The History of the NINETEENTH CENTURY CHEMISTRY.

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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. He laid down the definition of the modern meaning of the word "element;" he declined to accept the current view that the properties of matter could be modified by its assimilating the qualities of fire, air, earth, or water; and he defined an element as the constituent of a compound body.

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. It was, however, endowed with a semi-spiritual and scarcely corporeal nature, in the ideas of our ancestors, for it does not affect the senses of sight, smell or taste, and though it can be felt, yet it eludes our grasp. 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, and, indeed, it appeared to be almost as striking a feat of necromancy to produce a quantity of a gas of great volume from a small pinch of solid powder as for a "Jinn" of enormous stature but of delicate texture to issue from a brass pot, as related in the "Arabian Nights Entertainments." Gradually, however, it came to be recognized, not merely that gases have corporeal 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 Edinburgh, 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. According to this inverted theory, a substance capable of burning was imagined to contain more or less phlogiston, a principle which it parted with on burning, leaving an aura deprived of phlogiston, or "dephlogisticated," behind if a metal. This earth when heated with substances rich in phlogiston, such as coal, wood, flour and similar bodies, reimbibed the phlogiston, which it had lost on burning, and with the added phlogiston its metallic character. Other substances, such as phosphorous and sulphur, gave oxides or acid liquids, to which phlogiston was not so easy to add; but even they could be rephlogisticated. 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 the coup de grace to these phenomena. It was then recognized that combustion was union with oxygen; that an "earth" or "calx" was to be regarded as the compound of a metal with oxygen; that when a metal becomes tarnished, and converted into such an earthy powder, it is being oxidized; that this oxide, on ignition with charcoal or carbon, or with compounds such as coal, flour, or wood, of which carbon is a constituent, gives up its oxygen to the carbon, forming an oxide of carbon, carbonic oxide on the one hand, or carbonic "acid" on the other, while the metal is reproduced in its "regulus" or metallic condition, and that the true elements are metals, carbon, sulphur, phosphorus, and similar bodies, and not the products of their oxidation.

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 forty-four; 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.

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 1797, and in 1798 he became director of the "Pneumatic Institution," an undertaking founded by Dr. 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 metal potassium were subjected to combination. 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 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 "calxes" of iron, copper, lead and other well-known metals compounds of the respective metals with oxygen, but Davy showed that lime, an earth, was an oxide of a metal; that allies, strontia and baryta, and even silica at first, were to be regarded as oxides of elements of metallic appearance. To complete our review of this part of the subject, suffice it to say that aluminium, a metal now produced on an industrial scale, was prepared for the first time in 1827 by Wöhler, 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 Schaffhausen-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 a metal; a "sulphate" of the oxide of a metal with one of the oxides of sulphur, and so on. Davy, by discovering that the mercury 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."

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 same monoxalate and binoxalate of potash were applied to these com-

pounds, 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. Placing the relative weight of an atom of hydrogen equal to unity, we have:

	Marsh gas.	Olefiant gas.	Carbonic oxide.	Carbonic acid.
Carbon ...	6	6	6	6
Hydrogen ...	1	2	Oxygen ... 8	16

Thus the first compound, marsh gas, was regarded by Dalton as composed of one atom of carbon in union with an atom of hydrogen; or to reproduce his symbols, as ⊙ ⊙ while the second, olefiant gas, on this hypothesis, was a compound of two atoms of hydrogen with one of carbon, or ⊙ ⊙ ○. Similarly the symbols ⊙ ○, and ⊙ ⊙ ○ were given to the two compounds of carbon with oxygen. So water was assigned the symbol ○ ○, for Dalton imagined it to be a compound of one atom of hydrogen with one of oxygen. Compounds containing only two atoms were termed by him "binary;" those containing three, "ternary;" four, "quaternary," and so on. The weight of an atom of oxygen was eight times that of an atom of hydrogen; while that of an atom of carbon was six times as great as the unit. By assigning symbols to the elements, consisting of the initial letters of their names, or of the first two letters, formulæ were developed, indicating the composition of the compound, the atomic weights of the elements being assured. Thus, Na O signified a compound of an atom of sodium (natrium) weighing 23 times as much as a similar atom of hydrogen, with an atom of oxygen, possessing eight times the weight of an atom of hydrogen. Therefore 31 pounds of soda should consist of 23 pounds of sodium in combination with eight pounds of oxygen, for, according to Dalton, each smallest particle of soda contains an atom of each element, and the proportion is not changed, however many particles be considered.

