, bluestone, and many others, might be mentioned. Various vegetable medicines had been hitherto used in the form of decoctions or simply sweetened with sugar. He began the search after the active principles of these plants, and brought them into use as tinctures, essences, and extracts. Tincture of opium was first prepared by him, and given its present name of laudanum.

Extracts from his Writings. — Two or three extracts may be given from his works. First as to air: "When wood burns, air is the cause of it. If there is no air, then the wood will not burn."

He noticed the appearance which is seen when oil of vitriol acts upon a metal, and spoke of the evolution of the gas as the "rising of a wind." This is the first notice of hydrogen.

"Metals," he says, "are composed of three elements, — the spirit, the soul, and the body; in other words, mercury, sulphur, and salt. Dead metals may be revivified or reduced to the state of metals by means of soot."

His Followers. — The Paracelsists, who arose afterwards, seem to have been largely mystics, and have been confused with the Rosicrucians. The name was also applied to such physicians as defended his medical views. They often copied the roughness and the wandering life of their master, but were without his mental gifts. Some were alchemists and charlatans.

Thurneyser was one of the more noted of the Paracelsists. He was a physician of Berlin, and defended the views of Paracelsus, but his contributions to chemistry were unimportant.

The views of Paracelsus met with especial opposition from the Paris medical faculty, though Quercetanus and Turquet de Mayerne stood up for their defence. These and others had little critical ability, so that there was no attempt at separating the false from the true in the philosophy of Paracelsus.

Libavius (1540–1616). — The first to put these matters to the proof was Andreas Libau, or Libavius. He was born at Halle, and there studied medicine and settled as a physician. He did not stay there long, changing both residence and pursuits, though still keeping up his medicine and chemistry. Libavius is distinguished from most of the Paracelsists by his temperate language and independent spirit. He fully believed in the transmutation of the metals. Still, he did much to point out the meaningless nature of the mystical writings of the Paracelsists, and the worthlessness of many of their remedies and medicinal preparations. He made many valuable chemical discoveries. Sulphuric acid was first prepared by him by burning sulphur and saltpetre, and he showed that this was contained in the various vitriols and was the same as oil of vitriol. He discovered the tetra-chloride of tin, which is still called *Spiritus fumans Libavii*. He wrote the first text-book of chemistry, which put, clearly and in order, all that belonged to the science. This was frequently reprinted, and held in high esteem for a long time.

Agricola (1494–1555). — Contemporaneous with Paracelsus, but forming a strong contrast to him, was the distinguished technical chemist George Agricola, who was born near Meissen. He studied at Leipsic, and attended the Italian universities. He was a physician, but devoted his attention more particularly to the advancement of metallurgy and the industrial arts. Many improvements were introduced by him. He wrote little on medical subjects, and took no part in the hot strife over the revolution of Paracelsus.

His works are characterized by clearness and intelligibility. His chief work is called, "*De Re Metallica,*" and is a connected treatise on metallurgy. This went through many editions, and was for a long time considered an authority on the subject. Agricola had no contemporary pursuing a like course of study and work. He was the first and for a long time the only industrial chemist; and his book is very useful as giving a clear account of the conditions of the various industries in his day, and the different methods and operations in use then.

THE IATRO–CHEMISTS.

Paracelsus and his followers had turned chemistry into new lines. In the years following this new aim was confirmed, and chemistry became an adjunct to medicine. The position held by it was subordinate to that of the healing art. The chief object of research was the finding of new medicines, or the explanations of natural processes. Hence the name given to this period is that of the iatro-chemists or medico-chemists.

Van Helmont (1577–1644). — The first of these and the most distinguished was John Baptist Van Helmont, who was born in Brussels, and belonged to one of the aristocratic families of Brabant. He studied at Louvain, and showed both brilliancy and eccentricity of intellect. He was much attracted by the mysticism of the earlier writers, and was led to renounce rank and property, and practised medicine as a work of charity and benevolence. He became disgusted with the system of the Galenists, and resolved to reform medicine as Paracelsus had done. His knowledge being greater, he was not satisfied with the works of Paracelsus. After travelling through France and Italy, and returning home, he married a rich lady, and spent the remainder of his life at work in his laboratory.

His Theories. — Van Helmont considered water as the primal principle or element, and brought forward many ingenious arguments in support of his theory from the animal and vegetable world. He performed the famous experiment with the willow, and it is the most plausible among his experiments adduced as proofs of his theory. He took a large earthen vessel, and filled it with two hundred pounds of dried earth. In it he planted a willow weighing five pounds, which he duly watered with rain and distilled water. After five years he pulled up the willow, and found that it now weighed one hundred and sixty-nine pounds and three ounces. The earth had decreased two ounces in weight. Thus, according to his reasoning, one hundred and sixty-four pounds of root, bark, leaves, etc., were produced from water alone. Fish, he said, live on water, and yet they contain all the peculiar animal substances. These are then made from water.

Study of the Gases. — He introduced the term gas to distinguish water vapor and other elastic fluids from the air, and was the first to study aeriform bodies. The vapor coming from fermentation, that is, carbon dioxide, he called gas sylvestre. He recognized other gases, gas pingue, etc., and was the first one to attempt any study of these most interesting bodies, dividing them into inflammable and non-inflammable. As he was ignorant of any method of collecting and separating them, his knowledge was very imperfect. He even maintained that gases could not be imprisoned in any vessel, but would penetrate anything in order to mix with the surrounding air.

Views on Transmutation. — He denied the truth of the theory, so long prevailing, that the metals were composed of salt, sulphur, and mercury. He rejected and overthrew the Aristotelian four-element theory, proving that fire was no element, and that cold and warmth were not material. Further, he found that a substance could enter into many different combinations without losing its peculiar properties.

Ideas of Physiology. — His ideas of physiology were, of course, very crude, but still an advance upon those of Paracelsus. He believed in curing diseases by dietetics, by working on the imagination, by incantations, etc.; still, he made use of chemical preparations, and greatly advanced them in popular favor. He believed in the transmutation of metals and in magic. Much of this came from the mysticism in his early training. He was even more of an enthusiast than Paracelsus, accounting himself appointed of God for the reform of medicine. He believed that he had once seen his soul as a brightly shining crystal. Mice, he thought, could be made by placing a soiled shirt with some flour in a barrel or other vessel. He claimed to have the philosopher's stone and the alcahest, or universal medicine, in his possession, but declined to write out clearly their modes of preparation. His works were collected and published, after his death, by his son, under the title, "*Ortus Medicinæ vel Opera et Opuscula Omnia.*" This was translated into French, English, and German.

Sennert (1572–1637). — In Germany and the Netherlands the greater part of the distinguished physicians came over to the views of Van Helmont. Among them was Daniel Sennert, professor of medicine at Wittenberg. He did much to reconcile the adherents of the Hippokratic school to the new medicine, pointing out that it did not do away with the facts learned empirically under the old system, but attempted to clear up and explain them.

Glauber (1604-1668). — A more distinguished name is that of Johann Rudolph Glauber. Very little is known of his life and surroundings, beyond that he lived in various German towns and then went to Holland, dying in Amsterdam. His early education was much neglected, and his writings show him to have been a strange mixture of a sharp observer and a mystery-loving braggart. He believed fully in the aims of alchemy, but does not seem to have pursued them himself. He discovered and introduced many chemical preparations, preparing, for instance, purer and stronger hydrochloric and nitric acids than had been prepared before, and at the same time discovering sodium sulphate, to which he ascribed wonderful curative powers, and gave it the name *sal mirabile.* It is still called Glauber's salt. Various other sulphates and chlorides were first prepared by him.

Theory of Double Decomposition. — His observations upon double decomposition are interesting. "Aqua regia which has taken gold into solution kills the salt of tartar (potash) of the liquor of flints (silicate of potash) in such a way as to cause it to abandon the silica, and in exchange the salt of tartar paralyzes the action of the aqua regia in such a way as to make it let go the gold which it had dissolved. It is thus that the silica and gold are both deprived of their solvents. The precipitate is composed, then, at the same time of gold and of silica, the weights of which together represent that of the gold and of the silica originally employed."

Suggestions for Industrial Improvements. — He also showed interest in technical methods, and made many improvements in them. He first recommended the use of what are called Hessian crucibles. He was an ardent patriot, especially desirous that Germany should learn to manufacture her own crude materials. His improvements in glass-making and in the use of mordants deserve especial mention. He wrote several books in the German and Latin languages.

Sylvius (1614-1672). — Sylvius (Franz de la Boe) was another influential man of this time. He was born at Hanau, though he was of a Dutch family, and his life was mainly spent in Holland. In learning and culture he was above all of his predecessors, and he ably filled a professorship in the University of Leyden. His views were in the main those of Van Helmont, with the mysticism and spiritualism left out. His life was mainly devoted to medicine, but still he was a skilled chemist. He accepted the belief of his times in gold-making and in the alcahest. Other names of this period are Tachenius, Thomas Willis, etc.; but it is unnecessary to speak of these in detail.

Mistakes of the Iatro-chemists. — Two mistakes were made by the iatro-chemists. They attempted to explain, on chemical principles, all the changes and processes going on in the body. This was certainly not possible for the chemistry of that day. To Van Helmont, for instance, disease consisted in the excess or preponderance of base or acid in the juices of the body. Secondly, too narrow a limit was set to chemistry. It was destined to fill a much larger sphere than to be an adjunct to any other science.

PHLOGISTIC CHEMISTS.

The science could not long remain in this subordinate position. It so grew in extent and importance that it was able to burst the bonds of its too close alliance with medicine, and take for its field the study of the combinations and decompositions of all known substances. The inductive philosophy of Francis Bacon began to have its due effect. Chemistry assumed its proper place as a science. Its study was no longer obscured by gold-hunting, nor limited to the concoction of medicines. It was an age of qualitative chemistry, a step towards the higher quantitative work of the next era, and an immense step forward from the haphazard chemistry of the past. There are, of course, many dangers in relying on qualitative tests alone, and many mistakes were made during this period. The guiding principle of the work seems to have been the dictum, *similar appearances are due to similar causes*, a saying which carries with it much of plausibility, and yet might lead into serious error.

Phlogiston Theory. — The theory as to combustion phenomena, rightly regarded as the central processes of chemistry, called the phlogiston theory, especially characterized this period. This theory was gradually evolved, was imperfectly stated by Becher, elaborated by Stahl, and attained complete domination only toward the latter part of the eighteenth century. The existence of a combustible principle, named phlogiston, was assumed in all combustible bodies. The residue left after combustion was supposed to be a constituent of the original substance. Thus the acid substance gotten on burning sulphur was supposed to have existed in the original sulphur, and sulphur itself was a compound of this with phlogiston which escaped in the burning. The calcination of the metals was regarded as a process analogous to combustion, and hence to be explained in the same way. The resulting body, which we call an oxide, was called a calx. The original metal, then, was, in the eyes of these chemists, a compound of this calx with phlogiston. The more energetic the combustion, the more phlogiston did the body contain. Coal, for instance, was regarded as containing a great deal. Phlogiston could be restored by bringing together a calx and a body rich in phlogiston. Thus a metallic calx heated with coal yielded the original metal. This theorizing as to phlogiston resembles in its methods the dreaming of the Greek philosophers, who preferred to base their theories on pure reasoning rather than on observation and experiment. No attempt at first was made at the isolation of phlogiston, nor were experiments adduced in support of the theory. Efforts of this kind were only brought out by the vigorous attacks of opponents in the last stages of the controversy over the theory. There were various suppositions as to the nature of this phlogiston, some of them ridiculous. Thus it was identified with light or flame, with the coloring matter of Berlin blue, and with hydrogen. This last identification was the latest made, and was more the result of experiment, and hence was the more difficult to disprove. For instance, a metal was observed to give off hydrogen when acted upon by an acid. Now, hydrogen acted upon hot calces and restored the original metal. Lastly, a calx united with an acid to give a salt. The supposition that the metal was a compound of hydrogen and the calx is then very plausible.

General Characteristics of the Period. — There was not an entire breaking away from the sister science which had done so much to lift chemistry from the mire of alchemy. It was still useful to medicine and pursued by physicians, only its horizon was wider by far than ever before. Nor was alchemy dead. Many were still infected by the craze of the old alchemists, but the work was largely secret and looked down upon. The line was a distinct one between alchemy and chemistry, and their courses diverged more and more widely. Many learned societies were founded in this age, usually centring at the seat of some great university. By the bringing together of men of like pursuits, and the publication of their memoirs, they proved powerful incentives to the advancement of science. The most notable of these has been the Royal

Society of England, founded in 1645 by Charles II. Among others were the French Academy, the Swedish Academy, and the Royal Society of Berlin. All of the great scientific men of this time were connected with one or the other of these, and gave to the world their discoveries through their periodical publications.

Boyle (1626–1691). — First among the names of this age stands that of Robert Boyle. He was born in Ireland in the year 1626. His father, the Earl of Cork, intended him for the ministry, and his studies took that direction. He received his education at Eton and at home. Afterwards he travelled for six years on the Continent, spending two of them in Geneva. The political and other troubles in his native land called him home, and he returned to find his father dead. The fortune left him sufficing for his modest needs, he retired to his estate in England, and devoted his time to work upon his favorite studies, physics and chemistry. He went to Oxford, where he aided in the foundation of the Royal Society. His life was spent quietly and uneventfully, part of the time in Oxford, and part in London, and was devoted to scientific work of high order, to fostering the aims of the society, of which at one time he was offered the presidency but declined, and to works of benevolence and charity. Boyle was the first to pursue the study of chemistry from the noble desire for a deeper insight into nature. Not the craze for gold, nor the wish to apply his knowledge to any art or industry, but the earnest desire for truth, inspired him.

Character of his Work. — He antagonized the alchemists, except in respect to a belief in the transmutation of the metals, and also contended with the iatro-chemists, refuting some of their doctrines, though he agreed with Van Helmont that one must look to chemistry for the solution of the greatest problems of medicine. He was the first to apply

Bacon's inductive method in its fulness to the science. He maintained that experiment alone was the proper basis for theory, and that all theories must be tested by experiment. Before attempting any theorizing himself, he set to work to correct the faulty experiments and imperfect observations of others, and so to clear the road for true knowledge.

Experiments upon Air. — His experiments were largely upon air and water, choosing two of the commonest and yet most instructive substances in nature. The knowledge of the first, physically and chemically, was greatly advanced by him. He made use of and improved the air-pump, and examined the behavior of different bodies in vacuo. He enunciated the famous Law of Pressure upon Gases, still known as Boyle's Law. He experimented upon the height and weight and density of the atmosphere. Furthermore, he showed that something in the air was destroyed by breathing, or by the burning of a body in it. This was, of course, only a verification of an observation made long before. He proved that an increase of weight was caused by calcination, and that the calx was specifically lighter. The calcining of such a body as lead, he showed, consumed air. It is strange how near his experiments brought him to important truths. He was not happy in the interpretation of his results, however. He could see many faults in the theories of the times, but seldom felt his way clear to establishing a theory of his own.

Constitution of Matter. — His ideas as to matter were much like the present. He considered all bodies to consist of very small particles, and that the union of these particles gave compounds. Decomposition was impossible until the attraction between them had been overcome. According to this hypothesis, the differences between bodies was due to the inequalities in the form, structure, and movement of the elementary molecules. One or two primal elements would suffice to explain all the varieties of bodies in nature. Thus, he supposed, the molecules of water may, in certain conditions, be so grouped and set in motion as to form the body we call air. It is easy to see that all through the ages one of the great puzzles set for thinking men has been the invisible atmosphere surrounding us, forming and buoying up its cloud masses, and pouring down its floods of water or hail or snow. He knew the relative affinity of various metals towards the acids. A chemical compound was defined by him as one formed by the union of two or more components which lose their properties, the compound having new and different properties.

Improvements in Qualitative Analysis. — He systematized qualitative analysis, arranging bodies into classes or groups. Vegetable coloring matters were used by him as indicators for acids and bases. Regular reagents were introduced by him with directions for their use. Many of his tests we make use of at the present day, as, for instance, ammonia is driven out by lime or caustic potash, and tested for by its fuming with hydrochloric acid. His chief writings were the "*Sceptical Chymist,*" "*Experiments and Considerations Touching Colors,*" and "*Memoirs for the Natural History of Human Blood.*"

Kunckel (1630–1702). — Johann Kunckel was a contemporary of Robert Boyle, but not his equal in learning. He was born in Holstein, where his father was supported by the duke as an alchemist. He was largely active in pharmaceutical and technical chemistry, and was at different times in the service of several princes as alchemist and gold-maker. In this there seemed to be no intention to deceive on his part, but an honest working for his employers, and often with them, over what he regarded as a possible problem. Later he writes as to the transmutation of the metals: "In chemistry we have separations, combinations, and purifications, but never transmutations. The egg is hatched by the warmth of the hen. With all our art we cannot make an egg. We can destroy it and analyze it, but that is all."

He was at one time professor of chemistry at the University of Wittenberg, and died in Sweden, where he had held high position in connection with the mines, and had been raised to the nobility.

His Work. — Kunckel did not originate nor add much to the theories of the times. He demanded facts, first of all, and left theorizing to others. He aided more by his observations and experiments in overthrowing the old theories, and he made some important additions to chemical knowledge. One of his greatest achievements was the discovery of the mode of preparing phosphorus, the element having been really discovered by Brand, who showed it to him, yet held the method of preparation secret. This discovery was made by Boyle at the same time.

Becher (1635–1682). — Johann Joachim Becher was a fellow-countryman of Kunckel. His father was a clergyman; he himself was a physician, leading a wandering life and dying in England. His work consisted not so much in the discovery of new facts, as in the collating of those already known and their explanation. His writings are mainly theoretical. He believed in alchemy, but maintained that science was dearer to him than gold, and wisely refused to make the gold search the object of his work.

His Theories. — His important chemical theories are those in connection with the constitution of bodies and combustion. All inorganic substances were, in his estimation, of an earthy nature. There were three fundamental elements of which the metals and minerals were composed: an earth vitreous and transparent; an earth mercurial, subtle, and volatile; and a principle igneous and combustible. These, with water, gave rise to a primal acid, which was the generating principle of all acids. Becher wrote many works on various subjects. His writings and theories were brought to notice afterwards by

Stahl, and had great influence upon the development of chemistry. It was from Becher principally that Stahl got the germ of the phlogiston theory.

Homberg (1652-1715). — Two members of the French Academy became prominent at this period, Lemery and Homberg. The French Academy of Science had been founded in 1666 by Colbert, the minister of Louis XIV., but did not publish its memoirs until nearly forty years afterwards. Homberg was a lawyer, but gave up the practice of his profession to study natural science and medicine. He knew both Boyle and Kunckel, and was a good observer and skilful in carrying out his experiments, but a poor interpreter of results. He held to the ancient theories, and took little part in establishing the new. He contributed a large number of papers on chemical, zoölogical, botanical, and physical subjects to the French Academy.

Lemery (1645-1715). — Nicholas Lemery was especially renowned as a teacher, though he was also a good worker, dealing in the practical rather than the theoretical. His son, Ludwig Lemery, was also a distinguished chemist. The elder Lemery's greatest work was the writing of his text-book of chemistry, "*Cours de Chimie*" (1675), which embraced all that was known of chemistry, and endeavored to give a suitable connection between the facts recorded, and to systematize them. This was for many years the best text-book on the science, and was issued in repeated editions as the science advanced. Thirteen editions appeared during the author's lifetime, and a last much-changed one was issued eighty odd years after the first publication.

Stahl (1660-1734). — At the close of the seventeenth century chemists began to take up again the views and theories of Becher. The greatest chemist of the time was George Ernst Stahl. He was born in Bavaria, received a medical education at Jena, and was a physician and a professor at Halle. He moved later to Berlin, wrote many books, and died there in 1734.

