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stances known in his day, or the changes earth, or water; and he defined an element as the constituent of a compound body. The first problem, then, to be solved, was to determine which of the numerous forms of matter were to be regarded as elementary, and which are compound, or composed of two or more elements in a state of combination; and to produce such compounds by causing the appropriate elements to unite with each other.

One of the first objects to excite curiosi. ty and interest was the air which surds 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 light, smell or taste, and though it can be Selt, yet it cludes our grasp. The word 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 unds 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 'Jinn" of enormous stature but of delicate texture to issue from a brass pot, as re-lated 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 Torricilli, Jean Rev and others, was first clearly proved by Black, profes sor 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 detom of the phlogistic theory, at the the meland and the manalysis of the only compounds of carbon, viz. by
the manalysis of the only compound of zinc
the manalysis o beating with charcoal or allied bodies. According to this inverted theory, a substance capable of burning was imagined to contain more or less phlogiston, a princiing an carth deprived of phlogiston, or "dephlogicated," behind if a metal. This earth when heated with substances rich in phiogiston, such as coal, wood, flour and similar bodies, recovered the phiogiston, which it had lost on burning, and with the added phiogiston its metallic character. Other substances, such as phosphorous and sulphur, gave solids or acid liquids, to which philogiston 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

The discovery of oxygen by Priestley and by Scheele in 1774, and the explanation of its functions by Lavelsier during the following ten years, gave their true meaning to these phenomena. It was then rec ognized 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 earthy powder, it is being oxidized; that 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 "neid" on the other, while the metal is repro duced in its "reguline" 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 proportion of carbonic "acid" (or, as it is now termed, anhydride)-a discorery perfected by Rutherford, Black, and Cavendish-and that water is a compound with exygen 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 de fended by Priestley until his death in 1804. Such, in brief, was the condition of chemical thought in the year 1809. Scheele had died in 1786, at the early age of fortyfour; Lavoisier was one of the victims of the French Revolution, having been guillotined in 1791; Cavendish had censed 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 penceful old age, enlivened by occasional incursions into the region of sectarion con-

tury 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 study of chemistry self taught, in 1796; and in 1709 he became director of the matic Institution." an undertaking

HE progress of the science of purpose of experiments on the curative chemistry forms one phase of effects of gases in general. Here he at the progress of human thought. once made his mark by the discovery of While at first mankind was contented to observe certain phenomena, or nitrous oxide. At the same time ena, and to utilize them for industrial purhabe constructed a galvanic battery, and beposes, if they were found suitable, "philos- gan to perform experiments with it in at-" as the thinking portion of our tempting to decompose chemical comrace loved to call themselves, have always pounds by its means. In 1901 Davy was attempted to assign some explanation for appointed professor of chemistry at the observed facts, and to group them into similars and dissimilars. It was for long imagined, following the doctrines of the Greeks by Benjamin Thomson, Count Rumford, of hydrogen with one of oxygen. Com-and of their predecessors, that all matter for the purpose of instructing and pounds containing only two atoms were consisted of four elements or principles, amusing its members with recent distermed by him 'binary;" those containing names which survive to this day in popular language. These were "fire," "air," philosophy. In 1807 Davy applied his so on. The weight of an atom of oxygen "water" and "earth." It was not until galvanic battery to the decomposithe seventeenth century that Boyle in his tion of damp caustic potash and soda, gen; while that of an atom of carbon was "Sceptical Chymist" (1961) laid the founda- using platinum poles. He was awarded | six times as great as the unit. By assignthat it was impossible to explain the existence of the fairly numerous chemical sub- pole; and he subsequently proved that first two letters, formulas were developed, these globules, when burned, reproduced indicating the composition of the comwhich they can be made to undergo, by the alkali from which they had been de- pound, the atomic weights of the elements means of the ancient Greek hypotheses re- rived. They also combined with "oxy- being assured. Thus, Na O signified a garding the constitution of matter. He muriatic acid," as chlorine (discovered by laid flown the definition of the modern scheele) was then termed, forming ordimers of the word "element;" he denary salt, if sodium be employed, and the atom of hydrogen, with an atom of oxyclined to accept the current view that the unalogous salt, "muriate of potash," if gen, possessing eight times the weight of properties of matter could be modified by the allied methal potassium were subjecting the qualities of fire, air, ed to combustion. By using mercury as of soda should consist of 22 pounds of sothe negative pole, and passing a current through a strong solution of the chloride of calcium, strontlum or barium, Davy succeeded in procuring mixtures with mer- of each element, and the proportion is not cury or "amalgams" of their metals, to changed, however many particles be conwhich he gave the names calcium, strontium, and barium. Distillation removed dium, were found to attack glass, liberat-

