

RADIOACTIVITY.

THE year's work has been notable for the very large number of important investigations, with interesting theoretical bearings, but chiefly concerned with points of detail rather than with any great general extension of the boundaries of the subject. Radioactivity at the present time resembles somewhat the science of organic chemistry in its early days, both in its bewildering wealth of detail and in the opportunities it affords for the crucial examination of theoretical predictions. On this account, however, it becomes increasingly difficult to give any connected account of the progress made. The various investigations in different parts of the subject are so closely interconnected that they cannot well be separated into distinct sections, and some latitude in the order in which the subjects are taken must be allowed. It is impossible to draw a distinction between researches which are more nearly physical and those which are mainly of chemical interest, for it seems that the more clearly an investigation falls under the one head the more surely does it become indispensable to the other side of the subject. Thus the electro-chemical researches, particularly of von Lerch, on the separation of successive disintegration products are indispensable to physicists in the analysis of the complex radiations, and the determination of the physical constants of each type of radiation separately. Bragg's work on the ionisation ranges of the α -rays, dealt with at length last year,¹ has developed this year in the hands of Hahn into a method of analysis of two successive products hitherto regarded as single, and which so far chemical methods have proved powerless to separate. Rutherford's final results, to be considered at length, on the constants of the α -particle, threaten to raise again the problem of the atomic weights of the inert gases, and the validity of the theoretical grounds on which the accepted values are based, whilst Bragg's method of ionisation ranges, as already indicated, affords a novel and independent method of determining the atomic weight of gases. In the wealth of information concerning the properties of each of the new separate disintegration products, now become too numerous almost to remember, no detail is too unimportant to be dealt with, for at any moment some

¹ *Ann. Report* 1905, 295.

such apparently trivial fact may furnish a clue to the laws underlying the arbitrary and mysterious courses along which the devolution of matter is proceeding before our eyes. Already it is becoming increasingly evident that there is familiar method in the apparent madness, and in the strange resemblances and analogies between the successive members from different parent elements we have a new and varied phase of the old problem of the relations between the elements themselves which finds its most complete expression, although no explanation, in the Periodic Law. When it is considered that each of these disintegration products is a new elementary form of matter and that the total number of elements known has been increased by nearly one-fourth through the study of radioactivity in the last five years, we have a sufficient answer to the view the writer has heard expressed that radioactivity is outside the sphere of chemistry and must be considered the exclusive territory of the physicist. Since all the newcomers are derived from and related to two only of the previously known elements, it may be realised how little the possibilities of matter have been exhausted by the older chemistry. But the prospect of any simple and complete hypothesis of matter seems to have been rendered more remote rather than brought within measurable distance of realisation by the recent extensions.

Constants of the α -particle.—Some of the problems in connexion with the nature of the α -ray will be first considered, as these have again occupied a prominent place in the year's work. The controversy¹ between Becquerel on the one hand² and Rutherford³ and Bragg⁴ on the other has been satisfactorily settled. In a later communication, Becquerel⁵ gives the results of further experiments in which a beam of α -rays, deflected in a magnetic field, was made to register its deflection on a photographic plate both after passage through a thickness of aluminium foil and when the foil was removed, and he obtained the same result as in Rutherford's experiments, that the beam is more easily deviated after passage through aluminium foil, and therefore suffers retardation of velocity in its passage through matter. The earlier view that there was an increase in the radius of curvature along the trajectory is shown by the new experiments to have been erroneous, and the traces conform to a circular trajectory.

Rutherford⁶ reproduces photographs of a very striking character, showing clearly the displacement of the trace in the direction of greater deviability when the α -rays are caused to pass through 0.003 cm. of aluminium foil, using the homogeneous α -radiation from

¹ *Ann. Report*, 1905, 302.

² *Compt. rend.*, 1905, **141**, 485.

³ *Phil. Mag.*, 1906, [vi], **11**, 166.

⁴ *Ibid.*, 627.

⁵ *Compt. rend.*, 1906, **142**, 365; *Phil. Mag.*, 1906, [vi], **11**, 722; *Phys. Zeit.*, 1906, **7**, 177.

⁶ *Loc. cit.*

radium *C*, whilst in another photograph the broad diffuse trace obtained by using a thick layer of a radium salt, emitting several types of α -rays travelling with different velocities, is contrasted with the result when a homogeneous source of α -rays is employed. In addition, the photographs establish a slight but distinct *scattering* of the beam consequent upon its passage through matter. Thus in one photograph the impressions produced by the rays of radium *C*, (1) in a vacuum, (2) after passage through air, are contrasted, and it is clear that not only can the rays be deviated to a greater extent, but the trace is broader and less well defined in the second case than in the first. This is an important result, as Bragg and Kleeman¹ had shown that if any such scattering in passage through matter occurs it can only be small, and is sharply to be distinguished from the very marked scattering that is shown by the β -rays.

Rutherford,² in a paper entitled "The Retardation of the α -Particle in passing through Matter," gives some data differing somewhat from the preliminary measurements already given.³ It will be recalled that there exists a certain sharply defined "critical velocity" at which all action of the α -ray abruptly ceases, so that even although it is moving at great speed it produces no ionising, photographic, or fluorescent action. This critical velocity is now given as $0.43 V$, where V indicates in all cases the initial velocity at which the α -particle of radium *C*, the fastest of those from radium, is expelled. It was found when successive thicknesses of aluminium foil were placed over the source of α -rays that each layer caused a reduction of velocity by an amount greater than the last, but the simple law was established that the diminution of the kinetic energy, or the square of the velocity, of the α -particle was the same amount for each layer of foil added. If the kinetic energy is plotted against the thickness of matter traversed, a straight line is obtained which if produced cuts the axis of zero energy at a point represented by 8.31 centimetres of air, that is, 1.25 cm. beyond the critical distance at which the rays cease abruptly to ionise. This has proved a very useful result, although it may be said at once that we have at present no knowledge of what becomes of the α -particle after it has passed through its critical distance. Bronson⁴ made a search for any small ionisation by the α -rays beyond their critical distance, but with negative results. The drain on the energy of the α -particle on account of ionisation ceases after the critical distance is passed, so that unless other actions, of which we have at present no knowledge, occur, there may be no cause acting to retard the velocity further once the critical velocity is reached. J. J. Thomson⁵ has

¹ *Ann. Report*, 1906, 297.

² *Phil. Mag.*, 1906, [vi], 12, 134.

³ *Ann. Report*, 1906, 300.

⁴ *Phil. Mag.*, 1906, [vi], 11, 806.

⁵ *Proc. Camb. Phil. Soc.*, 1906, 13, 212.

suggested that the most probable cause of the loss of ionising power by the α -particle is that below the critical velocity it retains an electron and becomes an uncharged atom.¹

If r is the range of any α -particle in air, its energy is proportional to $r + 1.25$ and its velocity to $\sqrt{r + 1.25}$. The ratio of the velocity of two particles with ranges r_1 and r_2 respectively is therefore $\sqrt{\frac{r_1 + 1.25}{r_2 + 1.25}}$. In this way Rutherford has calculated, in terms of that of radium C as V , the velocities of each of the α -particles expelled by radium and its products, using the ionisation ranges as determined by Bragg. These are: Radium, 0.750 V; emanation, 0.814 V (see p. 344); radium A , 0.858 V; radium F (polonium), 0.787 V. These results agree closely with the direct measurements about to be considered. From the scattering of the α -rays in passage through matter it was deduced that some of the rays must suffer a deflection of at least 2° from their course, which is equivalent to the effect of an electric field of a hundred million volts per centimetre (compare preceding footnote).

After four years' efforts, Rutherford has now obtained satisfactory measurements of the electrostatic as well as of the electromagnetic deviations suffered by the α -particle.² The former gives the value mv^2/e and the latter the value mv/e , so that from the combined results the velocity v and the ratio e/m of the charge to the mass of the particle can be deduced. The α -rays of radium C , from an uncovered wire made active by exposure to the emanation, were taken as the standard, and the values in other cases deduced by comparison with this standard. The initial velocity of the α -rays from radium C , designated by V previously, is given as 2.06×10^9 cm. per second, and the ratio e/m as 5.07×10^3 . These values are both somewhat lower than those previously given from more or less indirect data, and for the future they must be taken as the most trustworthy determinations of these important and difficultly-determined constants.

Rutherford next proceeded to examine whether the ratio e/m is the same for all α -particles, and whether it is altered by passage of the α -particle through matter. Direct determinations of the electrostatic and magnetic deviation of the α -particle of radium C after passing through various thicknesses of matter showed that the ratio e/m is constant within the limit of experimental error. Similar direct deter-

¹ The assumption seems to be made here that only electrical forces are acting in the collision of the radiant α -particle with the molecules of obstructing matter. But this view presupposes that an uncharged radiant atom would neither ionise nor be retarded or deviated in its passage through matter, an assumption which is far from proved.

² *Phil. Mag.*, 1906, [vi], 12, 348.

minations were also made of the α -particles of radium *A*, radium *F*, and actinium *B*, and, in conjunction with Dr. Hahn,¹ of the α -rays from the excited activity of thorium (thorium *B* and thorium *C*, p. 342). An independent determination in the case of radium *F'* or polonium has been carried out by Huff² in continuation of the work of A. Stanley Mackenzie. The general result goes to show that the ratio e/m is the same for all the α -particles within the limits of experimental error.