Character and Work. — He was very successful as a teacher, gathering large numbers of young men around him as pupils, and inspiring them to become investigators. Through them he spread his theories. His scientific character was highly honorable. He very carefully kept his medicine and his chemistry from one another. Though a distinguished physician, and the first chemist of his time, he did not attempt to fuse the two together. He never sought to carry off the honors of others, but gave full credit to all for work done. Nor did he hesitate to acknowledge his own errors. In youth he maintained that the views of the alchemists were possible of fulfilment. In old age he acknowledged their impossibility, and advised and warned against the pursuit of them.

His Theory of Combustion. — His theory of combustion he states that he derived from the writings of Becher. Certainly the latter had very imperfectly stated it, and the most of the credit was due to Stahl. He introduced the name phlogiston, and extended the ideas as to the nature of this combustible principle. Among other things he maintained that phlogiston determined the color, and that chemical properties were dependent upon it. He presented two views with regard to this dependence of chemical properties, one of which was true and the other false.

1. Metals combine with sulphur only so long as they retain their phlogiston; no metal deprived of phlogiston would combine with sulphur.

2. No metal deprived of its phlogiston will combine with acids. This is true only of ignited oxides.

General Chemical Work. — Stahl made various additions to chemical knowledge. With regard to the question as to the relative strength of affinities, which had already engaged the attention of several chemists, he prepared lists in which the different metals were given in relation to various acids; also the order in which a metal at high temperatures was able to remove sulphur from a metallic sulphide; and further the acids in relation to the alkalies.

His knowledge of the acids was more thorough than that of any going before him. He recognized sulphurous acid, which is produced by burning sulphur alone, as different from oil of vitriol, gotten from burning sulphur and saltpetre. He improved the method of preparing acetic acid, and was the first to show that the concentrated acid would burn. Besides these, many other new observations are due to him. In 1697 he began the publication of the first chemical periodical, under the name, "*Observationes chymico-physico-medicæ, mensibus singulis, bono cum Deo, continuandæ.*" This soon became a purely medical publication and was then discontinued. He published several works on chemistry. His lecture notes were published by his students under his name.

Hoffmann (1660–1742). — Friedrich Hoffmann was more a physician than a chemist. He held a professorship at Halle and afterwards at Berlin, but forty-eight years of his life were spent at Halle. It was through him that Stahl was called to Halle, and there was close friendship between the two. In general, Hoffmann accepted the views of Stahl, and aided in their promulgation. His chemical work was more in the line of analyses of mineral waters. Among his achievements in experimental chemistry may be mentioned his pointing out the differences between lime, alumina, and magnesia, which up to his time had not been clearly distinguished from one another. In his qualitative work he set especial store by the taste and other physical properties as tests. He introduced the use of a mixture of equal parts of alcohol and ether as an anodyne, and this is still known as Hoffmann's drops. He was a prolific writer on medical and chemical subjects.

Stahl and Hoffmann exercised great influence upon the German chemists, and through them the new views as to combustion were generally introduced.

Boerhaave (1668–1738). — At the same time a very influential figure arose in Holland. Hermann Boerhaave was born near Leyden, where he received his education, and became professor of medicine and afterwards of chemistry and botany. The thirty-six years of his residence there were the most brilliant in the history of this university. Looking at his chemical work alone, we find him distinguished in the main as a teacher, and for his skill in interpreting chemical facts and the clearness of his theoretical views. He exposed the errors of the iatro-chemists, and recognized chemistry as a distinct science.

Overthrow of Alchemical Notions. — He also showed the falsity of the views held by the alchemists. He spoke only of things tested and observed by himself, and spared neither pains nor time to have his observations correct. For instance, the alchemists maintained that mercury could be fixed in the form of a fire-proof metal, without the addition of any other substance. Boerhaave kept mercury at a somewhat raised temperature in an open vessel for fifteen years without noting any change. So, too, when heated higher in a closed vessel for six months, no change could be discovered. This convinced him that the fixing of mercury was an impossibility. The alchemists said also that if mercury was repeatedly distilled, a more volatile essence with peculiar properties could be obtained. Boerhaave carried out this distillation five hundred times without securing the essence. And so he tested other of their peculiar notions and prescribed methods without obtaining the results promised; and as the methods were still credited in some quarters, he did good service in disproving them, and won for himself the reputation of being a most excellent and painstaking worker.

Writings. — His lectures were published first without his knowledge, and afterwards corrected by him under the title, "*Elementa Chemiæ.*" Repeated editions and translations were published in Germany, France, and England. He took very little notice of the views and theories of Stahl, though these must have been known to him, as they were making great headway in Germany.

Other Phlogistics in Germany. — The theories of Stahl had been pushed and spread by Neumann, Eller, Pott, and others, though these had added little to the store of chemical facts already known. Marggraf of Berlin was another supporter of the Stahl system. He is best known as the discoverer of sugar in beets and other garden vegetables, and the first to suggest its commercial preparation from them.

PHLOGISTIC CHEMISTS IN FRANCE.

In France, Geoffroy gave voice to views but little different from those of Stahl. Helot and Duhamel deserve mention also as distinguished French chemists of this time.

Macquer (1718–1784). — The last of the French chemists of renown to hold to the phlogistic theory was Peter Joseph Macquer, who was born at Paris. He became a member of the French Academy at the age of twenty-seven. Excellent opportunity for work was afforded him by his position as professor at the Jardin des Plantes, and his methods of research were more like those of the present. He determined the solubility of various salts in alcohol, and used this as a means of separating them from one another. Some of his researches were on potassium arseniate, and on the coloring matter of Berlin blue. The latter he identified with phlogiston because it was destroyed on heating. His great failing was in neglecting the quantitative side in his researches. He was the author of several text-books, which were highly thought of; but his chief work was his "*Dictionnaire de Chimie,*" which appeared first in 1766. This was the first dictionary of chemistry, and it was repeatedly enlarged and translated.

PHLOGISTIC CHEMISTS IN ENGLAND.

During the latter half of the eighteenth century three very distinguished chemists flourished in England, all of whom were adherents of the phlogiston theory of Stahl, and its most earnest defenders. They were either in ignorance of, or attached no importance to, the theory of their countryman Hooke as to combustion.

Hooke's Theory of Combustion. — Hooke's theory, published in 1665 in his "Micrographia," claims to be based upon experiment. It is contained in twelve propositions, but may be briefly stated thus: air supports combustion, but this combustion will take place only after the body has been sufficiently heated. There is no such thing as an elemental fire. This combustion is caused by a substance inherent in and mixed with the air, that is very much like, if not the very same with, that which is fixed in saltpetre. If this theory, which appeared so many years before the Stahl theory, had been accepted, it would have saved much error and a very bitter controversy.

Black (1728–1799). — Joseph Black was of Scotch parentage. He studied at the University of Glasgow, devoting himself especially to physical science. He attended the lectures of Dr. Cullen, the most distinguished teacher of chemistry in

Scotland, and became a co-worker and special friend as well as pupil.

Research upon the Causticity of Lime and the Alkalies.— Black first set to work to discover the cause of the differences between limestone and lime, and of the causticity of the alkalies. The former theory was that lime received its caustic properties from the fire with which it was burned, and that it conferred this upon the alkalies made by means of it. By skilful work he showed the part played by carbonic acid in these changes. This carbon dioxide he called fixed air, and Black is properly regarded as its discoverer. This research, prepared as his inaugural dissertation for the doctor's degree, won for him the professorship at Glasgow, Dr. Cullen having removed to Edinburgh.

Latent Heat and Other Work. — At Glasgow he made the brilliant discovery of latent heat, and showed its beneficial action in nature. He devoted much time to experiments upon heat. James Watt was his pupil and friend. He was most successful as a teacher. His writings were few, his manuscript lectures being published after his death. Ill-health did much to prevent his entering upon the promising field of chemical research opened up by his discoveries. He kept up an active correspondence with the chief chemists of his day, and exerted a widespread influence upon the progress of chemistry.

Cavendish (1731–1810). — An able and eccentric young Englishman followed up the work of Black with most gratifying success. This was Lord Henry Cavendish. He was born in London, his father being a younger son of the house of Devonshire. In early life Cavendish was in very straitened circumstances, and acquired habits of economy or parsimony, and certain odd traits which stuck to him through life. Afterwards he inherited large properties, until he became the largest holder of stock in the bank of England. He was exceedingly reserved and shy, refraining as far as possible from communications with any save his scientific friends. His education was very complete, a thorough training being given him as a mathematician, chemist, and afterwards as an electrician. His literary labors consisted of eighteen papers published in the Philosophical Transactions of the Royal Society. Ten of these treat of chemical subjects.

Discovery of Hydrogen. — His most important work was the discovery of hydrogen, which he called inflammable air. This he distinguished from the fixed air of Black, concluding that this inflammable air was the unaltered phlogiston of the metals. He was the first to attempt to determine the specific gravity of the gases. He showed that lime carbonate was held in solution in water by dissolved fixed air or carbonic acid. He showed in his experiments on air that when hydrogen was burned water was formed, thus really determining the composition of water, though he did not recognize this fact. This led to a sharp controversy as to the phlogistication of the air or atmosphere, and in the hands of that great interpreter of results, Lavoisier, did much to clear up and advance chemical theory.

Analysis of the Atmosphere. — Cavendish also determined by analysis the composition of the atmosphere after oxygen had been discovered, and, further, the composition of nitric acid. His discoveries practically overthrew the phlogistic theory, though he failed to interpret them aright, and remained a steadfast adherent of the theory. To most fair-minded men the theory had been overthrown in 1786; and yet, until his death in 1810, he refused to give up his belief. He preferred to give up chemistry altogether, and devoted the later years of his life, in the main, to electricity.

Priestley (1733–1804). — Joseph Priestley was born near Leeds, and received his education at a public school and at n academy of the Dissenters. His studies were theological in character, and he became a dissenting minister. He was not a success in this work, becoming extremely unpopular even with his own sect. He also conducted a school, but was in very needy circumstances. He was able, however, to buy a few books and some instruments, as a small air-pump, an electrical machine, etc., and was tireless in his work, training himself and his scholars in natural science. Meeting Dr. Franklin in London, he was attracted to the study of electricity, and wrote a history of electricity. This, together with some new experiments on electricity performed by him, won some outside reputation and his election as Fellow of the Royal Society.

Invention of the Pneumatic Trough. — He moved to Leeds, settling near a brewery. This gave him opportunity for examining the fixed air discovered by Black, and which had been shown to be one of the products of fermentation. He collected this gas from the vats, and performed many experiments with it. Moving away from the brewery, he had to prepare the fixed air for himself; and this led to his devising the simple and useful pneumatic trough as we now have it, and without which we should be very much at a loss in experimenting with gases.

Emigration to America. — After staying six years at Leeds, he came under the patronage of the Earl of Shelburne, and travelled with him through Holland, France, and part of Germany. He was very fond of controversial writing, and became the object of dislike and attack on the part of those with whom he differed. In the heated times of the French Revolution, his church and dwelling-house were mobbed and burned, his library and apparatus destroyed, and he himself escaped with difficulty to London. He was here treated very badly by his former associates and others, and finally took refuge in America, where he settled in Pennsylvania. In this country he pursued his scientific experiments, discovering carbon monoxide. He died in retirement in the year 1804.

Character of his Work. — Priestley was a brilliant investigator, performing many most striking experiments. He was, however, not thorough nor very careful, and was lacking in the scientific acumen needed for the proper interpretation of his results. It was upon the gases that his most valuable work was done; his invention of the pneumatic trough enabling him not only to discover new gases, but to investigate the properties of many already partially known.

Discovery of Oxygen. — His method of experimenting is well illustrated by his own account of his discovery of oxygen: "Having procured a (burning) lens, I proceeded with great alacrity to examine, by the help of it, what kind of air a great variety of substances would yield, putting them into vessels filled with quicksilver, and kept inverted in a basin of the same. After a variety of other experiments, I endeavored to extract air from *mercurius calcinatus per se;* and I presently found that, by means of this lens, air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it. But what surprised me more than I can well express, was that a candle burned in this air with a remarkably vigorous flame. I was utterly at a loss how to account for it." His experiments showed him that this air "had all the properties of common air, only in much greater perfection;" and he called it "dephlogisticated air," regarding it simply as very pure ordinary air.

Relation of Plants and Animals to the Atmosphere. — He seems to have looked upon all gases as easily changeable, one into the other, at least in the first period of his work. Many experiments were made by him on the action of the various gases known to him upon animals and plants. He would place a mouse in a jar of the gas, and notice the effect upon its breathing and general life processes. Plants were grown in similar jars, and the result upon the growth noted. He showed that air which had become noxious through breathing or the burning of a candle could be restored to its original condition by growing a plant in it. This, he said, was due to the impregnation with phlogiston in the first case, and its removal in the second. "It is very probable," he says, "that the injury which is continually done to the atmosphere by the respiration of such a number of animals as breathe it, and the putrefaction of such vast masses, both of vegetable and animal substances exposed to it, is, in part at least, repaired by the vegetable creation." He was unable to explain how this was accomplished.

Imperfect Analytical Work. — As an analytical chemist, he seems to have possessed little skill. Thus, in his experiments on the formation of water by exploding mixtures of hydrogen and oxygen in a copper globe he obtained a blue liquid, whose nature he was unable to determine. The analyst whose aid he solicited showed him that it was a solution of copper nitrate in water. The fact that nitric acid was thus formed induced him to deny that water was a compound of oxygen and hydrogen. In the hands of Cavendish, a more thorough and careful investigator, this discovery led to the demonstration of the composition of nitric acid.

Views as to Combustion. — He held that all combustible bodies contained hydrogen. This was, in his view, phlogiston. The metals contained it, and their calces, or oxides, were simply the metals deprived of hydrogen. Thus, he showed that when iron oxide was heated in hydrogen gas the hydrogen was absorbed and metallic iron formed. Rich iron slag or cinder was, in his opinion, iron with some hydrogen retained. To prove this, it was mixed with the carbonates of the alkaline earths and heated strongly. This gave him an inflammable gas, and all inflammable gases were hydrogen in a more or less impure condition, according to his belief.

Other Researches. — That water could be impregnated with carbon dioxide was found out by him, and its use in disease suggested. Nitrogen dioxide and carbon monoxide were discovered by him, but his greatest discovery was that of oxygen gas. He examined sulphur dioxide, hydrochloric acid, and ammonia in the gaseous form. These are only the most important of his discoveries. Inaccurate in his experiments, he was decidedly weak as a theorizer. He was a firm believer in the phlogiston theory, and endeavored to explain the various phemomena noted by him by means of it.

PHLOGISTIC CHEMISTS IN SWEDEN.

Sweden, considering her limited area and scanty population, has held a high place as a producer of scientific men. This is especially true in chemistry. In the earlier part of the eighteenth century, there were several distinguished writers upon chemical and alchemical subjects. Among these may be mentioned Brandt, Schäffer, and Wallerius. In the middle of the century, there was Cronstedt, the great mineralogist; and the last half of the century produced two great chemists, Bergman and Scheele, to be followed by the illustrious Berzelius. The Royal Society of Sciences at Upsala and the Royal Academy at Stockholm had much to do with this scientific growth. The publications of these two societies contained the researches and discoveries of Bergman and Scheele, and did much for the progress of chemistry.

Bergman (1735-1784). — Torbern Bergman was born in the little town of Katherinaberg. He had the advantages of a training at the gymnasium and afterwards at the University of Upsala. His family had set him apart for the church or for law; but scientific studies proved a greater attraction for him, and he pursued them in secret. He studied mathematics especially, and was appointed adjunct professor of chemistry in 1761. In 1767 he became professor of chemistry and mineralogy, as he had also devoted much time to this study. From that time on he devoted every energy to chemistry, and his fame soon spread among chemists. Frederick the Great endeavored to induce him to go to Berlin, but he preferred to remain in his native land. He had many distinguished pupils. Hard and continuous application broke down his health, and he died in 1784.

Improvement in Analytical Methods. — His most important services were in connection with analytical chemistry. Analysis in the wet way, first outlined by Boyle, was still very imperfectly understood, and limited mainly to qualitative work, and that too upon mineral waters. Bergman enlarged the number of re-agents, and studied their action on such substances as occur most commonly. Under his guidance analytical chemistry began to be an exact science. In quantitative analysis he abandoned the plan of isolating the various constituents, and introduced the methods still used of transforming each constituent into some compound which could be easily isolated, and whose exact composition was known. He analyzed a very large number of bodies, examining especially into the composition of many salts. Ignorance of the law of constant proportions made such work imperfect and unsatisfactory. Bergman introduced the method of fusing insoluble minerals with caustic or carbonated alkalies, so as to bring them into solution, a most important step in analytical methods. Some of his researches were masterly and in the spirit of the present time. Such, for instance, was his work on the differences between wrought iron, steel, and cast iron; also upon the cause of cold shortness in iron. Sweden was a great iron-producing country, and this made the work of Bergman especially important for his native land. Among scientific men he won especial fame by his researches upon carbon dioxide and upon affinity.

Views as to the Atmosphere. — With regard to the atmosphere, he said, "Common air is a mixture of three elastic fluids: free aerial acid (carbonic acid), but in such small quantities that it does not sensibly alter the color of litmus; an air which can neither serve for combustion nor for the respiration of animals, which, therefore, we call vitiated air until we know its nature perfectly; lastly, an air absolutely necessary for fire and for animal life, which forms pretty nearly the fourth part of common air, and which I regard as pure air." In this he was the first to give a clear statement as to the composition of the air. This was based on his own and Scheele's experiments.

Theoretical Views, etc. — His theoretical views were in accord with those of his age. He regarded hydrogen as identical with phlogiston, and accepted in full the phlogistic theory. His chemical contributions were numerous; and besides these, many papers upon mineralogy, geology, physics, astronomy, and zoölogy were published by him in the Memoirs of the Stockholm and Upsala Academies.

Scheele (1742-1786). — Carl Wilhelm Scheele was a compatriot and contemporary of Bergman, and closely connected with him. His educational training was more limited than that of Bergman. While engaged as a pharmacist at Gothenburg, he read all the chemical works in his reach, and diligently experimented so far as his limited means would permit. He moved finally to Upsala, and there attracted the attention of Bergman; although there was at first, on the part of Scheele, some distrust, arising from their previous dealings with one another in regard to one of Scheele's first researches. A firm and lasting friendship sprang up between the two, helpful to each, and most beneficial to science. Scheele remained a pharmacist through life, poor and reserved, receiving a small stipend from the Stockholm

Academy, better known abroad than by his nearest neighbors, and yet out of his poverty and imperfect appliances achieving wonderful success in mastering nature's secrets. He died in 1786, when only forty-three years of age.

His Discoveries. — No one, before nor since his day, has made so many important discoveries. In fact, it is only the recent publication of his letters which has revealed how much he knew, and how far he was ahead of his times. His first work was upon the organic acids, many of which he isolated and examined. Among organic acids, he discovered tartaric, oxalic, malic, citric, and gallic acids; among inorganic, molybdic, tungstic, and arsenic acids. Manganese, chlorine, baryta, and oxygen were discovered by him. He adhered to the phlogiston theory which dominated the age, his chief deficiency lying in this matter of generalizing and formulating theories.

