

ON THE RANGE AND TOTAL IONIZATION OF THE
 α PARTICLE.

BY S. J. ALLEN.

INTRODUCTION.

THE original object of this investigation was to determine the range of the α particle from the excited activity of the atmosphere, and to compare it with that of radium C. Since, however, the method used by the author gave results which were not seemingly in accordance with the present theory of the α particle, a more detailed investigation was made, dealing with the total ionization of the α particle from radium, thorium and uranium. The results of this, together with those on the excited activity of the atmosphere, are embodied in the present paper.

The work of a number of investigators in different parts of the world has pretty conclusively shown that the excited activity of the atmosphere is due to the presence of radium and thorium in the earth's crust. The author has shown in a recent paper¹ that the excited activity at Cincinnati always contains RaC, generally RaB, and sometimes thorium B in very variable quantities. The presence of RaA is difficult to detect on account of its rapid rate of decay. There may also be a possibility of the presence of the excited activity due to actinium. In general then, by far the greater part of the excited activity of the atmosphere is due to RaC.

The range of the α particle from RaC as determined by Bragg and Kleeman is about 7.1 cm. and this ought, therefore, to be the maximum range of the α particle from the excited activity of the atmosphere if RaC is always present, since RaC has the longest range of any of the radio-active substances with the exception of thorium C.

The method used by Bragg and Kleeman to determine the range of the α particle necessitates a considerable quantity of the radio-active

¹S. J. Allen, PHYS. REV., June, 1908.

material of sufficient strength, such that, after passing through the grid of small vertical tubes, the activity is great enough to be measurable with accuracy.

For the weak radio-active substances, such as uranium, and the excited activity of the atmosphere, this method is not applicable. Some method must, therefore, be used in which the total ionization is measured. In order to obtain the range of the α particle from uranium Bragg¹ has made use of a simple method, which is applicable to a substance having but one range of its α particle, but not to a mixture of several substances, such as the excited activity of the atmosphere is in general. In this method the total ionization between two parallel plates, on the lower one of which is spread a uniform layer of the radio-active substance, is measured for different thicknesses of absorbing material placed over the radio-active layer. Formulæ, based on theoretical considerations of maximum range of the particle, variation of ionizing power with the velocity of the particle, and of the stopping power of the absorbing material, are deduced by him and show the theoretical relation between the current for the uncovered radio-active layer and that for any thickness of absorbing material. This same relation is experimentally obtained, and by a comparison between the two the range of the α particle can be deduced.

The method used in the present investigation is based on the following considerations :

The work of Bragg and Kleeman has shown that the α particle from a single radio-active substance is ejected with always the same velocity, and travels a certain distance in a gas before it has ceased to ionize. This distance is known as the range of the particle, and is a constant quantity for any one gas, the temperature and pressure being kept constant. Furthermore, when a layer of absorbing material is placed on the radio-active substance, the range of the particle is decreased by an amount proportional to the thickness of the layer.

If D represents the decrease of range of a particle traveling normal to the surface, ρ the density of the absorbing layer referred to air as unity, t the thickness of the absorbing layer, then

$$D = \rho t.$$

¹ Bragg, Phil. Mag., June, 1906.

The range of a particle making an angle θ with the normal will be given in general by the expression

$$r = R - D \sec. \theta = R - \rho t \sec \theta,$$

where R is the range when the radio-active substance is uncovered. A layer of radio-active substance of sufficient thickness to absorb those particles which come from the bottom would eject particles having all ranges from 0 to R .

The distribution of ionization between the plates will not be uniform but denser near the lower plate, and gradually falling off as we go toward the upper plate, and ceasing more or less abruptly as the maximum range of the particle is reached. The total ionization will, therefore, increase rapidly at first, then more slowly and finally reach a maximum value when the particles of maximum range have lost completely their power of ionizing. The distance between the plates, when this maximum value is reached, should represent the range of that α particle of the greatest velocity which is projected normally from its surface layer of the radio-active material.

If we measure the maximum ionizations for two radio-active substances, of which the range of one is known then the range of the other can be calculated: if R represent the range of the α particle and d the distance between the plates for maximum ionization of the known radio-active substance, R_x and D_x , the corresponding quantities for the unknown substance, then we have

$$R_x = \frac{RD_x}{d}.$$

This method gives of course only the range of the α particle of maximum velocity. If the excited activity of the atmosphere always contained RaC, then the range of the α particle from it should always be equal to that of RaC, viz., 7.1 cm., no matter what may be the rate of decay of its activity.

If we consider only those particles which come normally from the topmost layer of the radio-active substance, and assume that the ionization is uniform along the path of the particle, then the ionization can be expressed as follows:

$$i_1 = \int_0^d ndr = n_1 d (d \gg R),$$

The maximum value of this curve is given by $d = R$, the maximum range of the X particle from RaC.

Now consider the particles coming from a layer distant t below the top layer. The maximum range of these will be $R - \rho t$. The curves will be

$$i_1 = nd, \quad (d \gtrless R_1 - \rho t), \quad i_2 = nd_2, \quad (d \gtrless R_2 - \rho t), \text{ etc.,}$$

the same as before, except that the maximum values will be less and occur at a shorter distance between the plates. The summation of the curves for this layer will give a curve which is identical with $oa'b'c'd'e'$ up to $d = R_1 - \rho t$, after which it is less, rising to a maximum for $d = R - \rho t$.

If these two summation curves are added together, we obtain a curve which has its maximum at the same point as the first, viz., $d = R$.

The effect of adding curve after curve is to stretch the total ionization curve upwards and to the left, the position of maximum ionization always remaining the same.

Those particles which are projected in other than normal direction will not effect the position of maximum ionization, but will simply stretch the curve still further to the left and upward.

Finally there is obtained for the total ionization due to a layer of radio-active material a curve such as $ABC \dots$, which has its maximum value for a distance between the plates equal to the range of the α particle of maximum velocity.

EXPERIMENTAL ARRANGEMENT.