Lastly, the evidence is considered by Rutherford as to the connexion between the α -particle and the atom of helium. All the radio-elements expel α -particles which are identical in all respects save initial velocity of expulsion, and it is pointed out that whatever its nature the α -particle must be a fundamental constituent of the atoms of all the radio-elements. Now the new value for e/m , 5.07×10^3 , is almost exactly one-half that of the hydrogen ion in electrolysis (10^4), and since the atomic weight of helium is accepted as 4, the helium atom, if it carried the single ionic charge carried by the hydrogen ion, would have the value 2.5×10^3 for the ratio e/m , or one-half that of the α -particle. Several possibilities are discussed by Rutherford, and two may be here considered. The α -particle may be a helium atom with twice the ionic charge, or it may be one-half the chemical atom carrying a single charge. The first alternative is that favoured by Rutherford. Another possibility not discussed is that there is a flaw in the reasoning which has led in the case of the inert gases to the density being doubled to give the atomic weight. Beyond the general evidence already discussed³ in favour of regarding helium as a general product of radioactive matter, and therefore that the α -particle is or becomes an atom of helium, there is very little actual evidence at the present time on which to base a conclusion. A large number of calculations in radioactivity are based on the hitherto unquestioned assumption that the α -particle carries the single ionic charge, and if that assumption is abandoned, not only are the values of these calculations affected, but in addition much of the foundation on which the atomic theory of electricity has been based is weakened, for the existence of multiple charges, not confined to two units only, may be postulated in many other cases. Until the question is settled, doubt is thrown upon most of the calculated constants in radioactivity, for example, the number of α -particles expelled from a known weight of a radioactive substance in unit time, the periods of average life of the parent elements, the quantity of the disintegration products associated with the parent in state of radioactive equilibrium, &c., which must be either doubled or halved on the view that the α -particle carries two ionic charges. Rutherford calculates, on the latter assumption, the period

¹ *Phil. Mag.*, 1906, [vi], 12, 371.

² *Proc. Roy. Soc.*, 1906, 78 A, 77.

³ *Ann. Report*, 1905, 303.

of past time required for the generation of the helium in two minerals, thorianite and fergusonite, and arrives in each case at about the same result, namely 400 million years, which brings vividly into prominence the slowness of radioactive change and the extraordinary delicacy of our present means of investigation.

α -Ray Ionisation.—The phenomenon of “initial recombination” discovered by Bragg and Kleeman working with the α -rays of radium¹ has been the subject of a further investigation by Kleeman,² who has made the important discovery that the effect appears to be confined to ionisation produced by the α -rays alone. Gases ionised by the action of X-rays, β -rays, and γ -rays do not show the effect, and this is attributed to the relatively low velocity of the α -particle, and the consequently less violent character of the separation of the charged ions from the neutral atom in this case. The view that in α -ray ionisation the electron detached from the atom ionised travels at a low speed, and so is more readily dragged back into, or recombines with, the parent atom by the electric field existing between them, after the α -particle has passed, is supported by the fact that the α -rays produce no secondary radiation where they impinge, whereas the other radiations give rise to strong secondary radiation known to consist of electrons moving with great velocity. It was found that the effect of the initial recombination was the greater the lower the velocity of the α -particle.

Bragg³ has attacked an important problem in the nature of ionisation, namely, the determination of the relative total number of ions produced by the α -rays in various gases. Several distinct factors have to be considered separately in ionisation by α -rays. The ionisation per unit length of path of the α -particle, or the specific ionisation, increases with the distance traversed up to the critical velocity, and therefore with diminishing velocity and energy the α -particle becomes a more efficient ioniser right up to the point at which it ceases to ionise. Combining with his earlier results the direct measurements of the velocity by Rutherford, it appears that the ionisation increases inversely as the velocity. Since we have seen that the energy lost by the α -particle in traversing unit length of path (in aluminium) is constant, it may be inferred that the energy required to produce an ion cannot be constant, but must be greater at the beginning than at the end of the course of the α -particle.

The range of the α -particle in any gas, or conversely the “stopping power” of the gas, is easily measured to very great accuracy, and is simply proportional to the number of molecules in the layer of gas,

¹ *Ann. Report*, 1905, 298.

² *Phil. Mag.*, 1906, [vi], 12, 273.

³ *Trans. Roy. Soc. S. Australia* 1906, 30, two papers; *Phil. Mag.*, 1906, [vi], 11, 617.; 1907, [vi], 13, 333.

and with this reservation is not affected by pressure and temperature, and is independent of the chemical nature of the gas. It is a strictly colligative or additive property depending only on the number and nature of the individual atoms. The stopping power of different atoms is very nearly proportional to the square root of the atomic weight, but there is a slight systematic departure from this law, the value being more accurately expressed by $a\sqrt{w} + bw$ than by $a\sqrt{w}$ simply, where a and b are two constants the same for all the elements. Bragg considers stopping power more nearly a purely additive property of the atom than any other save mass. The proportionality of stopping power to the atomic square root is an effect quite apart from its additive nature, and the divergence from exactness is only marked for light atoms below 30, an effect which is curiously similar to the case of the atomic heats.

The total ionisation produced by the α -particle in different gases is a very difficult quantity to measure accurately, and, as is evident from the papers, a great deal of experimental skill has been spent on this part of the problem. The method employed is to determine the specific ionisation at some defined point on the curve connecting ionisation with distance from the source, and that point to which the rays from radium *A* (the second most penetrating type) just fail to penetrate was selected. The product of this quantity into the range of the α -particle in the gas in question gives a measure of the desired total ionisation, by means of which different gases can be compared together. Initial recombination was carefully guarded against by the use of extremely high voltages, which previous work had shown were necessary in many of the complex gases to produce complete saturation. It was definitely proved that the total ionisation in different gases was very different from that in air, being in the majority of gases tried about one-third higher. Thus the value in the case of carbon disulphide is 1.37 times air, and this is one of the highest determined. Then in order come pentane, methyl iodide, ethyl ether, ethyl chloride, carbon tetrachloride, chloroform, ethyl iodide, ethylene, and lastly acetylene with the value 1.26. The simple gases carbon dioxide, nitrous oxide, and hydrogen are very similar to air. The specific molecular ionisation, or the relative ionisation produced in the molecule by the passage of an α -particle of defined speed, obtained from these data is shown by Bragg to be closely related to other physical constants, such as molecular volume, molecular refractive power, and more closely still to Sutherland's molecular-volume constant B . Thus, although range is strictly additive, capacity for being ionised is a constitutive property of the molecule, and the energy required to produce an ion is not constant. This shows that in the special case of ionisation by radiant

atoms or α -particles, the act of ionisation is not entirely a sub-atomic process whatever it may be in other cases.¹

Initial recombination is an effect which varies greatly for different gases and, as Kleeman has also shown, with the speed of the α -particle. There does not appear to be any evidence against the view that a molecule which has already lost one ion or electron is any the less likely to be again ionised, or, in other words, there seems no evidence against the existence of gaseous ions with multiple charges, as concluded by Rutherford in the case of the α -particle itself.

In the same paper, Bragg draws attention to a suggestive fact also commented on by Rutherford independently.² The number of ions made in a day by radium would occupy the same volume approximately as the hydrogen and oxygen generated in the same time by the radium in aqueous solution. In other words, if the saturation current capable of passing through a gas ionised by radium were passed also through a water voltameter in series, the gas generated in the voltameter would be nearly equal in volume to the gas generated by the same radium in aqueous solution. The question naturally arises whether the hydrogen and oxygen liberated are not actually the ions formed by the α -rays in passing through liquid water. And this at once leads to fundamental questions affecting the ionisation of liquids which cannot at present be answered. Thus the whole subject of the nature of ionisation is in a very interesting state, and great advances are foreshadowed, which may have a bearing on chemistry and electrochemical problems. In particular, it is noteworthy that two of the main ideas, which served almost as a scaffolding on which the existing ionisation theory of gases was largely based during its development, namely, the confident assumption that the charge carried by the gas ion was always the same and equal to the single atomic charge, and secondly that the energy required to produce a pair of ions was independent of the nature of the gas, appear (in the light of fuller knowledge) not to have been warranted.

Ionisation ranges of α -rays.—Steady progress has been made in the determination of the ionisation ranges of the α -rays of other substances than radium by numerous investigators, following the methods of Bragg and Kleeman. McClung³ investigated in this way the α -radiation of radium *C* by itself and found it homogeneous, as was to be expected from the original curves of Bragg and Kleeman. The same homogeneity has been found independently by many investigators in the case of the radiation from polonium or radium *F*. Kleeman⁴ found a

¹ Compare *Ann. Report*, 1905, 298.

² *Radioactive Transformations*, 252. (Constable & Co., 1906.)

³ *Phil. Mag.*, 1906, [vi], 11, 131.

⁴ *Ibid.*, 12, 273.

range in air of 3.8 cm. at 77.34 cm. of mercury pressure. Levin¹ found 3.86 cm. at 76 cm., and Kučera and Mašek 4.1 cm. at 73.3 cm. The results of the latter investigators² are the most complete. They showed that the range of the rays is not affected by the decay of the activity of the polonium with time; the number of rays expelled grows less, but the character of the individual particle expelled remains the same. Absorption of the rays of polonium by metal films and gases confirmed the square-root law of Bragg and Kleeman. Lastly, they state that it is not possible to observe any secondary radiation from the α -rays where they impinge, and the effects previously ascribed to this are probably due to the scattering of the original beam, which increases with the atomic weight of the metal acted on. This agrees with the conclusion of Kleeman (p. 338). On the other hand, Edgar Meyer,³ investigating the nature of the absorption of the α -rays of polonium by metals, concludes that neither secondary radiation nor scattering are necessary to explain the results. The main fact in question is that if two screens of different metals, as aluminium and tin, are used to absorb the rays, the extent of absorption is different according to the order in which the screens are traversed by the rays.⁴ It would appear that all that is necessary to explain these and similar results is to suppose that the absorption like ionisation in gases increases as the velocity of the α -particle decreases. On this view, the effect of superimposing various screens in different ways can be calculated, and the results given agree closely with experiment. Further discussion must be held over.

In apparent contradiction to the above conclusions that the α -rays produce no secondary radiation by impact is a research of W. H. Logeman,⁵ who has proved in a very neat manner the existence of a secondary radiation from a metal plate in a vacuum bombarded by the α -rays of polonium. The contradiction is but apparent, for the secondary rays in question are so feeble in penetrating power that they could only be observed by working in a vacuum, and consist of the slow-moving electrons or δ -rays discovered by J. J. Thomson. With no electric field acting, a plate of polonium gives out to an opposed plate more - than + electricity, but by the application of an electric field in the right direction the emission of negative electricity from the polonium plate can be suppressed, so that the + emission predominates. If, however, a suitable magnetic field is employed to deviate the negative charges and to return them to their origin, the + emission is only one-fifth of that when the electric field is employed. The explanation is that the plate bombarded gives out slow-moving

¹ *Phys. Zeit.*, 1906, **7**, 519; *Amer. J. Sci.*, 1906, **22**, 8.

