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THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE[1]

ADDRESS OF THE PRESIDENT OF THE MATHEMATICAL AND PHYSICAL SECTION

IT is a great privilege and pleasure to address the members of this section on the occasion of the visit of the British Association to a country with which I have had such a long and pleasant connection. I feel myself in the presence of old friends, for the greater part of what may be called my scientific life has been spent in Canada, and I owe much to this country for the unusual facilities and opportunity for research so liberally provided by one of her great universities. Canada may well regard with pride her universities, which have made such liberal provision for teaching and research in pure and applied science. As a physicist, I may be allowed to refer in particular to the subject with which I am most intimately connected. After seeing the splendid home for physical science recently erected by the University of Toronto, and the older but no less serviceable and admirably equipped laboratories of McGill University, one can not but feel that Canada has recognized in a striking manner the great value attaching to teaching and research in physical science. In this, as in other branches of knowledge, Canada has made notable contributions in the past, and we may confidently anticipate that this is but an earnest of what will be accomplished in the future.

It is my intention to-day to say a few words upon the present position of the atomic theory in physical science, and to

[1] Winnipeg, 1909.

discuss briefly the various methods that have been devised to determine the values of certain fundamental atomic magnitudes. The present time seems very opportune for this purpose, for the rapid advance of physics during the last decade has not only given us a much clearer conception of the relation between electricity and matter and of the constitution of the atom, but has provided us with experimental methods of attack undreamt of a few years ago. At a time when, in the vision of the physicist, the atmosphere is dim with flying fragments of atoms, it may not be out of place to see how it has fared with the atoms themselves, and to look carefully at the atomic foundations on which the great superstructure of modern science has been raised. Every physicist and chemist can not but be aware of the great part the atomic hypothesis plays in science to-day. The idea that matter consists of a great number of small discrete particles forms practically the basis of the explanation of all properties of matter. As an indication of the importance of this theory in the advance of science it is of interest to read over the reports of this association and to note how many addresses, either wholly or in part, have been devoted to a consideration of this subject. Amongst numerous examples I may instance the famous and oft-quoted lecture of Maxwell on "Molecules," at Bradford in 1873; the discussion of the "Kinetic Theory of Gases" by Lord Kelvin, then Sir William Thomson, in Montreal in 1884; and the presidential address of Sir Arthur Rucker in 1901, which will be recalled by many here to-day.

It is far from my intention to discuss, except with extreme brevity, the gradual rise and development of the atomic theory. From the point of view of modern science, the atomic theory dates from the work of Dalton about 1805, who put it forward as an explanation of the combination of elements in definite proportions. The simplicity of this explanation of the facts of chemistry led to the rapid adoption of the atomic theory as a very convenient and valuable working hypothesis. By the labor of the chemists matter was shown to be composed of a number of elementary substances which could not be further decomposed by laboratory agencies, and the relative weights of the atoms of the elements were determined. On the physical side, the mathematical development of the kinetic or dynamical theory of gases by the labors of Clausius and Clerk Maxwell enormously extended the utility of this conception. It was shown that the properties of gases could be satisfactorily explained on the assumption that a gas consisted of a great assemblage of minute particles or molecules in continuous agitation, colliding with each other and with the walls of the containing vessel. Between encounters the molecules traveled in straight lines, and the free path of the molecules between collisions was supposed to be large compared with the linear dimensions of the molecules themselves. One can not but regard with admiration the remarkable success of this statistical theory in explaining the general properties of gases and even predicting unexpected relations. The strength and at the same time the limitations of the theory lie in the fact that it does not involve any definite conception of the nature of the molecules themselves or of the forces acting between them. The molecule, for example, may be considered as a perfectly elastic sphere or a Boscovitch center of force, as Lord Kelvin preferred to regard it, and yet on suitable assumptions the gas would show the same general statistical properties. We are consequently unable, without the aid of special subsidiary hypotheses, to draw conclusions of value in regard to the nature of the molecules themselves.