The experimental arrangement is very simple and is shown in Fig. 2. Inside a brass box A are supported two brass plates B and C , which are insulated from the casing by ebonite blocks D , E and F . The plate B can be moved up and down by means of a vertical rod, and is connected through this rod to one pair of quadrants of the null reading electrometer constructed by the author, and described in a recent paper.¹ The lower plate C contains the radio-active material, and is connected to one pole of a battery of small lead accumulators. The other pole of the battery is joined to the lower plate b

¹S. J. Allen, Phil. Mag., Dec., 1907.

of the uranium standard. The plate a of the standard is connected to the same pair of quadrants as the plate B of the testing vessel. The other pair of quadrants of the electrometer is joined to earth through a contact-key. The box A is joined to earth, as is also a point on the battery which is always adjusted to give the same potential difference (about 100 volts) to the plates a and b .

The cover of the uranium standard slides in, and out, by means of a rod carrying a vernier and moving over a scale graduated in millimeters. The calibration curve of the instrument is plotted in relative values of the ionization, half way on the scale being taken

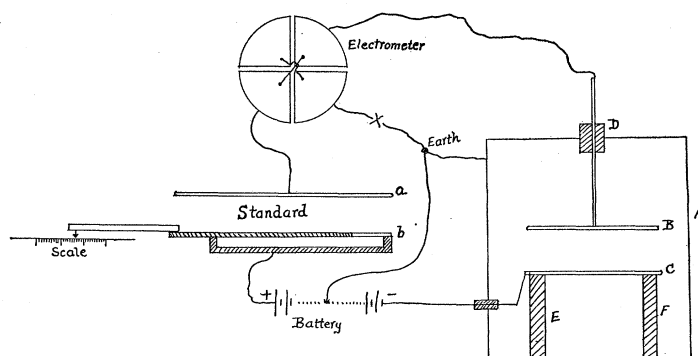


Fig. 2.

as 100 per cent. and the others expressed accordingly. The maximum position on the scale corresponds to 208 per cent.

The working of this arrangement is evident from the figure; a negative current from C to B charges the quadrants up to a negative potential. The cover of the standard is then opened until the positive current so obtained neutralizes the negative charge on the quadrants, when the needle comes to rest. The ionization between B and C is thus obtained in terms of that of the standard. The point of balance can easily be determined to one half, and with care to two tenths of a millimeter. Two currents through CB , differing as little as one half per cent., can be quite readily distinguished from one another.

The chief advantages of this instrument are, that the relative values obtained are independent of change of capacity in the system and of change in the sensitiveness of the electrometer; two very

desirable qualities in this experiment. The total maximum current available with the standard is about 400 times the natural leak of air, so that the ionizations used in this investigation do not exceed that amount, and are in general much less.

As stated above, the potential difference between the plates of the standard was kept constant at 100 volts, this being sufficient for saturation. On the other hand, the potential difference between *B* and *C* could be adjusted to any desirable amount, up to 1,000 volts, so as to obtain approximate saturation.

It was found in general that 150 volts was sufficient to produce the maximum current, which is what we are accustomed to call saturation.

EXPERIMENTS WITH RADIUM.

In these experiments the radium used was about 7,000 activity, and the active layers were prepared in several different ways. A thick layer of large area could not be used as the ionization from it was too large to be balanced by the standard. A piece of cardboard .5 cm. square was covered with a thin coating of shellac and then some powdered radium was dusted over it. When hard the radium was rubbed off until just sufficient was left to cause a current of the desired amount. This radium layer was then placed in the center of the plate *C*, and readings taken of the ionization for various distances between the plates. A sample set of readings for this case is shown in Table I.

TABLE I.

Radium Thin Layer. Area = .25 sq. cm.

Distance between Plates in cm.	Balance Point.	Relative Ionization.
0.6	38.0	60.0
1.1	55.2	98.5
1.6	66.0	122.0
2.1	73.5	138.5
26	78.0	148.5
29	79.8	152.0
32	81.1	155.0
34	81.6	156.0
36	82.0	156.5 max. position
41	82.0	156.5

These results are plotted in a curve *E*, Fig. 3, where the ordinates represent ionization and the abscissæ the distance between plates. This curve shows that the current between the plates increases with their distance apart, reaching a maximum at 3.6 cm.

Here we are dealing with radium in radio-active equilibrium and the α particles from the surface should have a range equal to that of RaC, viz., 7.1 cm., and consequently the theoretical maximum should occur at this distance. Instead of that the maximum is obtained experimentally at about half this distance. The error in finally determining this position is certainly not greater than 1 to 2 mm.

Radium films were next tried, and were prepared in two different

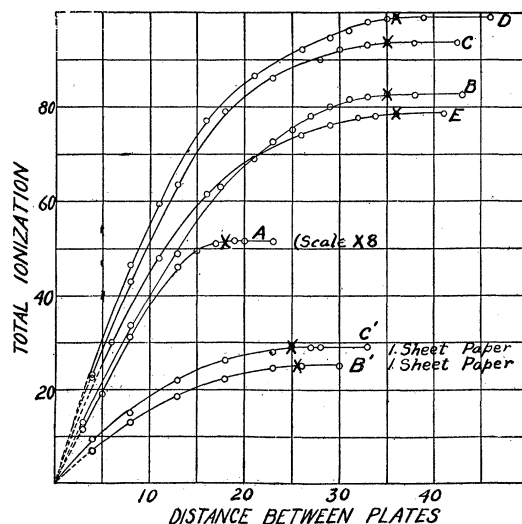


Fig. 3.

ways. In the first the radium was dissolved in water, and a small amount of the solution evaporated down to dryness on an iron plate. The radium bromide did not dissolve very thoroughly, but some remained suspended in fine particles, so that the films obtained were composed of small particles or crystals more or less isolated from one another. In fact, as Bragg states, all radium films thus prepared consist of fine particles distributed over the surface, and easily seen under the microscope.