² *Phys. Zeit.*, 1906, **7**, 337, 631 and 650.

³ *Ibid.*, 917.

⁴ Mme. Curie, *Thesis* reprinted from the *Chemical News*, p. 56.

⁵ *Proc. Roy. Soc.*, 1906, **73 A**, 212.

negative charges no less than the polonium plate, and these also are readily returned to their origin by the magnetic field. The electric field, on the other hand, which suppresses the negative charges from the polonium, carries those from the bombarded plate to the polonium plate, and the effect is added to the positive current conveyed by the α -particles from the polonium to the bombarded plate. The positive current then appears to be much greater than when a magnetic field is acting.

Returning to the subject of ionisation ranges, Hahn¹ has applied the method with fruitful and novel results to the α -rays of actinium and thorium. This has been rendered possible by the separation from these elements of intensely active new disintegration products, radioactinium and radiothorium, some account of which follows later (p. 363). Only very intensely active preparations are suitable for the determination of ionisation ranges, and the extension of the results to thorium, as also the case of Rutherford and Hahn's measurement of the constants of the α -rays from this element already described, exemplifies the very valuable results that have followed the separation of radiothorium. Both radiothorium and radioactinium are considered to be the *first* product of the parent element, the initial change of which is in each case rayless, so that these preparations exhibit in intensified degree *the whole* of the characteristic radioactivity of the parent elements. The excited activity of thorium was first investigated. Hitherto it has been supposed that the rays in this case come solely from thorium *B*, as thorium *A*, the first product deposited from the thorium emanation, undergoes an apparently rayless change (see, however, p. 348). It was at once seen that the curve connecting ionisation with distance was not due to a homogeneous type of α -radiation, but to two types of different ranges superimposed. The ranges in air were 8.6 cm. and 5.0 cm. Sufficient grounds are furnished in the paper for the conclusion that the radiation of thorium *B* is derived from two successive products, called thorium *B* and thorium *C*, both of which give out α -rays on disintegration, but it is not yet possible to say which change gives the more penetrating and which the less penetrating type. From analogy to radium it is provisionally concluded that the thorium *C* gives the more penetrating type and also the β - and γ -rays. According to the evidence, the change of thorium *B* into thorium *C* must be extremely rapid, for the two types occur together in all circumstances in unchanged relative amount, and for this reason no actual separation has been effected. The new type of α -rays here disclosed must not be confounded with yet another new type found this year from thorium *A* by von Lerch (p. 348).

The curve in the case of the α -radiation of radiothorium itself, freed

¹ *Phil. Mag.*, 1906, [vi], 11, 792; 12, 82.

from succeeding products, proved to be simple, the rays having a range of approximately 3.9 cm. The curve for thorium *X* freed from the later products disclosed also a homogeneous α -radiation of range 5.7 cm. The range of the rays from the thorium emanation was estimated by a special scintillation method to be about 5.5 cm. Thus the whole of the ranges of the five types of α -rays emitted by thorium have been determined, and it is interesting that the range is on the average higher and the velocity therefore greater than in the case of radium. Indeed, the α -particle of range 8.6 cm. from thorium *C* is the fastest moving α -particle known. A beautiful photograph showing the lesser deviation suffered by this particle in comparison with that from radium *C*, the swiftest particle from radium, is to be found in Rutherford and Hahn's paper on the mass and velocity of the α -particles from thorium already referred to. On the clear view afforded by the disintegration theory, it is of course a matter of no comment that a feebly active body like thorium should emit an α -particle with greater velocity and energy than in the case of an intensely active body like radium, but no more striking example could be deduced of the independence of the rate of atomic disintegration, not only on its external environment, but also on the quantity of internal energy liberated in the process.

Some observations of Lise Meitner¹ on the α -rays of thorium *B* resulted in the confirmation of the square-root law of absorption of Bragg. In the case of the β -rays the absorption does not follow the square-root law, but increases with, although slower than, the specific gravity of the metal.

For actinium, Hahn² gives the following ranges for the four types of α -radiation: radio-actinium, 4.8 cm.; actinium *X*, 6.55 cm.; actinium emanation, 5.8 cm.; actinium *B*, 5.50 cm. In the relative magnitude of the ranges of the rays of the successive products the actinium series bears a close resemblance to that of thorium, a resemblance which is extending itself to all the radioactive properties of the two substances. The various α -rays from actinium are the most nearly alike in range, those from thorium exhibit the greatest diversity, whilst those from radium occupy an intermediate position. The α -radiation from the excited activity of actinium (actinium *B*), unlike that from thorium, is completely homogeneous.

The researches of H. Willy Schmidt,³ remarkable in many directions discussed later, have resulted incidentally in settling the question left open from Bragg and Kleeman's work⁴ of the respective ranges of the α -rays from radium *A* and the radium emanation. Schmidt has

¹ *Phys. Zeit.*, 1906, **7**, 588.

² *Phil. Mag.*, 1906, [vi], **12**, 244.

³ *Phys. Zeit.*, 1905, **6**, 897; 1906, **7**, 764; *Ann. Physik.*, 1906, [iv], **21**, 609.

⁴ *Ann. Report* 1905, 296.

shown that the less penetrating of the two types of α -radiation present in the radiation from the active deposit immediately after its formation from the radium emanation, and which is due to radium *A*, has a range greater than 4.5 cm. and less than 5.1 cm., so that the range of 4.83 cm. measured by Bragg must be ascribed to the rays from radium *A*, and that of 4.23 cm. to the rays from the radium emanation.

For use in cases of feebly radioactive bodies where a direct determination of the range of the α -radiation is impossible, Bragg¹ has derived an indirect method which he has applied to the determination of the ranges of the α -rays from uranium and thorium. Bragg obtains mathematically an expression connecting ionisation current due to α -rays, from layers of radioactive matter of various depths covered with uniform sheets of metal of various thickness and known stopping power, with the range of the α -ray in question, in such a way that the range can be deduced from measurement of the ionisation current under various conditions. In this way it is shown that the initial α -ray expelled from both thorium and uranium has the same range as that of the initial α -ray expelled from radium, namely, about 3.5 cm. This is in fair agreement with the direct measurement of Hahn for thorium (radiothorium), which gave 3.9 cm. (p. 342). From the relative ionisation produced from similar quantities of uranium and thorium preparations, and the number of α -ray changes in each case contributing to the activity, Bragg has deduced the relative rates of change of these two elements to be in the ratio of 5 to 1. Uranium and thorium are of very similar α -activity, but since there are five successive changes contributing α -rays in thorium and only one in uranium, the uranium must be disintegrating much the more rapidly. The actual ratio of Bragg is, however, vitiated, as Rutherford has pointed out, by the subsequent work of Dadourian and Boltwood (p. 362), who has shown that commercial thorium preparations do not contain their full amount of radiothorium, about half being apparently separated during the process of manufacture. To get the true ratio, which is probably about 5 to 2, the measurements must be repeated with some thorium mineral, such as thorianite, containing a known percentage of thorium in equilibrium with its disintegration products.

Positive Charge carried by the α -Particle.—The difficult question as to whether the α -particle is charged at the moment of its expulsion from the parent atom² has this year been experimentally attacked by Ewers³ and Soddy.⁴ Ewers investigated the α -rays of polonium in the highest vacuum he could produce, and obtained no difference in the value of the charge carried by the α -rays on account of the high vacuum. He concluded against the hypothesis that the α -particle was uncharged

¹ *Phil. Mag.*, 1906, [vi], 11, 754.

² Compare *Ann. Report*, 1905, 302.

³ *Phys. Zeit.*, 1906, 7, 148.

⁴ *Nature*, Aug. 2nd, 1906, p. 316.

at the moment of its expulsion from the parent atom. He also measured the constants of the slow-velocity electrons (δ -rays) accompanying the α -radiation, and found for e/m 1.48×10^7 and for v 3.25×10^8 , which, however, are not in agreement with the experiments of Logeman (p. 341). It has been pointed out by Bragg¹ and Soddy² that the experiments of Ewers do not suffice to answer the question as to the initial state of the α -particle on expulsion, for in his experiments the α -particles must first pass through the thickness of the radioactive layer of polonium, and must, therefore, become charged before emerging into the vacuum. The conditions to be realised are, according to Soddy, not only a vacuum so high that no gas molecule is encountered by the α -particle in its path, but also a layer of radioactive matter as the source of α -rays, not exceeding one molecule in thickness. This was attempted experimentally by using radium *C* as the source of α -rays, the deposit being produced inside, and confined within a certain length of, thermometer tubing of the smallest possible bore, from one of the open ends of which a narrow pencil of α -rays emerged. Under the action of a magnetic field the rays are readily deviated, and none escapes the narrow tube. After many failures, it was found in three consecutive experiments that a magnetic field which completely deviated the beam in a low vacuum no longer affected it in the highest possible vacuum, and it was concluded that the α -particle was uncharged on expulsion. Only a preliminary account of this work has so far appeared.

The Disintegration Series radium *A*, radium *B*, radium *C*.—This series has hitherto presented some anomalies and unexplained divergences from the requirements of the simple theory, which have received during the year exhaustive and critical examination, resulting in the complete vindication of the theory in its original form. Rutherford concluded³ that his experimental results would agree more closely with theory if radium *A* and radium *B* were regarded as simultaneous rather than as successive products of the radium emanation, but that further work was required before so fundamental a conclusion could be accepted. A similar idea has been proposed by him⁴ to account for the position of actinium in the uranium-radium series, which is also anomalous. However, new results have, so far at least as the radium series is concerned, dispensed with the necessity of the above assumption. The conclusion of Bronson⁵ that radium *B* has a longer period of change than radium *C*, instead of the contrary as previously assumed, and that both periods must be reduced, has also been arrived at independently by H. W. Schmidt

¹ *Phys. Zeit.*, 1906, 7, 452.

