PLATES.

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I. *Comparison of the Radiations from Radioactive Substances* By E. Rutherford, *M.A., D.Sc., Macdonald Professor of Physics, and* Miss H. T. Brooks, *M.A., McGill University, Montreal* *.

ALL the radioactive substances possess in common the power of acting on a photographic plate and of ionizing the gas in their immediate neighbourhood. The intensity of the radiations may be compared by means of the photographic or electrical action ; and in the case of the strongly radioactive substances by the power of lighting up a fluorescent screen. Such comparisons, however, do not throw any light on the question whether the radiations are of the same or of different kinds. It is well known that such different types of radiation as the short waves of ultra-violet light, Röntgen and cathode rays all possess the property of producing ions throughout the volume of the gas, lighting up a fluorescent screen and acting on a photographic plate. None of the radiations from the various radioactive substances show any trace of regular reflexion, refraction, or polarization †.

There are two general methods of differentiating to some extent between the various types of radiations.

(1) By observing whether the rays are appreciably deviated by a magnetic field.

(2) By comparing the relative absorption of the rays by solids and gases.

* Communicated by the Authors.

† A very complete and admirable account of radioactive substances by Henri Becquerel and P. & Mme Curie is given in vol. iii. of the Reports of the Congrès International de Physique held at Paris, 1900.

The first method has been utilized by Giesel, Becquerel*, Curie, and others. Of the radioactive substances which have been most closely examined, viz. uranium, thorium, polonium, and radium, the latter has been shown by many observers to give out rays deflectable by a magnet. Debierne† states that the radioactive substance which he has termed actinium also gives out some rays deflectable by a magnet. In all cases these deflectable rays are similar in every respect to cathode-rays, and are thus probably streams of negatively charged particles moving with very great velocities. Becquerel‡ has shown that the ratio $\frac{e}{m}$ of the charge to the mass of these negatively charged carriers is about 10^4, which is about the same value observed for the cathode-rays produced in a vacuum-tube.

Radium, in addition to the deflectable rays, also emits non-deviable rays. The ionizing and fluorescent action of radium rays in air at atmospheric pressure, at a distance of from 5 or 6 cms. from the surface of the radium, is very largely due to the rays deflected by a magnetic field. For distances less than this, the ionization is partly due to the deflectable rays and partly to rays which are not acted on by a magnet. Close to the surface of the radium the ionization due to the non-deviable rays greatly preponderates over that due to the deviable rays. This is due to the fact that the non-deflectable rays are very largely absorbed in passing through a few centimetres of air at ordinary pressure.

Action of a Magnetic Field on Uranium Rays.

Becquerel has examined the rays of uranium in a magnetic field by the photographic method, and found that some of them are deflectable. We have confirmed these observations by the electrical method, and found that only the penetrating rays of uranium are deviable.

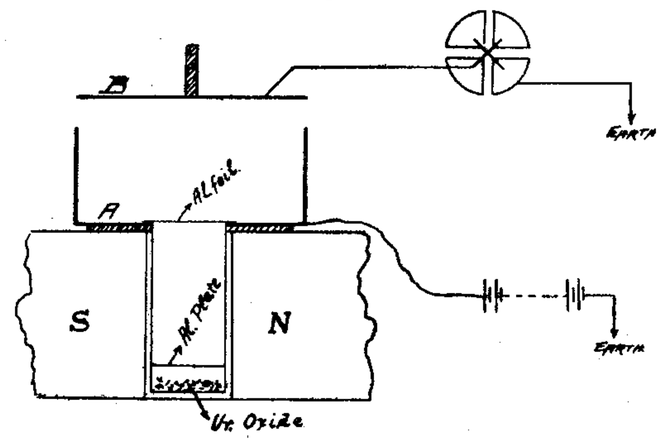
One of us§ has shown several years ago that the radiation from uranium was complex, and could be divided into two types of radiation, which were called for convenience the α and β radiations. The β radiation is far more penetrating in character than the α radiation, but is difficult to examine accurately on account of the small conductivity produced by it in the gas, compared with that due to the α radiation. In

* Paris Report, 1900.
† *Comptes Rendus*, cxxix. (1899), & cxxx. (1900).
‡ *Loc. cit.*
§ E. Rutherford, Phil. Mag. Jan. 1899.

order to measure with certainty the very small rate of leak involved, a very sensitive electrometer was employed. The instrument is described by Dolezalek* in a recent paper, and was constructed by Herr Bartels of Göttingen. It was of the usual quadrant type, but was provided with a very light needle suspended by a fine quartz fibre. When the needle was charged to 200 volts it gave a deflexion corresponding to 1500 mms., with the telescope and scale at a distance of about 150 cms, for 1 volt between the quadrants. For the special purpose for which it was employed, it was found necessary to improve the insulation of the quadrants and to alter the quadrant connexions. The instrument was easy to work and gave accurate results. It has been employed recently by one of us† to measure the small spontaneous ionization produced in the air, which has been shown by the experiments of Elster and Geitel‡ and C. T. R. Wilson§ who used specially designed electroscopes for that purpose.

In the experiments on the action of a magnetic field on uranium radiation (fig. 1) a thick layer of uranium oxide was

Fig. 1.



placed on the bottom of a rectangular lead box 5·7 cms. long, 1·8 cm. wide, and 4·0 cms. deep, which was placed between the flat pole-pieces of a large electromagnet. The rays, after passing out of the lead box, passed between two parallel insulated plates A and B. One of these plates A was charged to a P.D. of 50 volts above the earth by means of a battery. The other plate B was connected to one pair of quadrants of an electrometer in the usual manner.

* *Verh. d. D. Physik. Ges.* iii. (1901).
† Rutherford and Allen, *Phys. Zeit.* No. 11, 1902.
‡ *Phys. Zeit.* Nov. 24, 1900.
§ Proc. Roy. Soc. March, 1901.

Electrostatic disturbances were completely eliminated by covering the electromagnet and wires leading to it with tinfoil connected to earth.

