RADIOACTIVITY.

VALUABLE and interesting advances have been made in this subject during the year, both from the theoretical and the experimental side. On the theoretical side no important modification has been made in the theory of atomic disintegration outlined in the last Report. This hypothesis continues to account satisfactorily for the experimental knowledge, and there is a growing tendency to interpret it even more literally and to pursue it more strictly to its logical conclusions from the chemical side. The adequate application of the idea of disintegration to other sciences, and in particular to cosmical physics, remains almost virgin territory, although numerous isolated phenomena of the widest diversity of character are being recognised as probable results of such a universal process.

The problems which have occupied the front rank in the year's work are undoubtedly those connected with the α -radiation, and definite advances are to be recorded in our knowledge of the ejection of the α -particle from the parent atom, of its chemical identity, and of the processes accompanying its passage through matter. The line of work originated by Bragg and Kleeman¹ has been extended and completed,² and their methods have been developed into a most powerful engine of research. The authors have analysed the α -radiation of radium into four distinct types or groups of different range or penetrative power, and they have assigned each type to a definite disintegration in the series. In this work only the first rapid changes of radium affect the results, as the later changes are too slow in period to have as yet been studied. (The expression "radioactive equilibrium of radium" in this and many similar connections refers to the equilibrium of the first rapidly changing products.) The range of each of the four types of α -rays from radium has been determined to an accuracy of 0.05 cm. in air. By "range" is to be understood the distance each α -particle travels after leaving the parent atom before it loses its ionising power and passes beyond the means of detection. A result indicated in the earlier work,

¹ *Ann. Reports*, 1904, 255 and 269.

² *Phil. Mag.*, 1905, [vi], 10, 318 and 600.

but not included in the last Report, has been now definitely established. It is found that the ionising power, defined as the number of ions produced per unit length of path, *increases* with increasing length of path, and then ceases quite abruptly when at its maximum. The α -particles expelled from the radium atom itself in its change into the emanation have a range of 3.50 cm. and constitute the least penetrating type of the four. Those from radium C in its change into radium D are the most penetrating and have a range of 7.06 cm. Two intermediate types of range, 4.23 cm. and 4.83 cm. respectively, correspond to the two changes of the emanation into radium A and of the latter into radium B, but it has not yet been found possible to say which of the two types corresponds to each change.

It was definitely proved from the curves obtained that all the α -particles expelled in any one change have exactly the same range, and therefore, as the results to be considered show, the same initial velocity of expulsion. Moreover, when the radium preparation is in radioactive equilibrium the number of particles belonging to each type is the same, and the nature of the α -particles in the different types is identical in every respect save initial velocity of expulsion. This striking result is clearly proved in a graphical manner from the experimental curves; it has long been considered probable by Rutherford, from his earlier work on the nature of the α -radiation, and from the requirement of the simplest expression of the disintegration theory. If we suppose that only one α -particle is expelled from each atom in any change accompanied by α -radiation, it follows that the number of α -particles expelled in the successive disintegrations must be the same for each when the state of radioactive equilibrium is reached. This result, that all the α -particles expelled in each change are all alike among themselves, and that the different types expelled in different changes differ only in initial velocity of ejection, shows that Dalton's conception of the atom applies strictly to radioactive change. No difference of properties has ever been recognised between atoms of the same type; and when atoms disintegrate the lighter fragment is expelled with a definite measurable velocity, which is the same for all the atoms of the one type and different for atoms of different types. The speculations which have been advanced to account for the cause of disintegration, by attributing it to a gradual loss of the internal energy of the atom by radiation until a point of instability is reached, are on the other hand directly opposed to the Daltonian conception of the atom which the experience of chemistry and spectroscopy so strongly supports. It is satisfactory to note that the clear view of the disintegration process obtained from Bragg's work unequivocally supports the older view. The idea of a gradual change of the nature of atom with time derives no experimental support from radioactivity.

Bragg and Kleeman extended their researches to the passage of the α -particle through other substances than air. They deduced an important new general law, that the loss of range suffered by an α -particle in its passage through an atom was approximately proportional to the square-root of the atomic weight. Mixtures and compounds behave similarly. In either case the loss of range is proportional to the sum of the square-roots of the atomic weights of the constituent atoms. The law applies, so far as can be deduced, equally for each of the four types of α -particles expelled from radium, and therefore may be considered to apply generally to the α -radiation. The earlier researches on the absorption of the α -rays by matter, in which the existence of several distinct types in the α -radiation of one element was not recognised, are unreliable. There is no exponential law of absorption and no "density law" for the α -radiation. "Each α -particle pursues a rectilinear course, no matter what it encounters; it passes through all the atoms it meets, whether they form part of a solid or a gas (or in all probability of a liquid), suffering no deflection on account of any encounter until at any rate very near the end of its course. It loses energy as it goes, a portion of this at least being spent in producing ions. . . . A thin metal plate may be placed in the way of the stream, and so rob every particle of some of its energy, but not a single one is brought to rest by collision with the atoms of the metal, and the number of particles in the stream remains unchanged." This clear picture of the collision between a radiant atom and a stationary atom is fully justified by a consideration of the curves.

