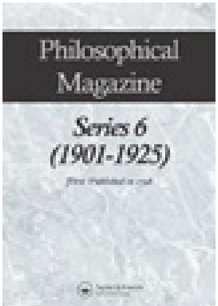

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LXXIII. On the absorption of α rays, and on the classification of the α rays from radium

Professor W.H. Bragg M.A. [a]
[a] University of Adelaide

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v is the velocity of the earth in its orbit, R the radius of earth's orbit, and δ the sun's declination.

If $A = 10 \times 10$ kilometres,

$$v/V = 10^{-4}, \qquad R = 1{\cdot}5 \times 10^{11}, \qquad \lambda = 5 \times 10^{-7},$$
$$\sin \phi = 0{\cdot}7, \qquad \cos \delta = 1, \qquad \text{then } \Delta = 0{\cdot}37.$$

To obtain this displacement would require a circuit 40 kilometres in length.

LXXIII. *On the Absorption of α Rays, and on the Classification of the α Rays from Radium.* By Professor W. H. Bragg, *M.A., University of Adelaide* *.

[Plate XVIII.]

BOTH the α and the β rays of radioactive substances are absorbed by their passage through matter; and in each case the rate of absorption depends almost entirely upon the density of the matter and not upon its nature. Apart from this striking similarity, there are important differences between the phenomena of the absorption of the two classes of rays. In a paper read at the Dunedin meeting of the Australasian Association for the Advancement of Science, in January 1904, I endeavoured to make the contrast clear, and to show that a sufficient explanation could be based on the hypothesis that the β rays are liable to deflexion through collision, whereas the α rays are not. Both kinds of rays suffer a continual diminution in speed through the expenditure of energy on ionization; but in the case of the α rays this is the only cause to which their so-called "absorption" is due. This hypothesis has many theoretical considerations in its favour, and I showed in the paper referred to that it provides a good explanation of many known facts. I have recently made a direct attempt to test its truth; and the results of the experiments are satisfactory. Moreover they show that it is possible to divide the α rays into classes: certainly two, and probably four. All the rays of the same class have the same initial velocity. Before setting out the experimental results, it will be well to recapitulate some theoretical considerations.

The β ray is an electron of high speed; and, as experiment shows, it may pierce millions of atoms without suffering appreciable deviation. It is well known that an electron flying past a similar electron which is stationary undergoes a deflexion which depends in part upon the relative velocity.

* Communicated by the Author.

If the encounter be not too close, both the deflexion and the amount of energy given by the moving to the stationary electron are inversely proportional to the energy of the former. The actual deflexion which an electron is likely to suffer in going through an atom, must not of course be calculated on the supposition that the atom consists merely of so many electrons, taken as at rest: the positive charge must be brought in, and the fact that the atom's electrons are also in motion. Indeed, it may be calculated that the more simple but defective supposition is unable to explain fully the penetrative power which the electron certainly possesses. Nevertheless, it is clear that the β rays are liable to deflexion through close encounters with the electrons of the atoms; and therefore the distance to which any given electron is likely to penetrate before it encounters a serious deflexion is a matter of chance. This, of course, brings in an exponential law. Such a law was, for example, obtained by Lenard in his original experiments on the cathode rays, which penetrated a thin aluminium window in the wall of the tube in which they were formed. By the aid of stops he isolated a small pencil of rays whose intensity, after they had traversed a certain distance of air, he measured by aid of a phosphorescent screen. If such a jet of electrons be projected into the air, some will go far without serious encounter with the electrons of the air molecules; some will be deflected at an early date from their original directions. The general effect will be that of a stream whose borders become ill-defined, which weakens as it goes, and is surrounded by a haze of scattered electrons. At a certain distance from the source all definition is gone, and the force of the stream is spent.

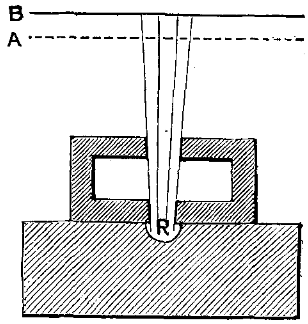
There is a second cause of the gradual "absorption" of a stream of β rays. Occasionally an electron in passing through an atom goes so near to one of the electrons of the atom as to tear it from its place, and so to cause ionization. In doing so, it expends some of its energy. It is easy to calculate from the data that Durack has given as to the number of new ions made in each centimetre, and Townsend as to the amount of energy required to make a new pair of ions, that the β ray must slow down considerably towards the end of its course; and the slower it goes, the more liable it is to deflexion.