There was always a small current observed between the plates on account of the spontaneous ionization of the air in the testing vessel when the uranium oxide was removed to a distance.

The layer of uranium oxide was covered with several thin layers of aluminium of sufficient thickness to completely absorb all the α radiation. The open end of the lead vessel was covered with thin aluminium-foil. In that case the rate of leak of the electrometer was due to ionization produced between the plates by the β radiation together with the ions spontaneously produced by the air itself. The latter was accurately determined before the lead vessel containing the oxide was placed between the poles of the electromagnet.

As the magnetic field was increased, the rate of leak observed by the electrometer steadily diminished, until with a strong field the rate of leak was reduced almost to that due to the spontaneous ionization of air. This diminution of the rate of leak between A and B is due to the curvature of the path of the rays by the magnetic field before they reach the testing vessel. Since the rate of leak, due to the action of the β radiation, with a strong magnetic field is reduced to a small fraction of its value when no magnetic field is acting, we may conclude that the β radiation is composed almost entirely of rays deviable by a magnetic field.

A comparison experiment with radium showed that the β rays of uranium were deflected to about the same extent as the radium rays for the same strength of field.

No action of a magnetic field on the α radiation of uranium was observed. Both radium and uranium resemble one another in emitting two types of radiation, one of which is deviated in a magnetic field, and the other not.

Absorption of the β Radiation by Substances.

Since the β radiation of uranium is acted on by a magnetic field to almost the same extent as radium rays, we may conclude that the deviable rays are due to negatively charged particles emitted with high velocities ; for Becquerel has shown that some of the radium rays move with a velocity of at least $1{\cdot}6 \times 10^{10}$ cms. per second. The penetrating power of the β rays is greater than that of the similar radiation for radium in our possession. It readily passes through 2 mms. of glass before complete absorption.

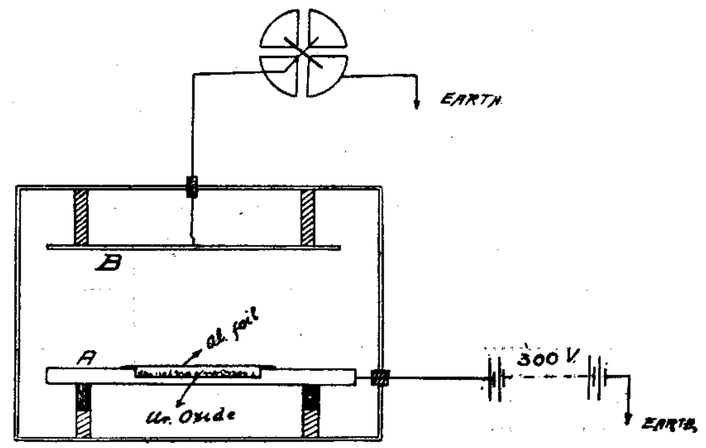
Lenard, in his well-known experiments on cathode-rays,

has shown that the absorption of cathode-rays in substances depends only on the density of the material through which they pass, and is approximately independent of its chemical constitution. On account of the constancy of the uranium rays, it is possible to determine their absorption in different media with accuracy.

A few experiments were consequently made to see how closely the absorption varied with the density for the high-velocity particles emitted by uranium.

The experimental arrangement is shown in fig. 2, where the dotted lines represent insulators.

Fig. 2.



A thick layer of uranium was uniformly spread over a shallow rectangular groove 6 cms. square in lower plate A. The plate A was charged to 300 volts by a battery of small accumulators, the other pole of which was to earth. The current was observed between the plates A and B by means of the sensitive Dolezalek electrometer previously described, with, if necessary, a suitable capacity in parallel.

In order to completely absorb the α radiation an aluminium plate ·003 cm. in thickness was fastened tightly over the layer of uranium. The P.D. of 300 volts between A and B (6 cms. apart) was sufficient to carry over all the ions to the electrodes before appreciable recombination occurred.

The rate of movement of the electrometer-needle was observed, for different layers of material of uniform thickness successively placed over the uranium.

If λ is the coefficient of absorption of the radiation in a material, the intensity I of the radiation after passing through a thickness d is given by

$$I = I_0 e^{-\lambda d},$$

where I_0 is the intensity of the radiation at the surface before

the plate was applied. The absorption of the radiation in a layer of air is negligible compared with that of an equal thickness of solid matter. The maximum current* between the plates is proportional to the intensity of the radiation.

Preliminary experiments showed that the current diminished very approximately in G.P. with the distance of material traversed, so that the value of λ determined was independent of the thickness of the plate.

This shows that most of the rays emitted have approximately the same penetrating power. The rays of radium, examined in a similar manner, did not fall off regularly, showing that the rays emitted consist of particles having a wide range of velocities, and consequently a wide range of penetrating power. This is clearly shown by Becquerel, who examined (by the photographic method) the amount of deflexion of the rays in a magnetic field after passing through different thicknesses of various metals.

The following table represents the results obtained.

Substance.	λ.	Density.	$\frac{\lambda}{\text{Density}}$
Glass	14·0	2·45	5·7
Mica	14·2	2·78	5·1
Ebonite	6·5	1·14	5·7
Wood	2·16	·40	5·4
Cardboard	3·7	·70	5·3
Iron	44	7·8	5·6
Aluminium	14·0	2·60	5·4
Copper	60	8·6	7·0
Silver	75	10·5	7·1
Lead	122	11·5	10·8
Tin	96	7·3	13·2

It will be observed that the value of the coefficient of absorption divided by the density is very approximately the same for such different substances as glass, mica, ebonite, wood, iron, and aluminium. The divergences from the law are, however, great for the other metals examined, viz. copper, silver, lead, and tin. In tin the value of λ divided by the density is 2·5 times its value for iron and aluminium. These differences show that the law of the absorption of cathode-rays depending only on the density, is not true for all substances.