Discovery of Oxygen. — One of his most important discoveries was the constitution of the atmosphere. His work in this was distinct from that of Lavoisier and Priestley. He examined the atmosphere with a view to determining what part it played in the phenomena of combustion. First, he examined the action of various substances upon the air. These substances were supposed to contain phlogiston, and hence, he reasoned, would give it off to the air held in an enclosed space. Some of the substances experimented upon were moist iron filings, fresh moist iron hydroxide, etc. He observed that the air diminished in amount, and that the portion left was incapable of supporting combustion. This diminution of volume, he reasoned, was due to an absorption of phlogiston by the air, hence the air should be specifically heavier. To his astonishment, he found the opposite to be true. A part of the air had disappeared, and the remainder was specifically lighter. Scheele concluded that the atmosphere consisted of two different kinds of air; one kind having no power of taking up phlogiston, and hence being left behind in combustions, the other taking up phlogiston in an enhanced degree. This was his fire-air, or Lavoisier's oxygen, though not yet known to the great French chemist. His experiments as to the relative proportions of these two constituents fall in accuracy far behind those made a little later by Cavendish. He pursued his research further, and was badly misled by the phlogiston fancy. Thus, in explanation of the experiment just described, he concluded that the union of phlogiston with one part of the air caused a diminution of volume, because a tenuous, delicate substance had been formed which escaped through the pores of the glass vessel. This delicate substance was, in his opinion, fire or heat. Fire, then, was a combination of fire-air and phlogiston. This fire or heat, he believed, could be decomposed into its constituents by the use of such substances as would combine with the phlogiston, and set the fire-air free. He thought he could do this with nitric acid. He distilled nitre and oil of vitriol, and obtained nitric acid and a gas which supported combustion better than the air itself.

This supposed decomposition of heat he effected further by heating other substances, as manganese dioxide, and nitre. Thus he isolated oxygen, or, as he called it, fire-air.

Theoretical Conclusions. — The theoretical conclusions reached by him from a number of experiments were: —

1. That phlogiston was a true element.
2. That by the affinity which it had for certain substances it could be transmitted from one body to another.
3. That it combined with fire-air to constitute caloric or heat.
4. That this heat, in the case of its formation from combustion, or by respiration, adheres to the corrupted air (nitrogen), and renders it lighter.

PART FOURTH.

QUANTITATIVE CHEMISTRY.

THE REVOLUTION IN CHEMISTRY.

The great chemists whose lives we have just given were the most distinguished exponents of the phlogiston theory and its last noteworthy defenders. We come now to one of the most illustrious of chemists, through whose labors a great revolution in chemistry was wrought, and the theory of phlogiston overthrown. So great were his services to chemistry that his countrymen seem almost justified in styling him the Father of Chemistry.

Lavoisier (1743–1794). — Antoine Laurent Lavoisier was born in Paris. No expense was spared in his education; and he made rapid progress in acquiring knowledge, especially of the sciences. At the age of twenty-one, he obtained a medal from the government for a memoir upon the best and most economical method of lighting the streets of a large city. This was a competitive prize, and in this early piece of work he showed the same painstaking care and accuracy which distinguished him in after life. He is said to have lived for six weeks in rooms lighted by artificial light, so as to accustom his eyes to the slight differences in light for the purpose of his investigations. He was chosen an adjunct member of the French Academy at the unusually youthful age of twenty-five; and from that time on the memoirs of the Academy were enriched by his contributions, and he became one of its most important members and officers. Chemistry did not receive the whole of his attention at first, but shared it with geology, mineralogy, and mathematics. The wonderful discoveries in chemistry, especially pneumatic chemistry, which were being made known by Black, Priestley, Scheele, and others, drew him, however, to devote all his energies to scientific chemistry. For more than twenty years he was indefatigable as a worker, repeating the experiments of others and pursuing fresh lines of inquiry. By good business management he greatly added to his property and became a man of wealth. He lived well, giving dinners which were famed for their excellence and for the company gathered at them. This drew attention to him as a man of wealth, and won for him some enemies whose influence was felt in the storm gathering against all that smacked of aristocracy. Besides, he was a *fermier-général;* and, though he brought about some reforms, some of his measures proposed to the government were exceedingly unpopular, as, for instance, his plan for taxing Paris. His scientific knowledge was turned to the service of the state, and he improved the nitre factories and the manufacture of gunpowder. When the revolution succeeded, and Paris was under the control of Robespierre, the Dictator, he was thrown into prison along with others who had been farmers of the revenue. The palpably ridiculous charge of "adulterating the tobacco with water and other ingredients hurtful to the health of the citizens" was brought against him and sufficed for his conviction. Appeals in his behalf, on account of his learning and his usefulness, were vain. The judge replied to all such appeals, "We have no need for savants."

He was guillotined in the year 1794, at the age of fifty-one; and France and the world lost one of the clearest intellects and most comprehensive minds that science has known.

Character of his Work. — Lavoisier's most valuable services were as an interpreter of the results of his own work and that of others. He showed a marvellous insight into the causes of things, a quick perception of the importance of the many discoveries of his times, and a comprehensive grasp of facts and their inter-relation and connection. These powers enabled him to detect the errors and falsity in the theory and reasoning of the chemists of his age, and to lay the basis for the new chemistry of the quantitative era. Exclusive importance had been attached hitherto to visible phenomena, whereas he introduced a deeper study of chemical reactions and the relations of quantity.

Experiments upon Combustion. — In 1774 he published his first strictly scientific volume under the title of "*Essays Physical and Chemical.*" In this he described all that had been done on the subject of gases, from the time of Paracelsus down through the work of Priestley. He further gave an account of his own experiments. He showed that when metals were calcined their weights increased, and that a portion of air, equal to their increase in weight, was absorbed from the surrounding atmosphere. He burned phosphorus in the air, and observed the decrease in the volume of air and the increase in weight of the phosphorus. We are apt to think that the mere proof that the metallic calx weighed more than the metal was sufficient to disprove the phlogiston theory. But both parts of the proof of Lavoisier were necessary; and even then it was insufficient, merely preliminary to his final work. It had long before been shown that the calces were heavier than the metals from which they came, and that they were specifically lighter. The phlogistics, however, thought these weight relations of little importance, claiming, in fact, that the presence of phlogiston added nothing to the weight of a body but made it specifically lighter.

Composition of the Atmosphere. — In his first book, he tells of nothing to show that he knew the composition of the air or the distinct nature of oxygen. They were discoveries reserved for Scheele and Priestley, but Lavoisier was evidently very near to their discovery, and was only anticipated in this work by these eminent investigators. When Priestley visited Lavoisier shortly afterwards, and showed him how to prepare oxygen from the red oxide of mercury, Lavoisier immediately saw what the discovery meant, and how it made plain much that was unexplained in his own work. It altered his views, and suggested to him the nature of atmospheric air, and of the changes taking place in the calcination of the metals. For twelve years he worked over these problems, performing a great number of experiments and with an accuracy hitherto unknown. He then boldly proclaimed the non-existence of phlogiston, and replaced this old theory by a new one, explaining the phenomena of combustion and reduction as combination with oxygen, or its separation. He first won to his views the distinguished French chemists of his day; and before many years all men of standing in the science gave in their adherence to his new theory, except a few who could not give up views which had formed the basis of all their scientific work. The year 1786 may be fixed as the one in which the death-blow was given to the phlogiston theory.

Professional Character. — Besides these volumes of essays, Lavoisier was the author of a treatise on chemistry and of about sixty memoirs published by the Academy of Sciences. It must be said that it seems that Lavoisier did not always show strict ideas of personal honor and uprightness in giving credit to others for their discoveries and work. This was notably the case in his tacit claim to the discovery of oxygen, although Priestley had shown him the method of preparation in the year previous to the publication of his memoir.

Composition of Water. — One of his most important memoirs was upon the composition of water, and it was this research which gave him his complete triumph over the supporters of the phlogiston theory. The hydrogen evolved when a metal was dissolved in an acid was held to be identical with the hypothetical phlogiston, and this reaction was the last argument brought forward in support of that theory. When Cavendish's discovery of the formation of water by the burning of hydrogen was told to him, Lavoisier saw his way to a solution of this puzzle, and lost no time in repeating so important an experiment. He claimed that the hydrogen came from the water, which took part in the reaction; at the same time the oxygen was fixed in the metal, and thus it was not the metal, but the metallic oxide, which was dissolved up by the acid. In other cases, as in the action of nitric acid upon copper, the metal decomposes the acid and not the water, taking oxygen from it to form an oxide, and this is dissolved by the remainder of the acid. The deoxidized part of the acid escapes as a gas.

Theory as to Acids. — Thus he recognized the parts played by oxygen in the formation of acids, of oxides, and of salts. For these he gave the simple definitions which form the foundation of the new chemistry.

1. An acid results from the union of a simple body, ordinarily non-metallic, with oxygen.
2. An oxide is a compound of a metal and oxygen.
3. A salt is formed by the union of an acid with an oxide.

This theory was extended farther for the sulphides, phosphides, etc., but the true nature of the chlorides was not known.

Transmutation of Water Refuted. — One of Lavoisier's earlier memoirs (1770) well illustrates his accuracy, thoroughness, and acute reasoning. It had been noted by many earlier investigators, that when water was boiled for a long time in a glass vessel, a mass of white residue was found in the vessel after evaporation. This was long regarded as a conclusive proof that water could be changed into earth. Lavoisier weighed his glass vessel, and then, after heating water therein for one hundred days, found there was no change in the weight of the vessel and its contents. When he evaporated the water he got a residue of earthy matter which he found corresponded, within the range of experimental error, with the loss in weight of the empty vessel. He therefore concluded that water on being boiled is not changed into earth, but that a part of the matter of which the glass is composed is dissolved out by the water; and the analytical work of Scheele afterwards showed that this residue did have the same composition as the glass, thus confirming the work of Lavoisier.

Indestructibility of Matter. — The old alchemical notion of transmutation was thus shown to be false, and was finally dismissed from chemistry. Lavoisier established the important generalization that matter may be changed, but not destroyed nor created. The matter lost from the glass vessel was merely dissolved in the water. This is the principle of the Indestructibility of Matter, the fundamental principle of modern science. Of course Lavoisier's work was only the beginning of the series of experiments on this subject which after many years established the principle.

The Relation of Plants and Animals to the Atmosphere. — Priestley had performed various experiments upon the gases or airs known to him; and, as has been said, had discovered the relation of the plants and animals to the atmosphere, and the approximate balance maintained by their action upon it. His ignorance of accurate analytical work and his devotion to the phlogiston theory prevented his reaching a true explanation of the facts observed by him. Lavoisier and Scheele determined the composition of the atmosphere, and afterwards Cavendish gave an exact analysis of it. Lavoisier had shown that it consisted of oxygen and nitrogen, and had determined the proportions of each. He was therefore in a position to complete and explain the work of Priestley. The processes of breathing and of calcination were chemically analogous. Oxygen was drawn into the lungs by the respiration of animals; there it combined with carbon, and the carbonic acid, or the fixed air of Black, was breathed out. This was noxious to other animals, and this it was which was removed by the plants. These experiments serve well to show the confusion of thought of the phlogistics, and the clearness of Lavoisier's methods.

Views as to the Nature of Heat and of Matter. — Lavoisier disproved the old ideas as to the elemental nature of heat, yet he believed it to have material existence. He writes of a *matière de chaleur*, which he also calls *calorique*. He ascribed to it a fluid nature, but said that it had no weight. His idea, and also his views upon the constitution of matter, are perhaps best given by a citation from his "*Réflexions sur le Phlogistique*." Matter, he says, consists of small particles which do not touch one another, otherwise the diminution in volume on cooling could not be explained; between these particles is the *calorique*. In gases there is most of this *calorique*, in solids least; and in his experiments with Laplace upon specific heat, he has shown that solids differed in their capacity for taking up this heat. His views are in partial agreement with the modern theory of heat, when he comes to define that form of energy. He says, "Heat is the result of invisible motion of the particles, the sum of the product of the masses multiplied by the square of the velocities." We may say that he laid the foundation for the modern thermo-chemistry.

Investigation of Organic Substances. — Lavoisier also occupied himself with organic chemistry, or the chemistry of life-products, and made a beginning towards a scientific study of it by devising a method of analysis by which these bodies could be burned, and the water and carbon dioxide which were formed measured. Of course such a system of analysis was impossible until the composition of these bodies themselves was definitely fixed. That these bodies, as well as carbon (in imperfect combustions), were gotten on burning organic substances had been long known; but their nature, and the question of their pre-existence in these substances, had been the subject of endless discussions. Through his analyses, Lavoisier determined that all organic substances were composed of carbon and hydrogen, sometimes oxygen, and less often nitrogen, sulphur, and other elements.

Chemical Nomenclature. — The nomenclature of chemistry was in a most unsettled and unsatisfactory condition at this time. Many of the terms used were abused, and many unwieldy; and throughout all there was a coloring from phlogistic ideas and a lack of system. It was impossible for Lavoisier to express his ideas clearly·and intelligibly, or to put the new chemistry into such language; and hence he joined with Guyton de Morveau in simplifying and systematizing the terminology. The new system came into use very rapidly because of its great superiority. Of course it was inadequate to supply fully the needs of later times, but it forms the basis of our present system.

THE NEW CHEMISTRY.

The overthrow of the followers of Stahl, and the acceptance of Lavoisier's ideas, ushered in a new era in chemistry. A new nomenclature was needed, and it was created by Lavoisier and the French Encyclopædists. Changes in the theories as to acids and bases were demanded; and Lavoisier gave them, at least in outline, to be filled up and modified afterwards as knowledge increased. These theories were not in every point correct, but they were far nearer to the truth than any which had preceded them. The name of oxygen, or acid-producer, which Lavoisier gave in 1778 to what was at first called dephlogisticated air, is a perpetual reminder of his theory, even though that theory was only partly true.

The Elements. — But the most striking and far-reaching change was in regard to the elements, a name to which chemists had not attached very much importance up to this time, and which was rather hazily defined. They had been hitherto mainly the subject of philosophical speculations. Henceforward they were to form the basis of systematic chemistry. The four-element theory of Empedokles and Aristotle was a dream, a philosophical figment, without basis or confirmation in experiment. These elements were regarded as principles, with certain material characteristics, entering, all or some of them, into every known substance, and not necessarily capable of independent existence themselves. Some chemists, indeed, undertook to prove that certain substances did contain these principles; as, for instance, when green wood burns, flame showed the existence of fire, the ascending smoke proved the presence of air, the hissing and boiling gave abundant evidence of water, and the remaining ashes vouched for the last element, earth. There was no attempt at a general proof, but the alchemists seem to have accepted the theory of Aristotle down to Boyle's publication of his "Sceptical Chymist" (1661). Boyle was in error in believing that one substance could be changed into another, as, for instance, that water could be transformed by prolonged boiling into earthy substances; but he undoubtedly overthrew the doctrine of elementary principles as held by those whom he styled "vulgar chymists."

He defined elements as "certain primitive and simple bodies, which, not being made of any other bodies, or of one another, are the ingredients of which all those called perfectly mixed bodies are immediately compounded, and into which they are ultimately resolved." He did not believe himself warranted, by the knowledge then possessed, in proclaiming the positive existence of such elements. It is true that Van Helmont had previously rejected the Aristotelian theory, at least with regard to fire, and had antagonized the ideas of the alchemists springing from Geber's hypothetical elements, mercury, sulphur, and salt. Still, he held on to water as an element, and did not have Boyle's clearness of vision regarding this matter.

During the phlogistic period, less and less importance was attached to the old ideas as to elements; and the belief gradually sprang up that a true element must be something which could be prepared, and which was not subject to change. Macquer, in his Dictionary of Chemistry (English translation, 1777), gives the modern definition, worded as follows: "Those bodies are called elements which are so simple that they cannot by any known method be decomposed or even altered, and which also enter as principal or constituent parts, into the combination of other bodies, which are therefore called compound bodies." But he adds, "The bodies in which this simplicity has been observed are fire, air, water, and the purest earths." Black proved that certain chemical substances were possessed of a constant and definite composition and fixed properties, unalterable, and hence simple bodies or elements. Lavoisier, in his "*Traité de Chimie*," enunciated the definition of an element which is in accord with our present knowledge and beliefs. "An element is a substance from which no simpler body has as yet been obtained; a body in which no change causes a diminution of weight. Every substance is to be regarded as an element until it is proved to be otherwise." With these clear definitions to build upon, a rational system of chemistry became for the first time a possibility. It is true that many substances were classed as elements which did not belong to the list. It is very possible that the same may be the case even now. Lavoisier first classed the metals as elements.

Spread of the New Chemistry. — The teachings of Lavoisier, or as Fourcroy styled it, the "French Chemistry," speedily found acceptance in France, in England, and through the influence of Klaproth, in Germany, among Stahl's own countrymen, where the opposition had been intense. By the close of the century chemists had almost universally given in their adherence to the new doctrines.

Chemistry now had the basis of a true theory; and what was of greater value, a knowledge that theories could be deduced only from the weight relations of actually occurring reactions. There were to be no baseless and delusive dreams for the future, although mistakes might be made in the interpretation of facts. Further, the grand division into elements and compounds had been effected, and a suitable nomenclature had been devised, capable of any expansion demanded by increase of knowledge. The balance, too, had been introduced as the instrument by which precision and accuracy were to be attained, and the great arbiter of the fate of theories. True progress now became possible; and the century which has since passed has seen this science develop and grow, until men have come scarcely to dare to put a limit to its possibilities.

In the latter part of the eighteenth century, it grew to be the fashion for ladies and gentlemen of rank, in large numbers, to attend the lectures of distinguished chemists. Thus Scheele entertained the Crown Prince of Prussia, and people of note crowded the lectures of Fourcroy and Lavoisier. An army of workers sprang up, and facts almost innumerable were added to the store. The succeeding history differs from that which has preceded largely in this, that the lives and achievements of individuals can no longer suffice to give us an idea of the growth of the science, and must occupy small space in these pages.

Still, we find that, though facts rapidly increased in number, theories were slowly evolved, and gained acceptance only after most careful weighing and testing in every known way. In this respect the experience of the past was invaluable. Great names, so-called authorities, might gain a hearing for a theory, but could never again secure recognition for it. Men had cast off forever the burden of authority in science. The work begun by Paracelsus was complete.

THE ATOMIC THEORY.

The ground-work of the new chemistry was laid by Lavoisier, in the following dicta: —

1. In all chemical reactions, only the form of the materials changed, the quantity remained the same. The substances used and the products gotten can be brought into an algebraic equation, by means of which any one unknown member may be calculated.
2. In all combustions the burning body unites with oxygen; and in general an acid is formed by combustions of a non-metal, and, by combustion of the metals, a metallic calx or oxide is formed.
3. All acids contain oxygen united with a base or a radical which, in the case of inorganic bodies, is generally an element; in organic, it is made up of carbon and hydrogen, and often contains nitrogen and phosphorus, as well as other elements.

The Constancy of Proportions. — With regard to the question whether chemical compounds are possible with all proportions of the constituents, or whether bodies can combine only in certain definite proportions, Lavoisier took the latter view; and this was generally accepted, although there was no direct general proof of its truth. But in 1803, Berthollet, in his "*Statique Chimique*," denied that compounds were formed only in certain definite proportions.

Berthollet (1748–1822). — Berthollet was, after the death of Lavoisier, the leading French chemist. His most important chemical work was in connection with the composition of ammonia, the properties and nature of chlorine, and the manufacture of bleaching compounds from it. His work in connection with hydrogen sulphide and hydrocyanic acid was of deep theoretic interest, and proved of great value in arriving at the true theory of acids. His greatest service to the science was in the publication of his "*Essai de Statique Chimique.*" This book excited a great deal of discussion among chemists, and was a most important contribution to chemical literature and theory. It contains much that is true, as Berthollet took the principles of mechanics and physics as the basis for his study of chemical reactions. Some of his deductions and inferences have been proved wrong, but there is truth in a good deal he has written.

Views of Affinity. — The work is especially directed against false views of affinity and the misuse of the so-called affinity tables which had been drawn up by many chemists. As specimens of such tables, those of Geoffroy and Bergman may be given: —

GEOFFROY'S TABLE.

Hydrochloric Acid	Sulphur	Fixed Alkali
Tin	Fixed Alkali	Sulphuric Acid
Antimony	Iron	Nitric Acid
Copper	Copper	Hydrochloric Acid
Silver	Lead	Acetic Acid
Mercury	Silver	Sulphur
Gold	Antimony	
	Mercury	
	Gold	

In this table, as one goes down the first column, for instance, each substance has a weaker affinity than the one just preceding it for hydrochloric acid; and so for the other columns.

