The equation to the lines of force is

$$\frac{dr}{dz} = r \cdot \frac{\pi\sqrt{z}}{\lambda} \cdot \frac{\sin\left(\frac{2\pi z}{\lambda} - \frac{\pi}{4}\right)}{\sin\frac{2\pi z}{\lambda}}, \quad . \quad . \quad . \quad . \quad (25)$$

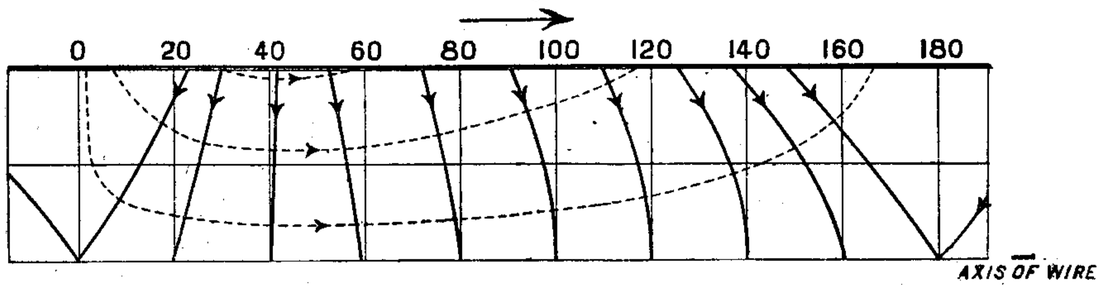
$$2\log r = \frac{2\pi z}{\lambda} - \log\sin\frac{2\pi z}{\lambda} + \text{const.} \quad . \quad . \quad (26)$$

The equation to the lines of flow comes out

$$-\frac{2\pi^2}{\lambda^2}r^2 = \frac{2\pi z}{\lambda} + \log\sin\left(\frac{2\pi z}{\lambda} - \frac{\pi}{4}\right). \quad . \quad . \quad (27)$$

These curves are shown on fig. 4, beginning, in this

Fig. 4.



case, from the *axis* of the wire. It may be noted that if we plot one line of force the others are got simply by extending proportionally the ordinates measured from the axis.

In this case the magnetic force vanishes along with the longitudinal electric. The energy-flow is backward and inward from 0° to 45°, and forward and inward for the remainder of the half wave-length. The exaggeration of the diagram in this case consists in making the radius of the wire much too great in comparison with the wave-length, in order to get room to show the trend of the curves.

Queen's College, Belfast,
20th June, 1902.

XXXIV. *Deviable Rays of Radioactive Substances.* *By* E. Rutherford, *M.A., D.Sc., Macdonald Professor of Physics, and* A. G. Grier, *M.Sc., Demonstrator in Physics, McGill University, Montreal* *.

§ 1. THE experiments † of Giesel, Becquerel, Curie, Meyer, and Schweidler have shown that radium gives out some rays deflectable by a magnet.

Becquerel, in addition, has shown that uranium, and the excited radioactivity due to radium, also emit rays deviable by a magnetic field. Becquerel has employed the photographic method for detecting deviable rays, while the Curies, Meyer, and Schweidler have used the electrical method for analysis of the deviable rays from radium.

Further experiments have shown that these deviable rays are similar in all respects to cathode-rays. Dorn ‡ showed that they were deflected in an electrostatic field, while the Curies § showed that they carried with them a negative charge. Becquerel determined the velocity of these "electrons" by observing the magnetic and electrostatic deviation of the rays. He found that the rays from radium were complex, and had widely different velocities. Some travelled at more than half the speed of light. The ratio of the charge to the mass $\frac{e}{m}$ was found to be about the same as for cathode-rays. These results have recently been confirmed by Kaufmann ‖, who has shown that some of these electrons travel with a speed nearly equal to that of light, while the ratio of $\frac{e}{m}$ is somewhat less than for the comparatively low velocity cathode-rays, and appears to decrease with the velocity of the electron. This points to the conclusion that for these high-speed electrons a portion of the effective mass is electrical in origin ¶.

The authors have found that, in addition to uranium and radium, thorium compounds, and also excited radioactivity due to thorium, give out some rays deviable by a magnetic field.

* Communicated by the Authors. Communicated to the American Physical Society, April 21, 1902.

† See reports on radioactivity by Becquerel and Curie to Congrès International de Physique, 1900, tome iii.

‡ *C. R.* cxxx. p. 1126.

§ *Ibid.* cxxx. p. 647.

‖ See Heaviside, 'Electrician,' April 4, 1902.

¶ *Gött. Nach.* ii. 1901.

The main object of the investigations described in this paper was to obtain some experimental evidence of the connexion, if any, between the deviable and non-deviable rays emitted by the radioactive substances uranium, thorium, and radium. It is known that cathode-rays striking on a solid body give rise to Röntgen rays, and also that Röntgen rays impinging on bodies in their turn give rise to a secondary radiation, part of which is composed of rays similar to cathode-rays.