Towards the close of the last century the ideas of the atomic theory had impregnated a very large part of the domain of physics and chemistry. The conception of atoms became more and more concrete. The atom in imagination was endowed with size and shape, and unconsciously in many cases with color. The simplicity and utility of atomic conceptions in explaining the most diverse phenomena of physics and chemistry naturally tended to enhance the importance of the theory in the eyes of the scientific worker. There was a tendency to regard the atomic theory as one of the established facts of nature, and not as a useful working hypothesis for which it was exceedingly difficult to obtain direct and convincing evidence. There were not wanting scientific men and philosophers to point out the uncertain foundations of the theory on which so much depended. Granting how useful molecular ideas were for the explanation of experimental facts, what evidence was there that the atoms were realities and not the figments of the imagination? It must be confessed that this lack of direct evidence did not in any way detract from the strength of the belief of the great majority of scientific men in the discreteness of matter. It was not unnatural, however, that there should be a reaction in some quarters against the domination of the atomic theory in physics and in chemistry. A school of thought arose that wished to do away with the atomic theory as the basis of explanation of chemistry, and substitute as its equivalent the law of combination in definite proportions. This movement was assisted by the possibility of explaining many chemical facts on the basis of thermodynamics without the aid of any hypothesis as to the particular structure of matter. Every one recognizes the great importance of such general methods of explanation, but the trouble is that few can think, or at any rate think correctly, in terms of thermodynamics. The negation of the atomic theory has not, and does not, help us to make new discoveries. The great advantage of the atomic theory is that it provides, so to speak, a tangible and concrete idea of matter which serves at once for the explanation of a multitude of facts and is of enormous aid as a working hypothesis. For the great majority of scientists it is not sufficient to group together a number of facts on general abstract principles. What is wanted is a concrete idea, however crude it may be, of the mechanism of the phenomena. This may be a weakness of the scientific mind, but it is one that deserves our sympathetic consideration. It represents an attitude of mind that appeals, I think, very strongly to the Anglo-Saxon temperament. It has no doubt as its basis the underlying idea that the facts of nature are ultimately explicable on general dynamical principles, and that there must consequently be some type of mechanism capable of accounting for the observed facts.

It has been generally considered that a decisive proof of the atomic structure of matter was in the nature of things impossible, and that the atomic theory must of necessity remain a hypothesis unverifiable by direct methods. Recent investigations have, however, disclosed such new and powerful methods of attack that we may well ask the question whether we do not now possess more decisive evidence of its truth.

Since molecules are invisible, it might appear, for example, an impossible hope that an experiment could be devised to show that the molecules of a fluid are in that state of continuous agitation which the kinetic theory leads us to suppose. In this connection I should like to draw your attention for a short time to a most striking phenomenon known as the "Brownian movement," which has been closely studied in recent years. Quite apart from its probable explanation the phenomenon is of unusual interest. In 1827 the English botanist Brown observed by means of a microscope that minute particles like spores of plants introduced into a fluid were always in a state of continuous irregular agitation, dancing to and fro in all directions at considerable speeds. For a long time this effect, known as the Brownian movement, was ascribed to inequalities in the temperature of the solution. This was disproved by a number of subsequent investigations, and especially by those of Gouy, who showed that the movement was spontaneous and continuous and was exhibited by very small particles of whatever kind when immersed in a fluid medium. The velocity of agitation increased with decrease of diameter of the particles and increased with temperature, and was dependent on the viscosity of the surrounding fluid. With the advent of the ultra-microscope it has been possible to follow the movements with more certainty and to experiment with much smaller particles. Exner and Zsigmondy have determined the mean velocity of particles of known diameter in various solutions, while Svedberg has devised an ingenious method of determining the mean free path and the average velocity of particles of different diameter. The experiments of Ehrenhaft in 1907 showed that the Brownian movement was not confined to liquids, but was exhibited far more markedly by small particles suspended in gases. By passing an arc discharge between silver poles he produced a fine dust of silver in the air. When examined by means of the ultra-microscope the suspended particles exhibited the characteristic Brownian movement, with the difference that the mean free path for particles of the same size was much greater in gases than in liquids.

The particles exhibit in general the character of the motion which the kinetic theory ascribes to the molecules themselves, although even the smallest particles examined have a mass which is undoubtedly very large compared with that of the molecule. The character of the Brownian movement irresistibly impresses the observer with the idea that the particles are hurled hither and thither by the action of forces resident in the solution, and that these can only arise from the continuous and ceaseless movement of the invisible molecules of which the fluid is composed. Smoluchowski and Einstein have suggested explanations which are based on the kinetic theory, and there is a fair agreement between calculation and experiment. Strong additional confirmation of this view has been supplied by the very recent experiments of Perrin (1909). He obtained an emulsion of gamboge in water which consisted of a great number of spherical particles nearly of the same size, which showed the characteristic Brownian movement. The particles settled under gravity and when equilibrium was set up the distribution of these particles in layers at different heights was determined by counting the particles with a microscope. The number was found to diminish from the bottom of the vessel upwards according to an exponential law, *i. e.*, according to the same law as the pressure of the atmosphere diminishes from the surface of the earth. In this case, however, on account of the great mass of the particles, their distribution was confined to a region only a fraction of a millimeter deep. In a particular experiment the number of particles per unit volume decreased to half in a distance of 0.038 millimeter, while the corresponding distance in our atmosphere is about 6,000 meters. From measurements of the diameter and weight of each particle, Perrin found that, within the limit of experimental error, the law of distribution with height indicated that each small particle had the same average kinetic energy of movement as the molecules of the solutions in which they were suspended; in fact, the particles in suspension behaved in all respects like molecules of very high molecular weight. This is a very important result, for it indicates that the law of equipartition of energy among molecules of different masses, which is an important deduction from the kinetic theory, holds, at any rate very approximately, for a distribution of particles in a medium whose masses and dimensions are exceedingly large compared with that of the molecules of the medium. Whatever may prove to be the exact explanation of this phenomenon, there can be little doubt that it results from the movement of the molecules of the solution and is thus a striking if somewhat indirect proof of the general correctness of the kinetic theory of matter.

