THE BORDERLAND BETWEEN PHYSICS AND CHEMISTRY.

BY GEORGE F. BARKER.

An Address delivered on assuming the Chair as President of the Society for 1891.

In thanking the American Chemical Society for the honor it has done me in electing me as its President for the year 1891, it seems fitting that I should use the present opportunity for the purpose of outlining very briefly one or two of the more important relations existing between chemistry and physics, which are now shaping the direction of investigation. The conception of the periodic law, first by Newlands, and subsequently by Lothar Meyer and Mendeléeff, will ever be regarded as marking an important epoch in the progress not only of pure chemistry, but also of the physics of chemistry as well. For not only does this law assert that the purely chemical properties of the elements are periodic functions of the masses of their atoms, but it asserts also that their physical properties are like functions. In consequence, the impetus which these assertions have given to investigation seems but little short of marvellous. Not only were new researches undertaken by the chemist to fix more precisely these atomic masses, new calculations made upon data already accumulated, and new relations experimentally established going to show the position of the doubtful elements in the periodic series ; but the most elaborate experiments were begun also by the physicist upon the phenomena of solution, of density, of specific heat, of refraction, of electric conductivity and the like, in order to connect these physical properties with the mass of the atom ; and thus to establish the predominant influence of the atom, even in molecular physics. Maxwell long before had pointed out the advantages to be secured by what he happily called "the cross fertilization of the sciences." And Lord Rayleigh in his presidential address at Montreal, in following out this suggestion, had instanced "the neglected borderland between two branches of knowledge" as that "which often best repays cultivation." "I cannot help thinking," he says, alluding to the progress already made by general chemistry, "that the next great advance, of which we have already some foreshadowing, will come on this side." "If I might without presumption" he adds "venture a word of recommendation, it would be in favor of a more minute study of the simpler chemical phenomena."

At the outset however, it seems to me that a word should be said concerning the terminology of these closely allied sciences. If it be true that in both physics and chemistry, taken separately, precision of thought and consequent precision of language are dependent upon a precise use of terms, how much more true is it in that limiting region which lies between them. The terms here employed are borrowed in the main either from chemistry on the one side or from physics on the other. So that the chemist is quite as much bound to use the terms of physics in the physical sense as the physicist is to use those of chemistry in the chemical sense. As an illustration of this let us take the terms atom and molecule for example. To the chemist they represent perfectly definite portions of matter, the latter in general larger than the former, since the molecule is itself made up of atoms. So that in chemistry the molecule is commonly defined as the smallest particle of any substance which can exhibit the properties distinctive of that particular kind of matter; while the atom is considered to be the smallest particle of simple matter which can enter into the formation of a molecule. To the physicist, however, this distinction is not so obvious. In a lecture, delivered in 1883 before the Royal Institution of Great Britain upon the size of atoms, Sir William Thomson said: "I speak somewhat vaguely and I do not do so inadvertently, when I speak of atoms and molecules. I must ask the chemists to forgive me if I even abuse the words and apply a misnomer occasionally. The chemists do not know what is to be the atom ; for instance, whether hydrogen gas is to consist of two pieces of matter in union constituting one molecule and these molecules flying about: or whether single molecules each indivisible, or at all events undivided in chemical action, constitute the structure." The evidence upon which this criticism is founded is unfortunately too common. Vagueness in the use of these terms even among chemists is far too frequent. Bloxam, for example, defines molecules as "the smallest physical particles of matter;" and an atom he says is "the smallest imaginable particle of matter." The subsequent use of the terms atom and molecule as synonymous, in Sir William Thomson's lecture, however, shows that his atom is the atom of the physicist and corresponds to the molecule of the chemist. It is greatly to be desired that some agreement should be reached in the definition of these words. The simplest solution of the problem would be, of course, the abandonment of the word atom by the physicist, except when he makes use of it in the purely chemical sense.