The square-root law was substantiated for silver, platinum, gold, tin, copper, aluminium, lead, iron, and nickel among the metals, and for methyl bromide, methyl iodide, ethyl chloride, ethyl iodide, carbon tetrachloride, chloroform, pentane, benzene, carbon disulphide, carbon dioxide, oxygen, and hydrogen among the gases. The law is approximate, but ether is slightly irregular, and in addition there is a small but distinct difference of stopping power between the metals and gases. If the stopping power is plotted against the square-root of the atomic weight (or the sum of the square-roots of the constituent atomic weights), the two classes of substances fall on straight lines inclined to each other at a slight angle, the complex gas molecules appearing to possess rather greater stopping power than the metals.

The results put into the hands of chemists a novel method for the determination of atomic weights, although the experimental difficulties are at present very great. Such a method should prove invaluable for the monatomic gases, for which the evidence of atomic weight is confined solely to density determinations. In view of the discrepancy between the accepted atomic weight of helium and Rutherford's determination of the mass of the α -particle, additional evidence of the atomic weight

of this element would be very welcome at the present time, and it is to be hoped that the observers will be able to extend their results to include the monatomic gases.

In a later paper, Bragg¹ deals with the question whether the number of ions produced by the α -ray in different gases is the same. In the simple ionisation theory for voltages above the saturating voltage the current should be independent of the voltage, and it is well known that this law is only approximate. With the complex gases the deviations are much exaggerated, and Bragg attributes them to a new kind of recombination between the ions, not allowed for in the simple theory. This special kind he terms "initial recombination," to distinguish it from general recombination. The initial recombination he attributes to the reunion of the newly formed pair of ions, which is proportional to the number of ions produced, whereas general recombination is proportional to the square of the number present. The latter effect can be reduced at will by making the ionisation very feeble. In such a particular case it was shown that only 1/3000th of the total number of ions produced was lost by general recombination, while the current with 25 volts was only 80 per cent. of the current with 1000 volts. In ethyl chloride under 60 cm. pressure, 2000 to 3000 volts were necessary to secure saturation, but when the latter condition was secured the total number of ions produced in ethyl chloride by the passage of an α -particle was considerably greater than in air, although in the first experiments under ordinary conditions it appeared less. The general explanation of the effect seems to be bound up with the fact that the act of ionisation is essentially an atomic and not a molecular process. In a complex molecule each atom has several very near neighbours, which may attract and recombine with an electron displaced from another atom in the same molecule before the electron moves beyond the sphere of attraction of its parent atom. If more than one atom in the complex molecule loses an electron, the electric field in its neighbourhood is more intense, and the chance of the ejected electron returning to the system is the greater.

Independently of the above results, Rutherford has continued his researches on the nature of the α -ray. The intimate connection between the conclusions drawn by the two authors independently form a feature of the year's work. A new series of determinations of the velocity and of the ratio e/m of the charge to the mass of the α -particles expelled from radium closely confirmed the earlier measurements.² Use was made of the discovery of Bragg that the α -particles expelled in any one disintegration all possess the same range, and therefore presumably travel at the same velocity, to give definiteness to the measurement of

¹ *Trans. Roy. Soc. S. Australia*, 1905, **29**, 187,

² *Phil. Mag.*, 1905, [vi], **10**, 163,

the velocity. Before, only the average velocity of the four groups was determined. In the present research, the measurements were made on a single type of homogeneous α -particles. The α -particles expelled from radium C were selected as the standard, for besides being the most penetrating they can be obtained homogeneous and under conditions where no absorption occurs in the active matter itself. A platinum wire was exposed to the action of the emanation and kept negatively charged to concentrate the excited activity on it. The rays from radium A decay practically to zero fifteen minutes after the removal of the wire from the emanation, and since radium B gives out no rays, from that time the α -radiation is homogeneous, comprising only the α -particles expelled from radium C. The actual mass of the active deposit is so insignificant that the real initial velocity of projection is obtained undiminished by absorption in passing through the material. The deflection of the rays was determined by Becquerel's photographic method in a partial vacuum. The value found for mv/e was 3.98×10^5 . The experiments on the electrostatic deviation are not complete. From other determinations of the heating effect or kinetic energy of the α -particles, and of the number of α -particles produced per gram of radium per second, it was calculated that $v = 2.6 \times 10^9$ cm. per second, and $e/m = 6.5 \times 10^3$ E.M. units. These results are practically identical with the earlier ones, but the author does not consider that sufficient weight can be attached to them to bear on the important question of the nature of the α -particle. The atomic weight of the α -particle calculated from the data is 1.51 ($H = 1$).

Another new determination of the magnetic and electrostatic deviation of the α -rays of radium has been carried out by A. Stanley Mackenzie.¹ The position of the deflected beam was determined by the phosphorescence of a zinc sulphide screen recorded photographically, and the whole complex beam was used. The mean value for mv/e was 3.0×10^5 , the extremes being 2.5×10^5 and 3.7×10^5 , but the rays had to pass through a thickness of mica estimated, to decrease the initial velocity by 6 per cent. The results of the electrostatic deviation gave $v = 1.18 \times 10^9$, 1.45×10^9 , and 1.74×10^9 cm. per second for the slowest, mean, and fastest particles respectively, whilst the value of e/m was 4.6×10^3 . For the α -particle of polonium the value of mv/e was 3.3×10^5 . It is doubtful whether these results can be given more weight than the earlier ones of Rutherford and Des Coudres in the discussion of the nature of the α -particle.

