VISUALIZING THE ATOM.*—II.

HOW THE MODERN SCIENTIST COUNTS AND MEASURES ATOMS.

BY ERNEST RUTHERFORD.

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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 radio-active 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 gramme of hydrogen in electrolysis, it can be deduced that $Ne = 1.29 \times 10^{14}$ 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 unit. 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 radio-active 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.

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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 cannot 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 radio-active 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 skepticism, 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 radio-active 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 rapid 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 radio-active 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 radio-active 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 radio-active 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 radio-active 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 radio-activity 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 radio-active 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 radio-active 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 radio-active 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 radio-active 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 radio-active 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 note paper, 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 cannot 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 fine 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.

THERMO-PENETRATION.

A NEW SYSTEM OF ELECTRO-THERAPEUTICS.

BY O. NAIRZ.

Two Vienna physicians, Von Preys and Von Bernd, have devised a new method of electrical therapeutics, which they have named thermo-penetration. For a number of years, especially in France, glow discharges from highly-charged coils have been used for medical purposes. For example, the healing of the wounds made by the excision of superficial cancers and other growths has been expedited by a process called fulguration, in which the wounds receive the glow discharges which are emitted by the secondary circuit of an induction coil when the primary circuit is traversed by the rapidly-alternating discharge of a condenser charged to a high potential, and the coil is attuned to resonance with the oscillating condenser discharge. In a common form of apparatus the secondary coil, containing many turns of fine wire, can be moved so as to inclose a greater or smaller proportion of the primary coil coarse wire. The protruding part of the primary coil is left bare and receives the spark discharge of four Leyden jars, which are charged by an auxiliary induction coil. The discharge of the Leyden jars is composed of about 100 partial discharges, alternately positive and negative, which follow each other at intervals of one-millionth of a second, the entire phenomenon occupying 1/10,000 second. This alternating current of brief duration and very high frequency, flowing through the primary circuit of the induction coil, induces an alternating current of the same duration and frequency and of much higher voltage, in the secondary circuit.

When the movable secondary coil has been adjusted to the position of resonance the outer end of the wire emits a flamelike discharge, resembling St. Elmo's fire, which is allowed to play upon the skin of the patient. The intensity of the effect can be regulated by making the resonance more or less perfect.

When the discharge is received directly by the skin some local pain is experienced, but the discharge is scarcely felt when it is received by a piece of metal held in the hand. Evidently the cells are unable to react quickly enough to feel the rapidly alternating current, just as the ear is unable to perceive sound waves of very high pitch.

The beneficial effects of fulguration are due to superficial burning or heating, but thermo-penetration heats the internal tissues. The human body, like any other conductor, is heated by electric currents which pass through it, the rate of generation of heat being proportional to the electrical resistance of the part of the body involved, multiplied by the square of the current strength. The direct current cannot be employed to heat the bodily tissues, because a current of 0.1 ampere (about one-fifth the current used in a 16-candle-power incandescent lamp) would, in most cases, cause death. The alternating currents which are used in lighting and transmission of power are still more dangerous, but the very rapidly-alternating currents which are produced by the methods described in this article are comparatively safe, for the reason already given, and they can be borne in considerably greater strength.

Physicians have long known that many physiological processes are favorably affected by increase of temperature. Such increase occurs spontaneously in fever, which is a natural curative process, and by which pain is alleviated, injurious micro-organisms are destroyed and eliminated, and other beneficial results are accomplished by the abnormally rapid flow of blood. Until recently it was impossible to increase the bodily temperature effectively by artificial means, as the hottest air and vapor baths that can be borne raise the temperature of the blood to barely 0.1 deg. F. above the normal.

The Vienna physicians employed, in their system of thermo-penetration, the so-called continuous and undamped rapid electrical oscillations produced by Poulsen's method. These oscillations are inconvenient in use and require for their production a direct current of from 220 to 440 volts, which is seldom obtainable. Siemens and Halske have constructed a simple apparatus by which essentially the same results are obtained more conveniently. A condenser, composed of alternate sheets of tinfoil and paper, is charged by a small sparking coil, and discharged through a new and peculiarly effective spark-gap to the primary circuit of an induction coil, as in the fulguration apparatus described above.

An oscillating current, the strength of which can be regulated by adjusting the relative positions of the two coils, is induced in the secondary coil, the terminals of which are placed in contact with the part of the body which is to be heated. Thus the current flows into the body directly, and not through an air space, as in fulguration. The patient feels no pain, but only an agreeable and beneficial warmth, although the strength of the current may be as high as ½ ampere. The skin, which can not endure a temperature higher than 120 deg. F., gives the indication for the limit of current strength. The apparatus includes devices by which the strength of the primary current and the frequency of interruption of the charging coil can be measured and controlled.

Although this process of thermo-penetration has been in use only a very short time it has already proved successful in numerous cases. Its employment appears especially promising in cancer. Cancerous tissue is a better electrical conductor than healthy tissue, and it is therefore very strongly heated by the current.—Prometheus.