pounds of the respective metals with oxygen, but Davy showed that lime, and its ments of metallic appearance. To complete our review of this part of the subject, suffice it to say that nluminum, a metal now produced on an industrial scale, was prepared for the first time in 1827 by Wohler, professor of chemistry at Gottingen, by the action of potassium on its chioa small pinch of solid powder as for a ride, and alumina, the earthy basis of clay, was shown to be the exide of the metal aluminum. Indeed, the preparation of this metal in quantity is now carried out at Schoffhausen-on-the-Rhine, and at trolysis of the oxide dissolved in melted cryolite, a mineral consisting of the fluoand potassium in 1896.

To Davy, too, belongs the merit of haveven represented in the name-only inof an oxide of nitrogen and an oxide of a metal; a "sulphate," of the oxide of a and so on. Davy, by discovering the elethat it is not an oxide of hydrochloric acid and second, that the latter acid is the compound of the element chlorine with hydrocen. 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 caron is thereby produced; by acting on certain chlorides, such as those of tin or phosphorus with ammonia, and showing formed; and, lastly, by decomposing "murintic acid gas" (gaseous hydrogen chloonly 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 introduced the simpler and correct view 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, 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 inlustrial application of the process. The difficulty of isolating fluorine is due to its extraordinary chemical energy; for there are few substances, elementary or comcound, which regist the action of this pate sellow, suffocating gas. In 1811 todine, separated by Courtols from the ashes of

have been termed "halogens," or "salt While Davy was pouring his researche nto the astonished ears of the scientific nd 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 sam proportions, or, as the phrase runs, "posess constant composition." Wolls ndeed, 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 binox-

sea plants, was shown by Davy to be an

sac subsequently investigated it and pre-

the last of these elements, bromine, was

by Balard. The elements of this group

ared many of its compounds; and in 183

iscovered in the mother liquor of sea sait

lement analogous to chlorine.

bounds, to indicate the respective propor the happy idea that by applying the an-cient Greek conception of atoms to such views with the two compounds of carbon with hydrogen, marsh gas and oleflant as, and with the two acids of carbon, carbonic axide, carbonic "acid," he re-garded the former as a compound of one atom of carbon and one of hydrogen, and carbon and two of hydrogen, and similarly the relative weights in which these ele-Placing the relative weight of an atom of hydrogen equal to unity, we have:

Marsh fiant	Car	Car			
Marsh fiant	bonic bonic				
Carbon	6	6	Carbon	5	6
Hydrogen	1	2	Oxygen	8	15

It has been pointed out by Judge Stallo most of the mercury, and the metal was left behind in a state of comparative purity. The alkali metals, potassium and sonature, as for example, the fact of simple ing "the basis of the silex," to which the and multiple proportions, is not explained name silicon has since been given.

by being minified. Allowing the general Thus nearly the last of the "earths" had truth of this statement, it is nevertheless been decomposed. It was proved that not undoubted that chemistry owes much to merely were the "calces" of iron, copper, Dalton's hypothesis; a lucky guess at first, lead and other well-known metals com- it represents one of the fundamental truths of nature, although its form must be somewhat modified from that in which allies, strontia and baryta, and even silica | Dalton conceived it. Dalton's work was or flint, were to be regarded as oxides of 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 1806, in 1816,

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 Berzellus, a Swede, who devoted his long the Falls of Foyers, in Scotland, by elecpounds, and to the determination of their composition, or as it is still termed, the rides of sodium and aluminum by a determination of the "atomic weights"method differing only in scale from that 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 ing dethroned oxygen from its central po-sition among the elements. Lavoisier Lavoisier had devised a method for the er that the term oxygen was not ume of carbon dioxide produced, as well as that of the residual oxygen, Berzelius ferred. Thus a "nitrate" is a compound achieved the same results more accurate ly and more expeditiously by heating the ubstance, mixed with chlorate of pometal with one of the oxides of sulphur, tassium and sodium chloride, and then extimating the hydrogen as well as the carmentary nature of chlorine, showed first | bon; this process was afterward perfected by Liebig. Berzelius, however, was able (or muriatic acid, as it was then called); to show that compounds of carbon, like those of other elements, were instances of