Bergman's is very similar. He gives the affinity of various substances for sulphuric acid, as determined by his experiments. The table shows a knowledge of the fact that the affinity depended upon the temperature and the physical state.

BERGMAN'S TABLE.

WET WAY.	DRY WAY.
Baryta	Phlogiston
Potash and Soda	Baryta
Ammonia	Potash
Alumina	Soda
Zinc oxide	Lime
Iron oxide	Magnesia
Copper oxide	Metallic oxides
Mercury oxide	Ammonia
Silver oxide	Alumina

Berthollet's work has exerted a lasting influence upon the views concerning affinity, and shows in high degree the power of abstract conception and of logical development of chemical ideas on the part of this, the first and ablest of Lavoisier's followers. He reasoned that affinity was by no means a simple force, and easy to determine or measure; but was influenced by temperature, physical state, cohesion, and especially by mass. The latter largely determined the course of chemical reactions. He went further, and stated that the mass of the combining bodies determined the proportions in which they would unite to form compounds.

His views as to the lack of any fixity or constancy of proportions in chemical compounds met with immediate opposition on the part of leading chemists, and gave a new direction to their researches. The absorbing object of search became the exact quantitative composition of the compounds known, so that, based on such knowledge, a true hypothesis might be framed.

Dalton (1766–1844). — Among these workers was the Englishman, John Dalton, the author of the atomic theory. It is interesting to note how Dalton's work led up to this great fundamental idea of modern chemistry. He was a mathematician and physicist, and for years had been interested in meteorological observations. His observations upon dew and upon aqueous vapor existing in the air led him to the publication, in 1801, of an important paper upon the "Constitution of Mixed Gases, etc." This was followed by other papers on the properties of gases, and they prove that he had formed the idea that gases were made up of small distinct particles. He speaks of the pressure on them, the repulsion between these particles, and says, "A vessel full of any pure elastic fluid (gas) presents to the imagination a picture like one full of small shot." In considering the question as to why water does not mechanically dissolve the same bulk of every gas, he says: "I am nearly persuaded that this circumstance depends upon the weight and number of the ultimate particles of the several gases, those whose particles are lightest and single being least absorbable, and the other more, accordingly as they increase in weight and perplexity. An inquiry into the relative weights of the ultimate particles of bodies is a subject, as far as I know, entirely new." He gives in this paper (1802) a "table of the relative weights of the ultimate particles of gaseous and other bodies." These views of Dalton attracted widespread attention and discussion, which Dalton welcomed, because he believed that "the truth will surely out at last;" and it was the truth that he aimed at. Dalton was often inaccurate as to facts, deficient in the details of chemical manipulation, and did not hold high rank as an experimenter; but he was good at drawing conclusions, and at stating generalizations, his aim being the establishment of general, underlying laws.

Atoms. — Of course the idea of the existence of atoms was not new nor original with Dalton. The conception of the

Greek philosophers was that "The bodies which we see and handle, which we can set in motion or leave at rest, which we can break in pieces and destroy, are composed of smaller bodies which we cannot see or handle, which are always in motion, and which can neither be stopped, nor broken in pieces, nor in any way destroyed or deprived of the least of their properties."

Now, something of this conception was held and felt all through the earlier days of chemistry. The physicists, Newton and Bernouilli, held it, the latter believing the pressure exerted by a gas upon the enclosing walls to be due to the constant bombardment of the atoms. We have seen how this idea was present in the mind of Lavoisier. It was then in the air, as it were, a dream, a fancy of the philosophers, without tangible proof, yet often incorporated in their views and theories. The credit which belongs to Dalton is that he took this dream, and, by means of collected facts and laws, gave it that confirmation which was necessary in order that it might be ranked as a theory.

Proust (1755–1826). — Most important aid was rendered Dalton in his work by the skilful and careful analytical labors of Proust, a countryman of Berthollet, and a strong opponent of his views. In fact, Proust very nearly anticipated Dalton in his discovery of the law of multiple proportions, which gave most support to the atomic theory.

Proust entered upon a brilliant defence of the law of constant, or definite, proportions, which had been partially established by the work of Lavoisier and Vauquelin, and which was now attacked by Berthollet. The interchange of letters between Proust and Berthollet lasted during eight years, and attracted the attention of all chemists. These were not mere theoretical disquisitions, but recounted the experiments and counter-experiments of the authors, and many new facts were brought out by them. Berthollet lost most of his adherents before the close of the controversy. One of the good results of this controversy was to bring about a definition of compounds and mixtures, and a clear distinction between them. In the course of it, also, Proust discovered the hydroxides, a class of compounds until then confused with the oxides.

Richter (1762-1807). — Another earnest supporter of the law of definite proportions was Richter, though probably his work was unknown to Dalton. He published (1792–1794) the results of his work upon the proportions by weight in various compounds, under the title of *"A Foundation for the Stoichiometry, or Art of Measuring Chemical Elements."* This is the first work on systematic quantitative analysis. It was a decade or more before Richter's excellent work received appropriate recognition.

Law of Multiple Proportions. — So the idea of the fixity of proportions became firmly incorporated in the science, and we can speak of it as a recognized law. With this proved, it needed but one step more to give a sure basis for Dalton's theory of the existence of atoms. When Dalton discovered the Law of Multiples, or, in other words, when he found that if two elements combined to form one compound, there were certain definite proportions in which they united, if they formed more than one, then the proportions progressed by regular increments, an increase of once or twice the first proportion, or of some simple multiple of it, he saw that his hypothesis of atoms gave a plausible, and the only plausible, explanation of these facts.

The Atomic Theory and its Extension. — Dalton told his theory to Thomson; and he published Dalton's views in his *"System of Chemistry,"* in 1807. Sir Humphry Davy opposed this new hypothesis, but was won over to it, and so were Wollaston and others, though they saw difficulties in its application which greatly delayed its general acceptance.

The essential parts of Dalton's theory can be put in two sentences. 1. Every element is made up of similar atoms of constant weight. 2. Chemical compounds are formed by the union of the atoms of the different elements in simple numerical relations.

His speculations as to the form of the atoms, declaring them to be spherical, and that they did not touch one another, are of subordinate importance, and had little to do with the after development of the theory.

VOLUME RELATIONS.

If the atomic hypothesis was a true explanation of the facts of chemical combination, then its first and most important application would lie in a determination of the relative weights of the atoms of the various elements. This might be arrived at by a determination of the combining proportions entering into different compounds, provided the number of atoms in such compounds were known. Now, it was in this that the supporters of the theory met their first and greatest difficulty.

Dalton's Rules for Determining Atomic Weights. — Dalton began to determine the weights of the atoms, taking as his standard hydrogen. A list of these weights determined by him was published as early as 1805. They show very faulty analytical work, and were entirely superseded by the later classical work of Berzelius. In fact, they seem to have come very slightly into use. To overcome the difficulty of telling how many atoms entered into combination to form a particle of any compound, he adopted certain very arbitrary rules, which were afterwards shown to be without just basis. These rules have the merit of simplicity, however, and were about the best that could be formulated at that time. First he divided compounds into binary, ternary, quaternary, etc., according as they contained two, three, four, or more atoms. Then he adopted the following rules: —

1. When only one combination of two bodies can be obtained, it must be presumed to be a binary one, unless some cause appear to the contrary.

2. When two combinations are observed, they must be presumed to be a binary and a ternary.

3. When three combinations are obtained, we may expect one to be a binary and the other two ternary.

4. When four combinations are observed, we should expect one binary, two ternary, and one quaternary, etc.

Besides this difficulty, Dalton's use of the term atom was confusing. He made no distinction between the ultimate particles of elements, or of compounds, or the ideal indivisible atom. This was a most serious flaw. It caused Dalton himself to reject the work of Gay Lussac; and it caused others to hesitate to accept Dalton's views, seeing these inconsistencies. Two things were much needed: a clearer definition of atoms, and some reliable method of determining the number of atoms in a compound particle.

Gay Lussac (1778–1850). — The latter problem was partially solved by the labors of Gay Lussac. This distinguished pupil of Berthollet was a trained chemist, capable of the most accurate analytical work, and possessing scientific acumen in a very high degree. He enriched chemical literature with many excellent researches, working often in company with Thénard, Humboldt, and Liebig. His most noteworthy work was upon iodine, cyanogen (the first compound radical), the alkaline oxides, the isolation of boron, improved methods for organic analysis, and many similar studies.

The Law of Volumes. — But his name is especially associated with his researches upon combining volumes of gases. He discovered the law of the expansion of gases under the influence of equal temperatures. He also studied the combining volumes of gases, and deduced from his experiments the Law of Volumes. This law of volumes may be stated thus: the volumes of combining gases bear a simple ratio to one another and to the volume of the resulting gaseous product. This law was announced by him in 1808.

Difficulties and Objections. — Gay Lussac was well acquainted with Dalton's hypothesis, and showed in part how his discoveries accorded with it. A similar molecular condition was essential in order that all gases should behave alike towards pressure and changes of temperature, and, besides, obey his law of volumes. In other words, equal volumes of gases must contain equal numbers of molecules. Gay Lussac made no distinction between these molecules and atoms, recognizing but one kind of final particle. Dalton took exception to this reasoning, and in his reply said that he too had once held the same idea as to combining volumes, but had seen that it was untenable. He further maintained that the experiments of Gay Lussac were inaccurate, and that the gases did not combine exactly by volumes, but often by fractions of volumes. His argument can be illustrated best by taking some substance, as hydrochloric acid, as an illustration. One atom of hydrogen chloride consists of one atom of hydrogen and one atom of chlorine. Now, if equal volumes of gases contain equal numbers of molecules, one volume of hydrogen and one volume of chlorine should give one volume of hydrogen chloride, but they really form two. Therefore each one of these can contain only half as many atoms as the original volumes of the constituents. This reasoning is manifestly final so far as the theory of the volumes containing the same number of atoms is concerned, unless some different definition of atoms is assumed.

Avogadro's Theory. — The solution of the difficulty was shown by Avogadro. This Italian physicist made a distinction between what he called *molécules intégrantes* and *molécules élémentaires*, or, as we may translate the terms, molecules and atoms. The molecules were compound particles, and were made up of the indivisible atoms. The researches of Gay Lussac show, then, that a molecule of water consists of one molecule of hydrogen and one-half molecule of oxygen. A molecule of hydrogen chloride consists of one-half molecule of hydrogen and one-half molecule of chlorine, and so the difficulty pointed out by Dalton disappeared.

Avogadro also pointed out how this law of volumes enabled one to determine the number of atoms in a molecule of a gaseous compound, whereas the rules of Dalton were purely arbitrary. He went farther, and determined the number of atoms in the molecules of various elements.

Ampère. — These discoveries of Avogadro are often credited to the French physicist, Ampère; but his memoir appeared three years later (1814), and lacks the clearness and fulness of that of Avogadro. His memoir first appeared in the form of a letter to Berthollet, and he showed in it his ignorance of Avogadro's work. The views of these two did not have an immediate effect upon the chemical world; and, indeed, a half century passed before the great importance of the theory was fully recognized.

Wollaston's Equivalents. — The uncertainty connected with the atomic weights as determined by Dalton, led Wollaston, his countryman, to suggest the use of the term equivalent instead. This term he drew from the work of Richter; and he meant by it the relative quantities, or proportions, in which bodies unite, thus doing away with the idea of atoms. Oxygen was taken as the standard, and given the value ten.

He hoped, by the substitution of the idea of equivalent proportions, to escape all questions as to the number of the atoms in a compound. It is easy to see that his method rather increased than diminished the complications.

Prout's Hypothesis. — In the year 1815 Prout published an hypothesis based on the assumption that all the atomic weights were whole numbers, and therefore multiples of hydrogen, and that these elements were consequently only different grades of condensation of hydrogen, which was therefore the primal element. No proofs whatever were offered in support of this bold theory. A little arithmetic only was needed to show its wildness, and the most approved work of chemists since has only shown the fallacy of the assumption on which it was based. Yet this hypothesis has proved itself exceedingly attractive to some of the master minds of chemistry, and has wrought much harm, as all false hypotheses must. Because of this very lack of foundation no overthrow could be complete. Although it has suffered many reversals, it still comes to life every now and then. Prout, the author of it, was a physician, and did little chemical work of value.

THE NEW ELEMENTS.

It has been necessary to devote a good deal of time and space to the growth of theories in these, the first two decades of the new chemistry. These form the foundation of the modern science, and a correct understanding of them and their development is most important. It is well to turn now to the multiplication of chemical facts, especially to the growing list of chemical elements.

Klaproth (1743–1817). — Among the eminent discoverers of this period stands Klaproth. As has been said, it was largely through his influence that the German chemists were won over to the views of Lavoisier. His work was mainly in connection with the analysis of minerals and the improvement of analytical methods. He added uranium, titanium, and zirconia to the known bodies.

Proust. — The work of Proust in connection with the study of tin, copper, iron, nickel, antimony, cobalt, silver, gold, and mercury, was most accurate and valuable for the extension of chemical knowledge. This was a part of the work brought out by the celebrated controversy over the Law of Definite Proportions already mentioned. But the two most distinguished discoverers in the first quarter of this century were Davy and Berzelius. Their influence upon the science has been very great.

Sir Humphry Davy (1778-1829). — The scientific training of Sir Humphry Davy was secured while apprenticed to a surgeon and apothecary at Penzance. At the age of twenty he was put in charge of the laboratory of the Pneumatic Institution at Bristol, founded by Dr. Beddoes for the application of gases to the treatment of diseases. Davy's surroundings here were most propitious for a successful career of scientific research. His laboratory was well furnished, and was supported by the subscriptions of scientific men. He had plenty of time at his disposal, and the age was one of discovery and rapid progress in the science. His experiments related chiefly to nitrogen monoxide, or nitrous oxide; and in a short time he published his "*Researches Chemical and Philosophical, chiefly concerning Nitrous Oxide and its Respiration.*" His courage and his determination were well proved by these experiments. The effects of this gas, supposed to be poisonous, were tried upon himself. He discovered its anæsthetic action. He exercised care, but was unflinching in his determination to get at the truth, and persevered, though often overpowered, weakened, and injured in health, by his tests imposed upon himself. While in this laboratory he gave some of his time also to experiments upon the decompositions caused by the aid of the electric current.

Davy next became professor of chemistry at the Royal Institution in London, where all apparatus needed by him was freely supplied, and only occasional lectures were required of him.

Decompositions by Means of Electricity. — He had for some time been thinking that the most needed step in chemistry was the decomposition of some of the bodies then regarded as simple or elementary, among them the alkalies and earths; and having already, before moving to London, begun to apply the voltaic pile in chemical work, he thought this the most promising means for the solution of the question as to whether these bodies were really elementary or not. Nicholson and Carlisle had made the observation, in the year 1800, that water was decomposed into its components by the discharge from the voltaic pile. This led to similar experiments upon other substances, among them the remarkable ones of Berzelius and Hisinger upon salt solutions, ammonia, sulphuric acid, etc.

Decomposition of Water. — Davy was among the first to busy himself with this most interesting and important question, the decomposition of water. From the very first it was noticed in this electrolysis that acid and alkaline substances were formed, and it was believed that water was changed into these under the action of electricity. By most careful experiments, Davy showed the error of this view. He carried out this electrolysis in vessels of various materials, and showed that the products mentioned, the acid and alkali, were due to the glass, or to the matter dissolved in the water, or to the air itself. If the water, distilled in silver, was electrolyzed in gold vessels, in an atmosphere of hydrogen, the acid and alkali did not appear.

Davy further repeated and confirmed the work of Berzelius upon salt solutions. He, too, made the observation which Berzelius had made, that the electric current separated hydrogen, the metals, metallic oxides, alkalies, and earths to the negative pole, and oxygen and the acids to the positive. He concluded that the first named substances have a positive electrical energy, and the latter a negative; and this was the beginning of the electro-chemical theory. Davy sought to explain all chemical combination and decomposition on this principle. According to him the heat noticed in certain cases of combination were manifestations of electricity.

Davy was the first to bring the thought to a fixed form that electric and chemical action may be referred to the same force. All the later doctrines that chemical changes are merely the evidences of electrical attractions depend upon his work and views.

Decomposition of the Alkalies. — In his first experiments upon potash and soda, Davy used strong solutions, and noticed that only hydrogen and oxygen were evolved. He next allowed the current to pass through melted potash. A flame appeared at the negative pole, and on changing the direction of the current "æriform globules which inflamed in the air, rose through the potash." When the potash was placed upon a piece of platinum which was made the negative pole of a powerful battery, and the positive pole, in the form of a platinum wire, brought in contact with the upper surface of the potash, the potash became hot, and even melted with the passage of the current; and on the lower (negative) platinum small globules, lustrous and metallic, much like quicksilver, were soon noticed, some bursting and burning, others tarnishing and coating over with a white film.

Great was Davy's delight at his discovery; and we can hardly exaggerate the impression made upon the chemical world by the decomposition of this supposed elementary body, and the wonderful new metal gotten from it. Its properties were most opposed to those which were held to be characteristic of the metals, light, oxidizing immediately in air, and decomposing water.

Davy decomposed soda also. He named the new metals potassium and sodium, and confirmed his discovery by oxidizing them back to the original alkalies. He learned how to prepare larger quantities and to preserve them under naphtha. These discoveries were made in 1807, and were followed next year by the decomposition of the alkaline earths, lime, baryta, and strontia. He also was convinced by his experiments that silica, alumina, zirconia, and beryllia could be decomposed by the electric current; but he failed to obtain any of the supposed elements existing in these substances. This he attributed to his current not being powerful enough. Davy's discoveries confirmed the view, which was already widely held, that the alkalies and earths were metallic oxides; that is, it confirmed this view in part, because it was not yet known that these were really hydroxides.

Composition of Muriatic Acid, and the Nature of Acids.—His next important services were in connection with the theory of acids. Berthollet, in his work upon hydrogen sulphide, hydrochloric acid, and hydrocyanic acid, had really shown the untenable character of Lavoisier's theory as to oxygen being present in all acids, and hence deserving of its name, the acid-maker. But Berthollet's experiments were not pressed to their legitimate conclusion; and the theory of Lavoisier still held its place, though the existence of hydrochloric acid became a serious stumbling-block. Oxygen, according to Lavoisier's theory, should have been one of its constituents, and yet no one could detect it. If this acid contained oxygen its salts should also. In 1774 Scheele had shown that by its action upon the black oxide of manganese, a yellow, pungent smelling gas was obtained. Berthollet showed that a solution of this gas in water gave off oxygen when exposed to sunlight, and hydrochloric acid was at the same time formed. Therefore it was called "oxidized muriatic acid." Muriatic acid was regarded as composed of oxygen and an unknown radical. These were not the views of Scheele, who called chlorine "dephlogisticated muriatic acid," and regarded it as hydrochloric acid deprived of its phlogiston or hydrogen. In 1809 Gay Lussac and Thénard showed that one volume of "oxidized muriatic acid" and one volume of hydrogen united to form muriatic acid. This proved that it contained hydrogen.

Davy next endeavored to find the oxygen which was supposed to be in this acid, but without success. He did show, however, that when "oxidized muriatic acid" acted upon metals, salt-like compounds were gotten, and that similar compounds, and at the same time water, were formed by the action of muriatic acid upon metallic oxides. Davy explained these facts by regarding "oxidized muriatic acid" as an elementary substance, and muriatic acid as its compound with hydrogen; but chemists were slow to accept his views. Davy held that this element, to which he gave the name chlorine, resembled oxygen in many respects, and, in a limited sense, was also to be regarded as an acidifier and supporter of combustion. In the ensuing discussion with Gay Lussac, who endeavored to prove from the work of Berzelius and Davy on ammonium amalgam, and from the action of potassium on ammonia, that hydrogen was an alkalizing principle, Davy uttered the following important but often overlooked truth: —

"The substitution of analogy for fact is the bane of chemical philosophy; the legitimate use of analogy is to connect facts together, and to guide to new experiments."