Experiments are at present in progress to see whether there is any simple numerical connexion between the values of λ divided by density for different metals, and to extend the

* Rutherford, Phil. Mag. Jan. 1899.

results so as to include a variety of substances in the solid and liquid state.

Absorption of the Rays by Solids and Gases.

The rays not acted on by a magnetic field can be distinguished from each other by their power of penetrating through thin layers of metal, and their absorption in gases. If, on examination, the penetrating power of two types of radiation proves to be the same in each case for all substances, it is extremely probable that the two radiations are identical. By examining the diminution of intensity of the radiation when sheets of metal of the same thickness are placed over the radioactive substance, the homogeneity or complexity of the radiations can be tested. If the intensity I of the radiation after passing through a distance of metal is given by $I_0 e^{-\lambda d}$, where I_0 is the original intensity and λ the coefficient of absorption, we can conclude that the radiation is homogeneous in character. If this condition is not fulfilled the radiation is complex.

One of us* has at different times given results for the absorption of some of the different radiations in solids and gases. In this paper we have extended the results and compared the different types of radiation under, as far as possible, the same conditions.

In the case of both uranium* and thorium† it has been shown that the absorption of the radiation is the same for all the different compounds of each element examined. When the types of radiation are complex, the relative amount of rays of different types may vary for different compounds, but so far there is no evidence that the actual radiations themselves are altered. It is only necessary therefore to examine one compound of each element for the purpose of comparison of the types of rays emitted.

The following substances have been employed in the experiments:—

Uranium Oxide & Thorium Oxide.—Two different samples of each obtained from Schuchart of Germany and Eimer and Amend of New York gave similar results.

Polonium.—This substance was kindly prepared for me by Dr. Walker of McGill University from pitchblende, after the method described in Curie's first paper. Since that time the intensity of the radiation given off has steadily diminished; but the type of radiation has been unaltered.

* E. Rutherford, Phil. Mag. Jan. 1899, Feb. and March 1900.
† Owens, Phil. Mag. Oct. 1900.

Radium.—Two different specimens were employed. One was of impure radium chloride kindly presented to me by Elster and Geitel two years ago; this did not give off any emanation and only a small proportion of deflectable rays. The other, from P. de Haen, Hannover, was not very strong in deflectable rays, but gave out a large amount of emanation when slightly heated.

In the course of the paper we shall examine the following types of radiation.

A. Uranium.
  (1) The α or early absorbed radiation.
  (2) The β or deflectable rays.

B. Thorium radiations.
  (3) The simple radiation given out by a thin layer.
  (4) The radiation from the "emanation."
  (5) The excited radiation.

C. Polonium.
  (6) Simple radiation.

D. Radium.
  (7) Radiation not affected by a magnetic field.
  (8) Radiation from the emanation.
  (9) Excited radiation.
  (10) Magnetically deflected rays.

Absorption of Radiation by Metals.

In examining the absorption of the radiation by metal-foil and other substances, the apparatus shown in fig. 2 was employed. The active compound in the form of fine powder was uniformly spread over a shallow depression 6·5 cm. square in a large lead plate. This corresponds to plate A in fig. 2. The rate of leak was observed by means of an electrometer between plates A and B with, if necessary, a suitable capacity in parallel. The plate A was connected to one pole of a battery of 300 volts, the other pole of which was earthed. Preliminary experiments showed that with this voltage the maximum or saturation current between the plates was obtained for all the radioactive substances examined.

In most of the experiments described in this paper an Ayrton electrometer was used. In some of the later experiments, however, the White pattern of Kelvin electrometer was used. The former electrometer could be readily arranged to give 200 mm. divisions for 1 volt P.D. between the

quadrants. As most of the experiments were carried out during the very dry Canadian winter, it was very essential to screen the electrometer and connexions with testing apparatus by wire gauze. Unless precautions of this kind were taken, every movement of the observer produced sufficient frictional electrification to disturb the electrometer. For the same reason and also for convenience the quadrants were separated by a cord connected to a suitable key and operated at a distance.

The method of observing the rate of leak was as follows:—A seconds-pendulum was placed before the observer. At the instant of passing the middle point of its swing the quadrants were separated by a sudden pull of the cord. After ten or more swings the connexion between testing-apparatus and the electrometer was broken by means of an insulated key, operated by a second cord. The deflexion of the electrometer-needle when it came to rest was then observed.

The number of scale-divisions passed over, divided by the time between the separation of the two keys, was taken as a measure of the rate of leak. This method is more accurate than the usual one of observing the time the electrometer-needle takes to pass over say 100 divisions of the scale. The final deflexion is independent of the amount of damping and of any oscillation or irregularity in the movement of the electrometer-needle.

In experiments with uranium, thorium, and polonium a very thin layer of the material was employed. This is essential in the case of thorium oxide, in order that the rate of leak *due to the emanation* from it may be negligible compared with the rate of leak produced by the ordinary radiation. In dealing with radium a very small amount of material was dusted by means of a gauze as uniformly as possible over a platinum plate. For the specimen of radium employed the rate of leak due to the emanation and rays deviable by a magnet was in this way rendered negligible compared with the rate of leak due to nondeviable radiation. Suitable capacity was, if necessary, placed in parallel with the electrometer to reduce the rate of leak.

In figs. 3 and 4 (p. 10) curves are given for the absorption of the different radiations by thin aluminium foil and Dutch-metal respectively. In order to plot the curves on the same scale the rate of leak for the bare radioactive plate is in each case taken as 100. The average thickness of aluminium-foil was ·00036 cm., and of Dutch-metal ·00012 cm. The curves are given for two specimens of radium, marked C and E, which

corresponded to two specimens of radium from P. de Haen, marked "concentrated" and "einfach" respectively. The

Fig. 3.

