"The Progress of the Century," by Famous Specialists.

Chemistry and Famous Chemists, by Professor Ramsay.

PROFESSOR WILLIAM RAMSAY.

Professor William Ramsay of the University College of London is one of the most eminent chemists. He comes of a family of bright, scientific men. His father was William Ramsay, civil engineer, of Glasgow, Scotland, the birthplace of the son, who was educated in his native city and at Tubingen University, Germany.

His special aptitude for the science of chemistry showed itself early. Born in 1852, his youth was spent in the time of the great modern development of the natural sciences. He went from Germany home to his native place, where he taught in the Glasgow University. In 1887 he was called to the University College at London, where he has remained.

For recreation Professor Ramsay turns to the study of the modern languages, but his chief pleasure is found in outdoor exercises, in cycling and in climbing mountains. A trip to the Alps is a joy to him.

His chief contributions to the literature of chemistry are the following: "The Molecular Surface—Energy of Liquids"; "Argon, a New Constituent of the Atmosphere" (in conjunction with Lord Rayleigh); "Helium, Constituent of Certain Minerals"; two text books on chemistry, and the "Discovery of the Constituents of the Air."

Professor Ramsay has been decorated with the cross of the Legion of Honor by France, and Great Britain has conferred many honors and degrees upon him.

THIS second of the series of special articles on scientific development in the past hundred years treats exhaustively of one of the most important branches of science. It will be followed by others, fourteen in all, which will review the various departments of literature, astronomy, surgery, medicine and religion.

Chemistry.

WRITTEN FOR THE SUNDAY REPUBLIC.

The progress of the science of chemistry forms one phase of the progress of human thought. While at first mankind was contented to observe certain phenomena, and to utilize them for industrial purposes, if they were found suitable, "philosophers," as the thinking portion of our race loved to call themselves, have always attempted to assign some explanation for observed facts, and to group them into similars and dissimilars. It was for long imagined, following the doctrines of the Greeks and of their predecessors, that all matter consisted of four elements or principles, names which survive to this day in popular language. These were "fire," "air," "water" and "earth." It was not until the Seventeenth Century that Boyle in his "Sceptical Chymist" (1661) laid the foundations of the modern science by pointing out that it was impossible to explain the existence of the fairly numerous chemical substances known in his day, or the changes which they can be made to undergo, by means of the ancient Greek hypotheses regarding the constitution of matter.

One of the first objects to excite curiosity and interest was the air which surrounds us, and in which we live and move and have our being. The word "gas," moreover, was not invented until Van Helmont devised it to designate various kinds of "airs" which he had observed. The important part which gases play in the constitution of many chemical compounds was accordingly overlooked.

Gradually, however, it came to be recognized, not merely that gases have corporal existence, but that they even possess weight. This, though foreshadowed by Torricelli, Jean Rey and others, was first clearly proved by Black, professor of chemistry in Edinborough, in 1752, through his masterly researches, as carbonic acid.

The ignorance of the material nature of gases and of their weight lies at the bottom of the phlogistic theory, a theory devised by Stahl about the year 1690 to account for the phenomena of combustion and respiration and the recovery or "reduction" of metals from their "earths" by heating with charcoal or allied bodies.

On this hypothesis, it was the earths, and such acid liquids as sulphuric or phosphoric acids, which were the elements; the metals and sulphur and phosphorus were their compounds with phlogiston.

The discovery of oxygen by Priestley and by Scheele in 1774, and the explanation of its functions by Lavoisier during the following ten years gave their true meaning to these phenomena.

The discovery that air is in the main a mixture of nitrogen, an inert gas, and oxygen, an active one, together with a small proportion of carbonic "acid" (or, as it is now termed, anhydride)—a discovery perfected by Rutherford, Black and Cavendish—and that water is a compound with oxygen of hydrogen, previously known as inflammable air, by Cavendish and by Watt, finally overthrew the theory of phlogiston; but at the beginning of this century it still lingered on, and was defended by Priestley until his death in 1804. Such, in brief, was the condition of chemical thought in the year 1800. Scheele had died in 1786, at the early age of 44; Lavoisier was one of the victims of the French Revolution, having been guillotined in 1794; Cavendish had ceased to work at chemical problems, and was devoting his extraordinary abilities to physical problems of the highest importance, while living the life of an eccentric recluse, and Priestley, driven by religious persecution from England to the more tolerant shores of America, was enjoying a peaceful old age, enlivened by occasional incursions into the region of sectarian controversy.

First Striking Discovery of the Nineteenth Century.