ombination in constant and in multiple proportions. In 1815 two papers were published in the 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 that no oxide of tin or phosphorus is time supposed to represent the "atomic weights" of the elements. Prout's hypothesis, based on only a few numbers, was ride) with sodium, and showing that the 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 Bernelius' numbers, with oxygen and the oxide of a metal, he | the balance of opinion was against it. But about the year 1849 Dumas discovered an that a chloride is merely a compound of error in the number (12.12) given by Ber the element chlorine with a metal. In 1813 zelius as the atomic weight of carton; and the established the similar nature of with his collaborator, Stas, undertook the redetermination of the atomic weights of the commoner elements, for example, carbon, oxygen, chlorine, and calcium. 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 com- Dumas (187) consists in vaporizing the pletely disproved by Stas' subsequent work, as well as by that of numerous atomic weights approximate to whole pacity of the bulb, the weight of hydro numbers than would be forctold by the doctrine of chances, and perhaps the last 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 Gayussac (1778-1856) 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 compine with one volume of oxygen to form water, the gases having been measured at the same temperature pressure. Humboldt suggested to Gayussae that it would be well to investigate whether similar simple relations exist be tween 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 volum of oxygen to form carbon dloxide; 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 altrogen, 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 multi-

the atomic theory; but it did not accord and hydrogen chloride unite to form amwith many of the then received atomic weights. The assumption that equal vol-umes of gases contain equal numbers of facts the relative weights of the atoms particles, or as they were termed by him, $(NH_3+HC1-NH_4C)$ could be determined. Illustrating his molecules integrantes, was made in 1811 14+30(1+35.5) 53.5. 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 follow the second as a compound of one atom of ling reasons: A certain volume of hydrogen, say one cubic inch, may be suppos for the two oxides of carbon. Knowing to contain an equal number of particles (atoms) as an equal volume of chlorine ments enter into combination, we can de-duce the relative weights of the atoms. Who describes the relative weights of the atoms. 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 hydroger chloride, the compound of the two ele ments, as one cubic inch originally con tained of hydrogen, or of chlorine. Thus we have two cubic inches containing, of uncombined gases, twice as many parcombinations. Avogadro's hypothesis solved the difficulty. By premising two different orders of particles, now termed plain. According to him, each particle or molecule of hydregen 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 onsists of a molecule, or double atom, Thus two cubic inches of hydrogen chlo-ride consists of a definite number of moleules, 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 make them fit it. But later he somewhat extend to liquids and solids a theory 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. It will be advisable to revert to this hypothesis at a later point, and to consider other guides for the determination of

omic weights. In 1819, Dulong (1785-1828), director of the (1791-1826) 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

or 1 gramme of water through 1 degree centigrade) which is necessary to raise the atomic weight expressed in grammes of any solid or liquid element through 1 de-gree centigrade is approximately 6.2; it answer is indicated by a study of the cavaries between 5.7 and 6.6 in actual part. pillary phenomena of liquids, one method This affords a means of determining the of measuring which is the height of their true value of the atomic weight of an ele-ment, as the following example will show: as the following example will show: is impossible in the space at our disposal 26.5 grains of hydrogen chloride; and as airendy remarked, one volume of hydro gen and one volume of chlorine combine. forming two volumes of hydrogen chlo ride. Applying Avogadro's hypothesis, one molecule of hydrogen and one molecule of chlorine react to yield two molecules of hydrogen chloride; and as each molecule is supposed to consist in this case of two atoms, hydrogen-chloride consists of one atom of each of its constituent elements. The amount of that ele ment, therefore, which combines with 35.5 grains of chlorine may give the numerical value of the atomic weight of the element the compound contains one atom of ach element; in that case the formula of he above compound would be zinc, and the atomic weight of zinc, 22.7; but if the formula is ZuClo, the atomic weight of zinc would be 32,7 x2: H ZnCl, 32.7 x2, and so on The specific heat of metallic zinc enables this estion to be selved. For it has been found experimentally to be about 0.095; and 2+0.095=55.2, a close approximation to 32.7×2=65.4. The conclusion is therefore atom of zinc in combination with two atoms of and that the molecular weight of zinc chloride tive weight of a mole, de of hydrogen is: that of an atom being 1), zinc chloride in the gaseous state should be 136.4-1-18.2 times that of hydrogen, measured at the same temperature and pressure. This has been found experimentally to be the case. The methods of determining the vapor densities, or relative weights of vapors, as three in number; the first method, due to substance in question in a bulb of glass or of porcelain, at a known temperature, other observers. It is nevertheless cu- closing the bulb while still hot, and weighrious that a much larger proportion of the ling it after it is cold. Knowing the cagen necessary to fill it at the desired tem perature can be calculated, and the densihas not been heard of Prout's hypothesis, ty of the vapor thus arrived at. A second method was devised by Gay-Lussac and