On the other hand there is, in the case of the α ray, only one cause of "absorption." The α ray is a very effective ionizer, and rapidly spends its energy on the process. It is of course far more likely than the β ray to ionize an atom through which it is passing, because it contains some thousands of electrons and ionizing collision is so much the more probable. But a collision between an electron of the flying atom of the α ray and an electron of the atom traversed, can have very little effect on the motion of the α atom as a whole. All the electrons of the α ray which do not go very close to electrons of the stationary atom, are practically undeflected; and probably even one which does, is steadied by its connexions with its fellows.

Deductions from this hypothesis harmonize very well with observed effects. In the first place, penetration of matter must be inversely proportional to the density of the matter. In the second place, there should be no scattered or secondary radiation as in the case of the β electrons, and this is found to be true. Again, since the α rays are undeviable by collision, a stream of them should be as sharply defined after traversing a thin material plate as it was before; which Becquerel found to be the case. Again, α rays emitted at a certain speed should reach a certain distance from the parent body which is proportional to the initial energy; so that an ionization chamber should be unaffected if just out of range, and much affected if just within it, as Madame Curie found. Also the α particle should penetrate much further than the β particle of the same initial velocity, since the former only loses its motion on account of the expenditure of energy on ionization, whereas the latter is liable also to deflexion by collision. This appears to be true from the experiments of Lenard and Rutherford. It is also easy to see that even if the α particle is uncharged when it leaves the parent body, it must immediately become positive, since in traversing an atom it is just as likely to lose one of its own electrons as to take one away from the atom traversed. This agrees with Rutherford's statement made in his Bakerian Lecture. It may very well be, however, that the loss of a second electron is much more unlikely than the loss of the first.

On the other hand, it is clear that on this hypothesis no exponential law can express the phenomena of the absorption of the α rays, and that if an exponential law is found to be approximately realized, the hypothesis must furnish some explanation of the fact. This test it can, I think, satisfy.

In the first place, however, it must be pointed out that in Rutherford's experiment, wherein he showed that the absorption curve was approximately exponential, the radioactive material was scattered over the floor of the ionization chamber. But if this hypothesis is correct, it is simpler to investigate the matter in a rather different way. Suppose a narrow pencil of α rays to be emitted from the material, and confined by suitable lead stops as in the diagram. Let the pencil cross an ionization chamber AB, A being a sheet of gauze, B a metal plate. Let B be connected to an electrometer and a saturating potential applied. Let us now calculate the ionization. Suppose the α rays to be all emitted with the same velocity. Let a be their range in air, h the distance from the surface of the radioactive material to the gauze, ρ the ratio of the density of the material to the density of the air, and let x be measured down into the material from its surface.



Remembering that when an α particle comes from a depth x in the material, it only has a path $a-\rho x$ in the air, we see that all the α particles belonging to the pencil and coming from a depth $(a-h)/\rho$ will enter the chamber. If the depth of the chamber be δh, and if it be assumed that each particle makes ions whose number is proportional to the distance traversed, then we may put the ionization equal to $n(a-h)\delta h/\rho$, where n is a constant. We are here supposing that the ionization does not depend on the speed, and this is reasonable; for Durack found that each β particle moving at a speed approaching that of light made a new pair of ions in every 6 cm., whereas the slower particle of the Lenard ray made a new pair in every 2·3 cm., the air traversed being in each case at a pressure of 1 mm. The speed of the α ray varies between far narrower limits than these.

If the depth of the chamber be b, the ionization is

$$\int_b^{h+b} n\frac{a-h}{\rho}\,dh=\frac{nb}{\rho}\left(a-h-\frac{b}{2}\right).$$

This supposes that part of the stream is strong enough to cross the chamber. If not the expression becomes

$$\int_h^a n\frac{a-h}{\rho}\,dh=\frac{n(a-h)^2}{2\rho}.$$

Thus, if the ionization is measured, and a curve plotted showing its relation to h, the curve should in the former case be a straight line whose slope is nb/ρ, and in the latter a parabola.

It should be observed that in this form of experiment a certain cone of α rays is tested at various points, and the inverse square law does not enter into the question.

With the assistance of Mr. R. Kleeman I have carried out a set of experiments of this kind. Since the results obtained by Rutherford and Madame Curie would lead us to expect a simpler result in the case of polonium than radium, it would have been preferable to have employed the former, but the latter was alone available.

In the case when all the rays are initially of uniform velocity, the curve obtained ought to show, when the radium is out of range of the ionization chamber, an effect due entirely to β and γ rays, which should slowly increase as the distance diminishes. When the α rays can just penetrate, there should be a somewhat sudden appearance of the ionization, and, for a short distance of the approach, equal to the depth of the chamber, the curve should be a parabola. Afterwards it should become a straight line.