The first striking discovery of our century was that of the compound nature of the alkalies and of the alkaline earths. This discovery was made by Humphry Davy. Born in Cornwall in 1778 he began the study of chemistry self taught, in 1798; and in 1799 he became director of the "Pneumatic Institution," an undertaking founded by Doctor Beddoes at Bristol for the purpose of experiments on the curative effects of gases in general. Here he at once made his mark by the discovery of the remarkable properties of "laughing gas," or nitrous oxide. At the same time he constructed a galvanic battery, and began to perform experiments with it in attempting to decompose chemical compounds by its means. In 1801 Davy was appointed professor of chemistry at the Royal Institution, a society or club which had been founded a few years previously by Benjamin Thomson, Count Rumford, for the purpose of instructing and amusing its members with recent discoveries in chemistry and natural philosophy. In 1807 Davy applied his galvanic battery to the decomposition of damp caustic potash and soda, using platinum poles. He was rewarded by seeing globules of metal resembling mercury in appearance, at the negative pole; and he subsequently proved that these globules, when burned, reproduced the alkali from which they had been derived. They also combined with "oxymuriatic acid," as chlorine (discovered by Scheele) was then termed, forming ordinary salt, if sodium be employed, and the analogous salt, "muriate of potash," if the allied methal potassium were subjected to combustion. By using mercury as the negative pole, and passing a current through a strong solution of the chloride of calcium, strontium or barium, Davy succeeded in procuring mixtures with mercury or "amalgams" of their metals, to which he gave the names of calcium, strontium, and barium. Distillation removed most of the mercury, and the metal was left behind in a state of comparative purity. The alkali metals, potassium and sodium, were found to attack glass, liberating "the basis of the silex," to which the name silicon has since been given.

Thus nearly the last of the "earths" had been decomposed. It was proved that not merely were the "calces" of iron, copper, lead and other well-known metals compounds of the respective metals with oxygen, but Davy showed that lime and its allies, strontia and baryta, and even silica or flint, were to be regarded as oxides of elements of metallic appearance.

Discovery of Aluminum and New Theories as to Oxygen.

To complete our review of this part of the subject, suffice it to say that aluminum, a metal now produced on an industrial scale, was prepared for the first time in 1827 by Wohler, professor of chemistry at Goettingen, by the action of potassium on its chloride, and alumina, the earthy basis of clay, was shown to be the oxide of the metal aluminum. Indeed, the preparation of this metal in quantity is now carried out at Schoffhausen-on-the-Rhine and at the Falls of Foyers in Scotland by electrolysis of the oxide dissolved in melted cryolite, a mineral consisting of the fluorides of sodium and aluminum by a method differing only in scale from that by means of which Davy isolated sodium and potassium in 1806.

To Davy, too, belongs the merit of having dethroned oxygen from its central position among the elements. Lavoisier gave to this important gas the name "oxygen," because he imagined it to be the constituent of all acids. He renamed the common compounds of oxygen in such a manner that the term oxygen was not even represented in the name—only inferred. Thus a "nitrate" is a compound of an oxide of nitrogen and an oxide of metal; a "sulphate," of the oxide of a metal with one of the oxides of sulphur, and so on. Davy, by discovering the elementary nature of chlorine, showed first that it is not an oxide of hydrochloric acid (or muriatic acid, as it was then called); and second, that the latter acid is the compound of the element chlorine with hydrogen. This he did by passing chlorine over white-hot carbon—a substance eminently suited to deprive oxy-compounds of their oxygen—and proving that no oxide of carbon is thereby produced; by acting on certain chlorides, such as those of tin or phosphorus with ammonia, and showing that no oxide of tin or phosphorus is formed; and lastly, by decomposing "muriatic acid gas" (gaseous hydrogen chloride) with sodium, and showing that the only product besides common salt is hydrogen. Instead, therefore, of the former theory that a chloride was a compound of the unknown basis of oxy-muriatic acid with oxygen and the oxide of a metal, he introduced the simpler and correct view that a chloride is merely a compound of the element chlorine with a metal. In 1813 he established the similar nature of fluorine, pointing out that on the analogy of the chlorides it was a fair deduction that the fluorides are compounds of an undiscovered element, fluorine, with metals; and that hydrofluoric acid is the true analogue of hydrochloric acid. The truth of this forecast has been established of recent years by Henri Moissan, who isolated gaseous fluorine by subjecting a mixture of hydrofluoric acid and hydrogen potassium fluoride contained in a platinum U tube to the action of a powerful electric current. He has recently found that the tube may be equally well constructed of copper, and this may soon lead to the industrial application of the process. The difficulty of isolating fluorine is due to its extraordinary chemical energy; for there are few substances, elementary or compound, which resist the action of this pale yellow, suffocating gas. In 1811 iodine, separated by Courtois from the ashes of sea plants, was shown by Davy to be an element analogous to chlorine. Gay-Lussac subsequently investigated it and prepared many of its compounds, and in 1826 the last of these elements, bromine, was discovered in the mother liquor of sea salt by Balard. The elements of this group have been termed "halogens," or "salt producers."

Dalton's Discovery of an Important Fact.