Rutherford² passed the radiation from radium C through successive thicknesses of aluminium foil, and determined the magnetic deviation after each penetration. A clear photographic effect could be obtained through 12 layers of thickness 0.00031 cm., but no effect at all

¹ *Phil. Mag.*, 1905, [vi], 10, 538.

² *Loc. cit.*

through 13 layers. The photographic effect ceases abruptly after passage through a thickness of aluminium greater than 0.0037 and less than 0.0040 cm. It was found that the velocity of the α -particle regularly decreased with each successive penetration of a thickness of foil. The velocity of the particle, as determined from the magnetic deviation, after passage through 0.0037 cm. was found to be still 64 per cent. of the initial. So that the particles still possess 41 per cent. of their initial kinetic energy when they cease to affect the photographic plate. It was shown that each layer of foil had the same effect in stopping the α -particles as 0.54 cm. of air, so that 12 layers would correspond to 6.5 cm., and 13 to 7 cm. of air. This showed that the α -particles ceased to produce a photographic effect at the same velocity as that at which Bragg showed they cease to ionise. In addition it was proved that the phosphorescent action of the α -rays of radium C ceased after passage through 6.5 cm. of air, or 12 thicknesses of aluminium foil. The α -particle of radium ceases to produce either photographic, fluorescent, or ionising action at the same speed, and in the case of radium C this speed is still over 60 per cent. of the initial speed of expulsion, or 1.3×10^9 cm. per second. This is a most remarkable and important result, and in the author's view indicates clearly that all three phenomena have a common cause, and that the photographic and fluorescent action are both primarily caused by ionisation. Rutherford shows from his results, and the value of the ranges in air given by Bragg, that the velocity of the other particles of radium can be calculated in terms of that of radium C. Expressing the latter by V , and using for the calculation the more recent determinations of Bragg, we have—from radium 0.87 V , from the emanation 0.89 V or 0.91 V , and from radium A 0.91 V or 0.89 V . The mean velocity is 0.92 V , and the different α -particles do not differ in velocity more than 8 per cent. from the mean value. In conclusion, Rutherford points out that if in any atomic disintegration an α -particle were expelled with a velocity below 1.5×10^9 cm. per second it would be beyond the means of detection and the change would be a rayless one, so that ordinary matter may be undergoing comparatively rapid transformation without producing appreciable effects.

The view that the photographic action and also the view that the fluorescent action of radiations is primarily an ionising action have been brought forward independently during the year. J. Joly¹ from general photographic evidence concluded that photographic action is due to ionisation. The main arguments used were—(1) the connection between photographically active and photoelectric substances, both the haloid salts of silver and the organic dyes used to produce colour-sensitiveness being strongly photoelectric; (2) the persistence of photographic effect

¹ *Nature*, 1905, **72**, 308.

at low temperature, proving that the action must be atomic and not molecular (Dewar), and the fact that photoelectric action also persists at low temperature; (3) the common ionising and photographic action of such a variety of different types of radiation; (4) the possibility of explaining photographic reversals on this view. In the latent image there may be a rising potential between the groups of ions until ultimately a point is reached where there is a spontaneous discharge and neutralisation causing photographic reversal.

G. T. Beilby¹ investigated the fluorescence of barium platinocyanide under the action of the β - and γ -rays of radium. He showed that the loss of fluorescent power or fatigue of the crystals after prolonged fluorescence was due to a change from the crystalline to the amorphous state analogous to that produced by mechanical flow in his experiments on metals. After prolonged action of the rays, the fluorescent power of the crystals fell to about 8 per cent. of the initial and did not further diminish. The crystals are reddened and the change is permanent, neither the original colour nor the fluorescence being recovered by keeping either in the dark or in the light. Exactly the same effect on the colour and fluorescence power is produced by causing the crystals to flow mechanically with an agate pestle, and both the fatigued and the flowed specimens recover their original properties partially by heating and completely by solution and recrystallising. The second part of the paper deals with the secondary phosphorescence exhibited by certain substances after removal from the action of the rays, and with the phenomenon of thermoluminescence or revived phosphorescence induced in a substance previously exposed to radium by the action of heat. He shows that the various actions can be explained on the view that the rays ionise the substance, and that the ions remain insulated and stored up in the substance under some conditions for considerable periods, the insulation being broken down on heating.

Referring to the important result of Rutherford that the α -particle still possesses 60 per cent. of its original velocity when it ceases to ionise, Bragg² deduces from his results that this critical velocity must be exactly the same in all gases, otherwise the curves obtained in dealing with a mixture of gases should consist of the several simple curves overlapping; but no trace of such an effect exists. This strengthens the argument that the act of ionisation must be the same for all gases. A further conclusion is drawn as to the relation between the velocity of the α -particle and its ionising power for unit-length of path. It is deduced that the ionising power is proportional to the square-root of the speed, a result which is to be expected if the force acting between the radiant atom and the atom with which it collides is a function of their mutual distance.