In recent years, perhaps no terms in physics have been more sharply and more properly differentiated, than the terms "mass" and "weight." The former is a quantity of matter and its standard unit of measure is the gramme. The latter is a quantity of force and its unit is the dyne. Hence, strictly speaking, it is as unscientific to speak of a weight of ten grammes, or of a mass of ten dynes, as it is commonly regarded to refer to the length of a rod as having the value of twenty seconds, or to a time as being six yards long. Unfortunately, however, custom has so long sanctioned the use of the former expressions that we have ceased to regard them as inadmissible. Moreover, the law of gravitation tells us that the force of this attraction measured in dynes is directly proportional to the product of the attracting masses, measured in grammes. Whence by ellipsis, we speak of a weight of ten grammes as meaning the attractive force which the earth exerts upon a mass of ten grammes ; *i. e.*, 9800 dynes. And of a mass of ten dynes as the mass upon which the earth's attraction would be ten dynes of force ; *i. e.*, nearly one centigramme. In consequence units of mass have come into use as gravitation units of force.

This confusion of terms is most unfortunate. Mass is invariable for any given body, no matter in what part of the universe it is and no matter to what conditions it may be subjected. It is an invariable attribute of matter itself. Weight, on the other hand, depends upon the presence and attraction of other bodies in the vicinity of the body in question, and is therefore an entirely accidental attribute of matter. Indeed, a body may have no weight, even in presence of other matter, provided that the sum of the attractions in opposite directions be zero ; as is the case, for example, at the centre of the earth. It is not surprising therefore that in physics it has been found essential to scientific precision, to use the word "mass" whenever quantity of matter is meant, and the word "weight" whenever the force of the earth's attraction is referred to.

Moreover, the distinction now drawn is practically recognized in ordinary life. Because of its convenience, weighing is the process by which mass is ordinarily measured. Coal is bought by the ton, beef by the pound and quinine by the ounce. In all these cases the purchaser desires the particular quantity of these substances indicated by these standards of mass respectively. Not only is the weight concerned, *i. e.*, the earth's attraction, entirely immaterial, but it is often undesirable. In other words, the less the weight, provided the mass be the same, the better. In rare cases it is true that weight as such, is the thing purchased ; as lead for the keel of a vessel or stone for ballast. In the same sense that mass, though proportional to weight is not weight, the standards used in weighing, while proportional to the earth's attraction, are not standards of weight but standards of mass ; *i. e.*, are not weights but are masses.

This confusion, so far from being lessened, is rather increased by the fact that the word "weight" is used in two senses. Not only is it employed to signify force, which is its legitimate definition, but it is also used as a synonym for "mass"; so that in many cases it is quite impossible to determine the particular sense intended. A definition, it has been well said, should clearly distinguish the thing defined from everything else. What place then can a term have in exact science, which, like the word "weight" connotes two entirely distinct ideas? For this reason it is that the use of the word "weight" in the sense of mass has well nigh disappeared from the terminology of pure physics. The quantity of matter in a body is now always called its mass and is expressed in units of mass or grammes. The earth's attraction upon this quantity of matter is called its weight and is expressed in units of weight or dynes. Standards used in determining mass by weighing are properly termed standard masses and not standard weights. Moreover, the same is true of the terms derived from these fundamental ones. Density is the mass contained in unit volume and the density of a substance is the number of grammes of mass which occupies a cubic centimetre. The idea of specific gravity is retained in the term "relative mass," which is defined as the ratio of the mass of a body to the mass of an equal volume of water. In the same way, one body is said to be more massive than another when its mass is absolutely greater; and denser, when its mass is relatively greater; instead of using the term "heavier" in both cases. In short, physics has decreed, in order to secure the precision essential to scientific progress, that an absolute divorce should be granted between the terms "mass" and "weight," each being used only in its proper sense.

Chemistry, however, has hardly yet begun to recognize the importance of this decree; and in consequence serious confusion of ideas continues to result. In the 7th edition of an English chemistry of considerable repute, just issued from the press, I find for example the following definition: "Matter, in a chemical sense, is anything which possesses weight." Evidently the word "weight" cannot here be used in its legitimate sense of gravitative force; because at the centre of the earth matter exists, although it has no weight. It must therefore be employed in the sense of mass; and the sentence may be read "matter is anything which possesses mass": *i. e.*, quantity of matter. Thus read it becomes a truism and not a definition. It is this use of the word "weight" as a synonym for "mass," and which is clearly illegitimate, which is so common in chemical literature and which is so unfortunate. Thus I find in the Chemistry just referred to, the statement that "the unit of weight now very generally adopted by scientific chemists is one gramme of hydrogen, which measures 11·16 litres at 0° C. and

760 m.m. Bar ;" a statement most perplexing to the average student, in comparison with the declaration "the unit of mass is a gramme," which is all that the quotation really states.