While Davy was pouring his researches into the astonished ears of the scientific and dilettante world, John Dalton, a Manchester schoolmaster, conceived a theory which has proved of the utmost service to the science of chemistry, and which bids fair to outlast our day. It had been noticed by Wenzel, by Richter, by Wollaston and by Cavendish, toward the end of the last century, that the same compounds contain the same constituents in the same proportions; or, as the phrase runs, "possess constant composition." Wollaston, indeed, had gone one step further, and had shown that when the vegetable acid, oxalic acid, is combined with potash, it forms two compounds, in one of which the acid is contained in twice as great an amount relatively to the potash as in the other. The names monoxalate and binoxalate of potash were applied to these compounds, to indicate the respective proportions of the ingredients. Dalton conceived the happy idea that by applying the ancient Greek conception of atoms to such facts the relative weights of the atoms could be determined. Illustrating his views with the two compounds of carbon with hydrogen, marsh gas and olefiant gas, and with the two acids of carbon, carbonic oxide, carbonic "acid," he regarded the former as a compound of one atom of carbon and one of hydrogen and the second as a compound of one atom of carbon and two of hydrogen, and similarly for the two oxides of carbon. Knowing the relative weights in which these elements enter into combination, we can deduce the relative weights of the atoms.

It has been pointed out by Judge Stallo of Philadelphia in his "Concepts of Physics" that such a hypothesis as that of Dalton is no explanation; that a fact of nature, as, for example, the fact of simple and multiple proportions, is not explained by being minified. Allowing the general truth of this statement, it is nevertheless undoubted that chemistry owes much to Dalton's hypothesis; a lucky guess at first, it represents one of the fundamental truths of nature, although its form must be somewhat modified from that in which Dalton conceived it. Dalton's work was first expounded by Thomas Thomson, professor at Glasgow, in his "System of Chemistry," published in 1805; and subsequently in Dalton's own "New System of Chemical Philosophy," the three volumes of which were published in 1808, in 1810 and in 1827.

The determination of these "Constants of Nature" was at once followed out by many chemists, Thomson among the first. But chief among the chemists who have pursued this branch of work was Jacob Berzelius, a Swede, who devoted his long life (1779-1848) to the manufacture of compounds and to the determination of their composition, or, as it is still termed, the determination of the "atomic weights"—more correctly, "equivalents"—of the elements of which they are composed. It is to him that we owe most of our analytical methods, for, prior to his time, there were few, if any, accurate analyses. Although Lavoisier had devised a method for the analysis of compounds of carbon, viz., by burning the compounds in an atmosphere of oxygen contained in a bell jar over mercury, and measuring the volume of carbon dioxide produced, as well as that of the residual oxygen, Berzelius achieved the same results more accurately and more expeditiously by heating the substance, mixed with chlorate of potassium and sodium chloride, and then estimating the hydrogen as well as the carbon; this process was afterwards perfected by Liebig. Berzelius, however, was able to show that compounds of carbon, like those of other elements, were instances of combination in constant and in multiple proportions.

Prout, Thomson, Berzelius and Dumas.

In 1815 two papers were published in the "Annals of Philosophy," by Doctor Prout, which have had much influence on the progress of chemistry. They dealt with the figures which were being obtained by Thomson, Berzelius and others, at that time supposed to represent the "atomic weights" of the elements. Prout's hypothesis, based only on a few numbers, was that the atomic weights of all elements were multiples of that of hydrogen, taken as unity. There was much dispute regarding this assertion at the time, but as it was contradicted by Berzelius's numbers the balance of opinion was against it. But about the year 1840 Dumas discovered an error in the number (12.12) given by Berzelius as the atomic weight of carbon, and with his collaborator, Stas undertook the redetermination of the atomic weights of the commoner elements; for example, carbon, oxygen, chlorine, and calcium. This line of research was subsequently pursued alone by Stas, whose name will always be remembered for the precision and accuracy of his experiments. At first Dumas and Stas inclined to the view that Prout's hypothesis was a just one, but it was completely disproved by Stas's subsequent work, as well as by that of numerous other observers. It is nevertheless curious that a much larger proportion of the atomic weights approximate the whole numbers than would be foretold by the doctrine of chances, and perhaps the last has not been heard of Prout's hypothesis, although in its original crude form it is no longer worthy of credence.

One of the most noteworthy of the discoveries of the century was made by Gay-Lussac (1778-1850) in the year 1808. In conjunction with Alexander von Humboldt, Gay-Lussac had rediscovered about three years before what had previously been established by Cavendish, namely, that as nearly as possible two volumes of hydrogen combine with one volume of oxygen to form water, the gases having been measured at the same temperature and pressure. Humboldt suggested to Gay-Lussac that it would be well to investigate whether similar simple relations exist between the volumes of other gaseous substances when they combine with each other. This turned out to be the case; it appeared that almost exactly two volumes of carbolic oxide unite with one volume of oxygen to form carbon dioxide; that equal volumes of chlorine and hydrogen unite to form hydrochloric acid gas; that two volumes of ammonia gas consist of three volumes of hydrogen in union with one volume of nitrogen and so on. From such facts Gay-Lussac was led to make the statement that: The weights of equal volumes of both simple and compound gases, and therefore their densities, are proportional to their empirically found combining weights or to rational multiples of the latter. Gay-Lussac recognized this discovery of his to be a support for the atomic theory; but it did not accord with many of the then received atomic weights. The assumption that equal volumes of gases contain equal numbers of particles, or, as they were termed by him, molecules integrantes, was made in 1811 by Avogadro, professor of physics at Turin (1776-1856). This theory, which has proved of the utmost importance to the sciences both of physics and of chemistry, had no doubt occurred to Gay-Lussac and had been rejected by him for the following reasons:

Avogadro's Hypothesis of Atoms and Molecules.