¹ *Proc. Roy. Soc.*, 1905, **74**, 506.

² *Phil. Mag.*, 1905, [vi], 600.

These conclusions of Rutherford and Bragg with regard to the nature of the α -ray have been criticised by Becquerel,¹ who maintains his earlier results that the α -rays behave as a homogeneous beam, all the particles possessing the same deviability in the magnetic field, and that the radius of curvature increases with the length of the path, instead of decreasing as Rutherford finds. To account for this increase, Becquerel has put forward the view that the value of the mass to the charge increases with the length of path owing to the mass being augmented by the particle attracting other particles to it. The replies of Rutherford and Bragg to this criticism are to be found in the current numbers of the *Philosophical Magazine* and *Physikalische Zeitschrift* respectively. The controversy is extremely interesting, but is too highly technical to be dealt with profitably without diagrams.

McClelland² has found that a relation holds between the atomic weight of a metal and the secondary radiation to which it gives rise when struck by the β -rays of radium. The secondary radiation is the greater the greater the atomic weight, but is not proportional to it, and increases less rapidly than the atomic weight.

The elements fall into well-defined divisions when the atomic weight is plotted against the secondary radiation, and these divisions correspond exactly to the division into periods of the periodic table. A broken curve is obtained, the increase of secondary radiation with the atomic weight being greatest for the electropositive and least for the electronegative elements, whilst in the change from one period to the next there is very little increase in the secondary radiation. The results tend to confirm the view of J. J. Thomson as to the electronic constitution of matter. They add another interesting example to the general periodicity of physical as well as chemical properties first elucidated by Lothar Meyer.

The important questions³ connected with the positive charge carried by the α -particle have been the subject of much work during the year, but no final conclusion is yet possible. J. J. Thomson⁴ showed that radium and polonium in a good vacuum emit besides α -particles a copious stream of slow-moving electrons, which in ordinary circumstances neutralise the positive charge carried by the α -particles. If a magnetic field is applied, the electrons can be disentangled from the α -particles, and the latter then conveyed a positive charge to a plate on which they impinged. Rutherford,⁵ using the same means for eliminating the slow-moving electrons, succeeded in measuring the total positive charge conveyed by the α -rays from a known weight of radium. If the α -particles are assumed to carry the atomic charge, that is, are

¹ *Compt. rend.*, 1905, **141**, 485.

² *Trans. Roy. Dub. Soc.*, 1905, **19**, [ii], 1.

³ *Ann. Reports*, 1904, 255.

⁴ *Proc. Cam. Phil. Soc.*, 1905, **13**, 49.

⁵ *Phil. Mag.*, 1905, [vi], **10**, 193.

minus one electron, it was deduced that 1 gram of radium (element) must expel 6.2×10^{10} α -particles per second for each change it undergoes, or 2.5×10^{11} α -particles in the first four rapid changes. Rutherford concluded that there was no obvious reason for supposing that the α -particles are not charged at the moment of their expulsion. The total number of β -particles expelled per gram of radium in radioactive equilibrium per second was 7.3×10^{10} , confirming in a most interesting manner the result indicated by theory that four α -particles are expelled to each β -particle. From the number of atoms disintegrating per second, Rutherford deduces that λ for radium is 5.4×10^{-4} (year)⁻¹, the time for half-transformation 1280 years, and the average life of the radium atom 1850 years, which is in good accordance with previous estimates.

J. J. Thomson¹ announced that uranium as well as radium and polonium emit the slow-moving electrons, and the writer² suggested that these electrons might be derived from the α -particles themselves, which are expelled initially unchanged, but lose electrons on collision with the gas molecules, so that the negative charge carried by these electrons exactly neutralises the positive charge carried by the α -particles. Miss Slater³ has shown that the emanations of both radium and thorium give out the slow-moving electrons as well as α -rays in their change into radium A and thorium A, so that it appears that the effect is general for the expulsion of the α -ray. It is clear from Bragg's curves that the α -particles from the thinnest so-called "film" of radium salt have on the average passed through many molecules of the salt. The experimental results so far recorded are to be expected on either view, and the question whether the α -particle is charged initially after expulsion has not been settled.

In connection with the nature of the α -particle there can be little doubt that it consists of an atom of helium. Debierne has shown that helium is produced from actinium to an extent comparable to its rate of production from radium of equal activity. First working with 100 milligrams of radium bromide in a manner similar to that employed by Ramsay and Soddy, he found that with practice he could repeat their results in a very regular manner, and obtained tubes showing an intense spectrum of helium. The solution did not appear to become exhausted, but the production took place regularly. Working with actinium, both in solution and in the state of fluoride free from water, Debierne found in each case a production of helium comparable to the activity of the preparation. Himstedt and Meyer⁴ have given the result of further experiments, mostly blank tests, on the production of helium from radium. The writer has attempted to measure accurately the amount of helium produced from uranium and thorium, and in one

¹ *Nature*, 1905, **71**, 438.