² *Loc. cit.*

³ Compare *Radioactive Transformations*, p. 115.

⁴ *Ibid.*, p. 177.

⁵ *Phil. Mag.*, 1906, [vi], 11, 143; *Ann. Report*, 1905, 307.

and by von Lerch. The latter¹ arrived at his conclusions by the electrochemical separation of the two products radium *B* and radium *C*, the former of which has been regarded as rayless, but as producing radium *C*, which then gives all three kinds of rays. Radium *C* behaves as electrochemically "nobler" than radium *B*, and by immersing a copper or nickel plate in the solution of the active deposit, or by electrolysis with small current density using a polished platinum cathode, only the radium *C* is deposited. In the same way, thorium *B* (+ thorium *C*) is separated from thorium *A*, hitherto regarded as rayless.² If barium is precipitated as sulphate in the solution, the radium *C* remains in solution while the radium *B* is carried down with the precipitate. Copper precipitated with caustic potash leaves some of the radium *B* in solution, the remainder, together with the radium *C*, being precipitated. The radium *C*, whether separated as in Bronson's methods by volatilisation of the radium *B*, or by the new methods of von Lerch, has the quicker period.

H. W. Schmidt,³ in addition to showing that the decay curves could be better explained by supposing that radium *C* possessed the quicker period, has shown that the change of radium *B* into radium *C* is not altogether rayless, as previously assumed, but that β -rays of a type unusually feeble in penetrating power are emitted, and with these two additions the experimental results agree perfectly with the theory without further assumptions. The same discovery of the emission of β -rays from radium *B* has been made independently by W. Duane⁴ and by Gruner,⁵ the latter in a mathematical contribution to the theory of radioactive change, from a study of the experimental results of Curie and Danne. Schmidt investigated the decay curves of the active deposit on a wire, immediately after short exposure to the radium emanation, through metal screens of successively increasing thickness. 0.03 mm. of aluminium cuts off all the α -rays from radium *A*, and the decay curve, instead of showing the sharp initial decay characteristic of the change of radium *A*, rises to a maximum steadily in thirty minutes. With increasing thickness of aluminium the maximum is reached sooner, and with 0.068 mm. in eleven minutes. Screens, successively added, of 0.1, 0.2, and 0.4 mm. caused the period of maximum again to increase until it reached thirty-five minutes. The only explanation is that radium *B* gives out rays somewhat more penetrating than α -rays and less penetrating than the common β -rays.

In a further examination, the methods of von Lerch in separating radium *B* and radium *C* were employed, and it was found that the β -rays of radium *B* could be deviated by a magnetic field, and more

¹ *Wien. Sitzungsber.*, 1906, **115**, Abt. IIa, 197; *Ann. Physik.*, 1906, [iv], **20**, 345.

² *Ibid.*, March, 1905.

³ *Loc. cit.*, p. 343.

⁴ *Science*, 1906, **24**, 48.

⁵ *Ann. Physik.*, 1906, [iv], **19**, 169.

readily, so that they must travel at a lower velocity than those of radium *C*. Duane has shown that they carry negative charges. The periods¹ of the three products may be taken as follows: radium *A*, three minutes; radium *B*, twenty-six minutes; radium *C*, nineteen minutes; and the theoretical curves calculated from these periods now agree far better with the experimental than if it is supposed that radium *A* and radium *B* are simultaneous products.

Bronson,² in a special research, examined the radiation of radium *B* to see if α -rays, possibly of very slight penetrating power, were also given out, but with a negative result.

Another question remains for consideration in connexion with this disintegration series. Curie and Danne had explained their experimental results originally on the view that the rate of transformation in this series is affected by high temperature, and the effect of submitting the active deposit to a high temperature has been examined both by Bronson and Makower with contradictory results. The former³ maintains that there is no alteration of the rate of change. Wires made active in the radium emanation were afterwards sealed into tubes of hard glass, so that none of the radioactive matter could escape by volatilisation, and were heated, it is stated, up to temperatures of at least 1100°. It is difficult, however, to believe that such high temperatures can be attained with glass tubes. Makower,⁴ working at much higher temperatures in vessels of sealed quartz, investigated the effect of heating on the external radiation from the excited activity inside the vessel. The rays in question are the β - and γ -rays derived from radium *C* and not from the emanation. The activity measured immediately after the tube had been heated for fifteen minutes to a temperature between the melting points of platinum and of nickel was found to have fallen about 15 per cent., but in the course of an hour recovered its original value. This was repeated five times for the same tube with similar results, and in a second experiment at lower temperatures (1000° to 1200°) it was found that while heating for ten minutes had little effect, heating for one hour produced a temporary lowering of activity of from 4 to 9 per cent., while longer heating produced no further effect. In a further paper to the Royal Society just published, Bronson⁵ has maintained his original conclusion, and states that there is no alteration in the constants between -180° and 1600°, so that the question therefore remains unsettled.

¹ By "period" used as above without further qualification is now commonly understood the period of half-transformation. Multiplying this by 1.45 gives the "average life" which is the time required for the quantity to be reduced to e^{-1} (0.368) of the initial. The reciprocal of the average life is the "radioactive constant" λ .

² *Phil. Mag.*, 1906, [vi], 11, 810.

⁴ *Proc. Roy. Soc.*, 1906, 77 A, 241.

³ *Ibid.*, 142.

⁵ *Ibid.*, 1907, 78, A, 494.

Other α -Radiations previously overlooked.—Closely connected with the preceding results are two researches which have resulted in the discovery of radiations previously overlooked in other disintegrations. Von Lerch¹ has concluded that thorium *A*, hitherto regarded as rayless, emits a small amount of ionising radiation, in part less penetrating, but chiefly more penetrating in character than the α -rays emitted by thorium *B* (+ thorium *C*). Thorium *B* was separated electrochemically from thorium *A*, and the radiation of the former compared with that of the unseparated activity using various thicknesses of absorbing screens. The close agreement between the decay curves and theory on the earlier assumption that the change of thorium *A* is rayless, shows that the amount of radiation from this body must be relatively small.

Moore and Schlundt,² in an investigation of new methods of separation of uranium *X* from uranium, have made the observation that the radiation of uranium *X* is not entirely due to β -rays, as before thought, but that there is a small amount of a feebly penetrating radiation also, which they ascribe without sufficient proof to α -rays. Hitherto, although it has been noticed that uranium *X* has a feeble non-penetrating radiation, this has been attributed to a trace of uranium not completely separated. Moore and Schlundt, however, show that this cannot be the case, for the two types of radiation both decay, and at the same rate. A more thorough examination of this radiation is much to be desired, for the results of the authors give no clue to the real nature of the radiation, whether it is an α -radiation as they assume, or a feebly penetrating β -radiation of the type given by radium *B*. The new methods of separation referred to consist in dissolving uranyl nitrate in various solvents, acetone, various alcohols, methyl and ethyl acetate, &c., stirring in a little freshly precipitated ferric hydroxide, and filtering. The filtrate containing the uranium is found to be quite free from uranium *X*, which remains with the precipitate. Another case of a feeble radiation previously overlooked is considered under actinium (p. 363).

β -Rays.—Important advances have also been made in our knowledge of the β -rays, and a beginning, perhaps, made in a theory of the mechanism of their absorption by matter, which is so markedly different in nature from that shown by Bragg for the α -rays.

It has always been suspected without actual proof that in thorium, as in radium, the β -rays result only in the last change, but until now the difficulty of separating thorium *X* from the later products, giving β -rays, has prevented a definite answer to the question. Levin³ has investigated from this point of view both thorium and actinium,

¹ *Phys. Zeit.*, 1906, 7, 913.

² *Phil. Mag.*, 1906, [vi], 12, 393

³ *Ibid.*, 177.

and has concluded that the only members of the series producing β -rays are in each case the last, thorium *B* (+ thorium *C*) and actinium *B*. Thorium *X* carefully separated from later products of change possesses only two or three per cent. of the β -activity ultimately attained, and actinium *X* is similar.

A very complete examination of the absorption of the β -rays of uranium has been made by J. A. Crowther.¹ As Rutherford has shown, this radiation is fairly homogeneous, and absorbed according to an exponential law, $I/I_0 = e^{-\lambda d}$, where I is the intensity of the radiation, initially of intensity I_0 , after passage through a thickness d of material. λ is the coefficient of absorption. This coefficient is not proportional to the density (ρ), and λ/ρ varies from 5.7 for glass, mica, wood, iron, and aluminium to 13.2 for tin, whereas Lenard found for the cathode rays of the Crookes tube that the absorption was strictly proportional to density (Lenard's density law). Godlewski has shown that the β -rays of actinium are also homogeneous and absorbed exponentially, while here the variations from the density law are smaller. Crowther has determined λ/ρ for thirty elements, and finds that the latter arrange themselves in groups according to the groups of the periodic table when the value of λ/ρ is plotted against the atomic weight. In compounds the absorption is strictly additive, and the secondary radiation set up by the β -rays of uranium is much less than that produced by the β -rays of radium.

H. W. Schmidt² has investigated the β -radiation of radium (derived from radium *B* and radium *C*), and made the remarkable observation that within certain screen thicknesses the absorption of both types proceeds according to an exponential law. In this way he analysed the β -radiation into five homogeneous types, three derived from radium *B* and two from radium *C*. For the former the respective thicknesses of aluminium required for half absorption are 0.0078, 0.087, and 0.53 mm., for the latter 0.131 and 0.53 mm. He points out that it is doubtful if such an analysis can have a real physical meaning, but if so, it seems to open the way to a clearer view of the mechanism of absorption. It seems possible, if the absorption of β -rays follows an exponential law, that the β -particle passes through the atoms of matter completely unchecked until it is suddenly and completely stopped. This view accords with Kaufmann's work that the velocity of the β -particles which escape an absorbing screen are not retarded during their passage through the screen, and with Kleeman's observation that ionisation produced by β -rays after passage through a thick aluminium plate shows little tendency to initial recombination.