From recent work in radioactivity we may take a second illustration which is novel and far more direct. It is well known that the α rays of radium are deflected by both magnetic and electric fields. It may be concluded from this evidence that the radiation is corpuscular in character, consisting of a stream of positively charged particles projected from the radium at a very high velocity. From the measurements of the deflection of the rays in passing through magnetic and electric fields the ratio e/m of the charge carried by the particle to its mass has been determined, and the magnitude of this quantity indicates that the particle is of atomic dimensions.

Rutherford and Geiger have recently developed a direct method of showing that this radiation is, as the other evidence indicated, discontinuous, and that it is possible to detect by a special electric method the passage of a single α particle into a suitable detecting vessel. The entrance of an α particle through a small opening was marked by a sudden movement of the needle of the electrometer which was used as a measuring instrument. In this way, by counting the number of separate impulses communicated to the electrometer needle, it was possible to determine by direct counting the number of α particles expelled per second from one gram of radium. But we can go further and confirm the result by counting the number of α particles by an entirely distinct method. Sir William Crookes has shown that when the α rays are allowed to fall upon a screen of phosphorescent zinc sulphide, a number of brilliant scintillations are observed. It appears as if the impact of each α particle produced a visible flash of light where it struck the screen. Using suitable screens the number of scintillations per second on a given area can be counted by means of a microscope. It has been shown that the number of scintillations determined in this way is equal to the number of impinging α particles when counted by the electric method. This shows that the impact of each α particle on the zinc sulphide produces a visible scintillation. There are thus two distinct methods—one electrical, the other optical—for detecting the emission of a single α particle from radium. The next question to consider is the nature of the α particle itself. The general evidence indicates that the α particle is a charged atom of helium, and this conclusion was decisively verified by Rutherford and Royds by showing that helium appeared in an exhausted space into which the α particles were fired. The helium, which is produced by radium, is due to the accumulated α particles which are so continuously expelled from it. If the rate of production of helium from radium is measured, we thus have a means of determining directly how many α particles are required to form a given volume of helium gas. This rate of production has recently been measured accurately by Sir James Dewar. He has informed me that his final measurements show that one gram of radium in radioactive equilibrium produces 0.46 cubic millimeters of helium per day, or 5.32×10^{-6} cubic millimeters per second. Now from the direct counting experiments it is known that 13.6×10^{10} α particles are shot out per second from one gram of radium in equilibrium. Consequently it requires 2.56×10^{19} α particles to form one cubic centimeter of helium gas at standard pressure and temperature.

From other lines of evidence it is known that all the α particles from whatever source are identical in mass and constitution. It is not then unreasonable to suppose that the α particle, which exists as a separate entity in its flight, can exist also as a separate entity when the α particles are collected together to form a measurable volume of helium gas, or, in other words, that the α particle on losing its charge becomes the fundamental unit or atom of helium. In the case of a monatomic gas like helium, where the atom and molecule are believed to be identical, no difficulty of deduction arises from the possible combination of two or more atoms to form a complex molecule.

We consequently conclude from these experiments that one cubic centimeter of helium at standard pressure and temperature contains 2.56×10^{19} atoms. Knowing the density of helium, it at once follows that each atom of helium has a mass of 6.8×10^{-24} grams, and that the average distance apart of the molecules in the gaseous state at standard pressure and temperature is 3.4×10^{-7} centimeters.

The above result can be confirmed in a different way. It is known that the value of e/m for the α particle is 5,070 electromagnetic units. The positive charge carried by each α particle has been deduced by measuring the total charge carried by a counted number of α particles. Its value is 9.3×10^{-10} electrostatic units, or 3.1×10^{-20} electromagnetic units. Substituting this number in the value of e/m, it is seen that m, the mass of the α particle, is equal to 6.1×10^{-24} grams—a value in fair agreement with the number previously given.

I trust that my judgment is not prejudiced by the fact that I have taken some share in these investigations; but the experiments, taken as a whole, appear to me to give an almost direct and convincing proof of the atomic hypothesis of matter. By direct counting, the number of identical entities required to form a known volume of gas has been measured. May we not conclude that the gas is discrete in structure, and that this number represents the actual number of atoms in the gas?