Davy's facts were clear and convincing, and in a few years chlorine was generally regarded as an element. In 1812 and 1813 iodine, discovered by Courtois, a French soapmaker, and investigated by Gay Lussac, was added to the list of acidifiers.

The New Theory of Acids. — These new facts necessitated a new theory of acids. No one element could be regarded any longer as the acid-making principle. Most, if not all, contained hydrogen; but the acid properties seemed to be dependent upon the other element or elements combined with the hydrogen. An acid might contain oxygen and be an oxy-acid, or contain no oxygen; and so, too, a salt might contain oxygen, or, like the chlorides or iodides, have none in its composition. Thus the old view, that a salt was a compound of the oxide of a non-metallic element, or acid, and of the oxide of a metal, or base, was overthrown, and salts came to be looked upon as metallic derivatives of acids, the metal replacing the hydrogen.

The Alkalizing Principle. — In this connection it is well to take up the discussion which arose as to the constitution of the alkali metals, sodium and potassium. Davy had observed that these metals separated at the negative pole, while oxygen appeared at the positive; also that they had the power of reducing metallic oxides; and showed that by their combustion in oxygen the alkalies seemed to be regenerated. Hence he concluded that these bodies were metallic and elementary. From his work upon ammonium amalgam, a little later, he concluded that this was composed of mercury and a hypothetical metal-like body, ammonium, which broke up into hydrogen and ammonia. The relationship between this body and the alkalies, and the analogy between their amalgams, gave rise to the theory that these also were combined with hydrogen, a theory which Davy was more inclined to accept because of the combustibility of these metals. Gay Lussac and Thénard had examined also the action of potassium upon ammonia gas, and noted the liberation of hydrogen and the formation of a green substance, the amount of hydrogen liberated being the same as that set free by potassium from water. From the green substance they regenerated the original amount of ammonia used. Therefore they said that potassium consisted of potash and hydrogen, and that this hydrogen was set free by treatment with water or with ammonia. According to this theory, there was an alkalizing hydrogen.

Davy soon returned to his original ideas as to these alkali metals, and gave as his explanation of the experiments of Gay Lussac and Thénard that the hydrogen came from the decomposition of the ammonia, and not from the potassium. In the year 1811, Gay Lussac and Thénard came over to Davy's views, having observed that the body gotten by the burning of potassium was not the same as potash, but contained less oxygen, and that the melted potash was not water-free, as Davy had imagined. Thus they gave up their theory that hydrogen was an alkalizing principle, giving bases when combined with ammonia, or soda, or potash, and similar bodies. The theory of acids, salts, and bases has become of much less interest and importance in the progress of chemistry than it was in the earlier period of the history.

Davy's Later Life.—For his services in inventing the safety-lamp, Davy was made a baronet. In 1820 he was elected President of the Royal Society of England; and he held this post for seven years, the highest position attainable by an English man of science. He died in 1829, one of the most brilliant chemists the world has ever seen, and the greatest England has produced.

THE BERZELIAN THEORIES.

It was peculiarly fortunate for chemistry that two such brilliant and accurate investigators as Davy and Berzelius should have appeared at a time when the framework erected by Lavoisier needed filling out, and the foundations of the science had to be deepened and broadened. A series of mediocre and inaccurate workmen coming just then would have more easily misled and more seriously retarded the science than at any later period. Berzelius was a greater chemist than Davy, and the chemist of to-day can scarcely overestimate his indebtedness to him.

Berzelius (1779–1848). — Johann Jacob Berzelius was born in Sweden, one year after the birth of Davy. Poverty greatly hampered both in their younger years, and both were forced to follow medicine and pharmacy as a means of livelihood at first. Berzelius became a professor of chemistry in Stockholm. Here he lacked the appliances and the leisure afforded Davy by the freedom from class-work at the Royal Institution. Still, his lectures and classes enabled Berzelius to impress himself and his views upon the rising generation of chemists. This end Davy could only partially attain through his published papers and books.

Among the most distinguished of his pupils may be mentioned Mitscherlich, Magnus, Mosander, Heinrich and Gustave Rose, Gmelin, and Wöhler. His career was further comparable to that of Davy in that he held an honored post, namely, that of permanent secretary to the scientific society of his native land, and was ennobled by his king. His later years were devoted to literary labors; and he died in 1848, nearly twenty years after the death of Davy.

The Work of Berzelius. — It is difficult to give a short and at the same time fair account of the work of this great man, as it covered almost the entire field of chemistry, and hence was of the most extensive and varied character. Only brief reference can be made to special chemical work. More stress will be laid upon his services in the direction of the development of chemical theory. Berzelius was a most accurate and painstaking worker, showing great powers of observation and a close attention to details. He was conservative, holding fast his allegiance to older views until he saw clearly that the new were substantiated by the facts. For instance, the imperfection of Dalton's atomic theory, and his arbitrary rules for determining the number of atoms in a compound, at first made him hesitate to accept it. When he did accept it, however, he endeavored to extend its application into every branch of chemistry.

Analytical and Experimental Work. — He brought about many improvements in analytical chemistry, devising many methods for the separation and determination of the elements. His close attention to details led him to the discovery of selenium, ceria, thoria, and many new compounds. He also first prepared the elements silicon, zirconium, and a purer tantalum, and did much towards enlarging the knowledge of the platinum metals. He made a great number of analyses to prove the constancy of proportions, and the truth of Dalton's law of multiples. He enriched mineralogy by a great number of analyses of minerals, and showed that minerals were simply chemical compounds obeying the atomic laws. Based upon this he introduced a chemical system of classification for them. He extended the law of multiple proportions to organic chemistry, and did much to systematize that branch of the science.

Determination of Atomic Weights. — Berzelius and the pupils in his laboratory undertook the determination of the atomic weights. The analytical work, of course, greatly excelled that of Dalton, and in the rules laid down for his guidance in deciding the number of atoms in a given compound or molecule, he showed a greater knowledge; still, his rules were, in some respects, arbitrary and unsatisfactory. His standard was oxygen taken as 100. Many of his determinations are still quoted, and made use of in settling these physical constants, over which chemists have been so long busied. This work was begun at a time when Wollaston was endeavoring, by his use of the term equivalents, to do away with the whole vexed question of atoms. Thomson, adhering to Dalton's theory, was using the standard oxygen equal to one, believing that this would give more of the atomic weights as whole numbers.

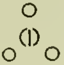
Berzelius, in 1813, made a great step forward in recognizing the distinction made by Avogadro between atoms and molecules, and in accepting the law of Gay Lussac that equal volumes of gases contain equal numbers of atoms. He limited its application, however, to elementary gases. The weights of the combining volumes of these gases were, he believed, the weights of their respective atoms. Still, Berzelius's use of Gay Lussac's law was too limited to free him from the necessity of adopting rules for deciding the number of atoms in compounds. He gave a fairly complete table of these weights in 1818.

The Introduction of Symbols. — Berzelius also greatly aided the progress of chemistry by the introduction of symbols. He proposed that the first letter of the Latin name of the element should be used to designate the element, and should represent one atom or one equivalent of it. A compound is thus represented by placing the proper number of these symbols side by side. Thus, H is hydrogen, Cl is chlorine, and HCl is hydrogen chloride. He supposed the existence of certain double atoms (where two atoms of an element occur together). These were indicated by a mark across the symbol; thus ĦO was water, or, as we write it, H_2O. For convenience' sake, an atom of oxygen was often indicated by a point or dot, an atom of sulphur by a mark at right angles, thus: —

Carbon Dioxide, $\ddot{C}$; "Nitrous Acid," $\overset{\cdot}{\ddot{N}}$; Potassium Nitrate, $K\overset{\cdots}{\ddot{N}}$.

These symbols were a great advance over those suggested by Dalton, which were diagrammatic and quite unpractical. For instance, the following are some of Dalton's symbols: —

Hydrogen, ⊙ Nitrogen, ⦶ Carbon, ●
Oxygen, ○ Water, ⊙○ Carbonic Acid, ○●○

Nitric Acid,  Potash,  Soda,  Barium Chloride, 

The symbols introduced by the ancient alchemists, and partly used by them in later times, carried with them the idea of the connection between the metals and the heavenly bodies, and were intended, apparently, to mystify rather than to simplify the science. Mention has already been made of their great number and diversity.

The Dualistic Theory. — The term atom was extended farther by Berzelius, to include what he looked upon as compound atoms. These were built up of two parts, each of which might be a simple atom or several atoms, in which each of the two parts acted as a single, simple atom. This was the dual structure, and forms the dualistic system of Berzelius. It dominated all of his ideas and theories with regard to chemical phenomena, and for more than a decade held a preeminent position in chemistry. Berzelius seemed to have formed this idea of dualism from his observations upon the volumes of gases. For a certain number of these gases the equivalent is formed of two atoms. This was true not only of hydrogen, but of nitrogen, chlorine, and others, in the form of vapor. The atomic weights of these bodies represent also the specific gravities, or the weights of one volume compared with one volume of the standard; but since it needs two volumes of nitrogen, two volumes of chlorine, etc., to form the first stage of oxidation with oxygen, two volumes of nitrogen, etc., represent the equivalents of these bodies compared with oxygen. He considered that these atoms, then, were united two and two, and called them the double or compound atoms.

The Electro-Chemical Theory. — Before any full discussion of the dualistic theory, it is necessary to study the electrochemical theory, which we owe partly to Davy, though chiefly to Berzelius. These two theories are so closely linked together that one is unintelligible without the other, at least as they were held by Berzelius. As to the author of this theory, it was mainly developed by Berzelius. That which was more a philosophical conception on the part of Davy, a vision of the two forces, electrical and chemical, existing side by side everywhere in nature, and holding all things in equilibrium, was reduced to precision and made the basis of a system of chemical classification by Berzelius. This theory was offered as, in a measure, explaining the nature of chemical affinity. The term affinity, as meaning the chemical attraction of a particle of one kind of matter for another, had been in use a long while. The differences in this force had been noticed; and, as we have seen, elaborate tables of affinity had been constructed by many chemists. Berthollet had caused a great depreciation in the value of these tables by showing how cohesion, mass, and temperature influenced the exhibition of affinity. Berzelius emphasized what had already been noted, that this force is exhibited between unlike atoms, and differs greatly in intensity between different atoms, some showing almost no affinity for one another, and others very great. According to Berzelius, this exhibition of affinity depended upon the electrical states of the different atoms. This view, of course, is based upon the two facts that compounds are decomposed by the electric current, and the constituents invariably seek the same respective poles; and, secondly, that chemical union can be caused by the action of electricity.

The Berzelian theory was, that every atom had a certain quantity of electricity belonging to it, partly positive and partly negative. This, accumulated at the extremities of the atoms, gave a positive and a negative pole. Because of the preponderance of one or the other of these kinds of electricity, however, the whole atom has the character of either a positively or a negatively electrified body. There is a neutralization of the positive electricity by the negative on the combination of the atoms. Obeying the ordinary rule, atoms similarly electrified would show little or no affinity for one another, whereas great affinity would be shown between those of very different electricities.

Although, in a compound atom, the union was brought about by a neutralization of the different electricities, still, in the Berzelian theory, the atom, as a whole, was characterized by either positive or negative electricity, according to which predominated, and exerted its attractive or repellent influence on the other atoms. Every compound atom, then, was built up of two parts, one positively and the other negatively electrified, and formed a dual structure. The system, hence, was known as the dualistic.

Thus a base became regarded as an electro-positive oxide, and an acid as electro-negative oxide; and Lavoisier's theory as to the acid-making oxygen could not possibly be used any longer. The electro-chemical theory dominated chemistry during the third and fourth decades of this century. It went too far in advance of observed and proved facts. It is strange that the conservatism of Berzelius should have permitted him to assume so much, and go so far beyond that which he could prove. In particular, his identification of chemical affinity with electrical polarity was one not justified by the facts. The beauty of the theory as one explaining, and that most plausibly, the mysterious chemical force or affinity which had puzzled chemists for so long a time, probably proved the attraction which overcame the scruples of Berzelius. The work of Berzelius in connection with organic chemistry will be spoken of later on.

IMPROVED METHODS AND NEW LAWS.

Summing up now the status of the science, as was done at the beginning of this period, we find chemistry in the possession of a rational and systematic nomenclature; a solid foundation in the laws of constant proportions and multiples, and a satisfactory working hypothesis and theory explaining them in the atomic theory of Dalton; a simple and practical system of symbols; and, lastly, a remarkably accurate table of those most important physical constants, the atomic weights, the determinations of Berzelius being a near approach to the more accurate work of the present day, as can be seen by the following table, in which the numbers of Berzelius have been calculated on a basis of hydrogen as unity, instead of oxygen equal to 100, as adopted by him: —

	BERZELIUS.	LATER.
H	· 1	1
O	16	15.96
C	12.2	11.97
S	32.2	31.98
Cu	63.4	63.18

The science was thus well furnished for entering upon the era of marvellous growth in the accumulation of facts and in the formation of theory which the seventy-five years since passed have seen.

New Appliances. — Improvements in the methods of research and in appliances were the great needs of the times. Volta and Galvani had brought electricity into a form to be useful to chemists; and so remarkable had been the results, that it is not surprising that too much should have been expected of it, and many phenomena, imperfectly understood, attributed to this energy, itself so mysterious.

There had been marked improvement in laboratory appliances. Glass, porcelain, and platinum were the materials of which the apparatus was made, and the forms were being constantly improved. Gold and silver were also used for some of the vessels. Yet one accustomed to the elegant furnishings of a modern laboratory would look with surprise upon the simplicity and even poverty of the rooms in which some of the great masters worked.

Berzelius's Laboratory. — Wöhler has described his first visit to the laboratory of Berzelius, in which so many famous discoveries had been made.

"No water, no gas, no hoods, no oven, were to be seen; a couple of plain tables, a blow-pipe, a few shelves with bottles, a little simple apparatus, and a large water-barrel whereat Anna, the ancient cook of the establishment, washed the laboratory dishes, completed the furnishings of this room, famous throughout Europe for the work which had been done in it. In the kitchen which adjoined, and where Anna cooked, was a small furnace and a sand-bath for heating purposes."

Apparatus. — It has required the combined ingenuity of chemists and of workers in glass, pottery, and metals for many years to produce the almost countless forms of delicate, costly, and often complicated apparatus of the present day; but the demand for greater accuracy and increased precision has made such inventions necessary. At the time of Davy and Berzelius, the chemist was expected to be something of a mechanic, able to cut and form, fashion and solder, the wood, brass, and iron into the various shapes he needed. He must also have skill as a glass-blower, for in most cases he would have to depend upon his own cunningness of hand for the success of his experiments. It would be well in these days, also, for chemists to have at least some of this mechanical training; but few have the time for it, or give the time to it, since far more skilful hands are ready to do their bidding.

Law of Dulong and Petit. — But new methods are even more valuable than improved forms of apparatus. It is impossible to give even in outline the improvements in analytical methods, in reagents, tests, modes of separation, etc. The larger field of methods based upon natural laws can, however, be touched upon. In the matter of atomic weight determinations, two methods were devised for securing greater accuracy and certainty. Both of these important physico-chemical discoveries were made in the year 1819.

Dulong and Petit, in experimenting upon the specific heats of the metals and other bodies, came upon the important truth that these were very nearly inversely proportional to their atomic weights. Multiplied by their atomic weights, the specific heats gave a constant quantity. This gave the law as stated by them: the atoms of the different elements have the same capacity for heat. It is easy to see that by means of the specific heat one could readily approximate to the true atomic weight, and arrive at a decision as to which of two or more possible figures represented the true weight.

There were exceptions to the law which have been explained away only in late years. Still, the law was extended to simple chemical compounds, and proved of great use after it was more fully understood. Berzelius opposed the acceptance of it at first, in part, because it would necessitate a revision of his table of atomic weights, and might endanger the accepted views as to some of the atomic relations. He gradually gave up this stand, however, when the law was confirmed by other workers, and more accurate determinations were made than the first ones of Dulong and Petit.

Law of Mitscherlich. — Another aid in this direction was the Law of Isomorphism, discovered by Mitscherlich. While engaged in a research upon the salts of phosphoric acid and arsenic acid, he conceived the law that compounds of analogous composition and containing the same number of atoms crystallize in the same crystalline form, or, in other words, are isomorphous. For this to be really useful in determining atomic weights, it was necessary to reverse it, and to have it hold true that isomorphous bodies were analogous and contained the same number of atoms. Here many difficulties presented themselves, necessitating narrower and narrower definitions of isomorphism. It is evident that, though analogy or similarity of crystal form may have a bearing upon the molecular composition and arrangement, we are unable as yet to determine fully this bearing. Berzelius took up the discovery of Mitscherlich as one of the most important of that age, and made frequent use of it in testing his atomic weights.

Corrected List of Atomic Weights. — Seven years later, or in 1826, he published a corrected table of the atomic weights, in which he made use of all of these discoveries and improvements. In this table, for the first time, the atomic weights of nitrogen and chlorine as elements are given.

Electro-chemical Equivalents. — Mention should be made in this connection also of Faraday's noteworthy observation that the same electric current, in decomposing different electrolytes, such as water, metallic chlorides, etc., separated at the negative or the positive pole equivalent amounts of the respective constituents. This was called the law of constant or fixed electrolytic action, and the amounts separated were the electro-chemical equivalents. Faraday thought that the determination of these equivalents would prove a valuable aid to the correct determination of the atomic weights. Berzelius, however, denied the usefulness of numbers derived in the electrolytic way.

Work of Dumas on the Atomic Weights. — In their work upon the atomic weights, Dumas and the French chemists made especial use of the law of volumes as given by Gay Lussac, and adopted the distinction made by Avogadro between the atoms and molecules. The equivalents suggested by Wollaston were rejected by them as applicable only to a limited range of substances, such as acids and bases, besides being indefinite or indeterminable when indentified with combining weights, as many bodies united in several different proportions to form compounds. Thus copper in one oxide bears the ratio of eight to one to the oxygen, in another the ratio of eight to two. Taking oxygen as unity, the equivalent of copper could be reckoned as either eight or four. Some of Dumas' determinations, as those of phosphorus, tin, and silicon, show that he did not realize the full importance of Avogadro's theory as an aid in such determinations. Still, he believed that this theory gave a surer basis for solving such questions as this about the copper; and he constructed a table of atomic weights, making use of this theory and the law of Dulong and Petit. Of course he made use of the writings of his countryman, Ampère, mentioning Avogadro only once. He made use of the term elementary molecules, and said that there was no means of deciding of how many smallest particles these molecules consisted. In accuracy and correctness these weights fell below those of Berzelius.

Vapor Densities. — To confirm his ideas, he extended his investigations of the truth of Avogadro's law, devising, in 1827, apparatus and a most excellent method for the determination of the specific gravities of gases at high temperatures, thus enabling him to experiment upon the vapor densities of iodine, phosphorus, sulphur, mercury, etc. His results, instead of confirming, tended rather to disprove the law of volumes. We know that the trouble lay in the complex nature of the molecules experimented upon, but of course this was unknown to Dumas. He finally declared that, even in case of the simple gases, like volumes did not contain equal numbers of chemical atoms. Berzelius also had been forced practically to give up the law of volumes, at least so far as any use in atomic weight determinations was concerned, limiting its application to the uncondensed or so-called permanent gases. Dumas' work would induce one to give it up even for these.

Unsatisfactory Condition of Chemical Theory. — Chemists, therefore, looked with indifference or disfavor on this law, which is the mainstay of modern work upon the atomic weights. The law of Dulong and Petit was shown also to have some notable and unexplained exceptions, and Mitscherlich, by his further discovery of dimorphism, had thrown much doubt upon his law of isomorphism. So, at the close of the thirtieth year of this century, the atomic theory was regarded by many chemists as either disproved or relegated to a very hypothetical position.