This is exactly realized; and so far the hypothesis is verified. But a further effect appears. As the radium is gradually brought nearer to the chamber, the straight line suddenly changes its direction; and indeed there appear to be two or three such changes. Thus the curve is really a rectilinear polygon, with the corners rounded off.

Moreover, the slope of the last side, representing effects close to the radium, is nearly four times the slope of the first side; whilst it seems probable that the slopes of two intermediate sides are two and three times that of the first, respectively.

For all this there is a ready explanation. The atom passes through several changes, and it is supposed that at four of these an α atom is expelled. Probably the α particles due to one change are all projected with the same speed. We ought therefore to expect four different streams of α particles, differing from each other only in initial energy. If the radium and its products are in equilibrium, the number of α particles due to each change is the same. Thus, if a_1 is the range of one stream, a_2 of another, and so on, the ionization should, when two streams reach the chamber, be

$$\frac{nb}{\rho}\left(a_1-h-\frac{b}{2}\right)+\frac{nb}{\rho}\left(a_2-h-\frac{b}{2}\right)$$

or

$$\frac{nb}{\rho}(a_1+a_2-2h-b).$$

Thus the slope of the curve should in this case be $\frac{2nb}{\rho}$, whereas if only one stream enters it should be nb/ρ. When three reach it, the slope should be $3nb/\rho$, and when four $4nb/\rho$.

In the diagram (Pl. XVIII.) the curve A represents the results obtained with an ionization chamber of depth 5 mm.; the ordinates represent distances from radium to gauze, and the abscissæ the leak per second, as shown on an arbitrary scale by a Kelvin and White electrometer. The cone of rays had an angle of about 20° ; 5 mmg. of radium bromide were used, only a small portion of which was exposed. The initial parabola and two straight lines joined by a short curve are well shown. The curve B was obtained with a smaller cone, and plotted more closely ; it shows the straight line character up to short distances from the radium. Traces of more than one corner are to be seen in it. With the view of searching more closely for these corners, observations were made as shown in curve E. Previous results seemed to show that there were three streams of nearly equal initial velocities, all finishing at about 3·5 to 4·5 cm. from the source. Hence the ionization chamber was made very shallow, only 2 mm. in depth, and readings were taken for every half millimetre of approach. The results are given in the following table, and plotted in curve E. They are at least partially successful, for there is clearly a corner at Q, and probably others at R and S. Also the slopes of PQ, QR, RS, ST, as drawn in the diagram, are in the proportion of 16, 34, 45, 65, *i. e.*, nearly as 1, 2, 3, 4.

Distance from radium to gauze.	Leak per second.	Distance from radium to gauze.	Leak per second.
4·76	2·62	4·01	4·25
4·71	2·68	3·96	4·43
4·66	2·75	3·91	4·60
4·61	2·80	3·86	4·76
4·56	2·86	3·81	4·96
4·51	2·93	3·76	5·23
4·46	3·02	3·71	5·44
4·41	3·15	3·66	5·66
4·36	3·26	3·61	5·94
4·31	3·41	3·56	6·17
4·26	3·56	3·51	6·40
4·21	3·68	3·46	6·70
4·16	3·79	3·41	6·96
4·11	3·92	3·36	7·26
4·06	4·06		

Since radium freed from its emanation exhibits at first only one disintegration process, the curve obtained from such radium should be of simpler character. This was found to be the case. The results are plotted in curve D_1, and reduced, as regards abscissæ, to curve D_2. The cone used was in this case rather wide. It is clear that the most energetic α particles are almost, perhaps entirely, absent, and the first breakdown of the radium atom is responsible for the α particle of perhaps the least range of the four.

A thin layer traversed by the α particle should reduce the ranges of all of them by the same distance. This effect is shown in curve C, which shows the result of interposing a thin film of goldbeaters' skin. With this exception the arrangements were the same as in the case of curve A. The effect is simply to reduce all the ordinates by the same quantity.