We have seen that under special conditions it is possible to detect easily by an electrical method the emission of a single α particle—*i. e.*, of a single charged atom of matter. This has been rendered possible by the great velocity and energy of the expelled α particle, which confers on it the power of dissociating or ionizing the gas through which it passes. It is obviously only possible to detect the presence of a single atom of matter when it is endowed with some special property or properties which distinguishes it from the molecules of the gas with which it is surrounded. There is a very important and striking method, for example, of visibly differentiating between the ordinary molecules of a gas and the ions produced in the gas by various agencies. C. T. R. Wilson showed in 1897 that under certain conditions each charged ion became a center of condensation of water vapor, so that the presence of each ion was rendered visible to the eye. Sir Joseph Thomson, H. A. Wilson and others have employed this method to count the number of ions present and to determine the magnitude of the electric charge carried by each.

A few examples will now be given which illustrate the older methods of estimating the mass and dimensions of molecules. As soon as the idea of the discrete structure of matter had taken firm hold, it was natural that attempts should be made to estimate the degree of coarse-grainedness of matter, and to form an idea of the dimension of molecules, assuming that they have extension in space. Lord Rayleigh has drawn attention to the fact that the earliest estimate of this kind was made by Thomas Young in 1805, from considerations of the theory of capillarity. Space does not allow me to consider the great variety of methods that have later been employed to form an idea of the thickness of a film of matter in which a molecular structure is discernible. This phase of the subject was always a favorite one with Lord Kelvin, who developed a number of important methods of estimating the probable dimensions of molecular structure.

The development of the kinetic theory of gases on a mathematical basis at once suggested methods of estimating the number of molecules in a cubic centimeter of any gas at normal pressure and temperature. This number, which will throughout be denoted by the symbol N, is a fundamental constant of gases; for, according to the hypothesis of Avogadro, and also on the kinetic theory, all gases at normal pressure and temperature have an identical number of molecules in unit volume. Knowing the value of N, approximate estimates can be made of the diameter of the molecule; but in our ignorance of the constitution of the molecule, the meaning of the term diameter is somewhat indefinite. It is usually considered to refer to the diameter of the sphere of action of the forces surrounding the molecule. This diameter is not necessarily the same for the molecules of all gases, so that it is preferable to consider the magnitude of the fundamental constant N. The earliest estimates based on the kinetic theory were made by Loschmidt, Johnstone Stoney and Maxwell. From the data then at his disposal, the latter found N to be 1.9×10^{19}. Meyer, in his "Kinetic Theory of Gases," discusses the various methods of estimating the dimensions of molecules on the theory, and concludes that the most probable estimate of N is 6.1×10^{19}. Estimates of N based on the kinetic theory are only approximate, and in many cases serve merely to fix an inferior or superior limit to the number of the molecules. Such estimates are, however, of considerable interest and historical importance, since for a long time they served as the most reliable methods of forming an idea of molecular magnitudes.

A very interesting and impressive method of determining the value of N was given by Lord Rayleigh in 1899 as a deduction from his theory of the blue color in the cloudless sky. This theory supposes that the molecules of the air scatter the waves of light incident upon them. This scattering for particles, small compared with the wave-length of light, is proportional to the fourth power of the wave-length, so that the proportion of scattered to incident light is much greater for the violet than for the red end of the spectrum, and consequently the sky which is viewed by the scattered light is of a deep blue color. This scattering of the light in passing through the atmosphere causes alterations of brightness of stars when viewed at different altitudes, and determinations of this loss of brightness have been made experimentally. Knowing this value, the number N of molecules in unit volume can be deduced by aid of the theory. From the data thus available, Lord Rayleigh concluded that the value of N was not less than 7×10^{18}. Lord Kelvin in 1902 recalculated the value of N on the theory by using more recent and more accurate data, and found it to be 2.47×10^{19}. Since in the simple theory no account is taken of the additional scattering due to fine suspended particles which are undoubtedly present in the atmosphere, this method only serves to fix an inferior limit to the value of N. It is difficult to estimate with accuracy the correction to be applied for this effect, but it will be seen that the uncorrected number deduced by Lord Kelvin is not much smaller than the most probable value 2.77×10^{19} given later. Assuming the correctness of the theory and data employed, this would indicate that the scattering due to suspended particles in the atmosphere is only a small portion of the total scattering due to molecules of air. This is an interesting example of how an accurate knowledge of the value of N may possibly assist in forming an estimate of unknown magnitudes.

It is now necessary to consider some of the more recent and direct methods of estimating N which are based on recent additions to our scientific knowledge. The newer methods allow us to fix the value of N with much more certainty and precision than was possible a few years ago.