It thus appears possible, as Becquerel has suggested, that the non-deviable rays may be due directly to the action of the deviable rays. A similar suggestion was put forward by one of the authors * to account for the presence of the two types of rays given out by uranium, one of which was far more penetrating than the other. The relation is, however, much more complicated than such simple analogies would suggest. A discussion of the question, with especial reference to the important results on the partial separation of the active products of uranium and thorium, is reserved till the conclusion of this paper.

§ 2. In these experiments the electric method has been employed throughout. It has many advantages over the photographic method, especially where quantitative comparisons and rapidity of measurement are required.

Fig. 1 shows the general experimental arrangement. The radioactive substance to be investigated was spread uniformly on the bottom of a shallow paper vessel, which fitted inside a lead box 3 cms. square and 2 cms. deep. The paper vessel rested on a wire gauze 1 cm. from bottom of vessel, and, by means of a water-pump, a steady stream of air was drawn downwards through the apparatus. This carried off the radioactive *emanation* emitted by thorium and radium, the presence of which in the testing-apparatus would seriously interfere with the measurements. The lead box was placed between pole-pieces, 3·2 cms. square, of a large electromagnet, which were generally placed 3·2 cms. apart.

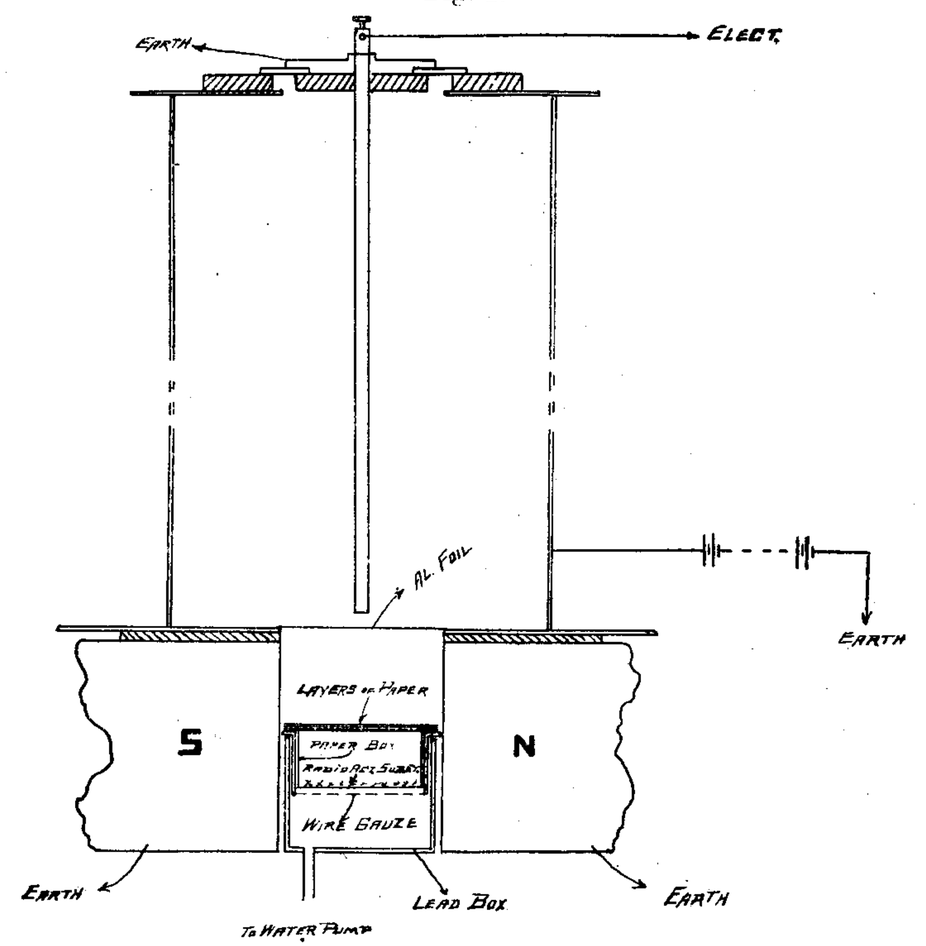
The testing-vessel V was a rectangular zinc vessel, 10·5 cms. square and 30 cms. high. The outside was connected to one pole of a battery of 100 volts. A brass rod formed the inside electrode, which was connected to the electrometer. A guard-ring, connected to earth, ensured that there was no natural leak from the charged cylinder to the inside electrode.

The testing-vessel was placed on an insulated metal plate, with a hole in the centre 3·2 cms. square, over the air-gap of

* E. Rutherford, Phil. Mag. Jan. 1899.

the electromagnet. This was covered over with a layer of aluminium-foil ·00034 cm. thick.

Fig. 1.



Special precautions were taken to completely secure the electrometer and connexions from electrostatic disturbances of all kinds.