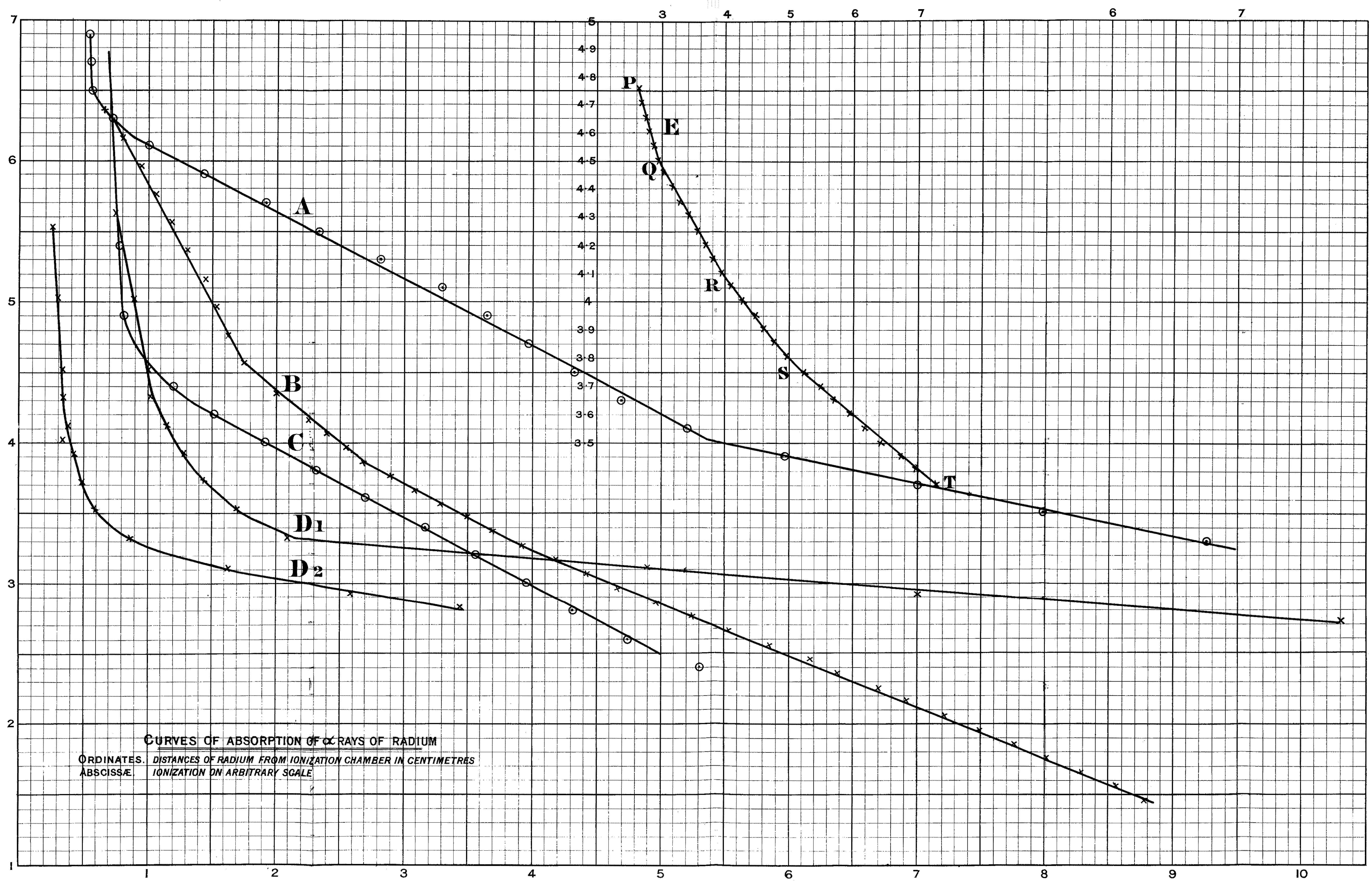
It should be added that the β and γ rays were not eliminated, but were found by frequent trial to be of small and practically constant effect at all ranges. Also the meshes of the gauze did not interfere, for when the gauze was hung by long silk cords and set swinging in its own plane, the general effects were exactly the same.

It thus appears that there are several classes, perhaps four, of α rays, which may be distinguished from each other by their difference in initial energy. The slowest are probably due to the first act of disintegration, and this is in accordance with Rutherford's experiments. Also the results go to show that the α particles are never deflected, but are "absorbed" only because they spend their energy on ionization.

Finally, we may calculate the ionization that should on this hypothesis be produced in a chamber such as Rutherford used. If the film of radium be supposed very thin; if an obliquity factor $\cos\theta$ be introduced, and if the chamber be deep enough to absorb all the rays, the ionization should be approximately:—

$$\int_0^{\cos^{-1}\frac{\rho d}{a}} 2\pi \sin\theta \cos\theta \, (a-\rho d \sec\theta) d\theta = \pi(a-\rho d)^2/a,$$

where d is the thickness of metal traversed, and ρ is the ratio of the densities of metal and air. Thus the curve for simple substances like uranium and polonium should be parabolic with respect to d, and this is nearly the case. For radium the curve should be much more complicated, and might well approach the exponential form.



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