We have referred earlier in the paper to the investigations of Perrin on the law of distribution in a fluid of a great number of minute granules, and his proof that the granules behave like molecules of high molecular weight. The value of N can be deduced at once from the experimental results, and is found to be 3.14×10^{19}. The method developed by Perrin is a very novel and ingenious one, and is of great importance in throwing light on the law of equipartition of energy. This new method of attack of fundamental problems will no doubt be much further developed in the future.

It has already been shown that the value $N = 2.56 \times 10^{19}$ has been obtained by the direct method of counting the α particles and determining the corresponding volume of helium produced. Another very simple method of determining N from radioactive data is based on the rate of transformation of radium. Boltwood has shown by direct experiment that radium is half transformed in 2,000 years. From this it follows that initially in a gram of radium .346 milligram breaks up per year. Now it is known from the counting method that 3.4×10^{10} α particles are expelled per second from one gram of radium, and the evidence indicates that one α particle accompanies the disintegration of each atom. Consequently the number of α particles expelled per year is a measure of the number of atoms of radium present in .346 milligram. From this it follows that there are 3.1×10^{21} atoms in one gram of radium, and taking the atomic weight of radium as 226, it is simply deduced that the value of N is 3.1×10^{19}.

The study of the properties of ionized gases in recent years has led to the development of a number of important methods of determining the charge carried by the ion, produced in gases by α rays or the rays from radioactive substances. On modern views, electricity, like matter, is supposed to be discrete in structure, and the charge carried by the hydrogen atom set free by the electrolysis of water is taken as the fundamental unit of quantity of electricity. On this view, which is supported by strong evidence, the charge carried by the hydrogen atom is the smallest unit of electricity that can be obtained, and every quantity of electricity consists of an integral multiple of this unit. The experiments of Townsend have shown that the charge carried by a gaseous ion is, in the majority of cases, the same and equal in magnitude to the charge carried by a hydrogen atom in the electrolysis of water. From measurement of the quantity of electricity required to set free one gram of hydrogen in electrolysis, it can be deduced that $Ne = 1.29 \times 10^{10}$ electrostatic units where N, as before, is the number of molecules of hydrogen in one cubic centimeter of gas, and e the charge carried by each ion. If e be determined experimentally, the value of N can at once be deduced from this relation.

The first direct measurement of the charge carried by the ion was made by Townsend in 1897. When a solution of sulphuric acid is electrolyzed, the liberated oxygen is found in a moist atmosphere to give rise to a dense cloud composed of minute globules of water. Each of these minute drops carries a negative charge of electricity. The size of the globules, and consequently the weight, was deduced with the aid of Stokes's formula by observing the rate of fall of the cloud under gravity. The weight of the cloud was measured, and, knowing the weight of each globule, the total number of drops present was determined. Since the total charge carried by the cloud was measured, the charge e carried by each drop was deduced. The value of e, the charge carried by each drop, was found by this method to be about 3.0×10^{-10} electrostatic units. The corresponding value of N is about 4.3×10^{19}.

We have already referred to the method discovered by C. T. R. Wilson of rendering each ion visible by the condensation of water upon it by a sudden expansion of the gas. The property was utilized by Sir Joseph Thomson to measure the charge e carried by each ion. When the expansion of the gas exceeds a certain value, the water condenses on both the negative and positive ions, and a dense cloud of small water drops is seen. J. J. Thomson found $e = 3.4 \times 10^{-10}$, H. A. Wilson $e = 3.1 \times 10^{-10}$, and Millikan and Begeman 4.06×10^{-10}. The corresponding values of N are 3.8, 4.2 and 3.2×10^{19} respectively. This method is of great interest and importance, as it provides a method of directly counting the number of ions produced in the gas. An exact determination of e by this method is, however, unfortunately beset with great experimental difficulties.

Moreau has recently measured the charge carried by the negative ions produced in flames. The values deduced for e and N were respectively 4.3×10^{-10} and 3.0×10^{19}.

We have referred earlier in the paper to the work of Ehrenhaft on the Brownian movement in air shown by ultra-microscopic dust of silver. In a recent paper (1909) he has shown that each of these particles carries a positive or negative charge. The size of each particle was measured by the ultra-microscope, and also by the rate of fall under gravity. The charge carried by each particle was deduced from the measured mass of the particle, and its rate of movement in an electric field. The mean value of e was found to be 4.6×10^{-10}, and thus N becomes 2.74×10^{19}.

A third important method of determination of N from radioactive data was given by Rutherford and Geiger in 1908. The charge carried by each α particle expelled from radium was measured by directly determining the total charge carried by a counted number of α particles. The value of the charge on each α particle was found to be 9.3×10^{-10}. From consideration of the general evidence, it was concluded that each α particle carries two unit positive charges, so that the value of e becomes 4.65×10^{-10}, and of N 2.77×10^{19}. This method is deserving of considerable confidence as the measurements involved are direct and capable of accuracy.