The iron plate containing the film was laid on the plate *C* of the testing vessel, and readings made in the same manner as before. The results of one of these tests are expressed in curve *B*, Fig. 3. The shape of this curve is somewhat different from that for the radium layer *E*, being straighter and not raising so rapidly at first. However, we see that the maximum occurs at 3.5 cm., about the same as for the radium layer. The area of the film was roughly 25 sq. cm. which is 100 times that of the radium layer, so that the distribution of the ionization in the two cases was quite different. This, together with the fact that the mean range of all the particles in the case of the film is greater than in the case of the layer, would account for the difference in shape of the two curves.

Since the maximum point is the same for both cases, it would indicate that the maximum range of the α particle was the same, and that therefore RaC was present in the films as well as in the layer. This curve was taken after the film had become dry, and long before the radium could again reach the state of radio-active equilibrium, so that the large proportion of RaC present is probably due to the solid particles of the film not allowing the emanation to escape.

The solution was allowed to settle for some days and then a little of the clear solution at the top drawn off and evaporated on a plate. The readings for this case are plotted in curve *A*, Fig. 3. The shape of this curve is much different from the other two already mentioned, rising straighter and more rapidly from the origin, and reaching a maximum at 1.8 cm.

These facts show us at once that we are concerned with a much simpler radiation of a smaller range than in the other two cases. This film would be very much finer in grain than the other two and contain very little emanation or radium C, so that we would expect the maximum range to be that of radium. The range given by the equation,

$$R_x = \frac{Rd_x}{d}, \text{ is equal to } \frac{7.1 \times 1.8}{3.6} = 3.55 \text{ cm.}$$

This is about the same value as obtained by Bragg for radium.

The second method of preparing the films was to suspend the iron plate over an evaporating dish containing a little radium, and

then to heat the radium to barely a dull red. In two hours' time a film too strong for the instrument to balance was obtained. The film was then rubbed over with a piece of emery cloth until the amount of activity left was small enough to be measured by the standard. The activity of this film did not decay with time but after a month was a little stronger than when first prepared.

The results of experiments on this film are expressed in curves *C* and *D*, Fig. 3. Curve *C* was taken a few hours after preparation, and *D* about one month later. Both curves are the same in shape and rise to a maximum at about 3.5 cm. which shows that radium C was present in both.

I have never seen this method of preparing films described and it might seem to be a very convenient one to use, when one does not like to dissolve valuable radium in water. The film must be very fine in grain, and attached very firmly to the metal to stand rubbing with emery.

The results of these experiments on radium give a position of maximum current which is only about one half what it should be according to theory.

At first sight several reasons occur to one which might account for this great difference. In the first place, as the plates are moved apart the electric field may fall below that necessary to saturate the gas, in which case the current after a certain distance apart would fail to represent the full ionization at that distance. In order that there should be no doubt with regard to this point, a number of experiments were made at different voltages.

The readings for these are shown in Table II.

These readings are also plotted in Fig. 4, curve *A* representing

TABLE II.

[illegible]

those for 155 volts, and curve *B* those for 55 volts. Both these curves are of the same shape, and both rise to a maximum at about the same point, viz., 3.5–3.6 cm. The maximum current only remains constant for a short distance, and then decreases rapidly, so that at a distance of 7.1 cm. (the theoretical range) the current is only about 78 per cent. of the maximum. As can be seen from the table the ionization is saturated at about 400 to 500 volts, that is to say, no more current can be obtained with further increase of voltage. At 155 volts the current is almost saturated and this voltage is the one used in most of the other experiments.

If the ionization is practically saturated at a distance of 7.1 cm. it certainly will be so for all distances less than that, since the electric field will get greater and greater. The great drop in the curve after 4 cm. cannot therefore be ascribed to lack of voltage. At any rate the position of the maximum current is not affected much by a lack of saturation, since it is practically the same at 50 volts as it is at 500 volts.

In curve *C* are plotted some results for a radium layer of very small area placed in the center of the upper plate *B* of the testing vessel. This case approximates quite closely to a point source. As is seen the first part of the curve is of the same shape as curves *A* and *B*, rising to a maximum at 3.6 cm. The curve after 3.6 cm. does not, however, drop as suddenly, and at 7.1 cm. the current is still about 97 per cent. of the maximum. The voltage used in this case was 150. At 550 volts the maximum current was a little greater, but occurred at the same point and remained constant up to 7.1 cm. and then decreased slowly.

The results when the radium layer was placed on the lower plate were exactly the same as when placed on the upper, the maximum current always occurring at about 3.6 cm., although the distribution of the ionization in the two cases is entirely reversed.

These results, thus far, would therefore seem to show that the total ionization between two parallel plates due to a layer, or film, of radium in radio-active equilibrium reaches a maximum at a distance of 3.6 cm. away from the active substance, instead of 7.1 as theory would demand. This conclusion is for weak ionizations where the amount of β rays present is too small to be considered.

Since in the case of a layer of radio-active material, the rays emerge equally in all directions, the quantity which passes vertically upwards is small compared to the total, and the ionization per unit volume near the radio-active plate much greater than near the other plate. The amount of ionization added per cm. as the distance between the plates is increased, is consequently decreasing and may become so small as to finally cause very little change in the total amount, being offset in many cases by decreases due to other causes. Still one does not see why this should be great enough to cause the position of maximum current to drop to nearly one half the range of the α particle.

In order to more fully test this latter point, the following experiment was tried. The upper plate *B* of the testing vessel was removed from the upright rod, and a plate of about 1 cm. diameter placed in its stead. In this small plate was cut a depression, on the bottom of which was placed a thin layer of radium cemented to the plate by shellac. The cone of rays from this made an angle with vertical of about 80° . The lower plate *C* was replaced by a brass hemisphere of 7.2 cm. radius, with its equator in a horizontal plane. The hemisphere was attached to the electrometer, and the rod containing the radium to the battery.

In this arrangement when the radium is at the center of curvature of the hemisphere, the range of the α particles from the RaC at the surface will be about the same as the radius of the hemisphere, and therefore the total ionization should reach its maximum more abruptly than with the parallel plates.