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 least, 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 organic 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 hydrogen, 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 afterward 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.

In 1815 two papers were published in the "Annals of Philosophy," by Dr. 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 on only 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' numbers, the balance of opinion was against it. But about the year 1840 Dumas discovered an error in the number 12.23 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 considerably disproved by Stas' 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 to 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 being 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 carbonic oxide unite with one volume of oxygen to form hydrochloric acid gas; 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 combination 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 chemically found combining weights, or to rational numbers 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, but had been rejected by him for the following reasons: 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 volume. The deduction appears as far quite legitimate that one atom of hydrogen has combined with one atom of chlorine. But 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. The conception thus proved of the utmost importance to the science, as will be seen in the sequel. To take the above instance of ammonium chloride, its abnormal density is due to its dissociation into ammonia and hydrogen chloride; and the gas which is obtained on raising its temperature consists, not of gaseous ammonium chloride, but of a mixture of ammonia and hydrogen chloride, which, as is easily seen, occupy, when separate, twice the volume that would be occupied by the gaseous compound. Of recent years it has been shown by Brereton Baker that if perfectly free from moisture, ammonium chloride gasifies as such, and that its density in the state of vapor is in fact 26.75.

The molecular complexity of gases has thus 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 square of their velocity, it has been possible to offer a mechanical explanation of Boyle'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 claim 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. For instance, the density of hydrogen being taken as unity, that of oxygen is 16 times as great; if a vessel containing hydrogen be made to communicate with one containing oxygen, the hydrogen will pass into the oxygen and mix with it; and conversely, the oxygen will pass into the hydrogen vessel. This is due to the intrinsic motion of the molecule of each gas. And Graham found experimentally that for each volume of oxygen which enters the hydrogen vessel four volumes of hydrogen enter the oxygen vessel. Now, 4=1⁄4; and as these masses are relatively 1 and 16, and their temperatures are equal, the square of their velocities are respectively 1 and 16.

The question of the molecular complexity of gases being thus disposed of, it remains to be considered what are the relative complexity of liquid molecules. The answer is indicated by a study of the capillary phenomena of liquids, one method of measuring which is the height of their ascent in narrow or capillary tubes. It is impossible in the space at our disposal to enter into detail as to the method and arguments necessary to its elucidation. Suffice it to say that the Hungarian physicist Eotvos was the first to indicate the direction of research, and that Ramsay and Shields succeeded in proving that the complexity of the molecules of most liquids is not greater than that of the gases which they form on being vaporized; and also that certain liquids, e. g., water, the alcohols, and other liquids, are more or less "associated;" i. e., their molecules occur in couplets of two, three, four, or more, and as the temperature is raised the complexity of molecular structure decreases.

As regards the molecular complexity of solids, nothing definite is known, and, moreover, there appears to be no method capable of revealing it.

While the researches of which a short account has now been given have led to knowledge regarding the nature of molecules, the structure of the molecule has excited interest since the early years of the century, and its investigation has led to important results. The fact of the decomposition of acidified water by an electric current, discovered by Nicholson and Carlisle, and of salts into "bases" and "acids" by Berzelius and Hisinger in 1803, led to the idea that 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 into 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 concomitant 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, positive, or else electro-negative; that combination ensues 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 noting whether the element or group separated at the positive or the negative pole of the galvanic battery, or electrolysis. For Berzelius, oxygen was the most electro-negative and potassium the most electro-positive 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 unites compound 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. Thus sulphate of magnesium and potash plus alum was to be regarded as composed of electro-positive potassium sulphate in combination with electro-negative magnesium sulphate; the former in its turn consisted of electro-negative sulphur trioxide

(SO₃) in combination with electro-positive oxide of potassium (K₂O); while each of these proximate constituents of potassium sulphate were themselves composed of the electro-negative oxygen in combination with electro-positive sulphur, or potassium. On contrasting sulphur with potassium, however, the former was considered more electro-negative than the latter; so that the group SO₃ as a whole was electro-negative, while K₂O was electro-positive. The symbols given above, which are still in universal use, were also devised by Berzelius for the purpose of illustrating and emphasizing his views. These views, however, met with little acceptance at the time in England.

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. The conception thus proved of the utmost importance to the science, as will be seen in the sequel.