It is easy to investigate the magnetic deviation of radium-rays in such an apparatus with an ordinary electrometer, as the ionization action of the radium-rays is very large.

For uranium and thorium, however, the ionization due to the deviable rays is very small, and a specially sensitive electrometer is required to measure the effects with accuracy. The Dolezalek electrometer, described in a previous paper by one of us *, was found sufficiently sensitive for this purpose.

All the radioactive substances emit non-deviable as well as deviable rays, and generally the ionizing action of the non-deviable rays is much greater than that caused by the

* *Phys. Zeit.* no. 11, p. 225 (1902).

deviable rays. With the bare radioactive substances the ionization in the testing-vessel is chiefly due to the non-deviable rays. In consequence of this a strong magnetic field does not much alter the ionization-current observed in the electrometer. The non-deviable rays can, however, be completely absorbed by two or more layers of paper, while the deviable rays pass through with very little absorption.

The deviable rays consist of rapidly moving electrons, and ionize the air in their passage through it by collision with the molecules. The average deviable rays are so penetrating that they will probably pass through more than a metre of air before the ionizing action is cut down to one half.

When a strong magnetic field is applied, the paths of the rays are curved, so that only a small fraction of the rays enter the testing-vessel.

In the experiment a magnetic field of 2200 C.G.S. units was generally employed. This usually reduced the ionization current in the testing-vessel to about 20 per cent. of its previous value. By increasing the strength of field the current steadily diminished, showing that the effect in testing was principally due to deviable rays. A small percentage of the amount of ionization in the testing-vessel was due, in the case of radium, to some extremely penetrating non-deviable rays. These rays have been examined by the photographic method by Villard and Becquerel. The difference between the current in testing-vessel with magnet on and off was taken as a measure of the amount of deviable rays.

§ 3. *Variation of Amount of Deviable Rays with Thickness of Radioactive Layer.*

Different weights of the radioactive substance to be tested were spread over an area of about 9 sq. cms. Four layers of paper over this completely absorbed the α-radiation.

The following numbers show the result from uranium and radium. The amount of deviable rays is expressed in divisions per sec. of the electrometer-scale, and represents the difference between ionization-current in the testing-vessel with the magnet off and on.

Uranium Oxide.		Radium Chloride.	
Wt.	Divns. per sec.	Wt.	Divns. per. sec.
·25 gr.	·47	·25	1·5
·50 „	·90	·5	2·9
1 „	1·26	1	5·5
2 „	1·70	1·55	6·7
5 „	1·96		

In the case of radium a capacity of ·005 microfarad was in parallel with the electrometer.

The results for uranium are in agreement with the view that each portion of the mass is sending out electrons uniformly. The number of electrons which escape is at first proportional to the thickness, but tends towards a maximum as the electrons from the lower layers are absorbed before reaching the surface.

The table for radium shows, as far as it goes, a similar action, only in that case we did not have a sufficient amount of substance to investigate the effect of thicker layers. In this sample of radium (from P. de Haen, Hannover) the deviable rays were 250 times as intense as from an equal weight of uranium oxide.

§ 4. *Deviable Rays from Thorium Compounds.*

Thorium oxide is much weaker in deviable rays than an equal weight of uranium oxide, although the non-deviable rays are of about the same intensity. For this reason the presence of the deviable rays in thorium is more difficult to detect and measure than for uranium. In measurements on thorium compounds precautions must be taken that the presence of the radioactive emanation and the excited radioactivity produced by it are not responsible for the deviable rays observed.

About 5 gr. of the thorium compound was spread uniformly in a rectangular lead vessel 3 cms. long, 2 cms. wide, and 1 cm. deep., and a very thin plate of mica waxed down over the top. This allowed most of the deviable rays to pass through, but absorbed most of the non-deviable rays, and was impervious to the emanation. Observations were taken as soon as possible after the thorium was placed in the vessel, and the difference of current observed with the magnetic field off and on. By means of side-tubes in the lead vessel a slow current of air was then passed over the thorium, carrying away the emanation. The amount of deviable rays was found to be unchanged, showing that the deviable rays (if any) from the emanation did not appreciably affect the result. If the side-tubes of the lead vessel were closed, and the thorium left undisturbed for 24 hours, the amount of deviable rays was considerably increased. This increase was found to be due to the deviable rays given out by the excited radioactivity produced by the emanation on the whole interior of the containing vessel. This was directly tested by removing the mica plate from the thorium vessel and placing it between the poles of the electromagnet. It was found to

give out both deviable and non-deviable rays, due to the excited radioactivity produced on it.

The amount of deviable rays for equal weights of different thorium compounds was found to vary considerably, as the following table shows :—

Compound.	Amount of Deviable Rays.
Oxide	1
Deemanated oxide	1·35
Nitrate	·94
Sulphate	·83
Oxalate.....	·76
Uranium oxide	6·7

In the above table the amount of deviable rays from ordinary thorium oxide is taken as unity, and the others expressed in terms of it. For the purpose of comparison the amount of deviable rays from an equal weight of black uranium oxide is added.