The obliquity of the rays ought now to be of less effect than before, and the position of maximum current approach more nearly to the range of the particle.

The results of this experiment are plotted in curve *F*, Fig. 4, which is seen to be of the same general shape as before with the maximum current occurring at about 3.8 cm. The voltage used was 350, which is quite sufficient for approximate saturation. The curve from 3.8 to 7.1 does not drop appreciably, but after 7.1 falls off quite rapidly reaching at 9.9 cm. a value about 84 per cent. of the maximum.

A brass tube was then placed vertically over the radium, so as to

narrow down the cone of rays to about 40° vertical angle. The position of maximum current was now about 4.3 cm. As the cone of rays is narrowed down the position of maximum current approaches nearer to the range of the particle.

The large portion of oblique rays thus seems to have a decided influence on the position of the maximum current.

In the case of the parallel plates the greater proportion of the rays are projected obliquely to the direction of the electric field, which, as Bragg observes, may cause a greater difficulty in saturating than if they were parallel. In the experiment with the hemi-

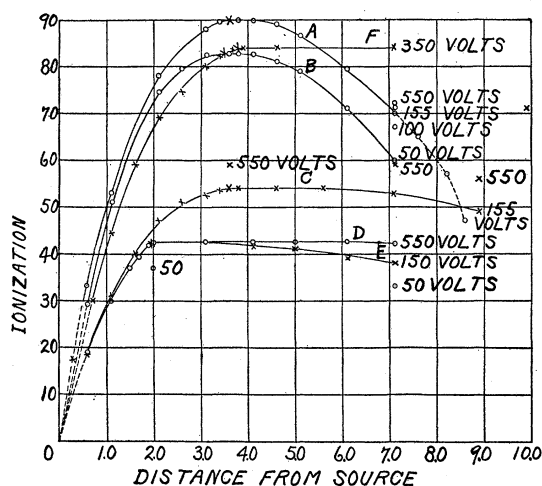


Fig. 4.

sphere this will not be the case, since most of the rays will be parallel to the electric field, which itself is more or less radial.

In order to gain some further information with regard to the connection between obliquity of the rays and the position of the maximum current the radium was placed below the lower plate *C*. For this purpose the brass plate *C* was replaced by a plate of fine gauze, through which the rays could pass. Under these conditions a great deal of the oblique radiation will be cut off by the wires of the gauze, while the vertical rays will not be affected to any great extent.

The amount of radium used in this case had to be considerably greater than in the former experiments in order to obtain between

the plates *B* and *C* sufficient current to measure with accuracy. The β rays now just began to make themselves felt, and where necessary their presence was allowed for in determining the total current due to the α rays. Experiments were made with the radium placed at different distances below the gauze. The curves obtained are shown plotted in Fig. 5. They are not all drawn to the same scale, but arranged so as not to overlap one another. The curves at the greatest distances were obtained from stronger radium layers than those

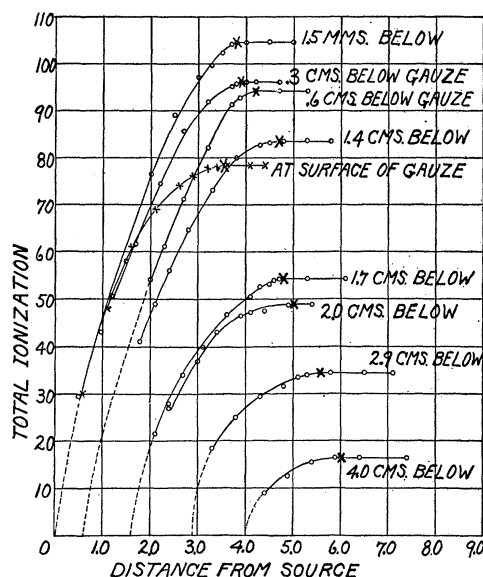


Fig. 5.

at shorter distances. The position of the maximum current in each case is indicated by the large cross.

From an examination of these curves we see that as the distance of the radium below the gauze increases, the position of the maximum current continually approaches to that of the range of the α particle from RaC. At the surface of the gauze the maximum occurs at 3.6 cm, at a distance of 1.7 cm. below it is at 4.8 cm., while at 4.0 cm. below it has increased to 6.0 cm.

This increase of the maximum position may be due to two causes. In the first place, as the distance between the radium and gauze in-

creases, the proportion of vertical rays gets greater and greater. Secondly, the distance between the gauze and upper plate of the testing vessel for maximum current continually decreases, and the ions produced there have a shorter and shorter distance to travel from one electrode to the other.

A grid made of a number of small glass tubes arranged vertically was then placed over the radium. The tubes were 7 mm. in height and about .5 mm. internal diameter. These tubes allowed only

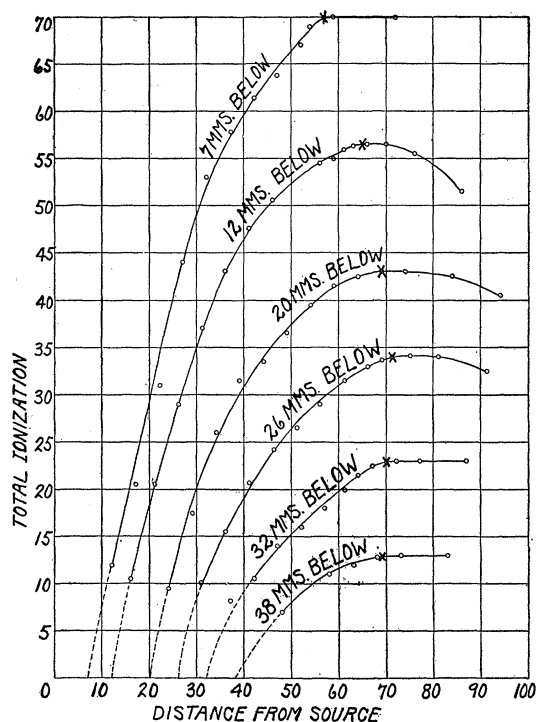


Fig. 6.

those rays which were nearly vertical to pass through. The strength of the radium had to be greatly increased, in order to get sufficient rays through for convenient measurement. The proportion of the ionization due to the β rays was quite considerable and had to be deducted from the total ionization to obtain the net leak caused by the α rays.