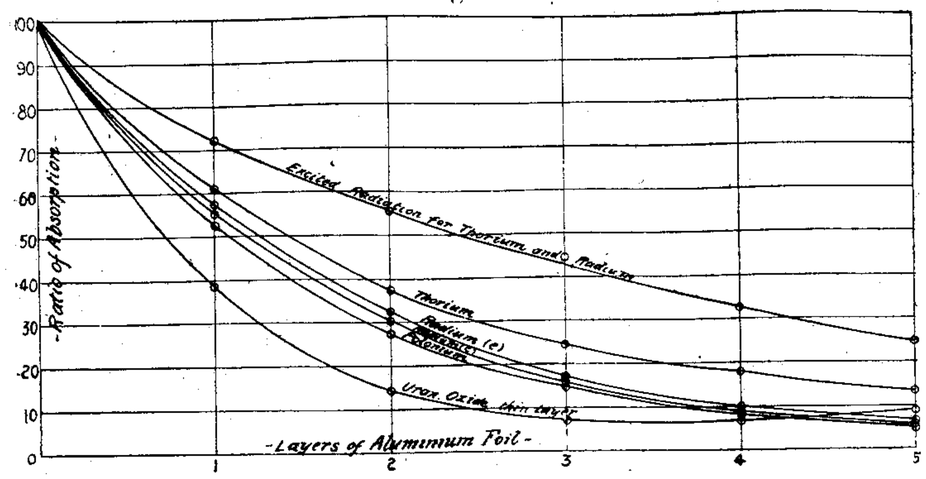
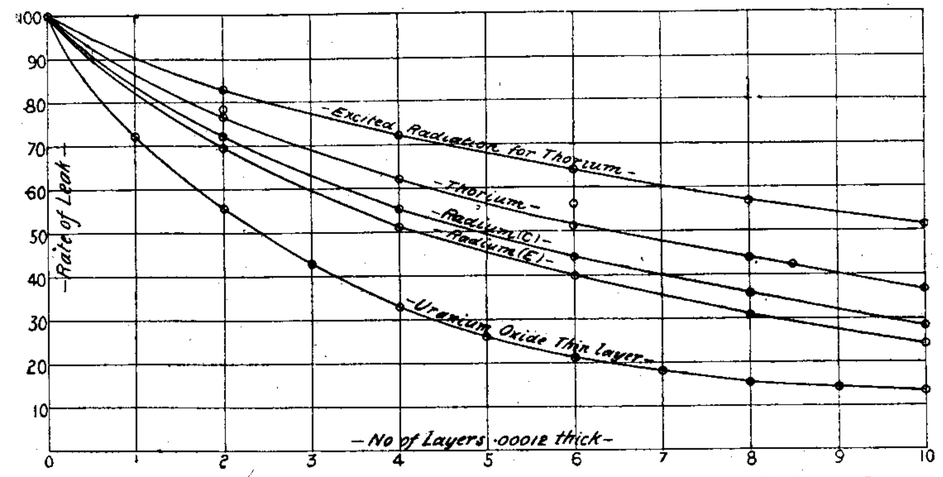


Fig. 4.



curve for the specimen sent by Herrn Elster and Geitel was not very different from the two shown. Curves obtained from specimens of the minerals "thorite" and "orangite" gave practically the same curves as for thoria.

The radiations may be arranged in the following order as regards the power of penetration, beginning with the most penetrating.

Excited radiations due to Thorium and Radium:

Thorium
Radium
Polonium
Uranium.

The same order of penetration is observed for all the

substances examined, viz. aluminium and Dutch-metal, tin-foil, and paper.

The same order, as will be shown later, holds also for the penetrating power of radiations in air.

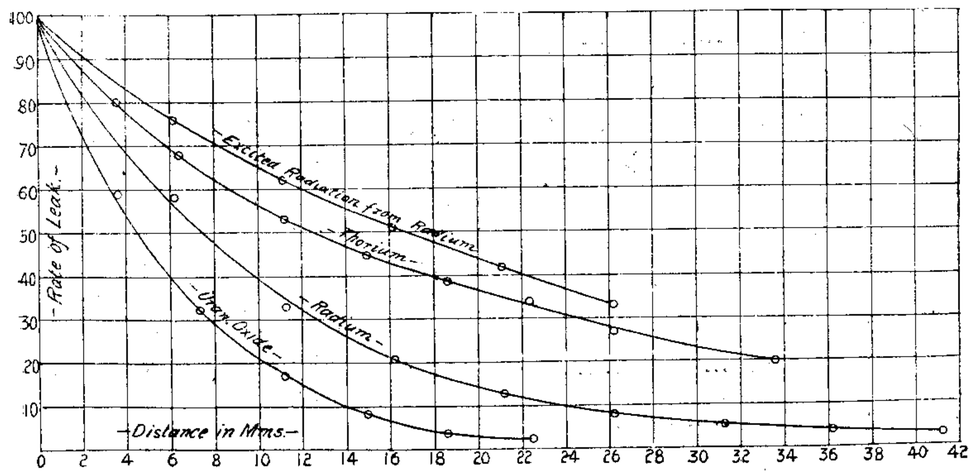
Absorption of the Radiation in Air.

The method employed of determining the absorption of the radiation in air was similar to that explained in a previous paper (Phil. Mag. Jan. 1899, p. 124).

Two insulated parallel plates kept a fixed distance of 2 cm. apart, could be moved by means of a screw to different distances from the parallel radioactive surface. The radiation from the active surface passed through a circular opening in the lower plate, covered with thin aluminium-foil, and was stopped by the upper plate. The current between the two fixed plates for a voltage sufficient in all cases to give the maximum or saturation current, was determined for different distances from the radioactive plate. If the radius of the active surface is large compared with the distance of the lower of the pair of plates from it, the current between two fixed plates for a distance x of the lower plate from the radioactive surface, can be readily shown from the theory of ionization (loc. cit.) to vary as $e^{-\lambda x}$, where λ is the coefficient of absorption of the radiation in the gas.

The results of the experiments are given in curves fig. 5. For each radiation the maximum rate of leak between the plates at a distance of about 2 mm. from the active surface is taken as 100, for the purpose of comparison. It will be

Fig. 5.



observed that the rate of leak, which is a measure of the intensity of the radiation, falls off approximately in G. P.

with the distance. The thickness of air through which each radiation passes before the intensity of the radiation falls to half its original value, is given in the following table.