The comparisons in the above table were not made directly by noting the effect of a magnetic field, but by an indirect method, explained in § 9, which is based on the observed fact that the penetrating rays from thorium as well as uranium are chiefly deviable rays.

Four grammes of the compound in the form of powder were uniformly spread in a lead vessel of area 22 sq. cms. A layer of aluminium, thickness ·006 cm., was waxed down over the top. This absorbed all the non-deviable rays, but allowed most of the deviable rays to pass through. The ionization-current due to these penetrating rays was determined in the usual way, and was taken as a measure of their intensity.

The deemanated oxide, *i e.* the oxide which had been largely deprived of its power of giving off a radioactive emanation by raising it to a white heat, gives more deviable rays than the ordinary oxide ; while the nitrate is nearly as active as the ordinary oxide, although containing only about half the amount of thorium.

It was also found that the increase of deviable rays with time, when the thorium was kept in a closed vessel for 24 hours, varied very considerably for different compounds. The increase was much greater for the ordinary oxide than for the deemanated sample, while thorium carbonate, which gives out five times as much emanation as the oxide, showed still greater differences.

This increase of deviable rays with time in a closed vessel

is directly proportional to the emanating power of the compound, and is due to the deviable rays produced by excited radioactivity on the walls of the vessel.

These results point to the conclusion that a portion, at least, of the deviable rays from thorium is due to the presence of excited radioactivity throughout the mass of the compound itself. If the emanation, which is apparently produced by all thorium compounds, is unable to escape rapidly into the air it produces excited radioactivity throughout the compound. In the deemanated oxide consequently more excited radioactivity is produced than in the ordinary oxide, from which more emanation escapes into the air. Since excited radioactivity gives rise to deviable rays the effect will be greater for the deemanated than the ordinary oxide.

§ 5. *Deviable Rays from Excited Radiations due to Thorium and Radium.*

A small proportion of the rays emitted by thorium- and radium-excited radiation is deviable by a magnetic field. As these excited radiations decay with the time it was of importance to see if the deviable rays decayed at the same rate.

A lead wire was made the cathode in a cylindrical closed vessel containing the emanation from radium, which had been obtained by bubbling air through a solution of radium chloride. The wire was left exposed for one day in order that the excited radiation should have reached a steady value. The lead wire was then bent into a small spiral and placed between the poles of the electromagnet of fig. 1.

Observations were taken at regular intervals, both of the current due to the deviable and non-deviable rays. Fig. 2 (p. 322) shows the results graphically ; Curve I. shows the decay with time of the non-deviable rays, Curve II. the decay with time of the deviable rays. For the purpose of comparison the maximum value of each is taken as 100.

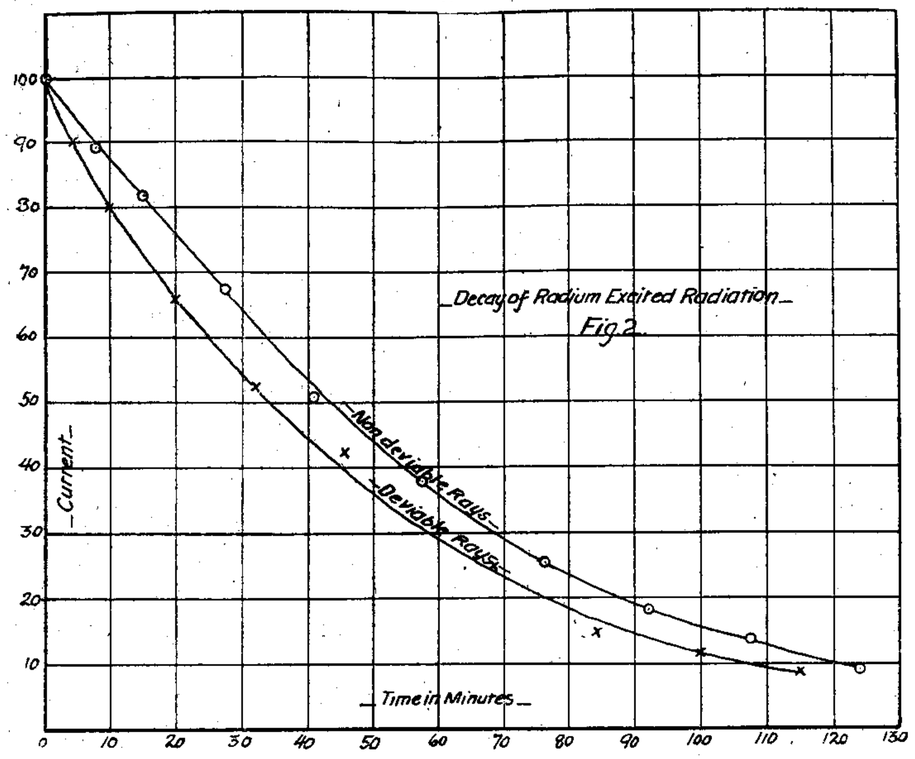
Similar observations were made on the excited radioactivity from thoria.