Secondary Radiation of β -Rays.—This view accounts well also for the

¹ *Phil. Mag.*, 1906, [vi], **12**, 379.

² *Phys. Zeit.*, 1906, **7**, 764; *Ann. Physik.*, 1906, [iv], **21**, 609.

fact observed by McClelland, and recently examined by S. J. Allen,¹ that the velocity and the penetrating power of the electrons constituting the secondary radiation set up by impact of the β -rays is not greatly, if at all, less than for the primary rays themselves, for the "stopping" of the primary rays may well consist in their being turned through a large arc, as a comet at perihelion, to reappear as secondary rays at the bombarded surface. S. J. Allen repeated and confirmed by an electrical method the work of Kaufmann, and found also that the ratio e/m of the secondary radiation, like that of the primary, increases with the velocity of the secondary ray. McClelland² and McClelland and Hackett,³ in continuation of their investigations on secondary radiation, found that the energy of the secondary radiation from a plate of lead, for example, was equal to one half of the energy of the primary rays. The ratio diminished with the atomic weight of the metal, being lowest for carbon and next lowest, but still above 20 per cent., for sodium, aluminium, and magnesium. The secondary radiation of compounds is an additive function of the component elements, and can be calculated from the radiating power of the constituents. The important influence of secondary radiation on the apparent coefficient of absorption of the primary rays is pointed out, and it is stated that owing to successive generation of fresh β -particles as secondary rays the apparent distance penetrated by the primary rays is much increased.

K. Seigl⁴ showed that the secondary radiation produced on impact by the β -rays of radium is capable of exciting strong fluorescence in barium platinocyanide. It was weakest for aluminium and strongest for lead, increasing with the atomic weight of the metal, as McClelland has shown. Using tinfoil, it was found that the effect increased with successive numbers of layers of foil up to 50 layers.

The Electronic Theory of Matter.—It may be stated without fear of contradiction that the theory that the atom is made up entirely or to any substantial extent of electrons is now generally regarded as being very much open to question. From spectroscopic and other evidence it is certain that electrons are universal constituents of atoms, but for the further very sweeping deduction that the atoms are composed of electrons there never has been much positive evidence in the past, whilst against the view some definite experimental evidence can now be urged. It is interesting to note that Prof. J. J. Thomson, to whom the electronic theory of matter is largely due, has himself this year brought forward considerations which have practically made the theory untenable. The view that the β -ray electrons do not in their passage through matter diminish continuously in speed, but proceed more or less unaffected

¹ *Phys. Review*, 1906, **22**, 375.

² *Trans. Roy. Dubl. Soc.*, 1906, ii, **9**, 9.

³ *Ibid.*, p. 27.

⁴ *Phys. Zeit.*, 1906, **7**, 106.

until they are suddenly stopped or turned through a large angle to reappear as secondary radiation, bears upon the present question. Considering the enormous number of atoms a β -ray electron can penetrate without being greatly affected, and the certainty that the approach of the radiant electron to an electron in an atom must result in deviation or loss of velocity of the former, it becomes extremely difficult to believe in the reality of the view that the atom is substantially constituted of swarms of electrons in regular motion. The penetrating power of the β -ray electron was one of three methods developed by J. J. Thomson¹ to determine the number of electrons in an atom, each of which led to the result, the importance of which cannot be overestimated, that the number of electrons in any atom is of the same order as, and probably equal to, the atomic weight in terms of hydrogen as unity, a conclusion which practically leaves the whole problem of the ultimate constitution of matter where it was, and which is in sharp conflict with the electronic theory of matter, which assumed a number of electrons a thousand times greater. The two other methods of attacking the question depended, the one on the scattering of Röntgen rays by gases, for which the work of Barkla on the ratio of the energy scattered to that in the primary radiation furnished the required data, and the other on the dispersion of light by gases. In the latter method a light wave is considered crossing the atom and subjecting it to the action of the electric field in the wave-front for a period the longer the longer the wave-length of the light. This field affects the displacement of the positively and negatively charged parts of the atom in opposite directions, polarising the atom and increasing the refractive index of the medium. This polarisation and increase of refractive index will in general be the greater the longer the wave-length causing dispersion, and the amount depends upon the relative masses of the positive and negative parts of the atom. For the mathematical development of these three methods the original paper must be consulted. The result that all but about one thousandth of the mass is associated with the positive part of the atom shows that an altogether exaggerated rôle has been attached to the electron in the constitution of matter.

A paper with revolutionary theoretical conclusions, which, however must await further confirmation before being accepted, has been published by H. A. Bumstead² on the heating effects produced by Röntgen rays in different metals. He found that the absorption of equal amounts of Röntgen radiation in lead and in zinc produced approximately double as much heat in the lead as in the zinc. A somewhat complicated method of measurement was employed, depending on a radiometer effect of the heated metal. The hypothesis is suggested

¹ *Phil. Mag.*, 1906, [vi], 11, 769.

² *Ibid.*, 292.

that by means of Röntgen rays the atoms of certain elements may be artificially broken up and the internal energy liberated, causing the excess of the heating effect observed, but such a fundamental conclusion can only be accepted after the most rigorous and exhaustive examination.

γ-Rays.—J. J. Thomson¹ has proved that the effects ascribed by Paschen to the γ -rays carrying negative charges are due to secondary radiation set up by the γ -rays, and that the latter do not carry charges. The same author has shown² that prolonged action of the γ -rays on metals does not cause induced radioactivity, and Bumstead has shown³ that even when arrangements are made to detect an extremely short-lived radioactivity, a negative result is also obtained.

Schmidt found no appreciable γ -radiation accompanying the new β -radiation of radium *B*. Stefan Meyer and von Schweidler⁴ found similarly for radium *E*, the β -ray constituent of radio-lead, that there was no appreciable γ -radiation accompanying the β -rays. If they exist their effect is less than 0.03 per cent. of the β -rays. The same conclusion was indirectly drawn by Eve,⁵ and may be inferred from a paper by Giesel⁶ on " β -Polonium," which, however, there is no doubt owes its β -activity to the presence of radium *E*.

Eve showed that the γ -radiation of uranium and actinium is more readily absorbed than that from radium and thorium, so that by the use of a screen consisting of 1 cm. thickness of lead, the effect of the former may be eliminated, and the rays penetrating such a screen used as a measure of the amount of radium and thorium, for example, in a mineral, without the necessity of powdering it or dissolving it, or even removing it from its containing vessel. On comparing the γ -activity of a kilogram of uraninite from Joachimsthal, which contains all the disintegration products of radium, including radium *E*, in radioactive equilibrium, with that from a known amount of pure radium bromide, which contains no appreciable amount of radium *E*, it was concluded that radium *E* either does not give γ -rays, or more probably that its γ -radiation is, like that of uranium, easily absorbed. However, Meyer and von Schweidler have proved that no γ -rays are emitted. Eve's research had an interesting sequel. Even assuming that the radium *E* give no γ -rays itself, the amount of γ -radiation from the mineral was low, so that the quantity of radium contained in it could only be one half of that to be expected from the work of Rutherford and Boltwood,⁷ who found 0.72 gram radium per ton of uranium. This

¹ *Proc. Camb. Phil. Soc.*, 1905, **13**, 121.

² *Ibid.*, p. 124.

³ *Ibid.*, p. 125.

⁴ *Wien Anzeiger*, 1906, 12; *Sitzung*, April 26th, 1906.

⁵ *Phil. Mag.*, 1906, [vi], **11**, 586; *Amer. J. Sci.*, 1906, **22**, 4.

⁶ *Ber.*, 1906, **39**, 780.

⁷ *Ann. Report*, 1905, 310.

led these investigators to redetermine this constant,¹ with the result that an error was discovered. It was found that about one half of the radium in the standard solution had precipitated on standing without having been noticed. A redetermination gave the value 0.38 gram per ton, a number agreeing with Eve's measurements by means of the γ -radiation, and more nearly what is actually extracted in practice. A later paper by Eve on the relative γ -activity of radium and thorium is considered in the section on radio-thorium (p. 362), and one on the γ -radiation from the earth's surface in the section on radioactive minerals (p. 359).

Action of Ultra-violet Light on Different Metals.—Sir William Ramsay and J. F. Spencer² have investigated the effect of ultra-violet light on a large number of metals and compounds. It is well known that when certain metals, particularly zinc and the alkali metals, are illuminated by ultra-violet light, electrons are expelled from the metal surface, which, if negatively charged, is rapidly discharged by the light. It was found that the order in which the metals arrange themselves in their action under ultra-violet light is the same as in the case of their electro-potentials, exceptions being noticed in the case of those elements, as iron, chromium, nickel, and cobalt, which readily assume the passive form. The compounds examined, sulphides and iodides of the metals, discharged negative electricity like the metals, only more slowly. An examination was also made of the "tiring" of magnesium, zinc, tin, and aluminium exposed to ultra-violet light, the rate of discharge becoming slower with prolonged action. They found on plotting rates of discharge against the times of exposure that the curves showed a number of breaks corresponding with the number of valencies of the metals, except for aluminium, which showed at least five or six breaks. The authors interpret their results on the view that atoms and electrons may be associated in three ways: (1) as in an ion in electrolysis; (2) as in an electrostatically charged object, where the electricity is confined to the surface and may be likened to the wetting of a solid by a liquid; and (3) in a more intimate manner, in such a way that the loss of an electron or electrons is attended by actual transmutation of the original element without the appearance of a positive charge.

The "tiring" of metals under the action of ultra-violet light has also been investigated by H. S. Allen,³ who finds the process can be represented as the sum of two exponentials, as in the case of two successive radioactive changes, and the author suggests that the metal suffers by the process successive transformation into two new modifications, but leaves open for further examination the question of the

¹ *Amer. J. Sci.*, 1906, **22**, 1.

² *Phil. Mag.*, 1906, [vi], **12**, 397.

³ *Proc. Roy. Soc.*, 1907, **78**, A, 483.

nature of the latter and the precise nature of the changes. These results are too recently published for full consideration.