The methods of determination of e, so far explained, have depended on direct experiment. This discussion would not be complete without a reference to an important determination of e from theoretical considerations by Planck. From the theory of the distribution of energy in the spectrum of a hot body, Planck found that $e = 4.69 \times 10^{-10}$, and $N = 2.80 \times 10^{19}$. For reasons that we can not enter into here, this theoretical deduction must be given great weight.

When we consider the great diversity of the theories and methods which have been utilized to determine the values of the atomic constants e and N, and the probable experimental errors, the agreement among the numbers is remarkably close. This is especially the case in considering the more recent measurements by very different methods, which are far more reliable than the older estimates. It is difficult to fix on one determination as more deserving of confidence than another; but I may be pardoned if I place some reliance on the radioactive method previously discussed, which depends on the charge carried by the α particle. The value obtained in this way is not only in close agreement with the theoretical estimate of Planck, but is in fair agreement with the recent determinations by several other distinct methods. We may consequently conclude that the number of molecules in a cubic centimeter of any gas at standard pressure and temperature is about 2.77×10^{19}, and that the value of the fundamental unit of quantity of electricity is about 4.65×10^{-10} electrostatic units. From these data it is a simple matter to deduce the mass of any atom whose atomic weight is known, and to determine the values of a number of related atomic and molecular magnitudes.

There is now no reason to view the values of these fundamental constants with scepticism, but they may be employed with confidence in calculations to advance still further our knowledge of the constitution of atoms and molecules. There will no doubt be a great number of investigations in the future to fix the values of these important constants with the greatest possible precision; but there is every reason to believe that the values are already known with reasonable certainty, and with a degree of accuracy far greater than it was possible to attain a few years ago. The remarkable agreement in the values of e and N, based on so many different theories, of itself affords exceedingly strong evidence of the correctness of the atomic theory of matter, and of electricity, for it is difficult to believe that such concordance would show itself if the atoms and their charges had no real existence.

There has been a tendency in some quarters to suppose that the development of physics in recent years has cast doubt on the validity of the atomic theory of matter. This view is quite erroneous, for it will be clear from the evidence already discussed that the recent discoveries have not only greatly strengthened the evidence in support of the theory, but have given an almost direct and convincing proof of its correctness. The chemical atom as a definite unit in the subdivision of matter is now fixed in an impregnable position in science. Leaving out of account considerations of etymology, the atom in chemistry has long been considered to refer only to the smallest unit of matter that enters into ordinary chemical combination. There is no assumption made that the atom itself is indestructible and eternal, or that methods may not ultimately be found for its subdivision into still more elementary units. The advent of the electron has shown that the atom is not the unit of smallest mass of which we have cognizance, while the study of radioactive bodies has shown that the atoms of a few elements of high atomic weight are not permanently stable, but break up spontaneously with the appearance of new types of matter. These advances in knowledge do not in any way invalidate the position of the chemical atom, but rather indicate its great importance as a subdivision of matter whose properties should be exhaustively studied.

The proof of the existence of corpuscles or electrons with an apparent mass very small compared with that of the hydrogen atom, marks an important stage in the extension of our ideas of atomic constitution. This discovery, which has exercised a profound influence on the development of modern physics, we owe mainly to the genius of the president of this association. The existence of the electron as a distinct entity is established by similar methods and with almost the same certainty as the existence of individual α particles. While it has not yet been found possible to detect a single electron by its electrical or optical effect, and thus to count the number directly as in the case of the α particles, there seems to be no reason why this should not be accomplished by the electric method. The effect to be anticipated for a single β particle is much smaller than that due to an α particle, but not too small for measurement. In this connection it is of interest to note that Regener has observed evidence of scintillations produced by the β particles of radium falling on a screen of platinocyanide of barium, but the scintillations are too feeble to count with certainty.

Experiment has shown that the apparent mass of the electron varies with its speed, and, by comparison of theory with experiment, it has been concluded that the mass of the electron is entirely electrical in origin and that there is no necessity to assume a material nucleus on which the electrical charge is distributed. While there can be no doubt that electrons can be released from the atom or molecule by a variety of agencies and, when in raipd motion, can retain an independent existence, there is still much room for discussion as to the actual constitution of electrons, if such a term may be employed, and of the part they play in atomic structure. There can be little doubt that the atom is a complex system, consisting of a number of positively and negatively charged masses which are held in equilibrium mainly by electrical forces; but it is difficult to assign the relative importance of the rôle played by the carriers of positive and negative electricity. While negative electricity can exist as a separate entity in the electron, there is yet no decisive proof of the existence of a corresponding positive electron. It is not known how much of the mass of an atom is due to electrons or other moving charges, or whether a type of mass quite distinct from electrical mass exists. Advance in this direction must be delayed until a clearer knowledge is gained of the character and structure of positive electricity and of its relation to the negative electron.