The results are expressed in Fig. 6, and are of the same char-

acter as those obtained without the tubes. The position of the maximum, however, is much nearer to the range of the particle than before. When the distance between the radium and gauze is 7 mm. the maximum occurs at 5.7 cm.; when the distance is 12 mm. the position is at 6.5 cm., while at the distance of 20 mm. it is at 6.9 cm. Beyond a distance of 20 mm. the position remains practically constant, the mean of several positions being 7.0 cm., which is about the same as the range of the X particle from RaC as obtained by the method of Bragg. Even with this arrangement of tubes when the radium is close to the gauze the difference between the position of maximum current and the range of the particle is very considerable.

From these experiments with the gauze electrode we can conclude that the distance between two parallel plates for maximum current only becomes equal to the range of the particle when all the rays are normal to the radio-active surface.

EXPERIMENTS WITH URANIUM OXIDE.

In order to test whether the ratio between the positions of the maximum current for two different types of radiation is the same as the ratio of their range, a number of experiments were carried out with uranium.

The uranium was finely powdered and then dusted over a plate covered with a thin coating of shellac. When dry the surplus uranium was tapped off leaving a comparatively thin and durable layer. This was placed between the plates *B* and *C* of the testing vessel, and readings made in the same manner as for the radium.

In Fig. 7 are shown a number of the curves obtained for uranium oxide.

Curves *A* and *B* were obtained from thin layers of about 25 sq. cm. area. The shapes of these curves are about the same as for those of radium, except that they are somewhat straighter and the position of maximum current is defined more abruptly. This position occurs in curve *A* at 1.9 cm., and in *B* at 1.8 cm. The mean position from a number of curves is about 1.9 cm.

If we substitute this value of d_x in the equation,

$$R_x = \frac{Rd_x}{d}, \text{ we obtain } R_x = \frac{7.06 \times 1.9}{3.6} = 3.7 \text{ cm.}$$

The value obtained by Bragg, making use of the stopping power of aluminum for the α rays, was in the neighborhood of 3.5 cm. The agreement between the two values is very good, considering the difference of the methods used. It also shows that the range of the α particle from uranium is very close to that of radium, if indeed not the same.

Curve *C* was obtained from a layer about 1 mm. in thickness, and it is of a slightly different shape, being rounder, and not having its maximum position so well defined.

In this case the ranges of the particle vary all the way from zero to the maximum, which will account for the shape of the curve.

In curve *D* are plotted the values taken from Rutherford's results on uranium oxide.¹ Unfortunately he does not give any readings

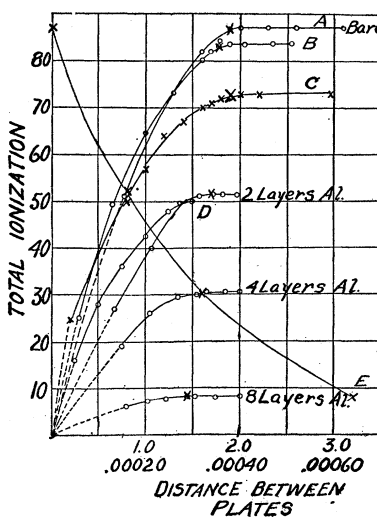


Fig. 7.

beyond 1.5 cm., so one does not know the ultimate maximum of the curve, though from the shape of the portion here given, one can see that it is rapidly approaching a maximum not much different from that of the author's curves.

These results for uranium would seem to show that the causes which make the position of maximum current between two plates

¹ Radioactivity, page 60.

different from the range of the α particle from the surface layer, are the same for uranium as for radium in radio-active equilibrium.

Curves *D* and *E* in Fig. 4 represent some readings for uranium oxide at different voltages. At 155 volts the curve drops a little from 3 cm. onward, but at 550 volts there is scarcely any drop.

EXPERIMENTS WITH THORIUM OXIDE.

A few experiments of the same nature were made with thorium oxide in radio-active equilibrium. The layers were prepared in the same manner as for uranium, and were of about the same area and thickness.

The results for two experiments are shown in curves *A* and *B*, Fig. 8. They are of the same general shape as those obtained for

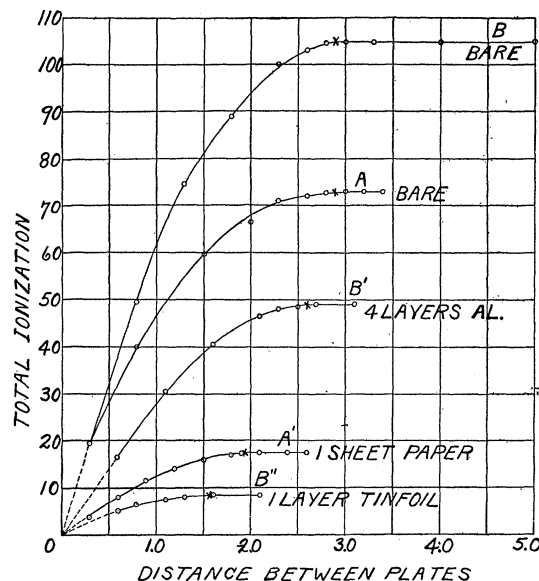


Fig. 8.

radium and uranium, and both rise to a maximum at 2.9 cm. We therefore have for the range of the particle of greatest velocity from the surface layers,

$$R_x = \frac{7.06 \times 2.9}{3.6} = 5.7 \text{ cm.}$$

The particle of greatest velocity from thorium in radio-active

equilibrium is that of ThX which has according to the method of Bragg a range of 5.7 cm. ThC has a range of 8.6 cm., but would be in such small quantities in the present experiments that its effect would not be appreciable. In some of the experiments the thorium oxide was placed below the gauze as in the experiments with radium. The results obtained were of the same nature as those for radium; a gradual increase of the position of maximum current as the thorium oxide was moved away from the gauze. At a distance between the gauze and the radio-active layer of 8 mm. the position of maximum current had increased to 3.4 cm. The corresponding position for the radium layer was about 4.3 cm. Therefore we obtain

$$R_x = \frac{7.06 \times 3.4}{4.3} = 5.6 \text{ cm.}$$

DECREASE OF MAXIMUM POSITION OF IONIZATION WITH ABSORBING LAYERS.