Gmelin's Views. — Some took up again the equivalents of Wollaston. Certainly, little distinction was made between these and the atoms of Dalton, and the dualistic system of Berzelius lost ground. Leopold Gmelin, the author of the most complete handbook or encyclopædia of chemistry up to his time, and the most influential, going through many editions and forming the basis subsequently of Watt's "*Dictionary of Chemistry*," was the leader in this new school of chemists. In the edition of his handbook published at this time, the fourth decade, he gave up the atomic theory completely. He recognized no difference between chemical compounds and mixtures. Two substances, according to his ideas, could combine in an unending number of proportions. This was especially true where the affinity between them was weak. In the case of a strong affinity the tendency was toward a limitation to a few proportions. To each body, then, a sort of mixing weight could be assigned, and this number could be used in stoichiometrical calculations.

His table of the equivalents halved most of the atomic weights. Thus $H = 1$, $O = 8$, $S = 16$, $C = 6$, etc. Water became HO. The rule was to make everything conform to the utmost simplicity. Where there was a choice between several possible equivalents for any one element, he took the least and simplest. These numbers and formulas were retained by many chemists for decades afterwards, and by some, in part, for as long as a half century.

Need of New Support for the Atomic Theory. — This long struggle over the atomic theory, and very unsatisfactory ending of it, led many to look upon theorizing as something to be avoided, and to regard as the true object of chemistry the search after facts. To such minds there was no place for the imagination in science. To rescue the theories of chemistry from this disrepute it was necessary to call in the aid of the growing science of organic chemistry; and it is through this branch of chemistry that the doubts and difficulties were mainly cleared away and chemical theory advanced.

PART FIFTH.

STRUCTURAL CHEMISTRY.

THE DEVELOPMENT OF ORGANIC CHEMISTRY.

In the text-book of Lemery, in use in the latter half of the seventeenth century, all chemical substances were classified and separately treated under the three headings, mineral, vegetable, and animal substances. This division was made first at this time, and was the usual one during the next century. This corresponded with the favorite grouping of the "three natural kingdoms" which were so much used in books of two or three generations ago.

Lavoisier's Views. — Lavoisier showed that organic substances were composed mainly of carbon, hydrogen, and oxygen, together with nitrogen, and, less frequently, phosphorus and sulphur. Before this there were great doubt and discussion as to their composition. Lavoisier was the first to devise a system of quantitative analysis for these bodies, and so to decide definitely as to their composition. Acid bodies were recognized among organic substances; and so, in his acid theory, Lavoisier accounted for their nature by supposing that in these cases the oxygen was combined with a compound radical or organic residue. This idea of the compound radicals was afterwards developed by Berzelius and his followers until organic chemistry became the chemistry of the compound radicals.

Organic Substances as the Products of Life Force. — First the barrier between vegetable and animal substances fell away when it became clear, from the work of Chevreul, that many of the fats and acids and other substances, occurring in both kingdoms, were identical; but the line was still very sharply drawn between mineral substances and the products of plant and animal life. These latter, it was believed, could not be artificially formed out of the elements that composed them. They were produced by some mysterious force, life, whose operations could not be imitated. The ordinary laws governing chemical affinity could not be expected to apply in this field; and hence chemical theories, as the atomic theory, could not explain the phenomena of life. This complete separation may have been a natural reaction from the attempt of the earlier chemists to explain all life processes by means of faulty chemical theories.

Views of Berzelius. — Berzelius was the first (1811) to attempt to prove that organic substances were nothing more than ordinary chemical compounds, obeying the laws of constant and multiple proportions, and offering a fair field for the application of the atomic and other theories. With improved appliances and analytical methods he succeeded in showing the correctness of his views, but only after years of labor.

The Theory of Compound Radicals. — In the third decade, Berzelius looked upon these substances as composed in the same way as the inorganic compounds, only having compound radicals in the place of elements. To the compound radicals he attempted to apply his dualistic theory. To his ideas as to these radicals he was especially led by the research of Gay Lussac upon cyanogen, in which he showed that this radical played the *rôle* of an element. Attempts were multiplied to discover the various organic substances having complex groupings of atoms which functioned as elements. Thus, Gay Lussac looked upon alcohol as ethylen and water. Döbereiner regarded oxalic acid as carbonic acid and carbon monoxide. As Berzelius pointed out, this was opposed to the electro-chemical theory, and there was danger of confusion and error.

Isomerism. — The search for the proximate constituents in organic substances brought about a rapid development of the science, leading especially to many efforts at settling the chemical constitution of these bodies. One of the most important of the discoveries in the third decade was that of isomerism. This was looked upon as an error by chemists at first, so little prepared were they to believe that bodies similarly composed could be chemically and physically different. It was in the year 1823 that Liebig announced that his analysis of silver fulminate yielded the same results as Wöhler had found in the preceding year for his silver cyanate. He was confident that his figures were correct, and believed that Wöhler must have made a mistake. A careful repetition of the analyses showed him that both were correct; and so it was proved that two bodies, totally unlike, could and did have the same composition. Gay Lussac saw that the only explanation of this lay in the different mode in which the elements were united with one another. Berzelius hesitated to accept the facts or any generalization from them. Then followed in 1825 Faraday's discovery of an isomer of ethylen chloride, and in 1827 Wöhler's transformation of ammonium cyanate into urea. Berzelius himself showed the isomerism existing between tartaric and racemic acids; and the chemical world became accustomed to the new fact of isomerism, for the explanation of which the atomic theory is so necessary. Berzelius suggested the name *isomerism.* He also adopted, as the most plausible explanation of isomerism, the different arrangement of the atoms; and he seems to have thought it a possibility to determine the mutual relations of the atoms in their compounds, or the manner in which the atoms were united to the compound radicals or proximate constituents.

The Synthesis of Urea. — One obstacle to the rapid growth of organic chemistry lay in the belief that while mineral substances could be artificially produced, or synthesized, the imitation of organic bodies was beyond the reach of experimental methods, as they were the products of life itself, and could be formed only in the plant or animal cell. It is true that new organic preparations had been made by distilling and otherwise treating various products of plant life, but the original source or starting-point remained the same life products. Chevreul had shown that the natural fats were compounds of certain acids and the glycerine discovered by Scheele. Still, all of this did not do away with the belief in the necessity for the action of the mysterious life force.

It was Wöhler's brilliant synthesis of urea which finally broke down this barrier, proving the forerunner of many syntheses, and inciting numbers of workers to labor in this lucrative field. It is true that the synthesis had not been made directly out of the elements; but still it was out of substances then regarded as inorganic that he had prepared one of the most interesting and best known of animal products. Of course the dying away of the old belief was slow, but Wöhler's discovery is commonly pointed to as marking the beginning of organic chemistry as a science.

Organic Analysis. — Another obstacle to the rapid development of this branch of chemistry lay in the imperfection of the analytical methods. Lavoisier had laid the foundations for the correct analysis of organic bodies, and Gay Lussac, Berzelius, and Döbereiner had successively improved upon them; but the operations were still slow, difficult, and not very accurate. In 1830 Liebig greatly perfected the methods of analysis, and his processes have not needed very many nor great modifications to fit them to the needs of the present times. Liebig's charcoal combustion furnace, his bulbs, and tubes are still sometimes used.

Classification of Organic Substances. — A true and helpful classification of these bodies, now multiplying so rapidly, was lacking. In 1811 Gay Lussac and Thénard, interpreting the results of their analyses, had divided these bodies into three classes: —

1. Those which contain just so much oxygen as is necessary to form water with the hydrogen present. These are carbo-hydrates.
2. Those containing less than that proportion of oxygen. These are resins and oils.
3. Those containing more oxygen. These are the acids.

Of course so primitive and faulty a classification as this was of little service. It merely serves to show that in the unsettled state of the ideas concerning these bodies no proper classification was possible.

Extension of the Electro-chemical Theory. — In 1819 Berzelius declared that his electro-chemical theory could not be extended into organic chemistry, as here the elements were under the influence of life force. In decay, fermentation, etc., he saw evidences of a striving on the part of these elements to return to their normal condition. Later he extended both this theory and that of dualism into this branch of chemistry, seeing in the compound radicals the same dualistic condition which he thought existed in the compound atoms of the inorganic bodies.

Further Extension of the Radical Theory. — There was continued effort at extending the radical theory to organic chemistry. Thus, in 1828, Dumas announced that ethylen was such a radical, and gave a table of its compounds, endeavoring to show their analogy to ammonia and its compounds: —

Olefiant gas or Ethylen, $2\,C_2H_2$.	NH_3, Ammonia.
Hydrochloric acid ether, $2\,C_2H_2 + H\,Cl$.	$NH_3 + H\,Cl$, Sal Ammoniac.
Ether, $4\,C_2H_2 + H_2O$.	$2\,NH_3 + 2\,H_2O$, Ammonium oxide.
Alcohol, $4\,C_2H_2$, $2\,H_2O$.	
Acetic Ether, $4\,C_2H_2$, $C_8H_6O_3$, H_2O.	$2\,NH_3$, $C_8H_6O_3$, H_2O, Ammonium Acetate.
Oxalic Ether, $4\,C_2H_2$, C_4O_3, H_2O.	$2\,NH_3$, C_4O_3, H_2O, Ammonium Oxalate.

This was the so-called Aetherin theory, and was largely based on the ease with which alcohol could be converted into ether and ethylen. Thus the supposed Aetherin (C_4H_4) was a base, forming hydrates with water, and salt-like ethers with acids. This must serve as an illustration of the imperfect attempts at discovering these radicals, and the great difficulties attending such researches.

The Radical of Benzoic Acid. — The radical theory received its greatest support from the classical research of Liebig and Wöhler (in 1832), "*On the Radical of Benzoic Acid.*" This was hailed by Berzelius as heralding the dawn of a new day. It was certainly an epoch-making research, standing out as a masterpiece amid a mass of erroneous and imperfect researches.

These two great chemists, then young men, showed that in the oil of bitter almonds (benzaldehyde) and its many derivatives one group of atoms remained unchanged, and characterized the whole. This they called benzoyl. This brilliant work contributed much to the advancement of organic chemistry by the valuable new methods of research which it introduced into the practice of the chemist.

Changes in the Radical Theory. — Furthermore, a new principle was recognized. Hitherto it had been thought necessary to isolate the radical, and it was upon this rock that many of the efforts at finding these radicals had suffered shipwreck. Now, although benzoyl had not been isolated, one could as little afford to doubt its existence as that of magnesium or titanium (these being metals whose compounds were known a long time before the metals themselves were isolated); and thus chemists were aroused to a search for the common radicals in bodies which showed by their chemical behavior or modes of preparation that they belonged together.

Berzelius and Liebig joined in this work with great success. The difficulty in recognizing benzoyl as a radical because of its containing oxygen was done away with by regarding it as the oxide of the radical proper. For the earliest idea of a radical was that it was a compound of carbon and hydrogen only, and contained no oxygen. Thus, ether was the oxide of the radical ethyl; but Berzelius entirely missed the connection with alcohol by regarding that as the oxide of the radical C_2H_6. This was corrected by Liebig, who, however, doubled the formula of the radical ethyl, C_2H_5. Thus for him alcohol was the hydrate of ethyl, $C_4H_{10}O, H_2O$. Chemists agreed as to the existence of compound radicals in these various compounds. It is not surprising that they should differ as to the nature of the radicals themselves, when we consider that this was really only the beginning of organic chemistry, and the knowledge of these substances was very imperfect. Berzelius was inclined to the belief that these radicals were unchangeable. Liebig took a wider view of them, looking upon his grouping of the elements merely as a means to a better understanding of the transformations these bodies undergo.

Chemistry of the Compound Radicals. — About 1837 this theory of the compound radicals reached its highest point of credit and influence. Liebig and Dumas united in valuable investigations, and this branch of chemistry was named after the dominating theory.

How far this comparison went may be gathered from a quotation from a joint work of Liebig and Dumas: —

"Organic chemistry possesses its own elements, playing at one time the *rôle* of chlorine or oxygen, at another that of a metal. Cyan, benzol, amide, the radicals of ammonia, of the fats, of alcohol, form the true elements of the organic nature; whilst the simplest constituents, as carbon, hydrogen, oxygen, and nitrogen, become recognizable only when the organic material is destroyed."

Liebig, in 1838, clearly defined a compound radical, giving three essential characteristics, and using cyanogen as a type.

1. We call cyan a radical because it is an unchanging constituent in a series of bodies or compounds.
2. Because it can be substituted in these by other simple bodies.
3. Because, in its compounds with a simple body, this last can be separated and substituted by another simple body.

At least two of these conditions must be fulfilled for a group of atoms to be regarded as a radical.

This radical theory unquestionably aroused great interest, and stimulated chemists to much fruitful and even brilliant work. Thus, one may mention the research of Bunsen upon the kakodyl compounds, which formed, indeed, one of the strongest supports of the theory.

The Atomic Theory Confirmed. — The dualistic theory and the theory of compound radicals were, of course, founded upon the atomic theory of Dalton; and as they were discussed and struggled over, and became more and more firmly intrenched in the science, they rendered the atomic theory an indispensable assumption. Even when dualism became discredited, and organic chemistry took on a different significance from that of the chemistry of the compound radicals, atoms were still necessary, and the only changes were in the ideas as to the nature of the ultimate particles.

The Substitution Theory and the Overthrow of Dualism. — Doubts began to arise as to the theory of dualism. Dumas and other chemists felt that Berzelius had pressed his theory too far. It was, however, the discovery of the principle of substitution which really dealt this theory its death-blow, and paved the way for the so-called unitary theory. Substitution might have been deduced from the old idea of equivalence. It was also really touched upon in the researches of Mitscherlich upon isomorphism. Other facts led up very nearly to it; but, as so often happens, the thought itself was brought out by an accident.

Substitution of Chlorine for Hydrogen. — In 1834 Dumas was called upon to examine into the cause of certain irritating vapors coming from wax candles used to illuminate the Tuileries. He found that, in bleaching the wax, chlorine had been used; and some of the chlorine remaining in the candles had caused the disagreeable fumes, which consisted of hydrochloric acid, the hydrogen coming from the wax. Dumas felt that this could not be explained on the ground of a mechanical retention of the chlorine as an impurity. He therefore fully investigated the action of chlorine upon wax and kindred organic substances. He announced, as a result of his investigations, that hydrogen in organic compounds can be exchanged for chlorine, volume for volume. Wöhler and Liebig had, in 1832, shown that, in preparing benzoyl-chloride out of bitter almond oil by the action of chlorine, two atoms of chlorine took the place of two atoms of hydrogen. This was contrary to the central idea of dualism; for chlorine was electro-negative, and ought never to substitute electro-positive hydrogen.

Facts accumulated, however. Liebig had further shown that, by the action of bleaching powder and chlorine upon alcohol, chloroform and chloral could be produced. He misunderstood the constitution of these bodies, and no one dreamed then of the wonderful part they were to play in alleviating pain and suffering. It was Dumas who correctly determined their nature and their relation to alcohol, showing here the far-going substitution of chlorine for hydrogen. Liebig promptly acknowledged his error.

Trichloracetic Acid. — Dumas also, by his substitution of chlorine for hydrogen in acetic acid, forming trichloracetic acid, secured the most important support for his theory of substitution, which, as has been stated, he formulated one year later (1834). We can see from what Dumas says of trichloracetic acid what his ideas were as to substitution, and how the discovery of this acid supported them.

It is well known that this acid differs from acetic acid by three atoms of chlorine substituted for three atoms of hydrogen. "It is a chlorinated vinegar," says Dumas; "but it is remarkable, and the more so for those who dislike to find in chlorine a body capable of substituting hydrogen in the exact and full sense of the word, that this chlorinated vinegar is still an acid like ordinary vinegar. Its acid power has not been changed. It neutralizes the same amount of base as before. It possesses the same avidity; and its salts, compared with the acetates, show an agreement full of interest."

Conflict with the Dualistic Theory. — Thus it was shown that the views of dualistic structure were too rigid, and were a hindrance to the development of organic chemistry. A negative atom could be substituted for a positive, and the compound radical began to be recognized as an atomic structure in which one atom could be substituted for another without regard to its electrical relation.

Laurent had convinced himself, by a great number of experiments, that Dumas' statement of the law of substitution did not hold good for all cases. Very often more chlorine was taken up, and sometimes less, than corresponded to the volume of hydrogen lost. As the substituted body showed certain analogies to the original, he maintained that the chlorine took the place held by the hydrogen in the molecule, and to a certain extent played the same *rôle*.

Unitary Theory. — This view met with vigorous opposition, and had to be modified in some particulars; but soon the molecule came to be regarded as a unitary structure, and not a dualistic. Thus, there were two opposed theories in chemistry; the older, dualistic, looked upon the molecules as double-natured and composite, yet forming one unchangeable whole in which the members lost their individuality, and the nature of these molecules was determined by the quality of the atoms; the new, unitary, theory maintained that the number of the atoms and their arrangement determined, in the main, the nature of the compound, and that this molecule was not unchangeable, but that the atoms comprising it could be substituted by others without a total change of nature.

Nucleus Theory. — Laurent was led to propound, further, the nucleus theory, which was largely adopted, notably in Gmelin's handbook. This was in some respects an elaboration of the idea of compound radicals; indeed, Laurent calls his nuclei *radicaux fondamentaux.* Many of the ideas in this theory have been adopted and incorporated in the science, though the theory itself has been dropped. In this theory the nuclei were of different kinds. First there were combinations of carbon and hydrogen, in which the ratio of the elements was a simple one. For any one ratio there might be several of these radicals polymeric with one another. These were the *stem nuclei;* and out of them, by the substitution of some other atom or group for hydrogen, *secondary nuclei* were formed.

This theory manifestly sprang from the old radical theory, but with an important change; namely, the radical here is not an unchanging group of atoms, but it is a combination which can be changed through the substitution of equivalents. It is but a step in the evolution of the modern theory, as seen in the benzen nucleus. The unimportant and the false have been stripped off, and the true has been retained.

Type Theory. — Laurent and Gerhardt did much to upbuild the unitary theory, and to introduce the new idea of types. These two friends well supplemented one another, and the joint work did much for the advancement of chemistry. Laurent was speculative and full of theories, possessing the valuable quality known as scientific imagination. Gerhardt was painstaking and accurate in his experiments, and paying more attention to details, supporting and confirming by his work the brilliant hypotheses of Laurent. Both were masters of the science.

This new theory of theirs, that of the types, was, like the theory of radicals, quickly taken up, and soon became the central theory of the chemistry of the fifth decade. According to Laurent, caustic potash was not a compound of oxide of potassium and water, but was rather to be looked upon as a derivative of water, being derived by replacing one atom of hydrogen in the latter by an atom of potassium. This was what was called the water type. Gerhardt recognized three types, water, hydrochloric acid, and ammonia, and tried to classify all compounds under one or the other of these types. Gradually it was seen that new types were necessary for newly discovered compounds, and the derivation from the types became more and more complicated. Organic chemistry, where this type theory was especially applied, became a Chemistry of Types, and was no longer one of Compound Radicals.

Berzelius, now an old man, contended most strenuously for his dualistic theory, and could not be reconciled to the change to the types and to the unitary theory. But the great master was engaged in a vain struggle. Even his favorite pupils deserted his side, and the "voice that once led no longer found an echo in science."

Copulas and Conjugated Compounds. — In the course of this discussion, Berzelius formulated a new theory, as giving a better explanation of the substitution phenomena, and as being in better consonance with his theory of dualism. This was the theory of the conjugated compounds (*gepaarte Verbindungen*) a translation of the term *accouplement* introduced by Gerhardt in 1839, to designate a certain kind of union of organic with inorganic substances, in which both are united in an intimate combination, the characteristic properties of the components becoming no longer recognizable, the combining power of the one, as an organic acid, for instance, being retained. The other substance entering into the union was called by Gerhardt the *Copule*, and by Berzelius *Paarling*. The idea is not a very clear one. Berzelius endeavored to introduce it as best explaining many of the substitution processes. It gave him, often, very complicated formulas; but, as he observed, the simplest are not always the right.