² *Ibid.*

³ *Phil. Mag.*, 1905, [vi], **10**, 460.

⁴ *Ann. Physik.*, 1905, [iv], **17**, 1005.

experiment—the only successful one so far obtained—got from uranium indications of helium in about the quantity to be expected from the theory that the α -particle is an atom of helium.¹ The only successful experiment with thorium was of the nature of a blank test, and proved that the rate of production was not greater than ten times that to be expected from theory. It is hoped, as the experimental difficulties in the detection of these infinitesimal quantities of helium have been overcome, the results will give in due course a definite answer to the question of the nature of the α -particle.

In the department of radioactive change, advances have been made in our knowledge of the disintegration series of each of the elements, uranium, thorium, radium, and actinium. One of the most important is the successful separation of a new radioactive constituent possessing thorium radioactivity from the Ceylon mineral thorianite, by Ramsay and Hahn. Thorianite has been shown by Dunstan and Blake² to consist of about 70 per cent. of thorium in the form of dioxide soluble in nitric acid. It possesses an activity comparable to that of the pitchblende from Joachimsthal, and contains several times as much helium as any mineral known. Ramsay worked up 250 kilograms for radium, and the carbonates of the alkaline earth group obtained from it weighed 18 grams and possessed an activity about 500 (uranium = 1). This was submitted to fractionation by Giesel's process,³ but it was found that the activity concentrated both in the more soluble and in the less soluble portions, the middle fractions being the least active. Ultimately it was proved that a small part only of the activity was due to radium, the major part being due to a new type of matter named appropriately "radiothorium" and possessing thorium radioactivity to a very intense degree. Weight for weight, the new product was shown to be at least 100,000 times as active as thorium. The activity was accurately determined by the relative amount of thorium emanation evolved from the two substances, and for one preparation an activity of 690,000 is recorded. The identity of the activity of radiothorium with that of thorium was shown by a comparison of the constant of decay of the emanation and excited activity from the two substances, and also by the fact that radiothorium produces thorium X exactly as in the case of thorium.

The results indicate that there is an intermediate substance, radiothorium, between thorium and thorium X, with a chemical nature extremely closely allied to thorium. Two questions arise. Since the radioactivity of radiothorium is comparable to radium, the period of average life must also be of the same order for each, or about a thousand

¹ *Nature*, 1905, **73**, 151.

² *Proc. Roy. Soc.*, 1905, **76**, Series B, 253.

³ Hahn, *Jahrb. Radioakt. Elektronik*, 1905, [ii], 233.

years. As the average life is short, radiothorium must possess a parent element in thorianite, and the question arises as to whether thorium is the parent. If thorium is the parent, it would seem that the original change of thorium into radiothorium is probably "rayless," so that pure thorium would be inactive, and the "non-separable activity" due to radiothorium. This would account at once for the apparent constancy of activity of thorium preparations, and for the existence of inactive thorium repeatedly affirmed by Hofmann and Zerban. This view, although rendered almost necessary by the results in Hahn's paper, has not yet been definitely established. No measurements are given in the paper of the activity of the thorium obtained from the thorianite to see if this is less than usual, and it has not been found possible to separate radiothorium from ordinary radioactive thorium.

Sackur¹ attempted to separate from thorium a radioactive constituent, but failed to obtain a constantly active substance, or to effect a lasting concentration of the radioactivity.

Elster and Geitel² obtained from the spring at Baden-Baden a precipitate which gave considerably more thorium emanation than a similar weight of thorium. Giesel³ obtained from the residues from monazite sand, after removal of thorium, preparations which possessed thorium radioactivity ten times as great as ordinary thorium. Presumably this activity was permanent, and, if so, must have been due to radiothorium, not merely to thorium X. Baskerville and Zerban⁴ describe a new source of inactive thorium, a rock obtained from South America, consisting mainly of barium carbonate with a very small percentage of thorium. As in previous communications on inactive thorium, the statement is made that no radiations are given off, but no details as to the method of testing are given. Such measurements as are given are merely photographic tests. It may be mentioned here that Baskerville's work on the separation of two new elements, carolinum and berzelium, from ordinary thorium is, as the author himself points out, purely chemical work, and does not bear directly on the question of the radioactivity of thorium. Zerban,⁵ in support of the view previously expressed by Hofmann and himself that active thorium is only obtained from minerals containing uranium, and when the latter element is absent the thorium obtained from the mineral is inactive, announced that he had detected 0.02 per cent. of uranium in crystallised Norwegian monazite, and that the composition of this mineral does not oppose the view. If Hofmann and Zerban's supposition is correct, it would appear to indicate that uranium rather than thorium was the parent of radiothorium, and that

¹ *Ber.*, 1905, **38**, 1756.

² *Phys. Zeit.*, 1905, **6**, 67.

³ *Ber.*, 1905, **38**, 2834.

⁴ *Chem. News*, 1905, **91**, 74.

⁵ *Ber.*, 1905, **38**, 557.

the latter's association with thorium was not generic but due to its great similarity of chemical nature.