Radiations.	Distance in cms.
Excited radiation from radium and thorium.	1·65
Thorium	1·0
Radium	75
Uranium	·45

The penetrating power of the different radiations in air thus follows the same order as metals and solid substances.

Connexion between Absorption and Density.

From the curves of absorption of the radiations in metals and air, the coefficient of absorption λ can be readily determined. The following table gives the value of λ for aluminium and air for the different radiations.

Radiation.	λ for aluminium.	λ for air.
Excited radiation.....	830	·42
Thorium	1250	·69
Radium	1600	·90
Uranium	2750	1·6

Taking the density of air at 20° C. and 760 mm. as ·00120 compared with water, the following table shows the value of λ divided by density for the different radiations.

Radiation.	Aluminium.	Air.
Excited	320	350
Thorium	480	550
Radium	620	740
Uranium	1060	1300

Comparing aluminium and air the absorption is thus roughly proportional to the density of all the radiations. The divergence, however, between the absorption-density numbers is large when we compare two metals like tin and aluminium.

The coefficient of absorption for tin is not much greater than for aluminium, although the density is nearly three times as great.

The result for the nondeviable radiations is in this respect exactly opposite to that for the deviable uranium rays, for in that case we have shown that the absorption is more than twice as great as would be expected on the absorption-density law.

Results of this kind point to the conclusion that the mechanism that causes absorption is different for the deviable and nondeviable rays.

The result of Strutt*, that the relative ionization of hydrogen compared with that of air and other gases is quite different for the deviable and nondeviable rays of radioactive substance, also supports such a view.

Emanating Power of Thorium and Radium.

In a previous paper by one of us it has been shown that thoria gives off a radioactive emanation which behaves in all respects like a radioactive gas. It can be carried along with a current of air, passes readily through tightly packed cotton-wool, and is not appreciably absorbed by bubbling through solutions. The radiating power of the emanation rapidly diminishes, falling to half its value in about one minute.

Dorn† later found that a preparation of radium from P. de Haen also gave out an emanation which decayed far more slowly than the thoria emanation.

The specimens of radium used by us gave out very little emanation at atmospheric temperature.

On heating radium, however, the amount of emanation increased very rapidly. In *Physikalische Zeitschrift*, April 20, 1901, one of us has given an account of the effect of temperature on the emanating power of both thorium and radium. The radioactive substance to be tested was placed in a platinum tube (see fig. 6) through which a slow current of air was passed. The emanation was carried with the air into a metal cylinder, where the rate of leak produced by the emanation was tested by an electrometer in the usual way.

* Phil. Trans. 1900.
† *Abh. der Nat. Ges. zu Halle*, 1900.

It was found that in the case of thorium compounds the emanating power increased to three or four times before a dull red heat of the platinum tube was reached, and remained constant if the temperature was unchanged. On heating to a white heat the emanating power was to a large extent destroyed.

The amount of emanation from radium increased over 10,000 times by heating below a red heat. Like thoria, if the temperature was raised to a white heat, the emanating power could not be recovered on cooling.

Unlike the thoria emanation, the radium emanation loses its radioactive power very slowly, with time.

The emanation kept in a closed metal vessel still preserved appreciable radioactivity after an interval of 14 days. The rate of decay of the emanation from radium does not appear to be the same under all conditions. The emanations from the two different radium compounds showed appreciable differences in this respect. The rate of decay also seems to depend on the temperature at which the emanations are produced.

Further experiments on this subject are delayed until preparations of radium of more definite composition are obtained.

Connexion between Emanation and Excited Radioactivity.

There is a very close connexion between the emanation from radium and thorium and their property of causing excited radioactivity. The presence of the emanation is necessary to produce excited radioactivity, and the amount of the latter depends upon the amount of emanation present.

Thoria, for example, which has been ignited to a white heat loses its power, to a large extent, of giving off an emanation, and its power of producing activity is diminished in a like ratio.

Excited radioactivity can be produced at long distances from the radioactive material provided the emanation is carried to that point. Intense excited radioactivity can be obtained from a radium emanation which has been left standing in a closed vessel for over a week, far removed from the radium compound from which the emanation was originally obtained.

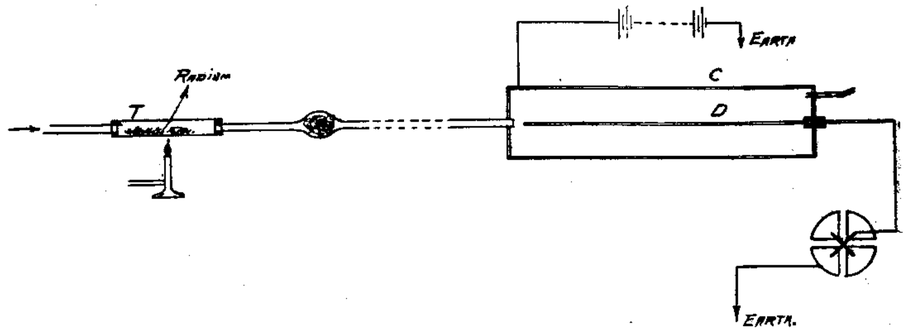
Excited radioactivity is due to the conveyance of some kind of radioactive matter to surrounding bodies. This radioactive material is either derived from the radioactive emanation itself, or in some way produced by it out of the surrounding gas.

This radioactive material is always associated with a positive charge and so can be concentrated on the cathode in a strong electric field.

A fuller discussion of the connexion between emanations and excited radioactivity, and the method of transmission of the latter, is reserved for a later communication.