To give an illustration, Berzelius thought, after Melsens had shown, in 1842, that the substitution derivative of acetic acid, chlor-acetic acid, could be changed back into the original acid, that acetic acid was a paired oxalic acid. Thus, its formula was written by him as $C_2H_3.C_2O_3$, and chlor-acetic acid was written $C_2Cl_3.C_2O_3$. This was practically giving up the fight, as by it he acknowledged that the *Paarling*, or copula, could undergo substitution, and that its exact nature did not have a predominating influence in determining the nature of the compound into which it entered. The idea was too complicated and difficult to carry out.

Kolbe's Remodelling of the Radical Theory. — In the fifth decade, Kolbe endeavored to revivify the radical theory of Berzelius. This had been somewhat modified by its author, but had fallen into disrepute. Kolbe's modifications, as, for instance, in the unchanging nature of the radical and the idea of copulas, introduced by Berzelius, restored it somewhat to favor. He strove to make this theory have a deeper bearing upon the constitution of organic compounds. His ideas as to copulas and conjugated compounds were changed several times, and were not very clear. Kolbe opposed strongly the theory of types.

THE SATURATION CAPACITY, OR VALENCE.

The substitution theory of Dumas, as developed by Laurent, led up naturally to the idea of the relative value of the atoms of the different elements. A comparison between these atoms was inevitable, as they were generally substituted for the same element, either hydrogen or oxygen. The quantities of the various elements thus substituting hydrogen were regarded as the equivalents, and up to the second half of the century there was much confusion between atoms and equivalents. A clearing up of this confusion was brought about by the important work of Frankland upon the saturation capacities of the atoms.

Frankland's Work upon the Organo-metallic Bodies. — The useless part of the radical theory was swept away by the work of Frankland upon the series of organic substances containing metals, known as the organo-metallic bodies. This work showed that the pairing of the radicals with the elements was to be explained on the ground of some characteristic property of the atoms. Upon these experiments Frankland founded the valence theory, the germ of which one can detect in much that has gone before, especially in the law of multiple proportions; but the idea had not been clear, nor even expressed in a name, except by the vague term of "replacement-value" introduced by Liebig.

Polybasic Acids. — What is known as the doctrine of the polybasic acids contributed to the growth of ideas upon the subject of the saturation capacity. Gay Lussac, Gmelin, and many others had held the idea that in the metallic oxides one atom of metal was united with one atom of oxygen, and these oxides united with one atom of acid to form neutral salts. By Graham's researches upon the acids of phosphorus, it was shown that this view could be held no longer. He proved that in the ortho, pyro, and meta acids, for each "atom" of P_2O_5, there were three, two, and one "atoms" of "basic water" which could be substituted by equivalent amounts of metallic oxides. The saturation capacity of these acids was then dependent upon the "basic water" belonging to their constitutions. Liebig extended this to many other acids, and distinguished between mono-, di-, and tri-basic acids. This term *basicity*, along with the ideas inherent in it, clung for some time to the theory of the valence, or saturation capacity, of the atoms. One sees in the above quotations from the work of Graham the confused use of the term atom.

Atomicity of the Complex Radicals. — The idea of basicity was extended farther to the compound organic radicals. Thus Wurtz, in his paper upon the glycerine compounds, spoke of glycerine as a tribasic alcohol. Williamson noticed that the propyl radical differed from that of glycerine by having two more atoms of hydrogen, and thus, he reasoned, by the loss of two atoms of hydrogen a monobasic radical became a tribasic. He attached the idea of capacity for saturation or atomicity of the radical to the number of hydrogen atoms capable of substitution. He called these radicals then monatomic, diatomic, etc. Wurtz' study of the amines also bore upon this point, and it is easy to see how the notion of atomicity was soon extended to the various compound radicals known.

Introduction of the Idea of Valence. — According to Wurtz, the idea of valence was introduced into the science in three steps, as it were: —

First, there was the discovery of the polyatomic combinations.

Secondly, the polyatomicity was referred to the state of saturation of the radicals.

Thirdly, this notion of saturation was extended to the elements themselves, which had first been applied to the radicals, and from this their atomicity was deduced.

Deduction of Valence from Inorganic Compounds. — When one considers the formulas of the inorganic chemical compounds, even a superficial observer is attracted by the general symmetry to be observed in them. Especially do the compounds of nitrogen, phosphorus, antimony, and arsenic show the tendency on the part of these elements to form compounds in which three or five equivalents of other elements are contained. Without formulating a hypothesis to account for this agreement in the grouping of the atoms, it is sufficiently clear that a tendency to such regularity exists, and the affinity of the atoms of the above mentioned elements entering into combination is always satisfied by the same number of atoms, without regard to their chemical character.

Frankland did not consider a higher atomicity than five. Though he speaks of the simple inorganic compounds, and uses them in illustration, he deduced the valence doctrine from his studies of complex organic bodies.

Progress made by the Valence Theory. — These ideas did not meet with immediate acceptance. The type theory was still dominant, in spite of Kolbe's attacks upon it as something altogether unscientific. The discussion over the constitution of the polybasic acids and other atomic groups, joined in by Odling, Williamson, Gerhardt, Wurtz, and others, showed the neccessity for this theory, and did much to introduce it into the science. In a memoir published in 1855, Wurtz spoke of nitrogen and phosphorus as tribasic. By 1858 the theory had made rapid progress. In this year Kekulé first deduced the valence of carbon from its simplest compounds, declaring it to be tetravalent. This had already been recognized by Kolbe and Frankland, if not expressly stated by them. But Kekulé rendered further and much greater service by examining into the manner in which two or more of these tetravalent carbons were united with one another. The doctrine of atomic chains, open and closed, sprang from this, and the domination of the structural idea in chemistry became complete.

PROGRESS IN INORGANIC CHEMISTRY.

The history of chemistry as a science for the thirty years just considered, that is approximately from 1830 to 1860, has consisted largely in an account of the rise and progress of one branch of it, namely, organic chemistry. The science was dominated by the theories deduced from the study of organic compounds, and we have seen how their number was multiplied and the knowledge of them increased.

Still, there was great and rapid growth along other lines. Great numbers of facts were accumulated and new bodies discovered. It becomes necessary to note briefly some of the advances made since the wonderful work of Davy and Gay Lussac.

Discovery of New Elements. — Several new elements were added to the list, but it was not until the introduction of a new instrument of research in the spectroscope that many new ones were discovered. In 1817 Stromeyer discovered cadmium, and in the same year Arfvedson added lithium to the list. Berzelius first prepared silicon in 1822, and in 1827 and 1828 his pupil Wöhler succeeded in preparing aluminium and glucinum or beryllium. Balard added bromine in 1826, and then for thirty years we have no notable additions, with the exception of those gotten from the rare earths as yttrium, by Wöhler, and several by Mosander.

The Halogen Acids. — The list of halogen acids was completed, Gay Lussac and Balard studying hydrogen bromide and hydrogen iodide, while Gay Lussac, Thénard, and Berzelius made many experiments upon hydrogen fluoride, learning much about its reactions. All attempts at separating fluorine from it were vain, but the energetic and dangerous nature of the acid was recognized. Later on, experiments upon this body cost Nicklés, a distinguished Swiss chemist, his life. Half a century later the element itself, fluorine, was isolated and studied by the French chemist Moissan.

Allotropism. — The fact that an element could exist in several different forms has been partially recognized in the case of the different forms of carbon. It was now fully recognized in several other cases, as sulphur, phosphorus, arsenic, and oxygen. Berzelius gave to this phenomenon the name of *allotropism.*

New Acids and Salts. — Of course the list of salts was greatly extended, especially with the discovery of new acids, and the recognition of differences in the capacities for saturation shown by these acids, or, as it is now styled, the different basicity of the acids. The discovery and study of the polybasicity of acids marked an important step forwards. The excellent work of Graham and Liebig did much to clear up this matter.

Permanent Gases. — Many important facts, physical and chemical, were learned about the gases. Most of them were condensed, especially by the experiments of Faraday, into liquids, or frozen into solids. Pressure was relied upon for this condensation, and little attention paid to the temperature. This ignorance of the important part played by the temperature led to the belief that certain of them, as hydrogen, oxygen, nitrogen, methan, carbon monoxide, and nitric oxide, were uncondensable, and for these the term permanent gases was retained.

Much later it was recognized that reduction of temperature was necessary as well as pressure; the critical temperature was studied by Andrews, and by the ingenious experiments of Pictet, and independently Cailletet (1877), all of the so-called permanent gases were condensed.

BLENDING OF PHYSICS AND CHEMISTRY.

The beginning of the century saw a blending of the two sciences of chemistry and physics along certain lines, a union of interests which promised and accomplished much for both.

Thus, we have the application of electricity to chemistry, and the work of Ampère and Avogadro. This was followed by the work of Dulong and Petit. But the cultivation of this border land between the two was first systematically pursued by Kopp and Graham. The former devoted himself, after 1840, to the study of relations existing between atomic weights and specific gravities, regularities in boiling-points, etc.

Graham's Work. — The work of Graham deserves more extended mention. In the first place, as has been stated, it is to him that we owe the conception of acids of different basicity, and a confirmation of Davy's view that acids were compounds of negative oxides and water. He laid especial stress upon the necessity for the presence of hydrogen in all acids. This hydrogen was replaceable by metals, and was analogous to them; and the molecule of the salt had the same general structure as the acid from which it was formed. Thus Graham classed hydrogen for the first time with the metals, a bold step at the time, but one fully justified by the increased knowledge of later years. Graham also did some interesting work upon the subject of water of crystallization; but his most important work was that bearing upon the physical side of chemistry, especially as to the motion of the ultimate particles of matter. These ultimate particles he called atoms, using this in pretty much the same way as Dalton did, not troubling himself to distinguish between atoms and molecules, as Avogadro had done, the distinction not being essential for his physical investigations.

Diffusion Experiments. — Graham's chief work in this line was upon the diffusion of gases. He seems to have been led first to the investigation of the phenomenon, reported by Döbereiner, that jars having light cracks in them, when filled with hydrogen over water, showed a rise of the water in the jar, whereas, if filled with nitrogen, or oxygen, or air, there was no rise noted. Graham proved that some of the hydrogen in the jar pressed outwards through the fissures, and but little air returned, therefore the pressure on the surface of the water outside was greater than inside, and the level rose inside. Any gas lighter than air behaved like hydrogen. If heavier gases were used, the level inside was somewhat lowered.

So Graham devised his diffusion tubes; and, experimenting upon many gases, he announced the law of diffusion. From this he was led to examine the transpiration of gases, or their passage through capillary tubes, and in 1863 to his researches upon the molecular mobility of gases.

Colloids and Crystalloids. — Graham also investigated the diffusion of liquids, and made application of this principle in analysis, particularly in regard to the dissolved solids in the liquids. Those diffusing readily he called crystalloids; the non-crystallizable, jelly-like, slowly diffusing bodies were called colloids. On the basis of this classification, and the difference between these classes, is founded the principle of dialysis.

But Graham saw deeper into the nature of these bodies. He recognized the colloids as eminently unstable bodies, ever on the verge of change, and readily affected by changes of external conditions; in the crystalloids he saw more definite properties and a greater stability.

Graham's life was largely spent in studying the movements of the particles of matter. As has been said of him: "A piece of lime or a drop of water was to the mind of Graham the scene of a continual strife; for that minute portion of matter appeared to him to be constructed of almost innumerable myriads of little parts, each in more or less rapid motion, one now striking against another, and now moving free for a little space."

The Spectroscope. — Physics again lent most efficient aid to chemistry by the introduction of the spectroscope as an instrument for research. The introduction of this instrument created a sensation almost on a par with the first applications of the electric current by Davy and others to the same end. By it an examination of certain optical properties of highly heated bodies became possible. The extreme delicacy of the instrument permitted a deeper insight to be taken into the nature of the atoms, and has opened up an entirely new branch of stellar or extra-terrestrial chemistry. Thus it has become possible to learn something of the chemical constituents of bodies outside of this earth.

Spectrum Analysis. — The introduction of spectrum analysis is especially due to the labors of Kirchhoff and Bunsen, and the first discoveries date from the year 1860. It became especially useful in their hands for the discovery of new elements, and for revealing the presence of traces of elements in various compounds, minerals, soils, etc., giving a truer idea of the natural occurrence of such, and an invaluable test for the purity of preparations. It opened up a new era of discovery of elements. Thus, we have rubidium and caesium discovered by Kirchhoff and Bunsen; indium by Richter; gallium by Lecoq de Boisbaudran; thallium by Crookes; and many rarer ones whose existence and properties have not yet been satisfactorily settled. Like other great discoveries, spectrum analysis was at first, perhaps, overestimated as to the part it would play in chemistry, but still it has been and is yet of very great service.

Polariscope and Microscope. — The polariscope and microscope have also proved most valuable aids to chemical research, and it seems likely that these three instruments will prove of still greater value in aiding in the solution of the many unsolved questions connected with the nature and relations of the atoms.

STRUCTURAL CHEMISTRY.

We will now take up again the development of the ideas as to the structure or constitution of chemical compounds, in particular those of organic chemistry. The valence theory, combined with the theories of radicals and types, led directly up to the structural chemistry of the last thirty years.

The radical and the type theories were attempts at gaining an idea of the structure of chemical compounds; but it was the valence theory which made it possible to give a clear answer to the question as to the constitution of such bodies. The determination of the structure or constitution of complex molecules became, with the beginning of the seventh decade, the higher aim of chemistry.

New Systems of Classification. — Some beginnings of systematic classification had already been introduced into organic chemistry, which greatly aided in the upbuilding of structural chemistry. Thus, the idea of homologous series, suggested by Schiel, was adopted by Dumas with regard to the fatty acids, and extended by Gerhardt. In 1849 there was the discovery of compound ammonias or amines, by Wurtz, and of mixed ethers by Williamson. Many systems of classification were suggested during the sixth decade, the classification by series as that of Schiel and Dumas, that of series depending upon formulas, series depending upon chemical behavior, and many other systems. The lack of agreement among chemists, however, as to the formulas belonging to the different compounds, as to the relative weights of the molecules, the atomic weights, and even the number of atoms, prevented a general acceptance of any of the classifications proposed until Kekulé established the fact of the tetravalence of the carbon atom, showed the difference between saturated and unsaturated compounds, and deduced his chain formulas.

Atomic Chains. — Kekulé's doctrine of the atomic chains was a necessary sequence of the valence theory. It was not necessary for this that the nature of valence or the cause of it should be known, and even yet no satisfactory solution of these questions has been offered.

In 1866 Kekulé offered his famous ring formula as an explanation of the nature of benzen, and the differences observed between its derivatives and those of the methan series. So great has been the influence exerted by this idea of a closed chain formula upon the development of organic chemistry and the great industries dependent on it, that twenty-five years later chemists from all parts of the world met in Berlin to do honor to the discoverer. And yet the details of structure and of linkage in this closed chain of the benzen nucleus are still the subject of much discussion and multiplied experiments.

While it is unquestionably true that the work done in examining into and determining the structure of organic bodies during the past quarter of a century has been so fruitful of results in the discovery of new substances and the synthesizing of natural products, that this younger branch of chemistry has far outstripped the older sister, and the shelves of libraries groan under the yearly added volumes, it must be constantly borne in mind that many of these structural formulas are dependent upon very slender lines of reasoning, and doubt can be thrown upon some of them which seem to be most accurately determined.

Physical Isomerism and Stereo-chemistry. — One of the difficulties met with in the assignment of structural formulas lay in certain cases of isomerism. In some cases a greater number of isomeric bodies were known than could possibly be accounted for by any arrangement of the atoms in formulas upon a plane surface, retaining the accepted views as to valence, etc. Instances of these are the four isometric lactic acids, with only two arrangements of the formula possible, and the four tartaric acids with only two arrangements, and many other cases. As these bodies differed mainly in certain physical properties, they were at first somewhat vaguely styled physical isomers.

The study of these led to what has been called the chemistry of Space, or Stereo-chemistry, in which a wider view of atomic grouping was attempted. The foundations of the theories as to the space relations of the atoms were laid by Van't Hoff and Le Bel, and much progress has been made in the last twenty years in filling out the outlines of this study. Among the most noted workers in this field have been Meyer, Bischof, Auwers, and others.

Atomic Linkage. — It is manifest that the manner of union of atom with atom, or atomic linkage, is one of the most important raised by the study of structural chemistry, and is most necessary to the proper understanding of it. There has been much written on this subject in the latter part of this century, and some preliminary work done; but the whole question of linkage, as that of valence, is still a most puzzling one to chemists. The views as to the structure of double salts, of salts containing water of crystallization, and as to the character of the union in solutions and in alloys, are still very unsettled.

THE ATOMIC WEIGHTS.

It has been seen how the atomic hypothesis became a necessity for the elucidation and development of organic chemistry. It had fallen into disfavor because of the difficulties met with by Berzelius and others in distinguishing between atoms and molecules; but much light was thrown upon this and other matters as the chemistry of the compounds of carbon was better understood; and the fact that the dominant doctrine of the new chemistry quietly assumed the truth of Dalton's theory in all its important particulars was reflected upon the older chemistry, so that this great theory became the basis for it all.

Confusion in the Sixth Decade. — After Frankland's researches on the organo-metallic bodies, the old confusion between atoms and equivalents was done away with. Then, too, the value of Avogadro's law as an aid to the correct determination of atomic weights became more fully recognized, and analytical methods were much more accurate. The middle of the century saw the condition of affairs concerning these physical constants a badly mixed one. Two units or standards were in use. Dalton had suggested hydrogen as unity, and this standard was adopted by Gmelin and many others. Wollaston and Berzelius took oxygen as the standard, Wollaston giving it the value 10, and Berzelius using it as 100; Thomson had given it the value 1. But far worse than having two standards, widely differing values were assigned for the atomic weights, and all needed revision. In Germany, following Gmelin, many used the numbers $H = 1$; $N = 14$; $Cl = 35.5$; $C = 6$; $O = 8$. Others used the Berzelian numbers, reduced for comparison to the same standard, $H = 0.5$; $Cl = 17.75$; $C = 6$; $O = 8$. Dumas, Laurent, and the French chemists used $C = 3$; $O = 8$.

Dumas' Revision of the Atomic Weights. — Dumas was especially active in the revision of these numbers. His determination of the atomic weight of carbon, and his work, in conjunction with Boussingault, to determine the ratio of hydrogen to oxygen in water, are classical. Dumas fixed the number sixteen for oxygen. This was afterwards determined as 15.96 by Stas; and this ratio has been the subject of more painstaking and careful determinations than any other in chemistry, yet without complete accord. Dumas also determined many other weights.

The Work of Stas. — Others taking part in this work were Marchand, Marignac, De Ville, Scheerer, and Erdmann; but easily the greatest of them all in care and accuracy was Jean Servais Stas. His work was monumental in the pains taken to secure absolute accuracy; and yet in a few years errors were found in it, and the so-called Dumas' correction, as well as others, had to be applied to the numbers found by him. The atomic weights determined by him with the greatest care were those of silver, potassium, sodium, lithium, lead, chlorine, bromine, iodine, sulphur, nitrogen, and oxygen.

Much of this work was undertaken to prove or disprove the correctness of Prout's hypothesis, based upon the elements having whole numbers for their atomic weights when hydrogen was taken as unity. As the result of his work, Stas stated that he had found no confirmation for it.

Continued Confusion of Standards. — Increased accuracy in the atomic weights has gradually led to the adoption of the fractional numbers found instead of the rounded-off integers. Lothar Meyer, in his "*Modern Theories of Chemistry*," took oxygen as 15.96, the number found by Dumas, instead of 16, previously accepted. This had been followed by Meyer and Seubert, in their table of the atomic weights as re-calculated by them, a book of wide authority. This move on the part of

Meyer has had the unfortunate result of starting up once more the old contest between hydrogen and oxygen as the standard for the atomic weights; and the chemistry of to-day finds two tables in use, one based on O = 16, and the other on O = 15.96. These are more dangerous and troublesome because of the close approximation of the standards than if they were widely different. The general tendency has been toward the adoption of the former standard, O = 16, and the abandonment of an attempt at unattainable accuracy in the matter of the oxygen-hydrogen ratio. This latter number must change with each new and improved determination of the ratio. Since most of the numbers for the other elements are determined by comparison with oxygen, and so are dependent upon its atomic weight, it seems best to let that number be fixed, even though its choice be somewhat arbitrary.