Miss Slater¹ has shown that the periods of thorium A and thorium B must be transposed. Thorium A changes into thorium B without emitting rays, but the time for half-transformation is eleven hours, whilst the period of fifty-five minutes belongs to the α - and β -ray change of thorium B into the unknown inactive end-product.

A careful examination of the conditions under which thorium X may be separated from thorium has been carried out by Schlundt and Moore.² They find the action of pyridine and fumaric acid similar to that of ammonia, in that all three reagents precipitate thorium and leave thorium X in solution. Pyridine leaves more thorium A in solution than ammonia, and thorium A may be obtained pure by precipitating first with ammonia, then redissolving the precipitate, and reprecipitating the thorium with pyridine. Fumaric acid, on the other hand, leaves all the thorium A in the solution and precipitates thorium B only with the thorium. The latter, therefore, after the lapse of five hours during which the thorium B changes completely, gives the 25 per cent. non-separable activity due to the first α -ray change. They confirmed Miss Slater's result of the relative period of thorium A and thorium B, and separated pure thorium B by electrolysis. A large number of organic reagents were found to precipitate thorium, leaving a part of the active matter in solution. Thorium fumarate is stated to possess the highest emanating power known of any thorium compound in the solid state. Inactive thorium was never obtained. F. v. Lerch,³ continuing his work on the electrolysis of thorium solutions and the separation of the active products, shows that electrolysis and the action of metals precipitate only the matter causing the excited activity (thorium A and thorium B) and no thorium X from acid solutions, but in alkaline solutions thorium X is precipitated. These results were obtained by a careful examination of the rate of decay of the activity of the preparations.

In the disintegration series of radium there is much new matter to be included. The diagram given in the last Report (p. 268) must be supplemented by the addition of another stage between radium D and radium E.⁴ In consequence, what was before named radium E (polonium, radiotellurium) must be termed radium F. The period of half-transformation before given for radium D (forty years) remains unchanged, but this is a rayless change. The β -ray results in the change of radium E into radium F, and the half-period for this

¹ *Phil. Mag.*, 1905, [vi], 9, 628.

² *J. Phys. Chem.*, 1905, 9, 682.

³ *Wien. Sitzungsber.*, 1905, 114, [iia], 1.

⁴ Rutherford, *Phil. Mag.*, 1905, [vi], 10, 290.

substance is six days. In addition it will be convenient to include here a recent paper of Bronson¹ which shows that the periods of radium B and radium C must be transposed and decreased, the correct rate for radium B being twenty-six minutes and of radium C twenty-one minutes (for half-transformation). Rutherford has incorporated all these results with the exception of the last (Bronson) in a new edition of his book,² and has dealt very fully with the experimental evidence and the theory in these succeeding changes. He points out that when a rayless change is followed by a change in which rays are expelled, the decay curves of the radiation reveal the constants of both changes but do not indicate which constant applies to each change. This can be determined only after a chemical separation of the products. Miss Slater separated thorium A from thorium B by volatilisation, the latter being more readily volatilised by heat than the former, whereas by the bombardment of the substance by cathode rays *in vacuo* the opposite obtains. The earlier results of v. Lerch and of Pegram obtained in the electrolysis of thorium solutions are in full agreement with the latest results. Bronson showed that radium B is more readily volatilised by heat than radium C, and succeeded in separating the latter and measuring its decay constant alone.

With reference to actinium, Godlewski³ succeeded in separating from this substance a product, actinium X, in every way analogous to thorium X and intermediate between the parent element and the emanation. The method employed was identical with that employed by Rutherford and Soddy for thorium X. The period of half-transformation was found to be 10.2 days. Unlike the case of thorium, the removal of actinium X reduces the activity of the parent element to only 5 per cent. of the initial value, so that it is indicated that the initial change of actinium into actinium X is a rayless change.

Giesel⁴ and Marckwald⁵ have both independently brought forward evidence agreeing with the above on the existence of actinium X.

Hahn and Sackur have established the identity of the actinium of Debierne and the emanium of Giesel⁶ by showing that the constants of decay of the emanation and excited activity are the same for both substances. They obtained for the periods of half-transformation 3.6 seconds and 3.9 seconds for the emanation of actinium and emanium respectively, and 36.5 minutes for the excited activity in each case.

Godlewski⁷ has shown that the β -rays of actinium are peculiar in that they are homogeneous, and are absorbed by matter according to a

¹ *Phil. Mag.*, 1906, [vi], 11, 143.

³ *Phil. Mag.*, 1905, [vi], 10, 35.

⁵ *Ibid.*, 2264.

⁷ *Phil. Mag.*, 1905, [vi], 10, 44.

² *Radioactivity*, Camb. Univ. Press, 1905.

⁴ *Ber.*, 1905, 38, 775.