General Properties of Radiations.—Rutherford¹ shows that the distribution of the intensity of radiation in space from a surface coated superficially, as for example in the case of radium *C*, with a radioactive substance is totally different from what would obtain in the case of a similar surface emitting light or heat. In the latter case the intensity varies with the cosine of the angle between the normal to the surface and the direction of the emitted ray, according to what is known as Lambert's law, and usually explained by supposing that the light comes from a sensible depth below the surface. In the case considered the radiation is strictly superficial, and there is no cosine law. Many beautiful and striking photographs of the effects obtained in consequence are given in the paper. In a paper entitled "Fluorescence and Lambert's Law," R. W. Wood² has imitated Rutherford's effect for radioactive substances with a surface coated with a thin layer of phosphorescent substance, by allowing, for example, a fine dust of Balmain's luminous paint suspended in air to deposit on the surface.

The glow from an uncovered radium preparation in air has been further examined by Sir William and Lady Huggins,³ and by Walter.⁴ The phosphorescent glow extends about 2 cm. in air when examined photographically, and shows the nitrogen bands. The rays from polonium possess the same property, and Walter⁵ has made the interesting observation that the spectrum in the case of radium most resembles the band spectrum of the blue cathode light, whilst that of polonium resembles the red positive glow of a nitrogen vacuum tube. Stark⁶ has shown that the glow in the case of polonium is not affected by an electric field, and argues that the molecules emitting the light are not charged electrically.

A. Miethe⁷ has investigated the action of radium rays, presumably the β - and γ -rays, on a large number of gems, and finds that many show coloration, whereas in the case of those brightly coloured originally the colour is readily changed. A colourless diamond from Brazil showed no coloration after long exposure, but a Borneo stone, originally colourless, turned bright citron-yellow in sixteen days, the colour being only partially discharged on heating to redness.⁸ A bright blue sapphire (corundum) from Ceylon showed a very remarkable series of colour changes under similar treatment, passing through green and bright

¹ *Phil. Mag.*, 1906, [vi], **11**, 152.

² *Ibid.*, 783.

³ *Proc. Roy. Soc.*, 1906, **78 A**, 212.

⁴ *Ann. Physik.*, 1903, [iv], **19**, 1030.

⁵ *Ibid.*, 1906, **20**, 327.

⁶ *Phys. Zeit.*, 1906, **7**, 892.

⁷ *Ann. Physik.*, 1906, [iv], **19**, 633.

⁸ Compare C. W. R., *Nature*, July 19 1906 p. 271.

yellow to a reddish-gold yellow, which was discharged on heating, but returned to some extent when the stone cooled. Ruby, Ceylon chrysoberyl, blue topaz, and Brazilian amethyst showed no change, whilst a colourless quartz rock-crystal turned blue-grey very slowly. Two crystals of Brazilian tourmaline, each colourless at the one end and the other rose-coloured the other bright green at the other end, showed, when the colourless ends were exposed to radium rays, each the same bright coloration as that of the other end of the crystal.

Jorissen and Ringer¹ investigated the action of β -rays of radium on a mixture of hydrogen and chlorine, and found a slow combination, about half a c.c. combining in ninety-six hours. With hydrogen and oxygen there was no combination, and the work of B. Davis and C. W. Edwards,² who found a rapid combination when the radium salt was actually placed in the gas, is probably due to the action of the α -rays in the latter case and may, indeed, be connected with the known large heating effect of the α -rays. Sir W. Ramsay has shown that the β -rays do not decompose liquid water. F. Kohlrausch³ found no sudden change in the conductivity of water when traversed by β -rays of radium, but after prolonged action of the rays the conductivity very slightly increased. Kohlrausch and F. Henning⁴ found that solutions of radium bromide behave as completely normal so far as their conductivity is concerned, and no peculiar behaviour due to the presence of the radium was observed.

General Properties of Radium.—The energy carried away by the penetrating radiations of radium has been the subject of an investigation by Precht,⁵ who finds that the heat evolved, measured in a Bunsen's ice-calorimeter, is increased 10 per cent. when the radium preparation is surrounded by 3 mm. of lead, but is not further increased by increasing the thickness of lead. Obviously some of the β -radiation must be absorbed in the calorimeter itself even with unscreened radium inside, so that the 10 per cent. difference must be for a part only of the energy of the β -rays. The actual heat evolution calculated for 1 gram of the element radium was 122.2 calories per hour unscreened and 134.4 screened. These are considerably higher than the usually accepted values. These experiments recall those of Bumstead with X-rays on metals (p. 351), and may be found to be closely connected with them.

The sample of 25 mg. of anhydrous radium bromide used by Precht in these experiments was sealed in a glass tube 2 mm. in bore and 0.5 mm. wall thickness, and about eleven months after sealing exploded violently.⁶ Precht ascribed the explosion to the generation of suffi-

¹ *Ber.*, 1906, **39**, 2093.

³ *Ann. Physik.*, 1906, [iv], **20**, 87.

⁵ *Ibid.*, 1906, **21**, 595.

² *J. Soc. Chem. Ind.*, 1905, **24**, 266.

⁴ *Ibid.*, p. 96.

⁶ *Phys. Zeit.*, 1906, **7**, 33.

cient gas (helium and emanation) to burst the tube, which, however, would probably require 20 atmospheres pressure. Mercanton¹ found no excess of pressure in a glass tube containing 15 mg. radium bromide after it had been kept sealed for more than three years, and this is to be expected from the common view that the effect is due to electrical strain, as the amount of gas generated from an anhydrous salt is for practical purposes negligible even after long periods. Mercanton also showed that radium emanation does not diffuse at all through glass heated to its softening point. Rutherford has found² that charcoal at the ordinary temperature possesses the property of absorbing the radium emanation completely, so that the escape of the latter from an open vessel containing radium may be entirely prevented if the exit tube is filled with charcoal. Loewenthal³ has investigated the physiological action of the radium emanation dissolved in water and injected into the system. There does not appear to be any injurious effect on healthy subjects, but with patients suffering from chronic rheumatism and similar infirmities there occurs a constant reaction after the treatment, accompanied by inflammation and swelling of the joints, which resembles closely the reaction induced by certain healing springs. The same effect can be produced by inhaling the emanation.

W. A. Douglas Rudge⁴ showed that the action of radium on sterilised gelatin, first noticed by Butler Burke, is exhibited by salts of barium and other metals producing an insoluble sulphate, and is due to the precipitation of the sulphate of the metal by sulphuric acid present in the gelatin. Purification of the gelatin from sulphate stops the action, which can be started again by introducing a soluble sulphate. Radium has no specific action on gelatin apart from the barium present, and other radioactive substances not containing barium are also without effect.

Boltwood⁵ has investigated the escape of the emanation from thin films of radium salts carefully protected from the action of moisture in a desiccator. Mme. Curie has stated that the activity of a radium barium preparation increases to five or six times the initial activity after some months. If first heated to a red heat the maximum ultimately attained is half again as great, while if the preparation is kept fused for two hours the maximum is twice as great. Boltwood evaporated a solution of radium barium chloride to produce thin films, and observed (1) the minimum or initial activity, (2) the equilibrium or maximum activity attained after the films had been kept some weeks in a desiccator, (3) the

¹ *Phys. Zeit.*, 1906, **7**, 372.

² *Nature*, Oct. 25, 1906, p. 635.

³ *Phys. Zeit.*, 1906, **7**, 563.

⁴ *Proc. Camb. Phil. Soc.*, 1906, **13**, 258; *Proc. Roy. Soc.*, 1906, **78**, *A*, 380.

⁵ *Amer. J. Sci.*, 1906, **21**, 409.

amount of emanation actually present in the film under the last conditions, and (4) the total emanation generated in the same time by a similar amount of radium in solution in a closed flask. In this way it was shown that only about 70 per cent. of the total emanation is retained by the dry film and 30 per cent. escapes into the air. The final activity that would be attained if the whole of the emanation were retained is 5.6 times the initial activity. In the case of a film of pure radium bromide, only 45 per cent. of the emanation was retained. Boltwood points out that the ratio 5.6 to 1 is that of the sum of the ranges of the four α -rays to the range of the α -ray from radium itself, but this is probably a mere coincidence.

Radioactivity of Thermal Springs.—A large number of papers, to which only passing reference can be made here, have appeared on the radioactivity of thermal and other springs, and the occurrence of argon and helium in the gases therefrom. H. W. Schmidt and K. Kurz¹ concluded from an examination of the springs of the Grand Duchy of Hesse that nearly all springs contain a radioactive emanation, generally that of radium, but in some few cases also that of thorium. The amount does not depend at all on the depth, temperature, or chemical quality of the spring, but only on the geological relations, springs from igneous rocks being the most active, whilst those from sedimentary rocks, and especially chalk and sand, are least. The most active springs are some well-known healing springs, but by no means all the latter exhibit strong activity. At Kreuznach there is a trace of a radium salt itself dissolved in the water, as Strutt found for the Bath waters. Further reference to this spring is made by Gehlhoff,² and other papers are by Hauser,³ Ewers,⁴ Curie and Laborde,⁵ Dienert and Bouquet,⁶ Mache and S. Meyer,⁷ and Moore and Schlundt.⁸

Radioactive Minerals.—This section usually receives full consideration in the report on Mineralogical Chemistry, and it remains here merely to direct attention to some mineralogical papers by Paul Gaubert on the distribution of uranium at St. Joachimsthal and in Saxony,⁹ and to an especially interesting paper by Marckwald¹⁰ on a new uranium mineral from German East Africa, more radioactive even than the Joachimsthal pitchblende. The mineral occurs disseminated through the mica from the quarries of the Uruguru mountains, and is a black, crystalline pitchblende, more or less weathered into a previously unknown mineral consisting almost entirely of the new compound uranyl carbonate, which is yellow and has never been artificially prepared. Marckwald suggests the name "Rutherfordine" for this

¹ *Phys. Zeit.*, 1906, **7**, 209.² *Ibid.*, 590.³ *Ibid.*, 593.⁴ *Ibid.*, 224.⁵ *Compt. rend.*, 1906, **142**, 146.⁶ *Ibid.*, 449.⁷ *1er Congrès pour l'Étude de la Radiologie, etc.*, Brussels.⁸ *Amer. Electrochem. Soc.*, Sept. 1905.⁹ *Le Radium*, 1906, **3**, 1, 132 and 167.¹⁰ *Centr. Min.*, 1906, **24**, 761.

new mineral, in honour of the distinguished pioneer in the study of radioactivity. The unaltered mineral mainly consists of U_3O_8 (87.7 per cent.), contains 7.5 per cent. of lead, has a sp. gr. 8.84, and is 20 per cent. more active than the pitchblende of Joachimsthal. The weathered mineral contains no less than 96 per cent. of uranyl carbonate and 1 per cent. of lead, with sp. gr. 4.82 and a radioactivity equal to the original pitchblende. It is greatly to be hoped that such a valuable mineral will be found in large quantities.