A certain volume of hydrogen, say one cubic inch, may be supposed to contain an equal number of particles (atoms) as an equal volume of chlorine. Now these two gases unite in equal volumes. The deduction appears so far quite legitimate that one atom of hydrogen has combined with one atom of chlorine. But the resulting gas occupies two cubic inches and must therefore contain the same number of particles of hydrogen chloride, the compound of the two elements, as one cubic inch originally contained of hydrogen or of chlorine. Thus we have two cubic inches containing, of uncombined gases, twice as many particles as is contained in that volume after combinations. Avogadro's hypothesis solved the difficulty.

By premising two different orders of particles, now termed atoms and molecules, the solution was plain. According to him, each particle or molecule of hydrogen is a complex and contains two atoms; the same is the case with chlorine. When these gases combine, or rather react to form hydrogen chloride, the phenomenon is one of a change of partners; the molecule, the double atom, of hydrogen splits; the same is the case with the molecule of chlorine; and each liberated atom of hydrogen unites with a liberated atom of chlorine, forming a compound, hydrogen chloride, which equally consists of a molecule, or double atom. Thus two cubic inches of hydrogen chloride consist of a definite number of molecules, equal in number to those contained in a cubic inch of hydrogen plus those contained in a cubic inch of chlorine. The case is precisely similar if other compounds of gases be considered.

Berzelius was at first inclined to adopt this theory, and, indeed, went so far as to change many of his atomic weights to make them fit it. But later he somewhat withdrew from his position, for it appeared to him that it was hazardous to extend to liquids and solids a theory which could be held only of gases. Avogadro's suggestion, therefore, rested in abeyance until the publication, in 1858, by Cannizzaro, now professor of chemistry in Rome, of an essay in which all the arguments in favor of the hypothesis were collected and stated in a masterly manner.

In 1819 Dulong (1785-1838), director of the Ecole Polytechnique at Paris, and Petit (1791-1820), professor of physics there, made the discovery that equal amounts of heat are required to raise equally the temperature of solid and liquid elements, provided quantities are taken proportional to their atomic weights. Thus to raise the temperature of 56 grammes of iron through one degree requires approximately the same amount of heat as is required to raise through one degree 32 grammes of sulphur, 63.5 grammes of copper, and so on; these numbers representing the atomic weights of the elements named. In other words, equal numbers of atoms have equal capacity for heat. The number of heat units or calories (one calory is the amount of heat required to raise the temperature of 1 gramme of water through 1 degree C.), which is necessary to raise the atomic weight expressed in grammes of any solid or liquid element through 1 degree C. is approximately 6.2; it varies between 5.7 and 6.6 in actual part. This affords a means of determining the true value of the atomic weight of an element.

Methods of Determining the Vapor Densities.

The methods of determining the vapor densities or relative weights of vapors are three in number; the first method, due to Dumas (1827), consists in vaporizing the substance in question in a bulb of glass or of porcelain, at a known temperature, closing the bulb while still hot and weighing it after it is cold. Knowing the capacity of the bulb the weight of hydrogen necessary to fill it at the desired temperature can be calculated and the density of the vapor thus arrived at. A second method was devised by Gay-Lussac and perfected by A. W. Hofmann (1868); and a third, preferable for its simplicity and ease of execution, is due to Victor Meyer (1881).

In 1858, as already remarked, Cannizzarro showed the connection between these known facts, and for the first time attention was called to the true atomic weights, which were, up to that time, confused with equivalents, or weights of elements required to replace one unit weight of hydrogen. These were generally regarded as atomic weights by Dalton and his contemporaries.

Some exceptions had been observed to the law of Dulong and Petit, viz: beryllium, or glucinium, an element occurring in emeralds, boron, of which borax is a compound; silicon, the component of quartz and flint, and carbon. It was found by Weber that at high temperatures, the specific heats of these elements are higher, and the atomic heats approximate to the number of 6.2; but this behavior is not peculiar to these elements, for it appears that the specific heat of all elements increases with rise of temperature.

A certain number of exceptions have also been noticed to the law of Gay-Lussac, which may be formulated: the molecular weight of a compound in a gaseous state is twice its density referred to hydrogen. Thus, equal volumes of ammonia and hydrogen chloride unite to form ammonium chloride. It was to be expected that the density should be half the molecular weight.