If all this be granted, and I think it must be, then another and a more radical change should be made in chemical terminology. I allude to a change in the expressions "molecular weight" and "atomic weight." Using the word "weight" absolutely and in its legitimate sense, these terms, as they are commonly used, have no meaning whatever. Neither the absolute attraction of the earth for a molecule nor its attraction for an atom, expressed in dynes, can have any constant value, since the earth's attraction is not the same at different points of its surface. How much more absurd then is it to speak of the absolute weight of an atom, say of hydrogen, as being the same upon the sun or upon a fixed star. If, however, the claim be made that the word "weight" is here used, not in an absolute but in a relative sense, then it appears to me that the whole question is conceded ; since it is granted that the attribute implied in the term used must of necessity be an invariable attribute, independent of time and place, and this, in its essence, the word "weight" is not. It is true, of course, that relative atomic and molecular weights are invariable ; but this is evidently only because the absolute weight of the standard of comparison varies from place to place, and in the same direction. Precisely as the apparent weight of a mass of lead would be constant everywhere if balanced against a standard kilogramme.

But this use of the word "weight" is not the use generally implied in the terms atomic and molecular weight. It is used in chemistry almost without exception as a synonym of the word mass. The very conception of an atom or of a molecule is that of a definite mass of matter. Atoms, says Lothar Meyer, are "individual isolated particles of matter, possessing definite and unvarying weights ;" *i. e.*, masses. Even vortex atoms "are small but finite systems of matter which rotate about an endless curve as axis, and which, according to the investigations of Helmholtz, possess the peculiar property that their mass cannot be affected by external influences." Muir tells us that "the symbol of an element, *e. g.*, H, O, Cl, or of a compound, *e. g.*, H_2O, HCl, represents a definite mass of that element or compound"; and he defines "the maximum atomic weight of an element" as "the smallest mass, in terms of hydrogen as unity, of that element in a molecule of any compound thereof." "To every element" he says, "a number may be given which expresses the smallest mass of that element which combines with unit mass of some element chosen as a standard. These numbers also express the smallest masses of the various elements which severally combine with each other." So Remsen, in stating the law of multiple proportions, says: "If two elements, A and B, form several compounds with each other and we consider any fixed mass of A, then the different masses of B which combine with the fixed mass of A, bear a simple ratio to one another." In illustrating this law he states: "The mass of oxygen combined with a given mass of carbon in carbon dioxide is exactly twice as great as the mass of oxygen combined with the same mass of carbon in carbon monoxide." Again, the law which underlies all chemical action is known as the law of the conservation of mass. It asserts that "the mass of matter which takes part in any change, whether physical or chemical, remains unaltered." And, finally, we have the important law of the action of mass, which is thus given by Remsen: "Chemical action is proportional to the active mass of each substance taking part in the change."

Moreover, the terms "atomic mass" and "molecular mass" refer equally to invariable quantities of matter, whether the word mass be taken in the absolute or in the relative sense. The absolute mass of an atom of sodium is the same, at least if we may judge from the period of its vibration, upon the sun, Sirius and Aldebaran, as upon the earth. And invariability of absolute mass necessarily involves invariability relatively. At present, the atomic masses of the elements given in our text books, are all relative, being expressed in terms of that of hydrogen, taken as unity. But it is evident that from these relative masses, the absolute atomic masses of all the elements can be obtained by simple multiplication, so soon as we know the absolute mass of the hydrogen atom. According to Lothar Meyer, "under a pressure of one atmosphere and at the mean temperature of about