As stated in the introduction to this paper the range of the α particle is decreased as layers of absorbing material are placed over the radioactive surface. If there is a definite connection between the position of maximum current and the range, then this position should also decrease with the addition of absorbing layers proportionally to the decrease in the range.

In order to test this a number of tests were made with the radio-active layer covered with various thicknesses of absorbing material. The materials used were aluminium leaf, tin-foil and tissue paper.

The results for aluminium leaf placed over a radium film are shown in the curves of Fig. 9. The curves for the different thicknesses all have the same shape, but rise to a maximum, which decreases with increasing number of layers. The fact that the shape of the curves is the same shows that all the particles, no matter what their velocities are, have their range cut down by the same amount, which is in good agreement with the results of Bragg.

The decrease in the position of maximum current is approximately proportional to the thickness of the absorbing layer, being at 8 layers equal to 6 mm. and at 16 layers to 10.5 mm. The layers of aluminium leaf were not very uniform in thickness which will account for most of the irregularities in the results.

The curve *A* represents the variation of the total ionization with the thickness of absorbing layer. This is approximately exponential and agrees with the well-known fact that the intensity of ionization for radium in radio-active equilibrium falls off exponentially with the

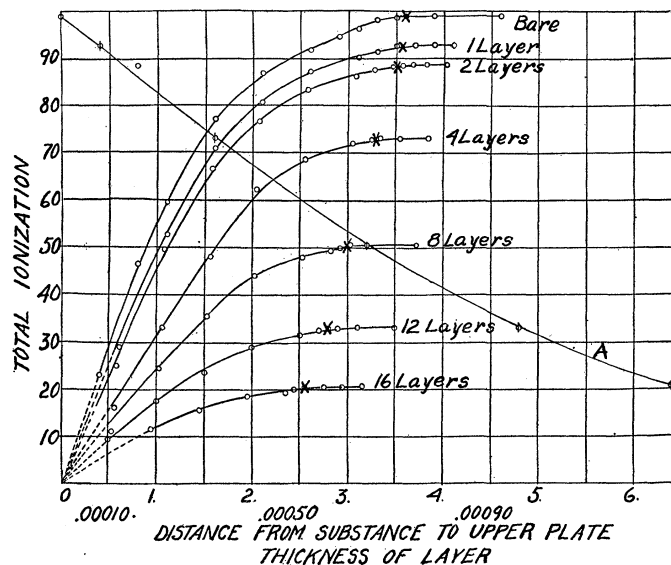


Fig. 9.

thickness of absorbing material. The lower horizontal scale represents the thickness of the leaf in cms.

In Fig. 10 is shown a similar set of curves for the radium layer of small area. The results are the same as in the case of the radium film, the decrease in position of the maximum being 10.5 mm. for 16 layers of aluminium. The decrease of the total ionization in this case is also approximately exponential, but considerably greater than for the film. The reason for this is probably that in the layer the proportion of particles of short range is greater than for the film.

In this figure is also shown a curve for one layer of tin foil, the decrease being 12.5 mm. In curves *B* and *C*, Fig. 3, are represented the readings for an absorbing layer of tissue paper.

Some results for thorium oxide are shown in Fig. 8, *B'* that for four layers of aluminium, *B''* that for one layer of tin foil, and *A'*

that for one sheet of tissue paper. The decrease in the case of tin foil is 13.5 mm., about the same as for radium, which shows that the decrease of range of the α particle is the same for thorium and radium, that is, independent of the velocity of projection.

For the uranium oxide layer the curves for 2, 4 and 8 layers of aluminium are shown in Fig. 7. The decrease of position of maximum current is about 4.5 mm. for the 8 layers of aluminium. The curve E showing the relation between current and thickness of layer is for the uranium almost exactly exponential, the total ionization being cut down to half value by a layer, .00022 cm. thick. If d_x' represents the position of maximum current, for any thick-

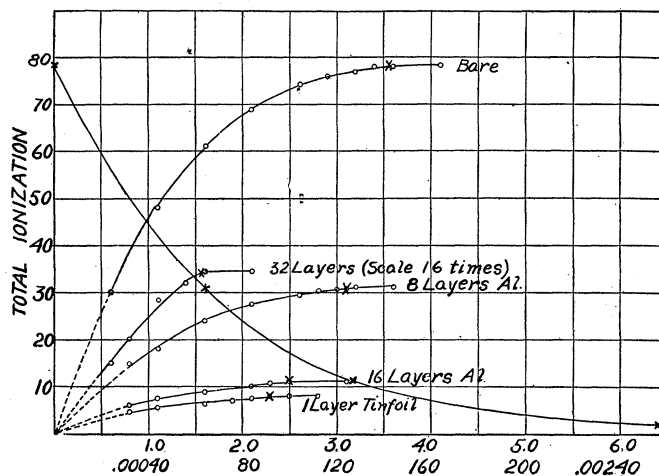


Fig. 10.

ness of absorbing layer, then the range of the particle after going through this layer should be given by

$$R_x' = \frac{R_1 d_x'}{d}$$

and the loss of range by

$$R_x - R_x' = \frac{R(d_x - d_x')}{d}$$

For example in the case of the radium film, for 16 layers of aluminium, $d_x = 3.6$, $d_x' = 2.55$, $d = 3.6$, and $R = 7.06$, therefore,

$$R_x - R_x' = \frac{7.06(3.6 - 2.55)}{3.6} = 2.06 \text{ cm.}$$

From these losses of range the stopping power of the absorbing material can be calculated. This has been done and the results are expressed in Table III.