But the density actually found is only half that number; and for long this and similar cases were supposed to be exceptions to the law of Gay-Lussac, viz., that equal volumes of gases at the same pressure expand equally for equal rise of temperature. In other instances the gradual decrease in density with rise of temperature can be followed, as with chloral hydrate, the products of which are chloral and water.

It was recognized by St. Claire Deville (1857) that the decrease in density of such mixtures of gases was due, not to their being exceptions to Avogadro's law, but to the gradual decomposition of the compound body with rise of temperature. To this gradual decomposition he gave the name dissociation. This conception has proved of the utmost importance to science.

The molecular complexity of gases has gradually become comprehended, and the truth of Avogadro's law has gained acceptance. And as a means of picturing the behavior of gaseous molecules the kinetic theory of gases has been devised by Joule, Clausius, Maxwell Thomson (Lord Kelvin) and others. On the assumption that the pressure of a gas on the walls of the vessel which contains it is due to the continued impacts of its molecules, and that the temperature of a gas is represented by the product of the mass of the molecules, or the square of their velocity, it has been possible to offer a mechanical explanation of Boyle's law, that at constant temperature the volume of a gas diminishes in proportion as the pressure increases; of Gay-Lussac's law, that all gases expand equally for equal rise of temperature, provided pressure is kept constant; the condition being that equal volumes of gases contain equal numbers of molecules. A striking support is lent to this chain of reasoning by the facts discovered by Thomas Graham (1805-1869) professor at University College, London, and subsequently master of the Royal Mint. Graham discovered that the rates of diffusion of gases into each other is inversely as the square roots of their densities.

Davy's Theories of Electrification.

In 1807 Davy propounded the theory that all compounds consist of two portions, one electro-positive and the other electro-negative. This idea was the result of experiments on the behavior of substances such, for example, as copper and sulphur; if portions of these elements be insulated and then brought in contact they become oppositely electrified. The degree of electrification is intensified by rise of temperature until, when combination ensues, the electrification vanishes. Combination, therefore according to Davy, is concurrent with the equalization of potentials.

In 1812, Berzelius brought forward an electro-chemical theory which for the following twenty years was generally accepted. His primary assumption was that the atoms of elements, or, in certain cases, groups of atoms, are themselves electrified; that each atom, or group of atoms, possesses two poles, one positive, the other negative; that the electrification of one of these poles predominates over that of the other, so that the atom or group is itself, as a whole, electro-positive, or electro-negative; that combination ensued between such oppositely electrified bodies by the neutralization, partial or complete, of their electric charges; and lastly, that the polarity of an element or group could be determined by nothing whether the element or group separated at the positive or at the negative pole of the galvanic battery, or electrolysis. For Berzelius, oxygen was the most electro-negative and potassium the most electropositive of the elements, the bridge between the "non-metals" and the "metals" being hydrogen, which, with nitrogen, forms a basic, or electro-positive, group, while with chlorine, etc., it forms electro-negative groups. The fact that an electric current splits compounds in solution into two portions led Berzelius to devise his "dualistic" system, which involved the assumption that all compounds consist of two portions, one electro-positive, the other electro-negative.

Lavoisier's idea, that oxygen was the necessary constituent of all acids began about this time to lose ground. For Davy had proved the elementary nature of chlorine; and hydrochloric acid, one of the strongest, was thus seen to contain no oxygen, and Davy expressed the view, founded on his observation, that iodic "acid" was devoid of acid properties, until dissolved in water, and that the essential constituent of all acids was hydrogen, not oxygen.

Faraday's electrolytic law, that when a current is passed through electrolytes in solution the elements are liberated in quantities proportional to their equivalents, led to the abandonment of the dualistic theory. For when a current is passed in succession through acidified water, fused lead chloride and a solution of potassium sulphate, the quantities of hydrogen and oxygen from the water, of lead and chlorin from the lead chloride, and the potassium of the sulphate are in accordance with Faraday's law. But in addition to the potassium, there is liberated at the same pole an equivalent of hydrogen. In 1833 Graham investigated the phosphoric acids, and prepared the salts of three, to which he gave the names, ortho, pyro and metaphosphoric acids.

First Clear Ideas of Structure of Molecule.

The first clear ideas of the structure of the molecule were, however, gained from the study of the compounds of carbon. It was difficult to apply the dualistic theory to them. For few of them are electrolytes, and therefore their products of electrolysis, being nonexistent, could not be classified. In 1823 Liebig discovered that silver fulminate and silver cyanate both possessed the empirical formula AgCNO; in 1825 this was followed by the discovery by Faraday that oil gas contains a hydrocarbon identical in composition with ethylene, yet differing from it in properties; and in 1828 Wohler, professor in Goettingen (1800-1882), discovered that urea, a constituent of urine, could be produced by heating ammonium cyanate, a substance of the same formula. It therefore became clear that the identity of a compound must depend upon some other cause than its ultimate composition.