20°, one cubic millimetre of any gaseous substance which obeys Avogadro's law contains about 21 trillions of molecules. But as one cubic centimetre of hydrogen under the given conditions weighs (*i. e.*, has the mass of) 0.0835 milligramme, the weight (mass) of a molecule of hydrogen must be $\mathfrak{H}=H_2=\frac{0.0835}{21.10^{18}}=\frac{4}{10^{21}}=0.000,000,000,000,000,000,004$ milligrammes; or a quadrillion molecules of hydrogen weigh (have a mass of) about four (milli) grammes."* Hence if we may assume that such a molecule as this is the molecule of Avogadro's law and consists of two atoms the conclusion is easy that a quadrillion hydrogen atoms have an absolute mass of two milligrammes. Whence the absolute mass of a quadrillion chlorine atoms is 70.74 milligrammes, of a quadrillion oxygen atoms 31.92 milligrammes, of a quadrillion nitrogen atoms 28.02 milligrammes, etc. In other words, the number expressing the relative molecular mass of an element, represents in milligrammes the absolute mass of a quadrillion atoms of that element.

These considerations make sufficiently evident, I think, the great gain that would accrue to chemistry in clearness of conception and precision of expression, were the word "mass" always to be employed whenever quantity of matter is referred to and the word "weight" only when the force of the earth's attraction is meant. True it is indeed, that the adoption of this rule will oblige us to give up the older and more familiar terms "atomic weight" and "molecular weight," and to substitute in their places the newer ones "atomic mass" and "molecular mass." But true progress in any science is attended with frequent revisions of its terminology; and in none more than in chemistry. It is a sufficient reason for such a change to show that thereby the science becomes better equipped for the further conquest of truth.

Returning now from this digression, it seems to me that one of the most noteworthy steps of progress recently taken is to be found in the analogy pointed out by Van't Hoff, between

---

* Modern Theories of Chemistry, p. 111.

gases and dilute solutions. In pure physics, the kinetic theory of gases as developed by Clausius, Maxwell, Boltzmann and others has led to the most important generalizations and has established the constitution of gaseous masses upon a firm foundation.. From the simple assumption that the molecules of matter in the gaseous state are moving in straight lines, and that they are subject in consequence only to the laws of mass motion, conclusions have been derived which agree so closely with the facts as to make it appear that the properties exhibited by substances when in the gaseous state are necessary results of this fundamental hypothesis. Permit me briefly to recapitulate some of these conclusions. It follows in the first place that the pressure exerted by a gas outwardly is due simply to the impact of its molecules; so that if m be the mass of a molecule and v its speed $\frac{1}{2}mv^2$ will represent its kinetic energy and $\Sigma\,\frac{1}{2}mv^2$ the kinetic energy of the mass of unit volume; a value which becomes $n.\frac{1}{2}mv^2$, if n like molecules having a mean speed v are contained in unit volume. For a second gas, the kinetic energy of unit volume will be $n'.\frac{1}{2}m'v'^2$, of course. But since the outward pressure exerted by the gas is due to its kinetic energy, this energy must be the same for equal volumes of any two gases when they are under the same pressure; *i.e.*, that of the atmosphere. Whence we have

$$n.mv^2 = n'.m'v'^2$$

If now these two gases have the same temperature, they are in thermal equilibrium and $mv^2 = m'v'^2$; whence $n = n'$ and the number of molecules in unit volume is the same for both gases; which is the law of Avogadro. Moreover, since $mv^2 = m'v'^2$, we have $v^2 : v'^2 :: m' : m$; or the speed of translatory motion in a gas is inversely proportional to the square root of its molecular mass; *i. e.*, of its density; which is Graham's law of diffusion. Again, since the molecules are moving in all directions we may resolve this motion along three perpendicular axes; so that the actual pressure in any one direction is $p = \frac{1}{3}mnv^2$. Now although we may not know the actual value of either m or n, yet we do know their product mn, which is the mass of the molecules in unit volume; *i. e.*, the density of the gas. Representing this by δ, we have $p = \frac{1}{3}\delta v^2$. Hence the density of a gas varies directly as the pressure upon it; which is the law of Boyle or Marriotte. Since $V=1/\delta$, or the volume of a gas is inversely as its density, the law may be stated in its ordinary form—the volume of a gas varies inversely as the pressure upon it. So, since $\delta=mn$, $\delta'=m'n'$, and $n=n'$, we have $m:m'::\delta:\delta'$; or the molecular masses of two gases are directly proportional to their densities, which is the law of Gay Lussac. If the temperature is constant, the mean speed is constant, and pV, which equals $\frac{1}{3}v^2$, is also constant. As pV is proportional to the absolute temperature, v must be so. Hence the volumes of all gases are proportional to the absolute temperatures, and therefore expand and contract equally by heat; which is the law of Charles. From the equation $v^2=3p/\delta$ we may calculate this mean speed of translation. Thus for hydrogen at 0°, Clausius obtained $v=\sqrt{\frac{3\times1033\times980}{.0000896}}$ or 1844 metres per second. For oxygen it is 461 and for nitrogen 492 metres. The fruitfulness of the kinetic theory, it will be noticed, is not confined to physics, even in the case of gases, since it is upon the law of Avogadro, a direct conclusion from it, that the ordinary method of fixing molecular masses by means of vapor-density depends.