TABLE III.

Radium Film with Aluminium as Absorber.

No. of Layers.	Thickness × Density.	Decrease of Range.	Effective Stopping Power.	Atomic Stopping Power.
4	.000848	0.6 cm.	1.21	1.41
8	.001696	1.2 "	1.22	
12	.002544	1.6 "	1.37	
16	.003392	2.1 "	1.39	

Radium Layer with Aluminium.

8	.001696	1.0 cm.	1.46	1.38	1.30
16	.003392	2.2 "	1.33		
32	.006784	4.3 "	1.36		

Tinfoil as Absorber.

1	.000790	2.6 cm.	2.60	3.16
---	---------	---------	------	------

Paper as Absorber.

1	.00180	1.8 cm.	1.16	1.09	0.77 (carbon)
2	.00360	3.2 "	1.03		

Uranium Oxide, Aluminium as Absorber.

2	.000424	0.3 cm.	1.22	1.34	1.37
4	.000848	0.6 "	1.21		
8	.001696	1.0 "	1.41		

Thorium, Paper as Absorber.

1	.00180	1.7 cm.	1.09	0.77 (carbon)
---	--------	---------	------	---------------

Aluminium as Absorber.

4	.000848	0.6 cm.	1.21	1.52
---	---------	---------	------	------

Tinfoil as Absorber.

1	.000790	2.6 cm.	2.60	3.16
---	---------	---------	------	------

As seen from the table the values of the stopping power of aluminium for RaC, thorium, and uranium, are about the same. The mean value of the effective stopping power for aluminium is 1.33 and of the atomic stopping power 1.40. The corresponding values

as obtained by Bragg are 1.23 and 1.53. The agreement of the values obtained by these two different methods is thus quite good. The mean value of the atomic stopping power for tin foil is 3.16, which agrees very well with Bragg's value of 3.42.

The effective stopping power of tissue paper is about 82 per cent. of that of aluminium. The effective stopping power of carbon as calculated from the atomic square root law of Bragg would be about 1.20, which is close to that for paper.

Since the stopping power of a substance is the same for the α particles of uranium and radium, it follows that the α particle of uranium is of the same nature as that of radium C, differing only in velocity. If we were to reduce the velocity of the RaC particle by an absorbing layer until the range was equal to that of uranium, then the two particles should be the same in ionizing power.

Bragg has deduced a theoretical formula for the relation of the current, between two parallel plates caused by a thick layer of radio-active material on the lower plate, to the loss in range due to an absorbing layer, which is as follows :

$$i = \frac{N'l'n_0}{8s} \left\{ (R - D)(R - 3D) + 2D^2 \log_e \frac{R}{D} \right\}.$$

Here R is the range of the particle from the surface layer, D the decrease in R , normal to the surface, N , l' , n_0 , and s constants for the particular radiation concerned. When the radio-active material is uncovered, $D = 0$, and we have for the maximum current

$$I = AR^2, \quad \text{where} \quad A = \frac{N'l'n_0}{8s},$$

$$\therefore i = \frac{I}{R^2} \left\{ (R - D)(R - 3D) + 2D^2 \log_e \frac{R}{D} \right\}.$$

Curves can be plotted showing the relation between i/I and D/R .

From this curve as given by Bragg,¹ and from the values of the total ionization as obtained in the present paper for the uranium oxide, I have calculated the product of density and thickness of the absorbing layer through which the rays can just penetrate. These values are shown in Table IV.

¹ Loc. cit.

TABLE IV.

$\rho d \times 10^6$.	i	$\frac{i}{T}$	From Theoretical Curve.	ρd of Full Range $\times 10^6$.
0	87	1.00		
424	51.6	.59	.13	326
848	30.5	.35	.24	353
1696	8.0	.09	.52	326
				Mean 335

The value obtained by Bragg for uranium was .00456, which is considerably larger than that in the last column of Table IV., though the agreement of the three values in the last column indicates the correctness of the theoretical formula.

EXCITED ACTIVITY OF THE ATMOSPHERE.

A large number of tests were made on the excited activity of the atmosphere collected on different days and under different weather conditions. The activity was collected on a negatively charged wire and also on an uncharged one. As I have shown, in the paper referred to above, an uncharged wire suspended in the atmosphere at Cincinnati has deposited on it a large quantity of soot which is quite radio-active. The rates of decay of the activity on an uncharged wire is the same as that on a charged one.

The activity was rubbed off on to a piece of thin linen, and placed between the plates of the testing vessel. Readings of the current were taken for various distances between the plates, note being taken of the time of each observation. At regular intervals of time the plates were moved apart the same distance, generally 3.3 cm., and readings of the ionization taken. From these readings the rate of decay curve of the activity could be drawn. Then, knowing the time at which any other reading was made, from this decay curve the current could be corrected for the decay of the activity.

The null reading instrument used by the author was found very convenient for determining the decay of the activity, since with it the activity can be ascertained at the exact instant of time considered. In practice the ionization of the standard was made a little less than that of the excited activity, and then as the activity gradually decayed the exact instant at which the two balanced could be read off on the top watch.

It is naturally much more difficult to decide on the position of maximum current in the case of a decaying activity, as the readings are more irregular and cannot be repeated like those for a steady activity. Still I think the position can be ascertained to within two or three mms. at least.

In Fig. 11 are represented a characteristic set of curves for the excited activity of the atmosphere. Curves 4 5 and 6 are for an uncharged wire, while 1, 2 and 3 are for a negatively charged one.