In 1832 Liebig and Wohler took an important step in elucidating this question by their investigations on benzoic acid and acid obtainable by distilling a resin named gum benzoin. This research was followed by one by Robert Bunsen, professor at Heidelberg, born in 1811, and recently (1899) dead, which bore reference to cacodyl, a compound of arsenic, carbon and hydrogen, in which the idea of a radical was confirmed and amplified.

The idea of a radical having thus become established, Jean Baptiste Andree Dumas, professor in Paris (1800-1884) propounded the theory of "substitution," i. e., that an element such as cholrine or oxygen (which, be it noticed, is electro-negative on Berzelius's scale) could replace hydrogen in carbon compounds, atom for atom, the resulting compound belonging to the same "type" as the one from which it was derived. And Laurent, warden of the mint at Paris (1807-1852, and Gerhardt, professor at Montpelier and at Strassburg (1816-1856), emphasized the fact that one element, be it what it may, can replace another without fundamentally altering its chemical character, and also that an atom of hydrogen can be replaced by a group of atoms or radical, behaving for the occasion like the atom of an element. It is to Laurent and Gerhardt that we owe the definition of an atom—the smallest quantity of an element which can be present in a compound; an equivalent—that weight of an element which combines with or replaces one part by weight of hydrogen; and a molecule—the smallest quantity which can exist in a free state, whether of an element or of a compound. They recognized, too, that a molecule of hydrogen, chlorine, etc., consists of two atoms.

In 1849 Wurtz, professor in Paris (1817-1884), and Hofmann, then professor in the College of Chemistry in London, afterwards at Berlin (1818-1892), discovered series of compounds allied to ammonia, in which one or more atoms of hydrogen were replaced by a group or radical, such as methy or ethyl or phenyl. Wurtz referred such compounds to ammonia "type." Shortly afterwards Williamson, professor at University College, London (1821 —), added the water type," in consequence of his researches on "mixed ethers"—bodies in which the hydrogen of water might be regarded as replaced by organic radicals.

The next important step was taken by Frankland, professor in the Royal School of Mines London. His work, however, had been anticipated by Cran Brown, professor at Edinburgh University, in a pamphlet even yet little known. It was to attribute to elements one or more powers of combination. To these he gave the name "valency," and the capacity of possessing valency was called "quantivalence." Thus hydrogen was taken as a "monad," or monovalent. Chlorine, because it unites with hydrogen atom to atom, is also a monad. Oxygen, having the power to combine with two atoms of hydrogen, was termed a dyad, or divalent; nitrogen a triad, or trivalent; carbon a tetrad, or tetravalent, and so on.

Notable Discoveries by Doctor Pasteur.

This was the key to unlock the structure of chemical compounds; and Frankland's views, just stated, are still held by chemists. The determination of the constitution of compounds, chiefly those of carbon, occupied the attention of chemists, almost exclusively, until 1880.

By means of conceptions such as these many interesting compounds have been built up out of the elements which they contain; e. g., urea and uric acid, constituents of urine; theobromine and caffeine, the essential principles of cocoa and tea; alizarine and indigo, valuable dyestuffs; and several of the alkaloids, bitter principles contained in plants, of great medicinal value.

They have led, too, to the discovery of many brilliant colors, now almost universally employed, to the exclusion of those less brilliant, because less pure, derived from plants, and in one or two cases from animals; the manufacture of gun cotton, dynamite and similar high explosives; and to the development of the candle industry; sugar manufacture; to the improvement in tanning, in brewing, and in the preparation of gas and oils for illuminating purposes. In short, it may be said that the industrial progress of the latter half of the century has been due to the theoretical views of which a short sketch has just been given.

Such formulae, however, can evidently not represent the true constitution of matter, inasmuch as the atoms are imagined to be on a plane, whereas it is evident that they must occupy space of three dimensions and possess the attributes of solidity. The conception which led to the formulation of such views was due first to Pasteur, in his later years director of the Institute known by his name at Paris, and more directly to LeBel and Van t' Hoff, now professor at Berlin, independently of each other. In 1848 Pasteur discovered that it was possible to separate the two varieties of tartaric acid from each other, and that that one which rotated the plane of polarized light to the right gave crystals with an extra face, unsymmetrically disposed with regard to the other faces of the crystal. The variety, the solution of which in water was capable of producing left-handed rotation, also possessed a similar face, but so placed that its reflection in a mirror reproduced the right-handed variety. Pasteur also showed that a mixture of these acids gave crystals not characterized by an unsymmetrically placed face, and also that the solution was without action on polarized light.

These observations remained unexplained until LeBel and Van t' Hoff, 1874, simultaneously and independently devised a theory which has up till now stood the test of research.