The general experimental evidence indicates that electrons play two distinct rôles in the structure of the atom, one as lightly attached and easily removable satellites or outliers of the atomic system, and the other as integral constituents of the interior structure of the atom. The former, which can be easily detached or set in vibration, probably play an important part in the combination of atoms to form molecules, and in the spectra of the elements; the latter, which are held in place by much stronger forces, can only be released as a result of an atomic explosion involving the disintegration of the atom. For example, the release of an electron with slow velocity by ordinary laboratory agencies does not appear to endanger the stability of the atom, but the expulsion of a high speed electron from a radioactive substance accompanies the transformation of the atom.

The idea that the atoms of the elements may be complex structures, made up either of lighter atoms or of the atoms of some fundamental substance, has long been familiar to science. So far no direct evidence has been obtained of the possibility of building up an atom of higher atomic weight from one of lower atomic weight, but in the case of the radioactive substances we have decisive and definite evidence that certain elements show the converse process of disintegration. It may be significant that this process has only been observed in the atoms of highest atomic weights, like those of uranium, thorium and radium. With the exception possibly of potassium, there is no reliable evidence that a similar process takes place in other elements. The transformation of the atom of a radioactive substance appears to result from an atomic explosion of great intensity in which a part of the atom is expelled with great speed. In the majority of cases, an α particle or atom of helium is ejected, in some cases a high-speed electron, while a few substances are transformed without the appearance of a detectable radiation. The fact that the α particles from a simple substance are all ejected with an identical and very high velocity suggests the probability that the charged helium atom before its expulsion is in rapid orbital movement in the atom. There is at present no definite evidence of the causes operative in these atomic transformations.

Since in a large number of cases the transformations of the atoms are accompanied by the expulsion of one or more charged atoms of helium, it is difficult to avoid the conclusion that the atoms of the radioactive elements are built up, in part at least, of helium atoms. It is certainly very remarkable and may prove of great significance, that helium, which is regarded from the ordinary chemical standpoint as an inert element, plays such an important part in the constitution of the atoms of uranium, thorium and radium.

The study of radioactivity has not only thrown great light on the character of atomic transformations, but it has also led to the development of methods for detecting the presence of almost infinitesimal quantities of radioactive matter. It has already been pointed out that two methods —one electrical, the other optical—have been devised for the detection of a single α particle. By the use of the optical or scintillation method, it is possible to count with accuracy the number of α particles when only one is expelled per minute. It is not a difficult matter, consequently, to follow the transformation of any radioactive substance in which only one atom breaks up per minute, provided that an α particle accompanies the transformation. In the case of a rapidly changing substance like the actinium emanation, which has a half period of 3.7 seconds, it is possible to detect with certainty the presence, if not of a single atom, at any rate of a few atoms, while the presence of a hundred atoms would in some cases give an inconveniently large effect. The counting of the scintillations affords an exceedingly powerful and direct quantitative method of studying the properties of radioactive substances which expel α particles. Not only is it a simple matter to count the number of α particles which are expelled in any given interval, but it is possible, for example, by suitably arranged experiments to decide whether one, two or more α particles are expelled at the disintegration of a single atom.

The possibility of detection of a single atom of matter has opened up a new field of investigation in the study of discontinuous phenomena. For example, the experimental law of transformation of radioactive matter expresses only the average rate of transformation, but by the aid of the scintillation or electric method it is possible to determine directly by experiment the actual interval between the disintegration of successive atoms and the probability law of distribution of the α particles about the average value.

Quite apart from the importance of studying radioactive changes, the radiations from active bodies provide very valuable information as to the effects produced by high velocity particles in traversing matter. The three types of radiation, the α, β and γ rays, emitted from active bodies, differ widely in character and their power of penetration of matter. The α particles, for example, are completely stopped by a sheet of notepaper, while the γ rays from radium can be easily detected after traversing twenty centimeters of lead. The differences in the character of the absorption of the radiations are no doubt partly due to the difference in type of the radiation and partly due to the differences of velocity.

The character of the effects produced by the α and β particles is most simply studied in gases. The α particle has such great energy of motion that it plunges through the molecules of the gas in its path, and leaves in its train more than a hundred thousand ionized or dissociated molecules. After traversing a certain distance, the α particle suddenly loses its characteristic properties and vanishes from the ken of our observational methods. It no doubt quickly loses its high velocity, and after its charge has been neutralized becomes a wandering atom of helium. The ionization produced by the α particle appears to consist of the liberation of one or more slow velocity electrons from the molecule, but in the case of complex gases there is no doubt that the act of ionization is accompanied by a chemical dissociation of the molecule itself, although it is difficult to decide whether this dissociation is a primary or secondary effect. The chemical dissociation produced by α particles opens up a wide field of investigation, on which, so far, only a beginning has been made.