An analysis of the new mineral thorianite has been published by Büchner,¹ together with the proportion in which the activity is distributed among the constituents. The quantity of helium is given as 8.2 c.c. per gram, and the radioactivity of the sample taken for analysis as 83 per cent. of standard uranium oxide.

Strutt² has found traces of neon, estimated as about 1/300th part, in the helium from two radioactive minerals, zircon and cyrtolite, both containing zirconia, by using Dewar's process of fractionating the gases with charcoal cooled in liquid air. The same investigator has made an exhaustive series of analyses of twenty-eight minerals of the earth's crust for the quantity of radium present.³ He found the igneous rocks contained far more radium than the sedimentary. Granite contains 9.56×10^{-12} gram of radium per gram of mineral, or 25.2×10^{-12} per c.c. of mineral; but these measurements must now all be halved owing to the error previously referred to (p. 353) in the amount of radium in uranium minerals. The amount of radium necessary to maintain the temperature of the earth is calculated by Strutt to be about 1.75×10^{-13} gram per c.c., a quantity which is fifty to sixty times less than the average amount in average igneous rocks, and ten times less than the amount in the poorest samples examined. The conclusion which Strutt draws is that the earth can only consist of a crust of igneous rocks some forty-five miles in depth, the interior being entirely free from radium and composed of a totally different material, which is in agreement with the views of Milne drawn from the study of seismological phenomena. This conclusion has been the source of much discussion, and many other explanations have been advanced. One of these, supported by Lord Kelvin, is that radioactive action ceases at the enormous pressures inside the earth. Soddy⁴ considered that Strutt's results may perhaps be evidence in favour of the view that there is proceeding in nature an as yet undiscovered process, complementary to disintegration, whereby the heavier elements are being slowly built up out of the lighter. Such a process must absorb energy in the same relatively enormous amount in which

¹ *Proc. Roy. Soc.*, 1906, **78**, A, 385.

² *Nature*, Nov. 29, 1906, 102.

³ *Proc. Roy. Soc.*, 1906, **77**, A, 472.

⁴ *B.A. Reports*, York, 1906; *Evolution of the Elements*, footnote.

it is evolved during disintegration. Since the heat that must be evolved in the disintegration of the known amounts of radioactive matter in the earth is far in excess of that required to maintain the loss of heat by radiation and keep the earth temperature constant, and since there is indisputable geological evidence of the constancy of the earth's temperature over a period estimated in hundreds of millions of years, there is at least now no *a priori* objection to the existence of an upbuilding process on the ground that the energy required is not available; but of course the whole subject is only at present in the speculative stage.

Eve,¹ in an examination of the radioactivity of the earth and atmosphere, showed that the ionisation of the latter is caused by the γ -radiation from the earth to the extent of only 1/16th of the total, the remainder being due to the radium emanation present in the atmosphere. He calculates the quantity of radium in the earth's crust necessary to cause the γ -radiation from the surface to be 1.8×10^{-11} gram per c.c., which is of the same order as, but about four times greater than, the average amount found by Strutt in rocks. These two widely different methods of measurement of the radium in the earth's crust are thus as concordant as can be expected considering the nature of the quantity investigated.

Advances in Experimental Methods.—An ingenious device has been suggested by Kurz² for reading the gold leaf of an electroscope. A circular segment is cut out of one side of the leaf near the end to be read, and a quartz fibre is waxed at the two ends and laid across the segment, and attached to the leaf by bringing a heated rod near to the wax. The quartz fibre gives a fine image for reading in the microscope. Bronson³ has worked out a constant deflection method of using the electrometer, in which the ionisation current to be measured is proportional to the deflection of the electrometer needle instead of to the rate of movement, as in the usual arrangement. N. R. Campbell⁴ has devised a null method of working in which the ionisation current to be measured is balanced against the current through a constant volume of gas ionised by a constant quantity of uranium oxide, the pressure of the ionised gas being varied. In this way the measurement is reduced to the adjustment and reading of a gas pressure.

Polonium.—The controversy as to the identity of polonium and radiotellurium, which has long ceased to present more than a nominal interest as to which of the two names should be retained, has now been ended.⁵ Mme. Curie repudiated and gave convincing proof

¹ *Phil. Mag.*, 1906, [vi], 12, 189.

² *Phys. Zeit.*, 1906, 7, 375.

³ *Phil. Mag.*, 1906, [vi], 11, 143.

⁴ *Proc. Camb. Phil. Soc.*, 1906, 3, 132.

⁵ S. Curie, *Phys. Zeit.*, 1906, 7, 146 and 180; Marckwald, *ibid.*, 369; Meyer and von Schweidler, *ibid.*, 257.

against the idea that the polonium as first prepared and named by her gave β -rays or was in a radioactive sense heterogeneous, and protested against the period of decay as published long ago by her being accepted as giving more than the order of the time constant. A new series of exact measurements gives the period one hundred and forty days, which conforms to that of Rutherford for radium *F* and of numerous investigators for "radiotellurium."¹ The greater resemblance of polonium to tellurium than to bismuth chemically is denied, and it is pointed out that in the insolubility of its sulphide in ammonium hydrogen sulphide, and of its oxide in caustic soda, polonium resembles bismuth and differs from tellurium. Mme. Curie considers it self-evident that polonium, the first strongly active substance separated by M. Curie and herself by a method first used by them, must keep the name it received from its discoverers. Marckwald in his communication agrees in future to use the name polonium instead of radiotellurium for his preparations, and it is to be hoped, this being the case, that the name radiotellurium will not be further used. Meyer and von Schweidler² examined polonium from four different sources: (1) the residual induced activity of radium (radium *F*), (2) from radiolead (radium *D*, radium *E*, and radium *F*), (3) "radiotellurium," (4) from radioactive bismuth ("polonium"), and found that all preparations possessed substantially the same rate of decay. The mean of the values for the period was one hundred and thirty-seven days.

Thorium.—A summary of the physical and chemical properties of the disintegration products of thorium is given by von Lerch,³ who himself has been one of the earliest and most fruitful investigators in this field. Our knowledge of the radiothorium, and the position of what has even come to be known as "the thorium question," has been advanced one stage further by the successful partial chemical separation of this constituent from commercial thorium compounds by Elster and Geitel⁴ and G. A. Blanc.⁵ The former separated from the sediment of the hot spring at Baden Baden a preparation with all the characteristics of the thorium radioactivity, but many more times more active, the activity being permanent over short periods. Seventy-five kilograms of these sediments from Bad Nauheim were worked up by Giesel, and gave a gram of a radium-barium preparation of strong activity but practically no thorium activity. Twenty kilograms of the sediments from Bad Kreuznach gave, besides strong radium preparations, small quantities

¹ *Ann. Report*, 1905, 310.

² *Wien. Sitzungsber.*, 1906, **115** II 4, 1.

³ *Jahrb. Radioakt. Elek.*, **2**, 463.

⁴ *Phys. Zeit.* 1906, **7**, 445.

⁵ *Ibid.*, 020.

of preparations with thorium activity fifty times that of thorium. With the experience obtained in the working up of these sediments, the separation of radiothorium from commercial thorium salts was attempted. The principle of the method was to precipitate a small quantity of iron with the thorium solution, and to separate the iron from the precipitate with oxalic acid. In this way preparations were obtained decaying rapidly at first (due to the presence of thorium *A* and thorium *B*), but reaching a minimum (radiothorium only), and finally attaining a maximum twice as great (due to the reproduction of thorium *X*, &c.). These preparations consisted of thorium hydroxide with an activity twelve times as great as the original material. The authors point out that radiothorium, like radium, is widely distributed, being found not only in springs and in the earth, but also in some varieties of crude petroleum.

G. A. Blanc¹ first discovered that the deposits from certain hot springs at Echaillon and Salins-Moutiers possess thorium activity without any noticeable quantity of thorium being present. Very active preparations could be separated from the deposits possessing the characteristic thorium radioactivity in a very intense degree. He succeeded in separating radiothorium from ordinary thorium preparations² by precipitating barium as sulphate in a solution of thorium nitrate, fusing the precipitate with carbonate of soda, and precipitating the solution of the carbonates in hydrochloric acid with ammonia. A few centigrams of thorium hydroxide with a trace of iron obtained in this way had an initial activity ten times and a final activity thirty times that of ordinary thorium hydroxide. From six kilograms of thorium nitrate was obtained a few milligrams of a preparation initially strongly radioactive but free from emanating power, and ultimately developing emanating power and radioactivity 5000 times that of thorium hydroxide in equilibrium. Thus the separation from ordinary thorium compounds of radiothorium, comparable in radioactivity with the preparations obtained by Hahn from thorianite, has been accomplished; but the complete removal of the active constituent is still very far from being accomplished, and the preparation of "inactive thorium" from active thorium salts has not been effected.

The radioactivity of thorium minerals and salts has formed the subject of investigations by Dadourian³ and Boltwood,⁴ and thorium salts have also been examined from a similar point of view by McCoy and Ross.⁵ The problem was to find the relation between the radioactivity of a thorium mineral or salt (due to radiothorium) and the thorium

¹ *Phil. Mag.*, 1905, [vi], 9, 148.