⁶ *Ibid.*, 1943.

strictly exponential law. They are moreover of only half the penetrating power of the β -rays of any other element, whilst the γ -rays of actinium are only one-quarter as penetrating as those of radium. The resemblance between actinium and thorium in their respective disintegration is almost complete, both in the number and nature of the changes. Bronson has pointed out that in all three elements, radium, actinium, and thorium, the rayless change is of a longer period than the one immediately following. This is true for both rayless changes of radium. In all four cases the change next following the rayless change is accompanied by the expulsion of a β -ray. The general resemblance in character and relative period of the succeeding members of the various disintegration series on the one hand, and their distinct individual peculiarities on the other, are most fascinating and mysterious. We seem to have here an extension of similar relations expressed for elementary matter generally by the periodic law, and there is no doubt that any explanation of the one will have an application to the other.

Godlewski¹ has satisfactorily explained some anomalies in the rate of decay of uranium X obtained by Meyer and von Schweidler² by showing that the uranium X was unequally distributed in the salts prepared in their experiments, and that the gradual equalisation of the concentration of the uranium X by diffusion through the mass accounts satisfactorily for the anomalies observed.

Becquerel has shown that uranium X can be removed from uranium solutions by boiling with lampblack, as the latter withdraws the uranium X from the solution.³

The production of radium from uranium has now been definitely established by direct experiment and also by indirect methods. The writer⁴ freed a kilogram of uranium nitrate from radium by successive precipitations in its solution of barium sulphate, and showed by means of the emanation test that the amount of radium 567 days after purification was more than a hundred times greater than at first. The rate of growth was estimated to be only of the order of one-thousandth part of that to be expected from the theory on the assumption that uranium X changes directly into radium. From this and other evidence to be given later, it is extremely probable that several intermediate forms exist between uranium X and radium, with long periods of transformation, causing the initial rate to be diminished.

Boltwood⁵ has criticised this result. Working with 100 grams of uranium nitrate, purified originally from radium by repeated crystallisation from water, he obtained no detectable increase in the

¹ *Phil. Mag.*, 1905, [vi], 10, 45.

² *Wien. Sitzungsber.*, 1904, 113, [iia], 1057.

³ *Compt. rend.*, 1905, 141, 485.

⁴ *Phil. Mag.*; 1905, [vi], 9, 768.

⁵ *Amer. J. Sci.*, 1905, 20, 239.

amount of emanation produced after a period of 390 days, and concludes that the results obtained by the writer are "without significance." Boltwood's experimental results are, however, in complete agreement with the writer's experience, for with so small a quantity for so short a time the effect would not be within the means of detection. The criticism appears to be based on a false comparison between the two experiments. The experiments are not comparable, and the relation between them need not here be further discussed.

McCoy¹ first showed that the radioactivity of the uranium minerals not containing thorium is proportional to the quantity of uranium present, which is indirect evidence that uranium is the parent of the other radio-elements, radium and actinium, present in the mineral. Strutt² and Boltwood³ have investigated the ratio between the uranium and radium in the various uranium minerals. Boltwood obtained results for twenty-one minerals showing that in all cases the ratio between the two elements is surprisingly constant and that the "inevitable and only possible conclusion is that uranium is the parent element of radium." He determined the amount of uranium by analysis, and the radium from the amount of emanation released on dissolving the mineral and the amount released spontaneously by the mineral in the solid state. Strutt used a more direct method of estimating the radium in that the solution of the mineral was allowed to accumulate emanation for a definite time. His results for 20 minerals showed much greater variations in the ratio than in the former case, but the approximate proportionality was clearly brought out. Strutt pointed out that thorium seemed to be inevitably accompanied by the uranium-radium series, although minerals containing the latter in which thorium is absent are common. The minerals richest in helium are richest in thorium although the converse does not hold.

Marckwald has continued his work on radiotellurium or polonium,⁴ and finds that this element comports itself chemically in every respect as the missing element of the sulphur-selenium-tellurium family. It thus bears the same relation to tellurium as radium bears to barium. Fifteen tons of pitchblende yielded 5 tons of residues after the extraction of the uranium, and from this material 16 grams of selenium, tellurium, and radiotellurium were precipitated by sulphur dioxide. The gradation of properties from selenium to radiotellurium is shown in the action of their oxides towards ammonia. Tellurium, although giving an oxide possessing acidic properties and dissolving in ammonia, does not form a stable compound. The oxide of radiotellurium is not dissolved by ammonia. The residue from the 16 grams after treatment with ammonia weighed 3 milligrams and contained all the active matter.

¹ *Ber.*, 1904, **37**, 2641.

² *Proc. Roy. Soc.*, 1905, **76**, Series A, 88.

³ *Phil. Mag.*, 1905, [vi], **9**, 599.

⁴ *Ber.*, 1905, **38**, 591.