A like richness of results seems likely to follow the application of the kinetic theory to solutions. Van't Hoff supposes "a solution contained in a vessel of semi-permeable material, that is to say material permeable only by water molecules but not by the molecules of the dissolved substance, and that this vessel is immersed in water. Then owing to the attraction of the molecules of the dissolved substance, water will enter the vessel, thus causing an increase of pressure, and this will continue until the pressure within the vessel is sufficient to counterbalance the attraction exercised by the molecules of the dissolved substance. Equilibrium being thus established the pressure within the vessel is equal to the osmotic pressure and may be taken as a measure of it." Evidently by providing the vessel with a piston the pressure may be varied so that water may be made to flow out of the vessel or into it, at will. Hence in this way it becomes possible to produce a reversible cycle of changes like that of Carnot, to which the second law of thermodynamics may be applied. Thus by decreasing the pressure water enters, and then by increasing it again water issues ; so that the liquid may be brought back to its original state, the sum of the positive and negative work done upon and by it being zero. Now Van't Hoff has experimentally shown that in isotonic solutions, *i. e.*, solutions for which the osmotic pressure is the same, the pressure is directly proportional to the concentration. But as the concentration is proportional to the density, this is evidently equivalent to the statement that the osmotic pressure of a solution is directly proportional to its density; which is Boyle's law applied to liquids. Moreover, "if we consider the entrance of the water and subsequent increase of pressure to be proportional to the number of molecules which come into contact with the walls of the cell in a given space of time, the argument is similar to that by which Boyle's law is looked upon as due to molecular bombardment" in the case of gases. The same result has been obtained by Duhem by applying the law of the thermodynamic potential to osmotic relations, as a purely theoretical deduction. Again, it has been experimentally shown that the theoretical conclusion deduced by the aid of one of the reversible changes just mentioned, to the effect that the osmotic pressure is proportional to the absolute temperature, is true for a variety of solutions. But this is the law of Gay Lussac applied to such solutions. A third theoretical deduction from the reversible cycle principle is that a gas when in solution, has an osmotic pressure equal to the pressure of the same gas when in a free state. But this is simply an extension of the law of Avogadro to solutions ; so that we may say "that for equal osmotic pressures and equal temperatures, equal volumes of different solutions contain the same number of molecules ;" this number being the same as that which is contained in the same volume of a gas under the same conditions of pressure and temperature. In fact, Van't Hoff has shown that the osmotic pressures of a one per cent. sugar solution at different temperatures agrees with the pressure exerted by hydrogen gas containing the same number of molecules at the same temperature. Further, Duhem has obtained an expression, as a deduction from thermodynamic theory, by means of which when the vapor-pressure of a solution is known, the law of compressibility of water vapor being also known, it becomes possible to calculate the vapor pressure of an isotonic solution. So that assuming the laws of Boyle and Gay Lussac to be applicable to water vapor, it follows that two isotonic solutions at the same temperature have approximately equal vapor pressures. Moreover, Duhem finds that theory proves the law of Van't Hoff that two isotonic solutions have the same solidifying point at the pressure for which they are isotonic, to be rigorously true. From the simple conclusion, deducible as a corollary from these laws, that solutions in the same solvent which have equal maximum vapor pressures or equal freezing points, must be isotonic, the well known law of Raoult, connecting the molecular reduction of the freezing point and the vapor-pressure with the molecular mass, may be readily obtained ; provided always that Avogadro's law holds for solutions. The great value of this law of Raoult in fixing the molecular mass, especially of organic nonvolatile solids, has been very generally recognized. It may be enunciated thus : A molecule of any compound substance when dissolved in 100 molecules of any liquid upon which it has no action reduces the freezing point of this liquid by a quantity which is nearly constant and which closely approximates to 0.62. As an example of the method of applying the law, the following experiment may here be cited. A solution of dextrose containing 8.3704 grammes in 94.86 grammes of water was observed to freeze at — 0.94°C. Hence its molecular mass is