> use of execution, is due to Victor Meyer 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 required to replace one unit weight of hydrogen. These were generally regarded as atomic weights by Dalton and his contemcaries:

perfected by A. W. Hofmann (1868); and

a third, preferable for its simplicity and

the law of Dulong and Petit, viz: berylium or glucinium, an element occurring in emeralds; boron, of which borax is compound; silicon, the component of uartz 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 be havior is not peculiar to these elements, for it appears that the specific heat of all lements increases with rise of temperature.

also been noticed to the law of Gay-Lus-sac, which may be formulated: the molecular weight of a compound in a gaseou ples of the latter. Gay-Lussac recognized state is twice its density referred to hyfounded by Dr. Beddees at Bristol for the lalate of potash were applied to these com- I this discovery of his to be a support for drogen. Thus, equal vol

monium chloride. It was to be expected that the density should be half the molecular weight, thus: (N Ha+H Cl=NH₄Cl; /.ad 53.5+2=26.75=density

But the density actually found is only half that number, viz, 12.37; 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 ressure expand equally for equal rise of temperature. In other instances the grad- are still in universal use, were also deperature can be followed, as with chloral hydrate, the products of which are chloral

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 com-pound body with rise of temperature. To this gradual decomposition he gave the name dissociation. This conception has 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, atoms and molecules, the solution was 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 Brereten Baker that if perfectly free from moisture, ammonium chloride gas-ifies as such, and that its density in the state of vapor is in fact 26.75. The molecular complexity of gases has

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 this theory, and indeed went so far as to gas is represented by the product of the change many of his atomic weights to 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 volum of a gas diminishes in proportion as the which could be held only of gases. Avo- pressure increases; of Gay-Lussac's law, gadro's suggestion, therefore, rested in that all gases expand equally for equal abeyance until the publication, in ISSS, by 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 (1965-1969), professor at University College, London, and subsequently master of the Royal Mint. Graham discovered that the rates of diffusion of gases into each other Ecole Polytechnique at Paris, and Petit is inversely as the square roots of their densities. For instance, the density of hydrogen being taken as unity, that of oxygen is 15 times as great; if a vessel con-taining hydrogen be made to communicata with one containing oxygen, the hydrogen will pass into the oxygen and mix with it; the hydrogen vessel. This is due to the hatriasic 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 will enter the oxygen vessel. Now, 4-176; 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 relaand that Ramsay and Shields succeeded in to them, for few of them are electrolytes 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 ciaicd:" L e., their molecules occur in couplices of two, three, four, or more, and as the temperature is raised the complex-

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

While the researches of which a short count has now been given have led to knowledge regarding the nature of moleexcited interest since the early years of the century, and its investigation has led to important results. The fact of the deomposition of acidified water by an electrie current, discovered by Nichelson and Carlisle, and of salts into "buses" and 'acids" by Berzelius and Hisinger in 1800, led to the belief that a close or drawn that zinc chloride is composed of one tion exists between electric energy, or, as it was then termed, "electric force," and hlorine, that the atomic weight of zinc is \$6.4, the affinity which holds the constituents of chemical compounds in combination 65.4+(35.5×P=136.4. Inasmuch as the rela- 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 and then brought into contact they beome 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, Berzellus 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 electripossesses 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 olarity of an element or group could be determined by noting 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 electro-positive of the elements, the bridge between the "non-metals" and the "metals" being hydrogen, which, with atem of hydrogen can be replaced by nitrogen, forms a basic, or electro-positive, group, while with chlorine, etc., it forms electro-negative groups. The fact It is to Laurent and Gerhardt that we own that an electric current splits of in solution into two portions, led Berzellus to devise his "dualistic" system, which involved the assumption that all comounds consist of two portions, one electro-positive, the other electro-negative, Thus sulphate of magnesium and potassium was to be regarded as composed of electro-positive potassium sulphate in mbination with electro-negative magne-

sium sulphate; the former in its turn con-

sted of electro-negative sulphur trioxide

(SO₂) in combination with electro-positive oxide of potassium (K-O); 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 SO₂ as a whole was electro-negative, while KaO was electro-positive. The symbols given above, which ual decrease in density with rise of tem- vised by Berselius for the purpose of illustrating and emphasizing his views. These views, however, met with little acceptance at the time in England.