Some experiments were made which illustrate the quantitative connexion between the rate of production of ions on the excited body, and the rate of production of ions by the emanation itself. Fig. 6 shows the general arrangement of

Fig. 6.



the experiment. The radium was placed inside a platinum tube T through which a slow current of air was passed into the testing cylinder C. The platinum tube T was heated by a gas-burner until a large supply of emanation was carried into the testing cylinder with the current of air. The openings of the cylinder were then closed, and by means of the electrometer, the ionization current was observed between the outer cylinder and the brass rod D fixed centrally along the axis of the cylinder. A strong electric field (P.D. 300 volts) was applied and the excited radioactivity concentrated on the central rod. After several hours' exposure the amount of excited radioactivity on the rod reaches an approximate maximum. The rod was then removed and placed in a testing cylinder of the same dimensions, with the same P.D. between electrodes. The rate of leak was observed with the electrometer. A fresh rod was immediately placed within the emanating cylinder, and the rate of leak observed as soon as possible. This rate of leak is a measure of the number of ions produced by the emanation in the surrounding gas.

For radium (e) the rate of leak due to the excited radiation was about $\frac{1}{5}$ of that due to the emanation. For radium (c) the ratio was as high as $\frac{4}{5}$ after a long exposure. Since half the energy of the excited radiation in the rod is absorbed in the rod itself, the rate of production of ions due to the excited

radiation is thus greater than that due to the emanation which causes it.

An experiment was tried to see whether the application of an electric field had any effect on the rate of production of excited radioactivity. The emanation was introduced into a long closed cylinder with an insulated central electrode and allowed to stand undisturbed for several hours with no electric field acting. The excited radioactivity in such a case was distributed by the processes of diffusion to all parts of the interior surface of the cylinder. On account of the small area of the central rod very little excited radiation was produced on it. After several hours a steady state is reached, such that the rate of conveyance of fresh radioactive material to the surface is balanced by the decay of radiating power of the matter already deposited. A P.D. of 300 volts was then applied so as to make the central rod the cathode, and the ionization current, observed with the electrometer, was immediately determined.

The excited radioactivity now decays on the inside of the cylinder and is concentrated on the brass rod. No appreciable change of the current was observed with time, although the rate of leak due to the excited radioactivity was quite comparable with that due to the emanation. This experiment shows that the rate of production of the excited radiation for a fixed quantity of emanation is the same whether an electric field is acting or not.

Excited Radioactivity due to Radium and Thorium Compounds.

The excited radiation from thorium compounds was obtained by placing a platinum plate, charged negatively, in a closed vessel containing thoria in the manner explained in a previous paper (*loc. cit.*). After about a day's exposure, the platinum plate was removed and placed inside the testing vessel in place of the radioactive material, and the diminution of the rate of leak observed for successive layers of thin metal foil. The same amount of absorption of the radiation was observed, if the platinum plate was made radioactive by being placed near some thoria in a closed vessel with no electric field acting. In such a case the excited radiation is not confined to the platinum plate, but is spread over the whole interior of the vessel in which the thoria is confined.

Two methods were adopted to obtain excited radiation due to radium. In one case, as with thorium, the platinum plate was made the cathode in a closed vessel containing radium.

With the sample of radium obtained from P. de Haen, Hannover, the amount of excited radiation obtained in this way was small. In order to obtain intense excited radiation the following course was adopted.

A small amount of the radium compound was placed on a small platinum plate which rested on a larger iron plate. A sheet of asbestos with a rectangular hole in the centre, smaller in area than the platinum plate, was placed over it. The platinum plate to be radioactive was placed over the hole in the asbestos and an iron plate placed on top of it. The top platinum plate was connected to the negative pole of a battery of 300 volts and the lower platinum plate to the positive pole. The iron plate was then slowly heated with a bunsen. After a short interval the top platinum plate was removed and found strongly radioactive.

Effects not much differing in intensity were obtained if the plates were uncharged. The only advantage in charging the top plate negatively is to concentrate to some extent the radioactivity on its surface. If the radium was not heated too strongly, the same specimen could be used several times before its power of exciting radioactivity was much diminished. If, however, the radium was heated to a red heat, its power of exciting radioactivity afterwards was to a large extent destroyed.

Some difficulty was experienced in determining the absorption of the excited radiation due to radium, on account of the rapid diminution of the intensity with time.

In order to correct for the loss of intensity with time, the rate of leak due to the bare excited plate was taken before and after the substance whose absorption was being examined was placed over it. The observations were taken at regular intervals as rapidly as possible. The mean of the two rates of leak due to the bare plate was taken as a measure of the intensity of the radiation for the intermediate time when the rate of leak due to the excited plate, covered with the absorbing substance, was being examined.

The absorption of the excited radiation due to both thorium and radium is shown in fig. 3 for aluminium foil, in fig. 4 for Dutch-metal, in fig. 5 for air at atmospheric pressure and temperature.

It was found that, for all the substances examined, the absorption of the excited radiation due to thorium compounds was the same as for the excited radiation due to radium, at any rate within the limits of experimental error. This points to the conclusion that these two radiations are the same.

It is of interest to observe that the power of penetration

of the excited radiations is much greater than that of the ordinary nondeviable rays of thorium and radium, which give rise to the emanations. The radiations are apparently fairly homogeneous in character.

The penetrating power of the radium-excited radiation is independent of the substance in which it is produced.

Decay of Excited Radioactivity.

In a previous paper it has been shown that the excited radiation due to thorium compounds decays regularly with the time, falling to half its value in about eleven hours. The decay of excited radioactivity due to radium is irregular and depends upon the sample of radium employed.

Fig. 7.