$$M = T\frac{P}{C} = T\frac{100x}{CF} = 19\frac{100 \times 8.3704}{0.94 \times 94.86} = 179$$

In this equation M is the molecular mass, T the molecular depression, C the observed depression, x the grammes of the substance and F the grammes of water in 100 grammes of the solution. Since this value is practically the same as 180, the value calculated from $C_6H_{12}O_6$, it follows that the formula ordinarily given for dextrose represents correctly its molecular mass. The results obtained by this method for colloids are extraordinary. Thus Sabanéeff finds for the molecular mass of colloidal tungstic acid values from 679 to 995, for molybdic acid 608–631, for glycogen 1545–1625, for silicic acid 800 to 1600, and for egg-albumin 15,000.

A second subject of recent interest lying in the borderland between physics and chemistry, to which I would ask your attention is that of electrolysis, a phenomenon now regarded as a true electrical convection of atoms ; "a procession of positively charged atoms travelling one way and a corresponding procession of negatively charged atoms the other way," as Lodge tells us. The charges thus carried are all precisely the same for atoms of the same valence ; and they have therefore a minimum value for monads, twice this value for dyads, three times this for triads, etc. This minimum value is the smallest quantity of electricity that is known to take part in any physical or chemical change and has been called therefore a natural unit of electricity. If we may assume the data given by the kinetic theory, this monad charge may be calculated. Since according to Lodge, to decompose one gramme of water 1.5×10^{13} electrostatic positive units must be expended in charging the two hydrogen atoms in each molecule ; and since in one gramme of water there are 10^{25} molecules, the charge upon the hydrogen of each molecule will be 1.5×10^{-12} electrostatic unit; or nearly 10^{-12} electrostatic unit on each hydrogen atom. This is about the 400 trillionth of a coulomb. Since the potential of a charged sphere is the ratio of its charge to its radius, the potential of the electrified hydrogen atom would be $10^{-12}/10^{-10}$ or 10^{-2} electrostatic unit ; about 3 volts. The attraction between two atoms, say of hydrogen and chlorine thus charged, being proportional to Q^2/d^2 is $10^{-24}/10^{-20}$ or 10^{-4}; about one ten thousandth of a dyne only. Owing to its small mass however, even this force is sufficient to impress upon it an acceleration nearly a trillion times greater than that produced by the attraction of gravity. Helmholtz in his Faraday lecture, has calculated the attraction exerted by these atomic charges, and finds that the charges on the atoms in one milligramme of water, if these could be separated and distributed upon two spheres a kilometre distant from each other, would produce a force of attraction equal to the weight of 26800 kilogrammes. This electric force, he calculates, is 71000 billion times greater than the gravitative attraction of the hydrogen and oxygen atoms. "Although therefore" he says "the attracting forces exerted by the poles of a little battery able to decompose water, on such electric charges as we can produce with our electric machines, are very moderate, the forces exerted by the same little apparatus on the enormous charges of the atoms in one milligram of water may very well compete with the mightiest chemical affinity." "I think" he concludes "the facts leave no doubt that the very mightiest among the chemical forces are of electric origin."