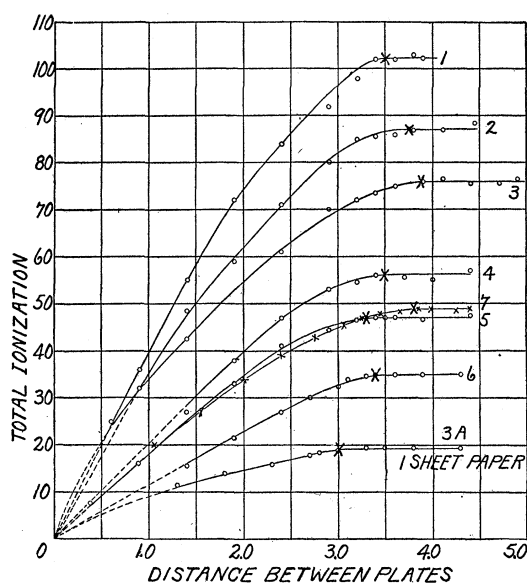


Fig. 11.

Fig. 12 represents the decay curves for the above set, the numbers of the curves corresponding. An examination of these decay curves shows that they are very irregular, the period (time taken to fall to half value) varying from 29 minutes for curve 4, to 43 minutes for curve 2. Curves 4 and 6 are almost exponential with a period of 29 minutes and undoubtedly consist of a very large proportion of RaC. Curve 1 contains probably also RaC, while the others are probably mixtures of RaB and RaC. Very little thorium activity is present in any of these curves.

The curves in Fig. 11 are somewhat similar in shape to those obtained for radium in radio-active equilibrium, but are much

straighter in the first part. The radium curves rise to half value for a distance between the plates of about 8 mm., while those for the excited activity of the atmosphere do not rise to half value until a distance of 12 to 14 mm. has been reached. This shows that the excited activity contains a much greater proportion of rays of long range than does the radium.

The position of maximum current for the activity from a charged wire varies from 3.6 to 3.9 cm. A large number of tests give a mean of about 3.8 cm. The position for that from the uncharged wire varies from 3.3 to 3.5 cm. with a mean about 3.4 cm. There thus seems to be a small difference between the positions for the two cases. This may be due to the fact that the activity from the uncharged wire is much less in general than that of the charged wire, and consequently it is more difficult to determine the position of maxi-

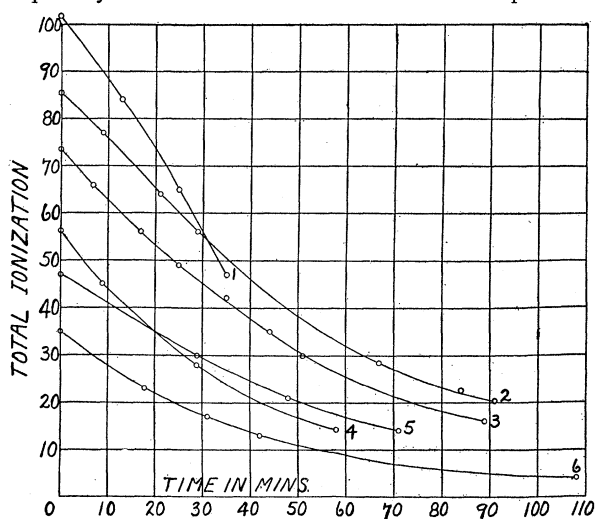


Fig. 12.

mum ionization. The ordinates for curves 4, 5 and 6 are multiplied by 4.

Curve 7, Fig. 11, was obtained from the excited activity due to radium. A small metal plate was suspended inside a vessel containing radium emanation, and charged to a negative potential for three hours. It was then allowed to remain for another hour in the testing vessel before readings were taken, this ensuring that the activity then re-

maining was practically all RaC. The decay curve of it was however taken along with the other readings and corrections made for the decay of the activity in the same manner as described for the excited activity of the atmosphere. The decay curve was practically exponential with a period of about 28 minutes.

As can be seen from the figure the curve is almost identical with those for the excited activity of the atmosphere, having its maximum at 3.8 cm.

The position of maximum current for the excited activity of the atmosphere is thus the same as that of RaC, and therefore we can assume that their ranges are the same.

It seems definitely proven then, that the excited activity of the atmosphere always contain a product, existing often in large proportions, which is identical with radium C, having the same range, and same rate of decay.

Curve 3, α , Fig. 11, represents a set of readings taken with the material of curve 3 covered with one sheet of tissue paper. The decrease of total ionization in this case is about 34 per cent. and the loss of range 1.6 cm. The stopping power of the paper as calculated from this loss of range is 1.03, which is about the same as that obtained for the RaC.

A large number of tests of the penetrating power of the excited activity of the atmosphere, made during the last two winters, shows that it never varies much, except when there is large proportion of thorium excited present, when it seems to decrease a little. A test of the penetrating power made on the excited activity of radium shows it to be the same as that of the atmosphere, the activity being reduced to about 65 per cent. by one sheet of tissue paper.

CONCLUSIONS.

1. The distance between two parallel plates for maximum current, due to the ionization caused by a uniform layer of radio-active material on the lower plate, bears a definite relation to the maximum range of the α particle from the surface of that substance.
2. When the rays are allowed to emerge in all directions to the normal, this maximum position is much less than the range of the particle, being, roughly, one half.

3. When the oblique rays are cut off in any manner, the position of maximum current increases with the value of the range, and for normal projection is equal to it.

4. There seems to be, even after apparent saturation is reached, a further decrease of current with increasing distance between the plates, the reason for which does not appear quite evident to me.

5. If maximum positions of current for two radio-active substances are observed, and the range of one is known, then the range of the other can be calculated from the ratio of the maximum positions.

6. If layers of absorbing material are placed over the radio-active material, the position of maximum current decreases proportionally to the decrease of the range, and from this decrease the stopping power may be calculated, with results agreeing very well with those of Bragg.

7. The maximum range of the α particle from the excited activity of the atmosphere is the same as that of RaC, which points to the conclusion that a great part of the excited activity of the atmosphere is always RaC, being often mixed with a portion of thorium excited and the other products of radium.

8. The method described in this paper is especially adapted to radio-active substances of low activity, and would seem useful for those experiments in which the observer wishes to find the total ionization in different gases, since the plates cannot be placed as far apart as the range of the particle, thereby ensuring better saturation for the heavy complex gases.

UNIVERSITY OF CINCINNATI,
April 1, 1908.