An aluminium plate, 3 × 2 cms., was made the cathode in a closed vessel containing about 200 grs. of thoria and left two days. The following table shows the decay of the two types of rays. The initial value of each is taken as unity for comparison :—

Time.	Non-deviable rays.	Deviable rays.
0	1	1
3 hrs.	·77	·83
19 „	·38	·33
42 „	·08	·07

The results for both thorium- and radium-excited radiation show that the deviable rays decay at nearly the same rate as

Fig. 2.



the non-deviable. This result shows that there is a very close connexion between the production of these two types of radiation.

§ 6. *Active Products Separated from Thorium and Uranium.*

In a previous paper (Rutherford and Soddy, Proc. Chem. Soc., Jan., and Trans. Chem. Soc., April 1902) it has been shown that a very active product can be separated from thorium as a result of the precipitation of thorium nitrate by ammonium hydroxide. If the filtrate, free from thorium, is evaporated down to dryness and the ammonium salts driven off by ignition, a very small residue is obtained intensely active, possessing in some cases 1000 times the activity of thoria. This radioactive fraction has been termed Thorium X. At the same time the radioactivity of the precipitated thoria is diminished in most cases to about ·36 of its original value.

The investigation on the radioactivity of thoria has been continued by E. Rutherford and F. Soddy, and at the same time parallel experiments have been made on the partial

separation of the active products from uranium by the methods of Crookes and Becquerel. The results of these investigations will appear shortly, but the authors of this communication are indebted to Mr. Soddy, of the Chemical Department, for his kindness in making the chemical preparations of thorium and uranium which are tested in this paper.

On examination it was found that the Th. X. emitted both deviable and non-deviable rays, and also a radioactive emanation. The deviable radiation is complex, as in the case of the ordinary thoria, and contains a large fraction of easily absorbed deviable rays. If a large number of successive precipitations are performed the thoria can be almost completely freed from deviable rays, although about 30 per cent. of the non-deviable rays still remain.

We thus see that non-deviable rays persist in thoria when the product responsible for deviable rays is completely removed.

Very similar actions have been observed for the active products separable from uranium by the methods of Crookes and Becquerel. Crookes* obtained very active residues from uranium by two methods. In one case it was found that if ether was added to uranium nitrate part of the nitrate was soluble in the ether. The part that was insoluble in the ether was far more radioactive than the part which was not. In the other case the nitrate was dissolved in water and an excess of ammonium carbonate added. A small precipitate remaining behind was found intensely active compared with an equal weight of uranium. This active fraction was called by Crookes Ur. X.

Becquerel† found that as a result of continued precipitation of barium sulphate in a mixture of uranium and barium chloride, he could entirely free the uranium from the photographic action, while the barium sulphate carried with it a very active fraction. In course of time the uranium recovered the original radioactivity, while the barium sulphate became inactive.

On examination of the Ur. X. of Crookes and the active barium sulphate of Becquerel, it was found that the radiation was composed almost entirely of deviable rays. The conductivity due to the deviable rays was more than $\frac{2}{3}$ of the total, while the conductivity due to the deviable rays of a thin layer of uranium is not more than one per cent. of the total (see § 7).

* Proc. Roy. Soc., May 1900.
† *C. R.* Dec. 9, 1901.

The uranium from which the active fraction had been removed by the three methods was found almost completely free from deviable rays, while the non-deviable rays were not much reduced. Not a trace of deviable rays was obtained from uranium after 12 precipitations with barium sulphate, although $\frac{1}{2}$ per cent. of the original amount could have been readily detected. We thus see that by different chemical methods the part responsible for the deviable radiation in both uranium and thorium can be separated from the main body, while part at least of the non-deviable radiation is unaffected.

§ 7. *Other Results.*

No trace of deviable rays could be detected by the electric method from polonium. This is in agreement with the results of Becquerel by the photographic method. We have so far been unable to obtain any conclusive evidence of the existence of deviable rays in the emanation of thorium, although the emanation gives off strong non-deviable rays.

§ 8. *Penetrating Power of the Deviable Rays.*

By noting the diminution of magnetic effect in the testing cylinder when successive layers of thin aluminium or tinfoil were placed over the radioactive substance, the penetrating power of the deviable rays can be compared.

When the magnetic effect falls off in geometric progression with the thickness the rays may be supposed to be fairly homogeneous in character. If the absorption is greater for the first few layers than for succeeding layers, the rays are complex, *i. e.* the rays are made up of streams of electrons differing in velocity, and consequently in penetrative power.

Tested in this way it was found:

(1) That uranium, and the excited radioactivity due to thorium, gave out deviable rays approximately homogeneous in character and of about the same penetrating power.