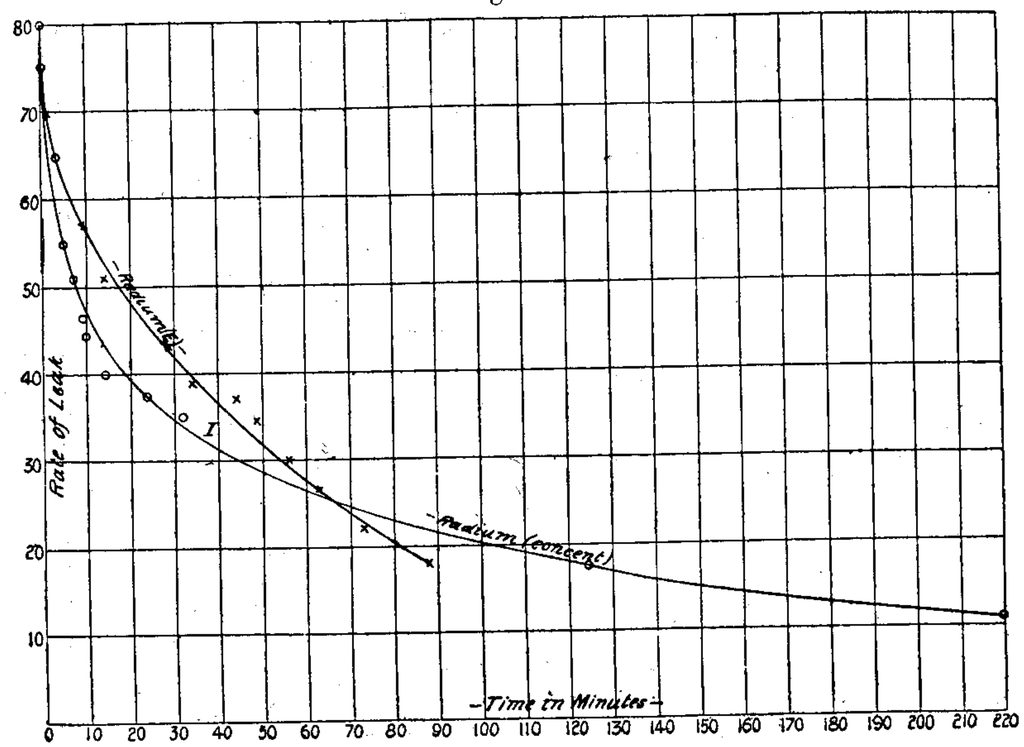


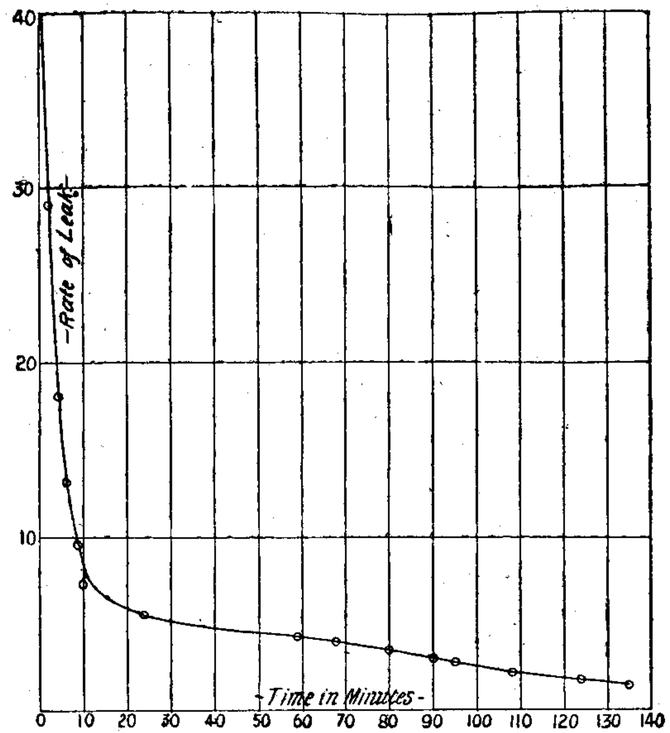
Fig. 7 shows the decay curves for the two samples of radium labelled "einfach" and "concentrated" respectively. The decay curve for the former is more regular than that for the latter. Fig. 8 is for radium (*c*) when the plate had been excited by exposure for a short interval to its emanation. In obtaining the curve of fig. 7 the plates were exposed for several hours in the presence of the emanations.

Curie* has given a curve of decay for excited radioactivity

* Paris Report, 1900.

due to radium which is very similar to the curve for radium (*e*) fig. 7.

Fig. 8.



The decay-curves shown all exhibit to a greater or less degree the following peculiarities :—

(1) An initial rapid rate of decay for about 10 minutes after removal.

(2) A very slow decrease for the next 20 minutes. Then follows

(3) A more rapid decrease till radioactivity disappears.

The rate of diminution of intensity thus passes through a minimum about 20 to 25 minutes after removal of the excited plate from the presence of the emanation.

An explanation of these changes can be given in the light of some recent experiments by one of us on thorium-excited radioactivity.

It has been found that the excited radiation from a plate exposed for a short interval in the presence of thorium emanation increases to three or four times its initial value in the course of a few hours after removal. A preliminary account of these experiments is given in *Physikalische Zeitschrift*, No. 11, 1902.

No increase is observed when a plate has been exposed for many hours in the presence of thoria. This is to be expected,

since the rate of decay of the excited radiation as a whole more than compensates for the increase of radiation due to radioactive particles deposited in the last few hours of exposure.

The general shape of the decay-curves for the two specimens of radium points to the conclusion that two kinds of radiation are emitted by the excited body which decay at different rates. The relative amount of excited radiation due to the two kinds is different for the two samples of radium. The amount of that radiation which decays more rapidly is greater for specimen (*c*) than for specimen (*e*).

If, in addition, we suppose, as in the case of thoria, that the excited radiation which has the slower normal rate of decay does not reach its maximum for some time after deposit of the radioactive matter, the general shape of the decay-curves can be satisfactorily explained.

The observed curve of decay is in that case due to the addition of the effect of two types of radiations, one of which decays regularly with the time, while the other increases at first, passes through a maximum, and then decays. Such a combination would completely explain the peculiarities exhibited by the experimental curves of the excited activity from radium (*c*) and (*e*).