H. O. H.; CH₃. O. H.; CH₃. O. CH₃; and NH₃; NH₄; R₂; NR(CH₃)₃; and N(CH₃)₄; the first representing compounds following the line. The theme had been previously made by Laurent in 1846. But Williamson extended his views to inorganic compounds; thus, sulphuric acid was represented as constructed on the double water type—H₂O. SO₃. OH, being derived from H. O. (?) H. O. H, the two hydrogen atoms replaced by parentheses being replaced by the radical SO₃. To these types Gerhard added the hydrogen and hydrogen chloride types, H.H. and H.Cl; and later Kekulé, professor in Bonn (1829), added the Marsh gas type CH₄. The next important step was taken by Frankland, professor in the Royal School of Mines, London; his work, however, had been anticipated by Cunn 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. This is evident from inspection of the formulae of their compounds with hydrogen, thus:

$$\text{H—Cl. H—O—H; H—N} \begin{matrix} H \\ H \\ H \end{matrix} \text{; H—C} \begin{matrix} H \\ H \\ H \\ H \end{matrix}$$

Instances of penta, hexa, and even hepta-valency are not wanting.

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. The plan of action is much the same as that of a mechanician who wishes to imitate a complicated mechanism. He must first dissect it into groups of mechanical contrivances; these are next constructed; and they are finally built together into the complete machine. In certain cases the atoms of carbon are arranged in "chains," as, for example, in pentyl alcohol:

$$\text{H}_3\text{C—C—C—C—C—O—H}$$
$$\phantom{\text{H}_3}\text{H}_2 \text{ H}_2 \text{ H}_2 \text{ H}_2$$

each atom being tetrad, and its "affinities," or powers of combination, saturated either with hydrogen or with those of neighboring atoms of carbon; in others they are in the form of a "ring," as in benzene, the formula of which was first suggested by Kekulé: viz:

One or more atoms of nitrogen, or of oxygen, may form part of the circle, as in pyridine,

and so on. 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; theo-bromine and caffeine, the essential principles of cocoa and tea; alizarine and indigo, valuable dye stuffs; 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, the sugar manufacture, to improvement in tanning, in brewing, 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 lie in one plane, whereas it is evident that they must occupy space or 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 professor at the Institute known by his name at Paris, and more directly to LeBel, and van't Hoff, professor at Berlin, independently of each other. In 1848 Pasteur observed that it was possible to separate the two varieties of tartaric acid from each other, and recently (1859) dead, which bore reference to carvol, a compound of arsenic, carbon, and hydrogen, in which the idea of a radical was confirmed and amplified.

In 1832 Liebig and Wöhler took an important step in elucidating this question by their investigations on benzoic acid obtainable by distilling a resin named gum benzoin. They showed that this acid, C₇H₆O₂, could be conceived as consisting of the group C₇H₅O, to which they gave the name "benzoyl," in combination with OH; that benzoic aldehyde, C₇H₆O, might be regarded as this compound united with hydrogen; that its chloride, C₇H₅OCl, as a combination of the same compound with chlorine, etc. The discovery of "isomeric compounds," i. e. of compounds which possess the same ultimate formula and yet differ entirely in their properties, forced upon chemists the necessity of attending to the structure of the molecule; for only by such a supposition could the difference between two isomeric bodies be explained. In 1823 Liebig discovered that silver fulminate and silver cyanate both possessed the empirical formula AgCNO; in 1825 this was followed by discovery by Faraday that oil gas contains a hydrocarbon identical in composition with ethylene, C₂H₄, yet differing from it in properties; and in 1822 Wöhler, professor in Gottingen (1800-1882), discovered that urea, a constituent of urine, could be produced by heating ammonium cyanate, NH₄CNO, a substance of the same formula. It therefore became clear that the identity of a compound must depend on some other cause than its ultimate composition.

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The idea of a radical having thus become established, Jean Baptiste Andre Dumas, professor in Paris (1800-1884), discovered the theory of "substitution," i. e., that an element such as chlorine or oxygen (which, be it noticed, is electro-negative on Berzelius' scale) could 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 noting whether the element or group separated at the positive or the negative pole of the galvanic battery, or cryolysis. For Berzelius, oxygen was the most electro-negative and potassium the most electro-positive 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 unites compound 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; so that a molecule—the smallest quantity which can exist in a free state, whether of an element or a compound. They recognized, too, that a molecule of hydrogen, chlorine, etc., consists of two atoms.

In 1849, Wurtz, professor in Paris (1817-