(2) Thorium and radium both gave out very complex rays. This has been shown by Becquerel for radium, using the photographic method. He found that the magnetic deviation of the rays varied within wide limits. Thorium X gives out a large proportion of easily absorbed deviable rays.

(3) Radium and thorium and the excited radioactivity due to them all emit some deviable rays of about the same penetrating power as those from uranium. The rays from uranium pass through about ·5 mm. of aluminium before the intensity is reduced to one half.

§ 9. *Comparison of the Amount of Ionization Produced by Deviable and Non-deviable Rays.*

In 1899 one of us* showed that uranium oxide emits two types of radiation which were for convenience termed the α and β radiations. The β radiation was far more penetrating in character than the α-rays. By the electrical method we have found that *the β radiation is made up almost entirely of deviable rays* of a penetrating character.

For brevity and convenience we will call the non-deviable rays of *all* radioactive substances *α-rays* and the deviable rays *β-rays.*

The magnetic-deviation apparatus of fig. 1 is not suitable for a direct comparison of the ionizing action of two types of rays. Since, however, the α-rays are in all cases easily absorbed, and we have experimentally found that the greater proportion of the penetrating rays of uranium, thorium, and radium are magnetically deviable, a simple indirect method can be employed.

The ionization current between two large parallel metal plates was observed with a large P.D. between the plates,

(1) with the radioactive substances bare,

(2) with a layer of metal over the substances sufficiently thick to absorb all the non-deviable rays.

In (1) we have the effect of the α- and β-rays, and in (2) that of the β-rays alone.

Since the amount of the α-rays emitted reaches a practical maximum for a very thin layer of radioactive substance a comparison of the ionizing effects of the two kinds is best made with a very thin layer.

In the apparatus employed about $\frac{1}{10}$ gr. of the finely powdered radioactive substance was uniformly spread over an area of about 80 sq. cms. The distance between the testing-plates was 5·7 cms. and the P.D. between the plates 300 volts.

The results of previous experiments have shown that the α-radiations of uranium, thorium, and radium are almost completely absorbed in passing through a distance of 5 cms. of air, so that the current with the bare substance was a measure of the *total* number of ions produced by α-rays, together with a small fraction only of the ions produced by β-rays.

A layer of aluminium ·009 cm. thick was found sufficient to completely absorb the α-radiation. The following table

* E. Rutherford, Phil. Mag. Jan. 1899.

illustrates the quantitative connexions between the ionizing action of α- and β-rays for the conditions of the experiment :—

	Total ionization. α-rays.	Ionization. β-rays.	Ratio ionization. $\frac{\beta}{\alpha}$.
Uranium ...	1	1	·0074
Thorium ...	1	·27	·0020
Radium ...	2000	1350	·0033

In the above table the total number of ions produced by α- and β-rays of uranium is, in each case, taken as unity for purposes of comparison. The third column gives the actual ratio of β to α observed for equal weights of substance.

The results are only approximate, for the ionizing action of the rays from a given weight of substance depends on its fineness of division.

It will be observed that the ratio ionization of β to α is greatest for uranium and least for thorium. The intensity of α- and β-rays of radium of course depends on the purity of radium. In this experiment radium obtained from Paris was used. The radium from P. de Haen, Hannover, gave similar results.

For increasing thicknesses of the radioactive substance the ratio of ionization $\frac{\alpha}{\beta}$ steadily decreases to a constant value, since the α-rays are more readily absorbed than the β in the radioactive substance itself.

§ 10. *Comparison of energy radiated by α- and β-rays.*

On the assumptions that

(1) The same energy is required to produce an ion for both α- and β-rays ;

(2) That all the energy emitted into the air from a radioactive substance is used up in producing ions ;

we can form an approximate estimate of the ratio of the energy radiated by the α- and β-rays.

If λ is the coefficient of absorption of the deviable rays in air, the rate of production of ions per unit volume at a distance x from the source is $qe^{-\lambda x}$, where q is the rate of ionization at the source.

The total number of ions produced by complete absorption of the rays is

$$\int_0 qe^{-\lambda x}dx = \frac{q}{\lambda}.$$

Now λ is difficult to measure experimentally for air, but we can get an approximate estimate of its value from Lenard's results that the absorption of cathode-rays is proportional to the density of any given substance and independent of its chemical nature.

Now λ for aluminium for β-rays from uranium is about 14, and λ divided by the density is 5·4. Now taking density of air as ·0012, we find that

$$\lambda \text{ for air} = ·0065.$$

The total number of ions produced in air is thus 154 q when rays are completely absorbed.

Now, from the above table, we see that the ionization of deviable rays is ·0074 of the ions produced by α-rays when β-rays passed over a distance of 5·7 cms. of air.