It may be mentioned in passing that Pasteur, having found that ordinary mold destroyed one variety of tartaric acid rather than the other in a mixture of the two, and made use of this observation in order to prepare the unattached variety in a state of purity, was led to study the action of organisms more or less resembling mold; and that this has led to the development of the science of bacteriology, which has had an enormous influence on our views regarding fermentation in general and guides the work of our physicians, our surgeons (witness Lister's antiseptic treatment), our sanitary engineers in their estimate of the purity of drinking water and of the disposal of sewage, of our manufacturers of beer and spirits, of wine growers, and more recently of farmers. All these processes depend upon the action of organisms in producing chemical changes, whether in the tissues of the body, causing or curing disease, or in the production of flavored alcohol from sugar, or in the manufacture of butter and cheese, or in preparing the land for the reception of crops. We also owe to the genius of Van t' Hoff the most important advance of recent times in the region of physical chemistry. It had been observed by Raoult, professor at Grenoble, that the freezing point of a solvent as a general rule is lowered to the same extent if there be dissolved in it quantities of substances proportional to the molecular weights. Similarly, Raoult found that quantities proportional to molecular weights dissolved in a solvent depress the vapor pressure of that solvent equally, or, what comes to the same thing, raise its boiling point by an equal number of degrees. But ordinary salts, such as sodium chloride, potassium nitrate, etc., dissolved in water, give too great a depression of the freezing point and too high a boiling point.

Next, it had been observed by botanists—Devries, Pfeffer and others, who had examined the ascent of sap in plants—that if a vessel of unglazed porcelain, so treated as to cause a film of cupric ferrocyanide (a slimy red compound) to deposit in the pores of its walls, be filled with a weak (about 1 per cent) solution of sugar or similar substance, and plunged in a vessel of pure water, water entered through the pores. By attaching a manometer to the porous vessel the pressure exerted by the entering water could be measured. Such pressure was termed "osmotic pressure," referring to the "osmosis" or passage through the walls of the vessel. Such prepared walls are permeable freely to water, but not to sugar or similar bodies. Van t' Hoff pointed out that the total pressure registered is proportional to the amount of substance in solution, and that it is proportional to the absolute temperature, and he showed, besides, that the pressure exerted by the sugar molecules is the same as that which would be exerted at the same temperature were an equal number of molecules of hydrogen to occupy the same volume as the sugar solution.

Periodic Arrangement of the Elements.

Here, again, however, it was noticed that salts tended to give a higher pressure; it was difficult to construct a semipermeable diaphragm, however, which would resist the passage of salt molecules while allowing those of water to pass freely. Lastly, Arrhenius of Stockholm had shown that the conductivity of salt solutions for electricity may be explained on the assumption that when a salt is dissolved in water it dissociates into portions similar in number and kind to those it would yield if electrolyzed (and if no secondary reactions were to take place). Such portions had been named ions by Faraday. The conductivity of such solutions becomes greater per unit of dissolved salt, the weaker the solution, until finally a limit is reached, after which further dilution no longer increases conductivity.

Now Van t' Hoff united all these isolated observations and showed their bearing on each other. Stated shortly, the hypothesis is as follows: When a substance is dissolved in a large quantity of a solvent, its molecules are separated from each other to a distance comparable with that which obtains in gases. They are, therefore, capable of independent action; and when placed in a vessel, the walls of which are permeable to the solvent, but not to the dissolved substance ("semipermeable membrane"), the imprisoned molecules of the latter exert pressure on the interior surface of these walls, as if they were gaseous. Van t' Hoff showed the intimate connection between this phenomenon and the depression of freezing point and the use of vapor pressure already alluded to. He pointed out further that the exceptions to this behavior noticed in the case of dissolved salts, is due to their "electric dissociation," or "ionization," as it is now termed; and that in a sufficiently dilute solution of potassium nitrate, for example, the osmotic pressure and the correlated depression of freezing point and rise of boiling point are practically equal to what would be produced were the salt to be split into its ions. These views were vigorously advocated by Ostwald (professor at Leipzig), in his Zeitschrift fur physikalishe Chemie, and he and his pupils have done much to gather together facts in confirmation of this theory, and in extending its scope.

It now remains to give a short account of the greatest generalization which has as yet been made in chemistry; it has been termed the Periodic arrangement of the elements.

In 1864, Newlands of London and Lothar Meyer, late of Tubingen, found that by arranging the elements in the order of their atomic weights, certain regularities were to be observed between each element, and in general the eighth in succession from it, in order of their numerical value. Such similar elements formed groups or quantities; while the elements separating them belong to a period, hence the name "periodic arrangement."

Mendeleef, professor at St. Petersburg, in 1869, amplified and extended these relations, and he and Meyer pointed out that the volume occupied by equal numbers of atoms of such elements underwent a periodic variation when the elements are classified as above. The prediction of undiscovered elements was made by Mendeleef in a more assured manner, and in several cases they have been realized. Thus, what Mendeleef called "ekaboron" has since been discovered by Lecocq de Boisbandron, and named patriotically "Gallium." Mendeleef's "eka-silicon" is now known as "germanium," discovered by Winkler; and "eka-aluminum" is now Cleve's "scandium." Moreover, the atomic weights of caesium, beryllium, molybdenum and mercury have been altered so that they fit the periodic table, and further research has justified the alteration.

Discoveries Made in the Last Ten Centuries.