One of the most noteworthy of the phenomena of electrolysis is the fact that the ions set free by the action of the current appear only at the electrodes; and this, although there is a continuous procession of these electrically charged ions traveling in each direction. The hypothesis of Grotthuss, that a series of decompositions and recompositions occurs along the line of molecules between the electrodes, although suggestive, is defective in that the molecules are assumed to be at rest; and moreover, it requires the expenditure of some energy within the electrolyte itself; "and no hypothesis which involves a tearing asunder of molecules in the interior of a homogeneous electrolyte can be permitted." As early as 1851, Williamson, in his classic paper on etherification, had suggested the idea that in the collisions between molecules, atomic exchanges were continually effected. In 1857, Clausius applied this hypothesis to electrolysis. In his view "the separation of the ions is due to the active movements of the particles, molecules as well as atoms, which tend to bring about the dissociation of the compound, so that only bodies capable of dissociation can act as electrolytes. For the purpose of electrolysis it is not necessary that this dissociation should proceed as far as the complete separation and isolation of the constituents, but it is sufficient that there should be a frequent exchange of their constituents when two particles collide, so that each constituent can for a very short time move apart from the others before it again finds an opportunity of uniting with another isolated particle. This sporadic occurrence of isolated molecular fractions is not perceptible to our senses, so long as they are uniformly distributed throughout the whole mass of the electrolyte, but it is only perceptible when some external action collects large quantities of one class of particles at one place and of the others at another." This view of continual decomposition and re-formation of molecules has a certain analogy with the theory of exchanges in heat. It "forms the basis of the kinetic theory of chemical changes now universally adopted." "In order to explain electrolysis it is necessary to assume that as each molecule decomposes, one portion of it carries off a definite fixed amount of positive electricity and the other an equivalent quantity of negative electricity. The electricity is either attached to each particle before the separation or else it is produced at the moment of decomposition. Clausius regards the movement of the charged ions in opposite directions as due to the free electricity present upon the electrodes. Here the ions receive from the electrodes an equal quantity of the opposite electricity, and so become neutral. Evidently the vast majority of molecules in an electrolyte are quite insusceptible to the influence of the electrodes. It is only the small number of these molecules which are dissociated by collision or otherwise and whose atoms are set free each with its appropriate charge that respond to the directive tendency of the electrodes. Hence the electrolytic conductivity of a solution depends not only upon the mobility of the molecules within it but also upon the number of such molecules dissociated. Researches by Wiedemann and others upon the relation exisiting between the internal friction or viscosity of liquids and their electrolytic conductivity have shown the close connection between this conductivity and the mobility of the molecules, and have proved resistance to conductivity to be a constant of the same order as resistance to friction. Morever, Long has observed that liquid conductivity and diffusion run parallel under similar external conditions; that a substance which diffuses rapidly, is, as a rule, a good conductor. This close connection between speed of diffusion and conducting power is evidence in favor of the view that it is only the movement of the ions and not their separation which is the work of the electricity. When a weak solution is made stronger, the increase of conductivity is due to increased dissociation. When a cold solution is made hotter, the increase is probably due to the diminished viscosity of the liquid.

This movement of the ions, the anion toward the anode and the kation toward the kathode, has been called by Hittorf the migration of the ions; and he has shown that the speed of travel of the ions is not the same for them all. Thus for example, if a dilute solution of copper sulphate be electrolysed with copper electrodes, the solution at the kathode becomes weaker while that at the anode becomes stronger. Evidently the explanation of this result is to be found in the fact that the anion SO_4 travels faster than the kation Cu. This subject has been further investigated by Kohlrausch, who adopts the view that electrolytic conduction is performed by dissociated atoms, each of which carries the same numerical charge of electricity, one set of these atoms being positive, the other negative. The speed of the ionic motion, he agrees with Quincke in believing to be proportional to the slope of potential through the liquid. But he maintains that every ion has a specific speed of its own in a given liquid and when urged by a given slope of potential; this speed being wholly independent of all other conditions. In proof of this position he has shown how to calculate this specific ionic velocity in absolute measure, from data founded on conductivity, concentration and migration. Hydrogen travels faster than any other kind of atom. And therefore since the conductivity of a liquid depends on the sum of the speeds of the two opposite atoms of the dissolved substance, acids are in general better conductors than their salts. The rates at which the following atoms can make their way through nearly pure water, when urged by a slope of potential of one volt per linear centimetre, are given by Kohlrausch as follows, in centimetres per hour: Hydrogen 1.08, potassium 0.205, sodium 0.126, lithium 0.094, silver 0.166, chlorine 0.213, iodine 0.216, and NO_3 0.174.