The vexed question as to the constancy or otherwise of the radiation from radiotellurium has been settled. Meyer and von Schweidler¹ have determined the decay constant and found it to be normal, the period of half-transformation being 135 days. Marckwald has confirmed this and obtained the value 139 days. Finally, Rutherford² compared the rate of decay of radiotellurium with radium F and obtained the same constant for each (143 days). He calculates from this the quantity of this substance in pitchblende containing 50 per cent. of uranium to be about a milligram in 7 tons, and the α -ray activity of pure radium F to be about 800 times that of radium in radioactive equilibrium. The constant proportion of radium in the uranium minerals he determined in conjunction with Boltwood to be 0.72 gram of radium per ton of uranium.³ A knowledge of this constant obviates the necessity of estimating the radium-content of minerals if the uranium-content is known. The evidence with reference to the polonium of Mme. Curie, although acquired only after great labour and by the co-operation of many, is now far more striking than for the case of radium. Here we have a case of an ordinary chemical element, the position of which has been found in the periodic table, and the chemical nature of which is completely determined, changing so rapidly that only half survives after five months, and giving out in the process nearly a thousand times the energy which a similar weight of radium gives out in a similar time. To-day, with our theoretical knowledge, however, such an amazing result calls for no special treatment and hardly awakens surprise.

Since radium F has been shown by Marckwald to comport itself as the missing heavy sulphur element, its atomic weight must be the next higher to bismuth, and therefore between 210 and 212. This very strongly supports the view that the α -particle is an atom of helium, for in the change from radium into radium F four α -particles are expelled, and a reduction of about fifteen units is therefore to be expected. A further step is possible because radium F expels an α -particle in its change into the unknown radium G. Radium G is the apparent end of the series and is unknown because it is not changing, so that it is to be expected that radium G is likely to prove to be a well-known element. If the atomic weight of radium F is 210 to 212 the choice of the identity of radium G would appear to rest between bismuth and lead. Boltwood has called attention to the presence of lead in the uranium minerals and has suggested that it is one of the final products. The experimental verification of this may be confidently expected owing to the rapid period of change of radium F and the easy methods of separating it from the mineral worked out by Marckwald.

The results also have a bearing on the question of the production of

¹ *Wien. Sitzungsber.*, 1905, **114**, [iii], 5.

² *Phil. Mag.*, 1905, [vi], **10**, 300.

³ *Radioactivity*, 1905, 462.

uranium from radium. Here, as in the case of the change of uranium into radium F, a reduction of 13 units occurs, so that it is to be expected that three or four changes accompanied by α -radiation would occur in the transformation. Only one change is at present known, but the existence of intermediate products of slow period between uranium and radium already suggested is made more probable by these considerations.

Donald Murray has suggested¹ that the constant companionship of lead and silver in their ores indicates that silver is a disintegration product of lead, and the writer² from economic evidence has suggested that gold is a member of a disintegration series, and that its concentration in its ores is, as in the uranium-radium minerals, fixed on the average by the ratio between its rate of change and that of its parent element.

In conclusion, attention may be directed to a highly interesting and suggestive paper by J. J. Thomson³ on the emission of electrons by the alkali metals. The paper breaks entirely new ground in that the author shows that the well-known phenomenon of the emission of electrons from metals exposed to the action of ultra-violet light, occurs also to a very small extent in absolute darkness in the case of rubidium and of the liquid alloy of sodium and potassium. An electroscope, sealed up in the flask which contained the alkali metal in a vacuum produced by Dewar's method, lost a positive charge even when kept in absolute darkness, although there was no perceptible leak when the leaf was negatively charged. It was also shown that sodium in the state of vapour gives out electrons the same as when in the solid state. In this experiment, light was not excluded. The sodium was vaporised in an exhausted glass flask, and in the vapour two oppositely charged wires were immersed. It was found that the sodium vapour tended to condense almost exclusively on the negatively charged electrode, in a manner exactly analogous to that in which the excited activity produced by the radioactive emanations is concentrated on the negative electrode.

If the emission of electrons from the alkali metals does take place spontaneously, and independently of the action of external influences, the phenomenon becomes in that respect allied to natural radioactivity. The author concludes therefore that it involves the explanation that the energy of the process is derived from the internal energy of the atom, or, in other words, the alkali metals no less than the radio-elements must be spontaneously undergoing atomic changes. The action of light in accelerating this process must be regarded as analogous to that of a detonator causing the atoms on which they impinge to explode, and the energy evolved in the process must be regarded as being derived

¹ *Nature*, 1905, **73**, 125.

² *Ibid.*, 151.

³ *Phil. Mag.*, 1905, [vi], **10**, 584.

from the internal energy of the atom rather than from the energy of the electric field in the light-wave. This view leads to the further conclusion that the tapping of the internal energy of the atom is to some extent under control and can in certain cases be effected by the action of light and other agencies.

These considerations are so opposed to the experience derived from the study of radioactive transformations that it may be considered very doubtful if the processes are analogous. It is certain that the mere loss or gain of an electron by an atom does not of itself constitute a change analogous to that suffered by the radio-elements. In the writer's opinion, the loss of electrons—produced, for example, in a piece of glass when it is rubbed on silk—should be distinguished from atomic disintegration in the sense it is employed in radioactivity, although sometimes, as in the disintegration of uranium X, radioactive change is accompanied by the expulsion of an electron alone. The loss of electrons by the alkali metals seems to be more nearly allied to the numerous ionic changes dealt with in chemistry—for example, the change of the ferrous into the ferric ion—and to possess the characteristics of the latter rather than to a disintegration like that of uranium X. The source of the energy on this view would be the ordinary chemical energy and not the internal energy of the atom.

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