The elements of no valency are of recent discovery. In 1894 Lord Rayleigh had determined the density of the nitrogen of the atmosphere, having separated from it the oxygen and carbon dioxide, which is mixed with nitrogen in air. He found it to be of somewhat higher density than that obtainable from ammonia and other compounds of nitrogen. In conjunction with Ramsay he investigated atmospheric nitrogen; it was absorbed either by a method devised by Cavendish, or by making it combine with magnesium at a red heat. They found that the unabsorbable residue possessed an unknown spectrum, and that its density was nearly 20. To this new gas they gave the name "argon," or inactive, seeing that all attempts to cause it to enter into combination had failed.

In 1895, Ramsay, searching for possible combinations of argon in minerals, experimented with one which had been previously examined by Hillebrand of Baltimore and obtained from it helium, a gas of density 2, possessing a spectrum which had been previously discovered in 1868 in the chromosphere of the sun by Janssen of Paris, and named helium by Frankland and Lockyer. Subsequent liquefaction of crude argon by means of liquid air, prepared by a process invented simultaneously by Linde and Hampson, gave a residue which was named by its discoverers, Ramsay and Travers, "neon." Liquid argon has yielded two other gases also "krypon" and "xenon." These elements form a separate group in the Periodic Table, commencing with helium, with atomic weight, 4; neon, 20; argon, 40; krypon, 82; and xenon, 128. They all agree in being mono-atomic; i. e., their molecules consist of single atoms, and they have no tendency to form compounds, i. e., they possess no valency.

In this sketch of the progress of chemistry during the century which has just passed, attention has been paid chiefly to the progress of thought. Allusions must, however, be made to the applications of chemistry to industrial purposes. The development of the soda industry, the preparation of carbonate of soda and caustic from common salt—initiated in France by LeBlanc (1742-1806)—has been developed by Tennant in Scotland and Muspeath and Gossage, and by Hargreaves, Weldon and Maetea in England; this process has at present a serious rival in the ammonia-soda process, developed by Solway in Belgium and by Brunner and Mond in England. The main action of sulphuric acid, so long associated with the alkali process, has made enormous strides during the present century, but is still, in the main, the original process of causing sulphur dioxide in presence of water to absorb the oxygen of the air through nitric oxide. But the saving of the oxides of nitrogen through the invention of a sulphuric acid power by Gay-Lussac, known by his name, and the reutilization of these oxides in the "Glover" power, invented by John Glover of Newcastle, have greatly lessened the cost of the acid. Concentration of the acid in iron vessels is now common, the cost of platinum or of fragile glass vessels being thereby saved. The desulphurization of iron and the removal of silicon, carbon and phosphorus by Bessemer's process, modified by Thomas and Gilchrist through the introduction of a "basic magnesia lining" for the converters, has made it possible to obtain pure iron and steel from ores previously regarded as of little value.

Chemistry's Assistance in the Art of Agriculture.

The use of artificial manures, prepared by mixing refuse animal matters with tetrahydrogen, calcium phosphate and nitrate of soda or sulphate of ammonia, first introduced by Liebig, has created a revolution in agricultural methods and in the weight of crops obtainable from a given area of soil. The influence of manures on crops has been fully studied by Lawes and Gilbert for more than fifty years in their experimental farm at Rothampstead. The most remarkable advances which have been made, however, are due to cheap electric current. The electrolysis of alumina, dissolved in fused cryolite to obtain aluminum, an operation carried out at Schaffhausen, on the Rhine, and at the Falls of Foyers in Scotland, the electrodeposition of pure copper for electric wires and cables, electrosilvering, gilding and nickeling, all these are instances where decomposition of a compound by the electric current has led to important industrial results. At present soda and chlorine are being manufactured by the electrolysis of salt solution contained in rocking trays, one of the electrodes being mercury, by the Castner-Kellner process. This manufacture is being carried on at Niagara, as well as in England. But electricity as a heating agent finds ever-extending applications. Louis Moisson (professor at Paris) led the way by utilizing the enormous heat of the ore in his electric furnace, thereby, among other interesting reactions, manufacturing diamonds, small, it is true, though none the less real. The use of electricity as a heating agent has received new applications. Phosphorus is now made by distilling a mixture of phosphates of lime and alumina with coke; a new polishing agent has been found in "carborundum," a compound of carbon and silicon, produced by heating in an electric furnace a mixture of sand and coke; and cyanide of potassium, almost indispensable for the extraction of gold from ores poor in gold, is now manufactured by heating a mixture of carbon and carbonate of barium in an electric furnace in a current of carbon monoxide. These are but some of the instances in which electricity has been adopted as an agent in effecting chemical changes, and it may be confidently predicted that the earlier years of the Twentieth Century will witness a great development in this direction. It may be pointed out that the later developments of industrial chemistry owe their success entirely to the growth of chemical theory, and it is obvious that that nation which possesses the most competent chemists, theoretical and practical, is destined to succeed in the competition with other nations for commercial supremacy and all its concomitant advantages.

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