² *Phys. Zeit.*, 1906, 7, 620.

³ *Ibid.*, 1906, 7, 453; *Amer. J. Sci.*, 1906, 21, 427.

⁴ *Phys. Zeit.*, 1906, 7, 482; *Amer. J. Sci.*, 1906, 21, 415.

⁵ *Ibid.*, 1906, 21, 433.

content, the thorium being in all probability itself without radioactivity. Both Dadourian and Boltwood by different methods found that the radioactivity was proportional to the content of thorium, and therefore that radiothorium must be a true disintegration product of thorium. Dadourian measured the amount of excited activity produced from the solution of a given amount of a thorium mineral, and used this as a measure of the thorium radioactivity. He found this activity, and therefore the amount of radiothorium present, to be proportional to the thorium content of the mineral as determined by analysis. In commercial salts, however, the activity in terms of the thorium content is only about one-half of that in minerals, which points clearly to the separation of a part of the radiothorium during the processes, secret for the most part, by which thorium is commercially extracted from its ores. Boltwood determined the total α -ray activity of several thorium minerals, subtracted the part due to the uranium present as determined by analysis, and found for four minerals the thorium activity per gram of thorium to be a constant. Whereas the specific activity of commercial thorium salts was only one-half of that of minerals, the specific activity of the salts prepared by himself from the minerals was equal to that of the minerals. In view of what has been said (p. 361) on the labour and difficulty in separating radiothorium from thorium, and the fact that in Hahn's work only about 2 per cent. of the radiothorium probably was separated from thorianite, it will be seen that the secret commercial processes are far more effective in removing radiothorium than the known laboratory methods. An investigation of the residues in the manufacture of thorium salts commercially for the radiothorium separated had only negative results. From these researches it is placed beyond doubt that radiothorium is a disintegration product of thorium with a relatively slow period (at least several years), that the change of thorium into radiothorium is probably rayless, and therefore that inactive thorium preparations should be capable of separation. Unless the initial change of thorium were rayless, the close agreement between the results of Dadourian and Boltwood obtained by different methods would not have been shown.

Eve¹ measured the γ -rays given out by known quantities of (1) radium bromide, (2) thorianite, (3) thorium nitrate, the last two containing a known percentage of thorium. He found that the ratio of the γ -activity of the mineral to the salt for quantities containing similar amounts of thorium was 2.5 to 1, again pointing to the poverty of the salt in radiothorium. Hence it is to be expected that the γ -activity of a thorium salt should steadily increase with age as the radiothorium is reproduced, and an earlier suggestion that a kilogram

¹ *Amer. J. Sci.*, 1906, [iv], 22, 477.

of a thorium salt should serve as the standard of γ -radiation is therefore to be abandoned. The γ -activity of pure radium bromide is given as 4.5 million times that of thorium oxide containing the full equilibrium amount of radiothorium.

The diffusion of thorium *X* in gelatin solutions has been investigated by G. Hoffmann.¹ The diffusion from an under layer to the free surface was followed by measuring the emanation from the free surface, passing a steady air stream over it. He concluded that thorium *X* diffuses as a single substance, and that radioactive bodies in infinitesimal quantity diffuse according to Fick's law exactly as with substances present in measurable concentration.

Actinium.—There are many problems of interest awaiting solution in connexion with this body, and the almost perfect resemblance from a radioactive point of view between thorium and actinium has been emphasised by several discoveries during the year. Hahn² separated a product he called radioactinium, intermediate between actinium and actinium *X*, and in every way analogous to radiothorium. If an ignited actinium preparation is dissolved in hydrochloric acid the residue contains relatively a greater proportion of the radioactinium than the solution. A complete separation of the product is obtained when actinium, freed from actinium *X* by repeated precipitation with ammonia, is treated with sodium thiosulphate in acid solution. Amorphous sulphur is precipitated, and carries down the radioactinium only. Another method is also given depending on the partial precipitation of actinium with ammonia when the active radioactinium is concentrated in the precipitate. The ranges of the various α -rays have already been given (p. 343), and also the conclusion that actinium *B* is the only β -ray product (p. 340). The period of radioactinium is given as twenty days, and actinium freed from this and the later products possesses no activity, so that the initial change is rayless as in the case of thorium. Godlewski in his separation of actinium *X*³ separated unawares some of the radioactinium as well as the actinium *X*, which accounts for the low activity of the actinium recorded by him. Hahn obtained no evidence of the existence of any residual activity in the case of actinium excited activity pointing to the existence of a possible actinium *D*, &c., analogous to radium *D*, radium *E*, and radium *F*. On the other hand, Meyer and von Schweidler⁴ detected a small residual activity, $\frac{1}{100000}$ th of the initial, after the ordinary induced activity, produced from the actinium emanation after forty-eight days' working, had been allowed to decay. But instead of being

¹ *Ann. Physik.*, 1906, [iv], **21**, 239.

² *Ber.*, 1906, **39**, 1605; *Nature*, April 12, 1906, 559; *Phys. Zeit.*, 1906, **7**, 855.

³ *Ann. Report*, 1905, 307.

⁴ *Wien Anzeiger*, 1906, 12; *Sitzung.*, April 26.

of a slow period, as in the case of radium, which is to be expected of a product so relatively feeble in activity, it decayed regularly with a period of 11.7 days. The ordinary view leads us to expect that the product of the activity into the period should be approximately the same for all the successive members of a true disintegration series, but the case in question, and also the other new cases of the α -radiation of uranium *X* and thorium *A*, and the β -radiation of radium *B*, constitute exceptions to this rule. We are faced with several examples of ray changes in which the total radiation emitted is very much less than in other cases for changes in the same disintegration series. The most important example of this is probably actinium itself.

Boltwood¹ examined the relative proportion of the α -ray activity of radioactive minerals due to the separate radioactive constituents, and found it could be expressed as the sum of two factors, one depending on the amount of uranium, and the other on the amount of thorium present. McCoy² found that the total radioactivity of five uranium minerals not containing thorium was proportional to the content of uranium being always 4.15 times the activity of the uranium present. This means that actinium must be a product of uranium, and that all the radioactive constituents must be successive members of two series, that of uranium and that of thorium.

The quantity of actinium, determined by separating it from the mineral, is proportional to the uranium. The conclusion was drawn that actinium must be a disintegration product of uranium. But Rutherford and Boltwood, in an examination of the activity of uraninite, found that it was almost accounted for by the radium and uranium present, so that the actinium contributes but a small fraction of the total activity. Yet since actinium gives four α -ray products in its disintegration to five furnished by radium, it is to be expected that the activity contributed by actinium should be comparable to that furnished by radium. In these circumstances Rutherford³ was inclined to view actinium as a simultaneous side-product out of the main line of descent, a suggestion similar to that proposed in the case of radium *A* and radium *B*, and since shown to be unnecessary. Here also the most recent development seems against the view. Boltwood⁴ separated as completely as possible the actinium from a kilogram of carnotite, and measured the amount of radium present in the actinium solution at first, and again 193 days later. In this interval the quantity of radium was found to have increased from 5.7 to 14.2 ($\times 10^{-9}$ gram), and the conclusion was drawn provisionally that actinium is the

¹ *Phys. Review*, 1906, **22**, 320.

² *Phil. Mag.*, 1906, [vi], **11**, 177.

³ *Radioactive Transformations*, p. 177.

⁴ *Nature*, Nov. 15, 1906, p. 54; *Amer. J. Sci.*, 1906, **22**, 537; *Phys. Zeit.*, 1906, **7**, 915.

parent of radium, and that the rate of production is approximately what is to be expected on the view that all the radium in a mineral results from the change of the actinium present. This, if confirmed, shows that actinium is in the main line of descent, and the relations of theory and fact have assumed a kind of stalemate.

Radiolead.—This substance, it is now quite clear, owes its activity to the presence of radium *E* (β -rays) and radium *F* (α -rays) formed from and in radioactive equilibrium with radium *D* (rayless). Although the initial change of radium *D* is slow, the succeeding changes are more rapid, so that the preparation rapidly grows in α - and β -activity, and reaches an equilibrium after a year or two. Meyer and von Schweidler by electrolysing the acetate solution with a current-density of four microamperes per sq. cm. separated polonium (radium *F*). With ten microamperes both polonium and radium *E* are deposited, and with 100 microamperes radium *D* also as well as lead separates. The period of radium *E* is given as 5.02 days. Giesel in his paper on β -polonium gives a somewhat higher period, 6.14 days, whilst Rutherford in his original paper gave 4.5 days.

Elster and Geitel,¹ starting from the observation of N. R. Campbell, that the natural ionisation inside lead vessels is abnormally large, and of A. Wood,² that no emanation is given out by lead solutions, and that the radiations from lead possess a greater penetrating power than the α -rays of radium, made a thorough examination of the activity of ordinary lead. They found that surrounding a zinc vessel with a lead mantle reduced the natural ionisation 11 per cent., showing that the lead gives no appreciable penetrating radiation, but absorbs the penetrating radiation from the earth discovered by Cooke. A kilogram of radiolead obtained from Giesel gave no radium emanation, although the minutest amount could be detected. Using methods which would effect the separation of the radioactive constituents from radiolead, they succeeded in separating from ordinary commercial lead salts preparations with feeble activity. The lead was precipitated successively with hydrochloric acid, sulphuric acid, and hydrogen sulphide, and the last minute precipitate of lead sulphide was feebly active and resembled radiolead. Since radium is very frequently contained in lead ores, it is possible that the radium *D*, which resembles lead chemically, is separated with the lead and is the cause of its feeble activity. This suggests to the authors an elegant piece of work, for old lead—for example, that obtained from the roofs of old buildings—should not be active, as the radium *D* would all disappear in two or three centuries, and unless the lead actually contained radium itself, its activity after this period should have completely decayed.

FREDERICK SODDY.

Phys. Zeit., 1906, 7, 841.

² *Phil. Mag.*, 1905, [vi], 9, 550.