The β particle differs from the α particle in its much greater power of penetration of matter, and the very small number of molecules it ionizes compared with the α particle traversing the same path in the gas. It is very easily deflected from its path by encounters with the gas molecules, and there is strong evidence that, unlike the α particle, the β particle can be stopped or entrapped by a molecule when traveling at a very high speed.

When the great energy of motion of the α particle and the small amount of energy absorbed in ionizing a single molecule are taken into consideration, there appears to be no doubt that the α particle, as Bragg pointed out, actually passes through the atom, or rather the sphere of action of the atom which lies in its path. There is, so to speak, no time for the atom to get out of the way of the swiftly moving α particle, but the latter must pass through the atomic system. On this view, the old dictum, no doubt true in most cases, that two bodies can not occupy the same space, no longer holds for atoms of matter if moving at a sufficiently high speed.

There would appear to be little doubt that a careful study of the effects produced by the α or β particle in passing through matter will ultimately throw much further light on the constitution of the atom itself. Work already done shows that the character of the absorption of the radiations is intimately connected with the atomic weights of the elements and their position in the periodic table. One of the most striking effects of the passage of β rays through matter is the scattering of the β particles, *i. e.*, the deflection from their rectilinear path by their encounters with the molecules. It was for some time thought that such a scattering could not be expected to occur in the case of the α particles in consequence of their much greater mass and energy of motion. The recent experiments of Geiger, however, show that the scattering of the α particles is very marked, and is so great that a small fraction of the α particles, which impinge on a screen of metal, have their velocity reversed in direction and emerge again on the same side. This scattering can be most conveniently studied by the method of scintillations. It can be shown that the deflection of the α particle from its path is quite perceptible after passing through very few atoms of matter. The conclusion is unavoidable that the atom is the seat of an intense electric field, for otherwise it would be impossible to change the direction of the particle in passing over such a minute distance as the diameter of a molecule.

In conclusion, I should like to emphasize the simplicity and directness of the methods of attack on atomic problems opened up by recent discoveries. As we have seen, not only is it a simple matter, for example, to count the number of α particles by the scintillations produced on a zinc sulphide screen, but it is possible to examine directly the deflection of an individual particle in passing through a magnetic or electric field, and to determine the deviation of each particle from a rectilinear path due to encounters with molecules of matter. We can determine directly the mass of each α particle, its charge, and its velocity, and can deduce at once the number of atoms present in a given weight of any known kind of matter. In the light of these and similar direct deductions, based on a minimum amount of assumption, the physicists have, I think, some justification for their faith that they are building on the solid rock of fact, and not, as we are often so solemnly warned by some of our scientific brethren, on the shifting sands of imaginative hypothesis.

E. Rutherford

THE HIGHEST BALLOON ASCENSION IN AMERICA

Although a large number of *ballons-sondes* were despatched from St. Louis in 1904–7 under the direction of the writer (see Science, Vol. 27, p. 315), none had been employed in the eastern states until last year. In May and July, 1908, four *ballons-sondes* were launched from Pittsfield, Mass., with special precautions to limit the time they remained in the air and so prevent them from drifting out to sea with the upper westerly wind. Three of the registering instruments have been returned to the Blue Hill Observatory with good records. The first instrument sent up on May 7 was not found for ten months and the record, forming the subject of the present article, is very interesting because it gives complete temperature data from the ground up to 17,700 meters, or 11 miles. This is 650 meters higher than the highest ascension from St. Louis, which, by a coincidence, was also the first one to be made there. On May 7 a general storm prevailed, so that the balloon, traveling from the east, was soon lost in the cloud and its subsequent drift could not be followed, but the resultant course was 59 miles from the southwest, as determined by the place where the instrument fell two hours later. At the ground the temperature was 4°.5 C., and this decreased as the balloon rose to the base of the cloud, which itself was considerably warmer than the underlying air. Above the cloud the temperature continued to fall with increasing rapidity up to a height of 12,500 meters (nearly eight miles) where the minimum of — 54°.5 C. was registered. Here the great warm stratum was entered and penetrated farther than ever before in this country, namely, to the height of 17,700 meters, where the temperature was — 46°.5 C. An increase of 8°.9 occurred, however, in the first 3,000 meters, for above 15,500 meters nearly isothermal conditions prevailed, confirming the belief of Teisserenc de Bort that what he calls the "stratosphere" is composed of a lower inverting layer with isothermal conditions above extending to an unknown height. In an ascension last November in Belgium the