We thus have approximately

$$\frac{\text{Total number of ions produced by } \beta\text{-rays}}{\text{Total number of ions produced by } \alpha\text{-rays}} = \frac{·0074}{5·7} \times 154 = ·2.$$

Thus about $\frac{1}{6}$ of energy radiated into air by a thin layer of uranium is carried by the electrons. The ratio for thoria is about $\frac{1}{22}$, and for radium about $\frac{1}{14}$, assuming the rays to have about the same average value of λ.

This calculation only takes into account the energy which is radiated out into the surrounding gas : but on account of the ease with which the α-rays are absorbed, even with a thin layer, the greater proportion of the radiation is absorbed by the radioactive substance itself. This is seen to be the case when we recall that the α-radiation of thorium or radium is reduced to half value after passing through a thickness of about ·0005 cm. of aluminium. Taking into consideration the great density of the radioactive substances, it is probable that most of the radiation which escapes into the air is due to a thin skin of the powder not much more than ·0001 cm. in thickness.

We can, however, form an estimate of the relative rate of emission of energy by the α- and β-rays in the following way :—

The total energy W_1 radiated to the surface per sec. by a thickness d, is given by

$$W_1 = \frac{1}{2}\int_0^d E_1\sigma e^{-\lambda_1 x}dx$$

$$= \frac{E_1\sigma}{2\lambda}(1 - e^{-\lambda_1 d})$$

$$= \frac{E_1\sigma}{2\lambda_1} \text{ if } \lambda_1 d \text{ is large.}$$

For simplicity let us suppose a thick layer of radioactive substance spread uniformly over a large plane area. There seems to be no doubt that the radiations are emitted uniformly from each portion of the mass; consequently, radiation which produces the ionizing actions in the gas above the radioactive layer is the sum total of all the radiation which reaches the surface of the layer. Let λ_1 be the average coefficient of absorption of the rays in the radioactive substance, and σ the specific gravity of the substance. Let E_1 be the total energy radiated per sec. per unit mass of the substance where the absorption of the rays in the substance itself is disregarded. The energy per sec. radiated to the surface by a thickness dx of a layer of unit area distant x from the surface is given by

$$\tfrac{1}{2}E_1\sigma e^{-\lambda x}dx.$$

In a similar way it may be shown that the energy W_2 radiated per sec. by the β-rays for a very thick layer is given by

$$W_2=\frac{E_2\sigma}{2\lambda_2}$$

where E_2 is the total rate of emission of energy of unit mass disregarding absorption, and λ_2 the coefficient of absorption of rays in the substance. Therefore

$$\frac{W_1}{W_2}=\frac{E_1}{E_2}\frac{\lambda_2}{\lambda_1},$$

or

$$\frac{E_1}{E_2}=\frac{\lambda_1}{\lambda_2}\frac{W_1}{W_2}.$$

It is difficult to determine λ_1 and λ_2 directly for the radioactive substance itself; but it is probable that the ratio is not widely different from the ratio of the absorption-coefficients for another substance like aluminium, which has been directly determined. This follows from the general result that the absorptions of α- and β-radiations in any substance are approximately proportional to the density of the substance.

$\frac{W_1}{W_2}$ is the ratio of the number of ions produced by the α-to those produced by the β-rays, and can be determined in the way already explained for a thin layer.

The ratio $\frac{E_1}{E_2}$ has been determined for uranium from the following experimental data. A thick layer of uranium oxide

was spread over an area 22 sq. cms., and the ratio of the current produced by the α- and β-rays determined between two parallel plates distant 6·1 cms. apart.

It was found that

$$\frac{\text{current due to }\alpha\text{-rays}}{\text{current due to }\beta\text{-rays}}=12{\cdot}7.$$

Thus

$$\frac{W_1}{W_2}=\frac{\text{total number of ions due to }\alpha\text{-rays}}{\text{total number of ions due to }\beta\text{-rays}}$$
$$=\frac{12{\cdot}7\times 6{\cdot}1}{154}$$
$$={\cdot}5\text{ approx.},$$

since we have previously calculated number of ions produced by the β-rays is 154 times the number produced for 1 cm. distance between the plates *.

Now

$$\frac{E_1}{E_2}=\frac{\lambda_1 W_1}{\lambda_2 W_2}=\frac{5\lambda_1}{\lambda_2}=\frac{5\times 2740}{14}=1000\text{ approx.},$$

since the value of λ_1 for aluminium = 2740 for the α-rays and λ_2 for the β-rays = 14.

We therefore see that for uranium about 1/1000 of the total energy radiated is carried off in the form of electrons. The ratio is still smaller for thorium and radium. It thus appears that in the permanent radioactive substances the electrons driven off represent only a small fraction of the energy dissipated.

§ 11. *Discussion of Results.*

We have seen that the three well-recognized radioactive substances, uranium, thorium, and radium, all emit both deviable and non-deviable rays. In this respect they differ from polonium, which gives out no deviable rays. As Becquerel has pointed out, there is little doubt that polonium (radioactive bismuth) cannot be considered as a permanent radioactive substance, for its radiation steadily diminishes with the time.