Cannizzaro's Revision. — Taking a step backward now to the middle of this century, we find that much of the credit of clearing away the difficulties attending the atomic weights, and placing them upon a more satisfactory footing, is due to Cannizzaro. He took a determined stand upon the necessity for the use of the law of Dulong and Petit, and Avogadro's statement of the law of volumes, in these determinations. He taught chemists to place reliance upon these methods, and so to correct many of the false atomic weights then in use. Thus an approximation to a correct table of atomic weights was secured, and the road opened up for the discovery of the great natural law underlying them. Cannizzaro's chief writings on the subject appeared in 1858.

Numerical Relations Between the Atomic Weights. — For some time strange numerical relations between the atomic weights of various elements, even in their then imperfectly known condition, had been observed by many chemists. Especially worthy of note are the work of Gmelin, the triads of Döbereiner (1829), and the more extended work of Pettenkofer, Dumas, and Cooke. But little attention was paid to these numerical curiosities. They seem to have been looked upon as mere jugglings with figures, or as having some hidden connection with Prout's hypothesis.

Newlands' Law of Octaves. — But more important numerical regularities very soon became apparent, after a trustworthy table of atomic weights was provided by Cannizzaro. The first to give up the old alphabetical arrangement of the elements, and suggest a table drawn up in the order of the atomic weights, was Newlands (1864). He deduced from this arrangement what he called the law of octaves, claiming that the elements when thus arranged fell into periods of seven, every eighth element showing analogous properties. However faulty the periods as arranged by Newlands, it is clear that he recognized the two principles of the natural arrangement of the elements.

Mendeléeff's Periodic Law. — Independently of Newlands, the same problem was worked out by the great Russian chemist, Mendeléeff; and it was worked out far more systematically and thoroughly by him, so that he is justly to be regarded as the originator and author of the periodic law. His papers appeared in 1868, and in 1869, and later.

The first announcements, as made by Newlands, were received with ridicule and soon forgotten; but the chemical world was forced to take note of this great discovery by the genius of Mendeléeff, and of Lothar Meyer, who also worked out this law independently.

Importance of this Law. — Soon it was known that, by means of Mendeléeff's table, atomic weights could be corrected, physical and chemical properties calculated, and, as a crowning achievement and confirmation, new elements together with their properties predicted. Thus, scandium, gallium, and germanium were predicted by Mendeléeff, and other elements not yet discovered.

Now all chemists recognize the dependence of the properties of the elements upon the atomic weights, and the periodic law has become the central idea in the classification and study of the elements and their compounds. This law is the greatest discovery in chemistry since the announcement of Dalton's atomic theory, and has been much more rapidly accepted. It promises to lead up to results of the utmost importance.

Primal Elements. — Although the author of the periodic law would warn off investigators from any speculations as to the origin of the elements, the mysterious relationship revealed between them by the periodic law has naturally drawn the minds of men to thoughts not unlike those of the early philosophers who dreamed of the primal elements. For these can be only dreams so long as the facts to form a basis for their confirmation are lacking. Thus, we have the speculations of Crookes, and the spectroscopic work of Grünwald and Lockyer; but such cannot be factors in the science of to-day.

THE CHEMISTRY OF THE FUTURE.

The chemistry of to-day is no longer analytical. That predominated during the first half of the century. Nor is it synthetical; the third quarter saw this rise to its highest point. Even the structural chemistry seems to have had its day, although these problems of structure are occupying more chemists to-day than any others. The great aim of chemistry is becoming, not the methods of tearing apart atoms, nor of building them up together, nor of settling their exact location in the molecule, nor their position in space, but far deeper than all of this, and carrying with it the explanation of it all, the nature of the atom itself. The molecule and its changes must be studied, for there is much to learn; but with the sharper vision and the clearer knowledge gained through the toil of this nineteenth century the atom is becoming the point of attack.

It can scarcely be hoped that the chemistry of the future will progress with the rapid leaps which the passing century has witnessed. Great generalizations will be worked out more slowly and painfully, because it has become almost impossible for one mind to grasp and master all of the broadened science. One man can hardly hope to be more than an analytical chemist, or an organic, or inorganic, or physical, or physiological, or agricultural, or technical chemist. The specialization of these different branches has gone on until they have become sciences in themselves. The periodicals publish vast and undigested masses of new facts. As one has said, the "chemistry of to-day is overburdened with its facts." This intense specialization may lead to the increased multiplication of facts and to minor discoveries, but it renders it more difficult to grasp the underlying laws. Such works as Meyer's "Modern Theories of Chemistry" show the great difficulties that lie in the path of the future discoverer.

PART SIXTH.

SPECIAL BRANCHES OF CHEMISTRY.

ANALYTICAL CHEMISTRY.

The services of Boyle, Hoffmann, and Bergman, and later of Klaproth, Vauquelin, and Berzelius, in this field of analytical chemistry, have already been briefly mentioned. Lampadius published his "*Handbook of Chemical Analysis of Minerals*" in 1801; and other books followed this, showing a systematic arrangement of the methods then in use. The use of the blow-pipe was systematized and improved by Bergman, de Saussure, and notably Berzelius; and in later times this art of dry assay was greatly advanced by the well-known flame reactions of Bunsen.

Followers of Berzelius. — Heinrich Rose and Wöhler were especially active in working out the methods suggested by their great teacher, Berzelius, and in adding to and perfecting them. Berzelius had shown great ingenuity in the discovery of new methods, and he seemed to inspire his pupils with like powers. Stromeyer, Will, Liebig, Dumas, Thénard, Marignac, and many others have aided in the discovery of improved tests and better modes of separation and determination, and in the invention of suitable apparatus for the many delicate operations.

The Work of Fresenius. — The great master of chemical analysis, however, has been Remigius Fresenius, and for fifty years his life and labors have been devoted to this side of chemistry. In 1841, at the age of twenty-three, he was Liebig's assistant in Giessen. In 1848 he founded his laboratory at Wiesbaden, devoted to analytical chemistry; and this has been the training-school of many analysts from all parts of the world, and now employs a large force of teachers, and is visited by many students, while Fresenius still presides over it.

His "*Handbook of Qualitative Analysis*" appeared first in 1841, and that of "*Quantitative Analysis*" in 1846. There have been published scores of editions and translations since, and these works have formed the basis for all modern literature of the kind. Besides, Fresenius has given to the science great numbers of analyses of minerals, waters, and commercial products. Perhaps his greatest service has been the establishment of the "*Zeitschrift für Analytische Chemie*," which has had a widespread circulation and influence since its first appearance in 1862. This has afforded a centre, a crystallizing point, for all work pertaining to analysis. This first periodical has been followed by many similar publications in various countries and languages, but it still retains the first place.

Associated Methods. — A glance at the recorded analyses of the past century will show great improvement in accuracy, rapidity, neatness, and ease as the decades have passed. The clumsy work of Dalton was greatly improved upon by Berzelius; yet his analyses not infrequently failed of the correct result by several integers, and were entirely out-classed by the work of Stas. The demand for accuracy has become greater, passing from the whole numbers of percentage to the decimals. The greatly improved methods enable even a tyro in these days to attain such closeness of results as was impossible for the earlier workers.

Still, from inherent imperfections in the methods, and from differences in manipulations on the part of the chemists, there is much to be desired in the way of accuracy and uniformity. This last is of especial importance where large business interests are at stake, as in the settling of valuations of manufacturing materials and in taxation. Hence late years have seen the organization of analysts, and their repeated meetings for the selection of methods and the careful arrangement of all details of manipulation, so as to exclude, if possible, all chance for variation. This co-operation in work, along sharply defined lines, is the latest phase in the development of analytical chemistry.

AGRICULTURAL CHEMISTRY.

In very early times there was an attempt at a classification of the soils according to fruitfulness, and also attempts at improving them by mixing, and by the addition of various manures. There was scarcely the foundation, however, for a systematic science until, during the last half of the eighteenth century, research and discovery along this line were stimulated by the offering of prizes by various French academies for methods of increasing the fertility of the soil. One of the first important writings upon this subject was the "*Agriculturæ Fundamenta Chemica*" (1761) of Wallerius, the Swedish chemist.

The Humus Theory. — Toward the close of the last century a distinct school of agriculturists had sprung up. Thus in Germany, Albrecht Thaer, and in France, Dombasle, were leaders in advancing the idea that the fertility of the soil was due to the presence of humus, and that plants fed upon this and similar organic food in complete analogy with the nutrition of animals. The inorganic salts were unnecessary for the building up of the plant; indeed, according to Thaer, it was possible that these "earths" were formed or created in the plant itself. Wallerius had endeavored to lay a much juster foundation for the science in a comparison between the constituents of the plants and of the soil upon which they grew.

The New Theory of Liebig. — The work of Priestley, Lavoisier, and de Saussure had thrown some light upon the relation of the plant to the atmosphere, but the old erroneous ideas as to plant nourishment received their death-blow at the hands of Liebig. The change of views was somewhat gradual, and came about through the discussion as to the reason for the improved yield of crops grown on lands treated with powdered bones. Thaer had maintained that burnt bones have simply the effect of lime. The good effect of the ordinary powdered bones was attributed to the gelatine and fatty matter, these being organic materials, and hence, according to the humus theory, the appropriate food for plants. Fawtier even maintained that the "phosphate of lime, one of the components of the bones," could be neglected in considering the question of the increased fertility, "because it is indestructible and insoluble." But the presence of phosphorus in seeds had been discovered by Polt, and confirmed by various chemists; and in 1840, supported by many experiments of his own and of his pupils, Liebig boldly stated the foundation principles of modern agricultural chemistry. They were as follows: —

1. Inorganic substances form the nutritive material for all plants.

2. Plants live upon carbonic acid, ammonia (nitric acid), water, phosphoric acid, sulphuric acid, silicic acid, lime, magnesia, potash, and iron; many need common salt.

3. Manure, the dung of animals, acts not through the organic elements directly upon plant-life, but indirectly through

the products of the decay and fermentative processes: thus carbon becomes carbonic acid, and nitrogen becomes ammonia or nitric acid. The organic manures which consist of parts of remains of plants and animals can be substituted by the inorganic constituents into which they would be resolved in the soil.

Field Trials. — Practical field trials, carried out by governments and large land-owners, proved the truth of Liebig's deductions from his laboratory experiments; and the many investigators in this line since have mainly developed his ideas. Liebig's conclusion, that one must restore to the soil that which the removal of the crop had withdrawn, if one would prevent its exhaustion, is the basis of successful agricultural practice to-day.

Other Investigators. — Boussingault had, independently of Liebig, arrived at the same or very similar conclusions. He also did much for the development of this new branch of science. Special attention was devoted to the chemical nature of the soil, its origin, the weathering of the original rocks, etc. The introduction of artificial manures was one great result of Liebig's work. In France this was more especially due to the labors of Boussingault and Ville. With this introduction and consequent demand for phosphates came a world-wide search for phosphatic materials, and the building up of the large industry based upon their preparation and utilization.

Agricultural chemistry employs now a large force of workers, and they are busied over many most important and interesting problems. Among these workers may be mentioned Wagner, Warington, Grandeau, Johnson, and Wiley.

The Experiment Stations. — It only remains to mention as a factor in the present and future growth of agricultural chemistry the experiment stations and laboratories established now by the governments of every civilized country. So great a number of trained scientific workers, whose entire time can be given to experiments and to researches, must bring about a great increase of knowledge in this very difficult field of work.

PHYSIOLOGICAL CHEMISTRY.

The study, from a chemical standpoint, of the substances and processes in the animal body presents even greater difficulties and complexities than the similar study of plants. These two lines of study have been in a measure mutually helpful. At first the same chemists were often engaged in both, as de Saussure, Chevreul, Liebig, and others. They have now become very distinct and separate fields of research.

The Problems to be solved. — In order to lay a foundation for physiological chemistry, it has been necessary first to have some knowledge of the multitudinous substances occurring in animal bodies, and, if possible, to learn the conditions under which these different bodies were formed. Several stumbling-blocks present themselves here. The delicacy and instability of many of these compounds, the possibility that their extraction from the living organism or the killing of the organism might cause radical changes in them, and the extreme complexity and probable size of the molecules, which render it difficult to decide between the several possible formulas derived by analyses, are among the problems to be faced. Because of the last-mentioned difficulty some of the most important substances occurring in animals have still no certain formula assigned them. Furthermore, there have, of course, been serious difficulties in the way of separation and purification.

Condition of the Science. — It is therefore not surprising that with these great problems before them, the condition of life-chemistry should be in a far less satisfactory condition than that of the inanimate creation. Much valuable work has been done and many questions successfully solved. There is already a large and growing literature, and several periodicals are entirely devoted to the development of this great branch of knowledge, so important because of its intimate relations to our health and welfare. Some of the best-known workers are Brücke, Bernard, Hammersten, Traube, Hoppe-Seyler, Lehmann, Kühne, Schützenberger, Thudichum, and Chittenden. It is impossible to do more than make mention of the names of these, without specifically describing the work of each.

Fermentation and Decay Processes. — This most interesting branch of life-chemistry, leading up to the science of bacteriology, has been built up by the labors of Pasteur and Schützenberger. Before it was known that yeast consisted of living cells, there was a mechanical-chemical theory as to these processes, especially that of alcoholic fermentation, devised by Liebig. This was proposed by him in 1839, and had many supporters. By this the yeast and such ferments were regarded as very unstable bodies; and when they broke up, the shock of their decomposition was transmitted to the fermentable medium in which they were present, as, for instance, the dilute solution of sugar.

Discovery of the Nature of Ferments. — Several investigators discovered, simultaneously and independently, that the yeast consisted of living organisms capable of self-multiplication. These discoverers were Schwann, Kützing, and Cagniard de Latour. This was followed by Pasteur's wonderful and epoch-making studies upon beer, wine, and vinegar, from which was deducted the vital or bacterial theory of fermentation. These discoveries and their development have had a far-reaching effect upon the wine and beer industries, upon agricultural science, and have revolutionized sanitary science and the theory of disease.

The chemistry of these processes is, again, a very difficult one, and needs much research. Among the valuable results so far attained, we have the discovery of the ptomains or cadaveric alkaloids by Selmi, and their study by Otto, Husemann, Dragendorff, and Vaughan, and the interesting work upon the so-called tox-albumins found among the life products of these bacteria, and looked upon by some as possibly forming a means of immunity against certain diseases.

PHYSICAL CHEMISTRY.

A partial review of the advances in physical chemistry has already been given. Its progress has not been as rapid as it should have been, other branches of chemistry absorbing most of the attention of investigators; but the future is much more promising. There seems to be an awakening in this direction. Only a few points can be touched upon here.

Molecular Weight Determinations. — For a long time the only class of substances whose molecular weight could be determined were those which could be obtained in the form of a gas without decomposition. The older method for determining this, by weighing a measured volume of the gas under question, was improved upon by Hofmann, who measured the volume of gas produced from a weighed quantity of substance; and by Victor Meyer, who measured the volume of air or some indifferent gas displaced by the gas evolved. These methods were satisfactory for gaseous bodies, but left one in ignorance as to the molecular weights of a large number of bodies which could not be turned into gases.

Determination by Means of Freezing-Points and Boiling-Points. — Raoult described in 1883 his method of determining the molecular weights of solids by means of the lowering of the freezing-points caused by them in various solvents. Several years later V. Meyer drew attention of chemists to the great value of this discovery. Frequent use has been made of the method since.

The use, for the same purpose, of the increase in the boiling-point caused by bodies in solution has been suggested and carried out by Beckmann and Wiley.

Electro-Chemistry. — The foundations of electro-chemistry proper were laid by Joule's discovery of the relation subsisting between electrical and chemical energy, and further the work of Favre upon the same subject. Many have investigated the facts of electrical conductivity and resistance, but the greatest progress has been in the use made of electrolysis for analytical and industrial purposes.

Electro-Chemical Analysis. — Lückow and Gibbs were the first to introduce the use of the electric current into chemical analysis, though work along the same line was done by Despretz, Bloxam, and Nicklès. Lückow (1865) proposed its use for the solution, detection, separation, and quantitative deposition of metals, and the reduction of metallic compounds. The development of these processes is largely due to the labors of Hampe, Riche, Smith, and Classen.

Electro-Metallurgy. — Jacobi announced in 1839 the first industrial application of the deposition of metals by electricity. The development was rapid. Much is due to the work of the Becquerels, Shaw, and Smee. Copper was first deposited, then many other metals, as silver, gold, and nickel. This forms the useful industry of electro-plating.

Electro-chemical action is further used in the reduction of metals from their ores, their purification, and in the preparation of such substances as phosphorus, caustic soda, chlorine, etc. The further extension seems most promising.

Thermo-Chemistry. — That heat was disengaged in many chemical reactions has been long noticed; and attempts were early made at measuring this, with the view of thus determining the strength of the chemical force, or affinity, concerned in the reactions. There are many experiments of Lavoisier, Laplace, Rumford, and Davy on this subject, but they are imperfect. The instrument used in determining this heat of reaction, the calorimeter, was greatly improved by Favre and Silbermann, who made a valuable series of experiments upon heats of combustion. It has been also modified and improved by many chemists, as Regnault, Thomson, and Bunsen. The fundamental principle of thermo-chemistry, the constancy of the sum of the amounts of heat evolved, was laid down by Hess in the year 1840, though his work lay unnoticed for many years until it was brought into notice by Ostwald. Hess's work established the fact that the amount of heat evolved in any chemical reaction was always the same, whether the reaction was completed in one step, or broken up into several. Long before it had been deduced by Lavoisier and Laplace that the amount of heat required for the dissociation of a compound was equal to the amount produced by its formation.

Thomson was the first to apply the mechanical theory of heat to thermo-chemical processes; and he has for more than forty years been busy with the thermo-chemical examination of all important chemical reactions, adding an immense number of facts to the knowledge of the subject. At one time a far greater importance was attached to these researches, and greater hopes held as to their outcome, than at present. Very distinguished chemists, as Berthelot, Stohmann, Ostwald, and Naumann, have been engaged in the work. The criticisms of Brühl have done much to show the imperfections of some of the deductions from thermo-chemical data.

Photo-Chemistry. — The chemical action of light has attracted a good deal of attention from chemists. The synthesis of organic substances under the action of light in the cells of the living organisms is the most complex phase of this, but light causes a whole range of actions besides this. Complex or simple, they are not yet well understood.

That side of the subject bearing upon the changes caused in certain metallic salts, as those of silver, has been more widely studied; and this is what is more especially meant by photo-chemistry.

Early Observations. — The singular action of light upon silver compounds was noted in very early times. Boyle had observed this darkening, but ascribed it to the air. Early in the eighteenth century Schultze had ascribed it to the real cause — the rays of light. Scheele examined the action of the different parts of the spectrum upon a layer of silver chloride spread upon paper, and proved that the violet rays were the ones causing the change. Davy was the first to make use of this for copying lights and shadows; that is, for photographing objects, but was unable to fix the image gotten. The discovery of the fixing agent in sodium thiosulphite by Herschel in 1836, of the first developing agent by Daguerre in 1839, and of the sensitizing agents by Talbot and others, laid the foundations for modern photography.

But photo-chemistry means more than the study of the chemical processes involved in the taking of photographs. Draper instituted experiments looking to the measurement of the action of light, and the researches of Bunsen and Roscoe added to the knowledge of actinometry. Vogel also aided in this work, and has done much for the science of photo-chemistry. The absorption of chemically active rays, and what has been called photo-chemical induction, have also received attention from these chemists.

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