Lavoisier's idea, that oxygen was the

cessary constituent of all acids, began

about this time to lose ground. For Davy had proved the elementary nature of chlo rine; and hydrochloric acid, one of the strongest, was thus seen to contain no oxygen, and Davy expressed the view, founded on his observation, that lodic "acid," I₀O₅ was devoid of acid properties. until dissolved in water, and that the essential constituent of all acids was hydrogen, not oxygen. The bearing of this by Berzellus as 202 containing no hydrogen, and was supposed to be separated as such at the positive pole of a battery, Davy's suggestion led to the opposite conclusion that the formula of sulphuric acid solved into H2 and SO. Faraday's electrolytic law, that when a current is passed through electrolytes in solution the elements are liberated in quantities propor-tional to their ecuivalents, 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. Now, if Berze-ilus' theory be true, the products should be SO2 and K2O, but if the opposite view be correct, then K- is liberated first and by its subsequent action on water it yields potash, and its equivalent of hydrogen, This was pointed out first by Daniell, professor at King's College, London, and it was regarded as a powerful argument against Berzelius' system. In 1822, too, Graham investigated the phosphoric acids, and prepared the salts of three, to which he gave the names ortho, pyro, and meta-phosphoric acids. To understand the bearing of this on the doctrine of views, just stated, are still held by chemnamed phosphoric acid. When dissolved water it reacts with bases, forming salis-the phosphates. But the quantity of water necessary was not then considered essential; Graham, however, showed pilcated mechanism. He must first dissect that there exist three series of salts; it into groups of mechanical contrivances; one set derived from P₂O₅3H₂O; one from P₂O₅2h₂O, and a third from P₂O₅H₂O. His way of stating the fact was that water machine. In certain cases the atoms of could play the part of a base; for example, the ordinary phosphate of commerce possessed, according to him, the formula P2O22Na2O, H2O; two-thirds of the "water of nstitution" being replaced by exide of odium. Liebig, then professor at Giessen (1803-1873), founded on these and on similar bservations of his own the doctrine of solybasic acids-acids in which one, two, three, or more atoms of hydrogen were replaceable by metals. Thus, instead of writing, as Graham did, P₂O₂ 2Na₂O.H₂O, he wrote PO₄Na₅H; and for orthophosphoric acid PO4H3. The group of therefore existed throughout the whole sa ries of orthophosphates, and could exist in combination with hydrogen, with hydrogen and metals, or with metals alone. Similarly the group (P2O2) was characteristic of pyrophosphates and (PO) of metaphos phates, for P2O,2H2O(P2O) H4; and P2O, H2O

2(PO₃)H. and therefore their products of electrolysis, being non-existent, could not be classsified. Nevertheless Gay-Lussac regarded alcohol, C_2H_4O , as a compound of C_2H_4 ethylene, and H₂O, water, and oxalic acid (antimate formula and yet differ entirely in 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 cules, the structure of the molecule has by the discovery by Faraday that oil gas contains a hydrocarbon identical in comfrom it in properties; and in 1829 Wohler, professor in Gottingen (1900-1882), discovered that urea, a constituent of urine, could be produced by heating ammonium cyanate. NH₆CNO, a substance of the formula. It therefore became clear that the identity of a compound must depend on some other cause than its ultimate In 1833 Liebig and Wohler took an im-

portant reep in elucidating this question by their investigations on benzoic acid this acid, C2H2O5, could be conceived as consisting of the group C. H.O. to which they gave portions of these elements be insulated the name "benzoyl," in combination with mensions and possess the attributes of OH; that benzoic aldehyde, C.H.O. might be solidity. The conception which led to the ine and bromine and sulphur, and replaced hydrogen is ammonia (C-H₀O,NH₀, They termed this group, benzoyl, a "compound element" or a "radical." This re-

e-nic, carbon, and hydrogen, in which tals with an extra face, unsymmetrically the idea of a radical was confirmed and The idea of a radical having thus be ome established, Jean Baptiste Andree Dumas, professor in Paris (1860-1886), propounded the thory of "substitution," L e., that an element such as chlorine or oxygen (which, be it notice), is electro-nega tive on Berzelius' 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 (1877-1853), and Gerhardt, professor at Montpeller and at Strassburg (1816-1856), emphasized the fact that one element, be it what it may, can replace mother without fundamentally altering ts chemical character, and also that an group of atoms or radical, behaving for the occasion like the atom of an element the definition of an atom-"the smalless quantity of an element which can be preent in a compound;" an equivalent-"that weight of an element which combines with er replaces one part by weight of hydrogen;" and a molecule-"the smallest quatity 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