We have shown that uranium gives out more deviable rays than radium or thorium, compared with the amount of non-deviable, but the ratio of the amounts of the two types of rays is of the same order.

In considering the question of the relation between the α- and β-rays, the results of the chemical separation are of

* Phil. Mag. June 1902.

great importance. It seems certain that we cannot regard the α-rays as having the same relation to β-rays as cathode-rays have to Röntgen rays which they produce; for we have shown that the separated active products from uranium and thorium contain all the substance responsible for the β-rays. The radioactive material, which has thus been temporarily freed from β-rays, still, however, retains its power of giving out, in the case of uranium a large proportion, and in the case of thorium about 30 per cent. of the original α-rays.

This α-radiation persists, in the case of uranium, several days, and, in the case of thorium several hours, without any appreciable change in intensity. If the α-rays are due directly to the β-rays, it is necessary to assume that the radiation persists for long intervals after its exciting cause is removed. This view also fails to explain, without additional assumptions, why the radiation from Ur.X. does not excite similar α-radiations in itself.

Without, at this stage, going into views on the mechanism of radioactivity, it seems probable that most of the deviable rays from uranium and thorium are given out by a secondary product produced by a disintegration of the uranium or thorium atom or molecule. These secondary products differ in chemical properties from the uranium and thorium, and can be separated from them by chemical means, and thus give rise to Ur.X. and Th.X. The non-deviable radiation may be either due to the other secondary product of the reaction, or may be due to an action of the product responsible for the deviable rays in the mass of the radioactive material.

McGill University, Montreal.
May 7, 1902.

XXXV. *On the Ebullition of Rotating Water.—A Lecture Experiment.* *By* T. C. Porter, *Eton, Bucks.**

IF the water in a beaker, having approximately vertical sides, be caused to rotate about an axis concentric with the vertical geometrical axis of the beaker, it is obvious that in any horizontal section of the water the pressure is least in the centre, and increases from the centre outwards. It is also a well-known fact that the temperature at which water boils depends upon the pressure to which it is subjected, being lower the lower this pressure is. Thus if a beaker of water were at a temperature just below the boiling-point, and it could be *suddenly* made to rotate throughout its mass without cooling it, the water would turn into vapour in and about the axis of least pressure, from the surface downwards, forming, at all events for the

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moment, a thin core of steam in the middle of the water. In practice, however, water cannot be made to rotate throughout its mass suddenly; and if the rotation is generated gradually, the water-vapour is also, as a rule, gradually formed, and is given off from the surface without ebullition, in the quantity sufficient to relieve the tension of those particles of water for which the pressure is diminished. The very form taken by the water as it rotates, increases its surface area, and thus tends to promote evaporation, and so to check ebullition. For these reasons the writer has failed to exhibit the experiment to be described in this its simplest form. If, however, the water is supplied with heat whilst it is rotating, the steam is formed only in the region of least pressure, forming a gaseous core in the rotating water, as in fig. 1. The experiment is an exceedingly simple one both to make and to photograph; it may be well to give a few details as to its performance, though the four figures given are only careful drawings from four of the original photographs.

In fig. 1 the spiral wire stirrer used is seen near the surface of the water; whilst beneath the wire gauze, on which the large beaker rests, and which serves to distribute the heat more evenly, are visible the flames and upper parts of the four Bunsen burners employed to heat the water. The spiral stirrer was driven by a small motor; but experience soon proved that results as good, if not better, could be obtained by stirring the water *by hand*, using a long glass rod completely covered by a piece of indiarubber tubing in order to avoid the risk of breaking the glass vessel. After giving to the water throughout its depth the necessary and rapid rotation, and before taking the photographs, this rod was rapidly withdrawn from the beaker, its stirring motion being carefully maintained during the act of withdrawal. Some of the photographs were taken by diffused daylight combined with that of the electric arc, the latter being concentrated by a lens, so as to illuminate the whole of the beaker and its contents as brightly as possible. The plates were Edwardes's Isochromatic Instantaneous, and the exposures were about the $\frac{1}{40}$ of a second. A dilute developer should be used, and as much as 30 min. or more allowed for development.

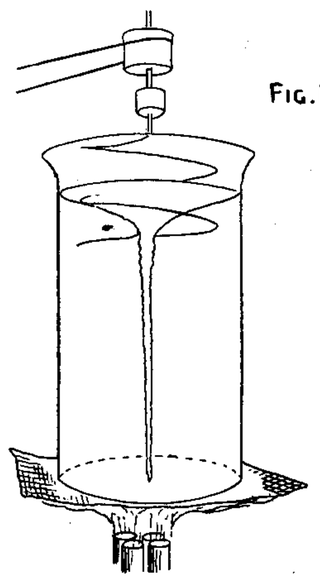

Fig. 1.

Thus far the experiment illustrates in an apparently simple