It would be interesting, did time permit, to consider the more recent progress made by spectrum analysis in its relation to chemical questions. The investigations of Auer, of Krüss and Nilson, of Boisbaudran and of Crookes have gone far to unsettle completely our previous conception of elementary matter. In place of atoms having identical masses, the new theory offers us a collection of variable masses, grouped about a definite mean position, representing the atomic mass. By the ordinary operations of chemistry groups only can be distinguished; these operations being far too coarse to discriminate between the variable masses of a group. But the application of more refined processes, especially when long continued and made cumulative, readily effects this differentiation, and resolves matter hitherto considered elementary into sub-groups of substances to which Crookes has given provisionally, the name "meta-elements." The oscillations of the mighty electric pendulum which he supposes distributed the primordial matter on alternate sides of a median line as the all-pervading "protyle" or "urstoff" periodically condensed into atomic groups under the influence of the slowly decreasing temperature, is a conception of the genesis of the elements worthy in every way of its distinguished author. "Swinging to and fro to points equidistant from a neutral centre ; the divergence from neutrality conferring atomicity (valence) of one, two, three and four degrees as the distance from the centre is one, two, three or four divisions ; the approach to or retreat from the neutral line deciding the electronegative or electropositive character of the element, all on the retreating half of the swing being positive and all on the approaching half negative," the oscillations gradually decreasing in amplitude and the masses of the atomic groups continually increasing as the temperature falls, "this oscillating force must be intimately connected with the imponderable matter, essence or source of energy we call electricity." "The pendulum begins its swing from the electropositive side ; lithium next to hydrogen in simplicity of atomic weight is now formed ; then glucinum, boron and carbon. Definite quantities of electricity are bestowed on each element at the moment of birth, on these quantities its atomicity (valence) depends and the types of monatomic, diatomic, triatomic and tetratomic elements are fixed. The electronegative part of the swing now commences ; nitrogen appears, and notice how curiously position governs the mean dominant atomicity. Nitrogen occupies the position below boron, a triatomic element, therefore nitrogen is triatomic. But nitrogen also follows carbon a tetratomic body and occupies the fifth position counting from the place of origin. How beautifully these opposing tendencies are harmonized by the endowment of nitrogen with at least a double atomicity and making its atom capable of acting as tri- and pentatomic. With oxygen (di- and hexatomic) and fluorine (mon- and heptatomic) the same law holds and one-half an oscillation of the pendulum is completed. Again, passing the neutral line the the electropositive elements sodium (monatomic) magnesium (diatomic), aluminum (triatomic) and silicon (tetratomic) are successively formed and the first complete oscillation of the pendulum is finished by the birth of the electronegative elements phosphorus, sulphur and chlorine; these three, like the corresponding elements formed on the opposite homeward swing, having each at least a double atomicity depending on position." The significance of this hypothesis, however, lies in the experimental data obtained by Crookes himself, upon which it is based. By fractional precipitation with ammonia, repeated many thousand times, he established the fact that the element called yttrium consists certainly of five and probably of eight constituents; these constituents being characterized by special spectrum bands. A similar research on didymium led Krüss and Nilson to conclude that this element may be split into nine distinct components. Other elements, examined likewise by fractional methods, give signs of breaking down and affording "meta-elements." But here the importance of the spectrum method appears. It is solely by the character of the spectrum, obtained either by emission, by phosphorescence, or by absorption, that these constituents can be satisfactorily distinguished. And the pertinent question at once arises, is the presence of a single spectrum line of definite wave-frequency, characteristic of a meta-element? Or, in other words, has the meta-elemental atom only a single rate of vibration, so that in a group of such atoms, constituting what we now term an element, we may reason to the elemental complexity from the number of such meta-elemental spectrum lines?

Such facts as these it is which the chemist of to-day is called upon to correlate with his older knowledge. Do they not indicate most clearly a tendency toward a true statics and dynamics of atoms; toward a condition of exact science which will confer upon chemistry the power of prediction? The future of such a chemistry will be glorious. It will become the grandest of the sciences and its phenomena will task the highest powers of intellectual activity. It is to the advancement of such a science, fellow members of the American Chemical Society, that we are privileged to devote our energies. May we each contribute something to hasten its progress.