1884), and Hofmann, then professor in the College of Chemistry in London, after-ward at Berlin (1818-1822), discovered series of compounds ailled to ammonia, NH₂ in which one or more atoms of hydrogen were replaced by a group or radical, such as methyl (CHa), ethyl (CaHa), or phenyl (CaHa). Wurtz referred such comp ammonia "type." They all resemble amnonia in their physical properties smell, taste, etc.-as well as in their uniting with acids to form salts resem-bling ammonium chloride (NH, Cl), and other ammonium compounds. Shortly after-ward Williamson, professor at University College, London (1824—), 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. Thus we

have the serie H. O. H.; CH. O. H.; CH. O. CH.; and NH.; NH₅; H₆; NH_{(CH₆)c}; and N(CH₆)c; the first representing compounds following the water type, the latter the ammonla type. This suggestion had been previously made by Laurent in 1846. But Williamson extended his views to inorganic compounds; thus, sulphuric theory on the dualistic theory is, that was represented as constructed on while, e. g., sulphuric acid was regarded the double water type-HO. SO, OH, being derived from H. O. (F. H) O. H, the two hydrogen atoms enclosed in parentheses being replaced by the radical SO₂. To these types Gerhardt added the hydrogen and hydrogen chloride types, H.H. and H.Cl; is H_SO_k and that, by the current, it is re- | and later Kekule, professor in Bonn (1829), added the Marsh gas type C(H). 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 novalent. 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; offrogen a triad, or trivalent; carbon a tetrad, or tetravalent, and so on. This is evident from inspection of the formulae of their

H-C1, H-O-H; H-N(H; H)CH

Instances of penta, hexa, and even hepta-

valency are not wanting.

This was the key to unlock the structure ism it must be remembered that P₂O₅, lsts. The determination of the constitupentoxide of phosphorus, was at that date tion of compounds, chiefly those of carben, 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 comthese are next constructed; and they are finally built together into the complete carbon are arranged in "chains," as, for example, in pentyl alcohol:

H₂C-C-C-C-C-O-H

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 Kekule: viz:

In pyridine,
$$N = \begin{array}{c} H & H \\ C - C \\ C = C \end{array}$$

$$CH \quad \text{furfuranc.} \quad 0 < \begin{array}{c} H & H \\ C & C \\ C & C \end{array}$$

and so on. By means of conceptions such hydrous), C.O. as one of CO. with CO. The discovery of "isomeric compounds," i. e., of compounds which possess the same ulas these many interesting compounds which they contain; e. g., urea and urio their properties, forced upon chemists the and caffeine, the essential principles of cocca and tea; alizarine and indige, valnable 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, 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 an acid obtainable by distilling a resin not represent the true constitution of matnamed gum benzoln. They showed that ter, inasmuch as the atoms are imagined to lie on a plane, whereas it is eviden that they must occupy space of three diregarded as its compound with hydrogen; formulation of such views was due first to that it also formed compounds with chior- 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 1818 Pasteur discovered search was followed by one by Robert that it was possible to separate the two Bunsen, professor at Heidelberg, born in varieties of tartaric acid from each other, 1811, and recently (1859) dead, which bore and that that one which rotated the plane reference to cacodyl, a compound of ar- of polarized light to the right gave crysdisposed 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 mix ture of these acids gave crystals not characterized by an unsymmetrically placed face; and also that the solution was without action on polarized light. servations remained unexplained until Le Bel and van t' Hoff, in 1874, simultaneous. ly and independently devised a theory which has up till now stood the test of research. It is briefly this: Imagine two regular tetrahedra, or three-sided pyramids, standing each on its triangular base. An idea can best be got by a model, easily made by laying on a table three lucifer matches so as to form an equilateral triangle, and erecting a tripod with three other matches, so that each leg of the tripod stands on one corner of the triangle. At the centre of such a tetrahedron, an atom of carbon is supposed to e placed. Marsh gas, CH6 is supposed to have such a structure, each corner. solid angle of the structure (of which there are four; being occupied by an atom of hydrogen. This represents the solid or marsh gas. Now suppose one of the atoms In 1849, Wurtz, professor in Paris (1817 be replaced by chlorine, the group (OH),