It will be observed that the shape of the decay-curves for radium depends upon the time of exposure to the emanation. The initial decrease of excited activity with time is greater for a body exposed a short interval (see fig. 8) than for a body exposed several hours (see fig. 7, curve I.).

From general theoretical considerations the rate of rise of excited activity with time of exposure can be deduced from the rate of decay and *vice versa* In a recent paper * it has been shown that excited radioactivity is due to the conveyance of radioactive matter of some kind on positively-charged carriers, which travel through air in an electric field with about the same velocity as the positive ions produced in air by Röntgen and Becquerel rays.

Suppose n_0 is the average number of ions produced per second by a single radioactive carrier at the instant of deposit. Let n=number after a lapse of time t.

Suppose $n=n_0 f(t)$ where $f(t)$ is a function of t,

such that $f(t)=1$ when $t=0$,

$f(t)=0$ when $t=\infty$;

$f(t)$ may in some cases pass through a maximum value greater than unity.

* *Phys. Zeit.* No. 10, 1902.

The variation of the rate of production of ions from a particle with the time of deposit, is supposed to include the effect of different kinds of radiations emitted, which may also have different rates of decay, and any effects of excited radioactivity on the body on which it is deposited.

For simplicity, suppose that the radioactive carriers are deposited at a uniform rate of q per second. (This is the case in practice where the amount of emanation present does not vary with the time)

The number of ions produced per second after a time t by the radioactive particles deposited for the first short interval of exposure dt is given by

$$qn_0 f(t)\,dt.$$

The number of ions N produced per second by the radioactive matter deposited during the time t is given by

$$\mathrm{N}=qn_0\int_0^t f(t)\,dt.$$

A steady state is reached when the rate of supply of fresh ions per second, by the addition of radioactive material, is equal to the rate of diminution due to decay of excited radiation as a whole.

This steady state is reached after a long interval of exposure, and the maximum rate of production of ions N_0 is given by

$$\mathrm{N}_0=qn_0\int_0^\infty f(t)\,dt.$$

If the curve of decay of excited radiation due to a single particle is plotted with the ratio $\frac{\mathrm{N}}{\mathrm{N}_0}$ as ordinate and t as abscissa, the value of these integrals can at once be obtained.

The rise of excited radioactivity with time can thus be at once deduced from the decay-curve of a single particle, and *vice versa.*

The rate of production of ions N_1 due to the excited radiation, after removal for a time t_1 from the emanation, is given by

$$\mathrm{N}_1=qn_0\int_t^{t+t_1} f(t)\,dt,$$

where t is the time of exposure.

If N is the rate of production of ions immediately after removal, it follows that

$$\frac{N_1}{N} = \frac{\int_t^{t+t_1} f(t)dt}{\int_0^t f(t)\,dt}.$$

The decay of excited radioactivity is thus a function of the time of exposure, and in some cases may vary very greatly for different values of t.

The decay-curve for a long time of exposure may be quite different in general shape from that of the individual particle which gives rise to excited radioactivity.

This is seen to be the case for radium (*c*) (compare figs. 7 and 8). It is, however, much more marked in the case of excited activity from thoria, where the radioactivity for a few minutes' exposure increases after removal to three or four times its value in the course of a few hours, and then decays at the normal rate. For a long exposure the radioactivity on removal at once begins to decay.

The decay-curve of the individual particle on which we have based the predetermination of the curves of decay and rise of excited radioactivity, is obviously very nearly the same as the decay-curve for a body which has been exposed for a short interval in the presence of an emanation. The only condition to be fulfilled is that the time of exposure is to be so short that the radiation from the individual particle does not appreciably vary.

This condition can readily be fulfilled in the case of thorium-excited radiation; but in the case of radium the initial rapid rate of decay introduces experimental difficulties.

As a rule it takes a minute or two to remove the excited conductor from the vessel containing the emanation, and to place it in position in the testing apparatus. During this time the radioactivity has appreciably diminished.

Fig. 8 shows approximately the decay-curve of a radioactive particle for radium (*c*). The plate was only exposed a short time and then immediately tested.

Some experiments have been made on the *rise* of excited radioactivity with time in the case of radium (*c*). A curve for thoria is given in a previous paper. From the general shape of the decay-curve we should expect the radioactivity to increase rapidly for about the first ten minutes and then more slowly afterwards. This was experimentally found to

be the case. The results obtained were only approximate on account of the initial rapid decay after removal.

Summary of Results.

From the differences observed in the behaviour of the radioactive substances most closely studied, viz. uranium, thorium, and radium, it will be seen that radioactivity is a very complicated phenomenon. Both uranium and radium * emit negatively charged particles with high velocities, similar in all respects to cathode-rays. In addition, uranium, radium, and thorium emit rays non-deviable by a magnetic field, which are readily absorbed by gases and thin layers of metal. These non-deflectable rays differ from one another in penetrating power and cannot consequently be ascribed to any radioactive impurity common to all these substances. In addition, thorium and radium possess the remarkable property of continuously emitting radioactive emanations which behave in all respects like radioactive gases. The emanations from thorium and radium differ greatly in their rates of decay of radiating power. The presence of an emanation gives rise to the complicated phenomenon of "excited" radioactivity. The nondeviable "excited" radiations due to thorium and radium, although apparently of the same penetrating power, decay at very different rates.

"Excited" radioactivity is not confined to radium and thorium, for Elster and Geitel † have recently shown that a negatively-charged wire, exposed in the open air, free from all possible contamination by radioactive substances in the laboratory, becomes strongly radioactive. This excited radioactivity ‡ decays at a different rate from that due to the emanations of thorium and radium, and also is of greater penetrating power.

Macdonald Physics Building,
McGill University, March 6, 1902.

* It has recently been found that thorium also emits some rays deviable by a magnetic field. The excited radiations produced by thorium and radium also possess the same property. (Rutherford and Grier, Amer. Phys. Soc. April 21, 1902.)

† *Phys. Zeit.* 1901.

‡ Rutherford & Allen, *Phys. Zeit.* 10, 1902.