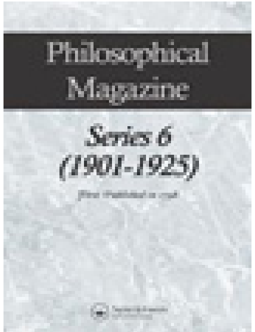


Philosophical Magazine Series 6

ISSN: 1941-5982 (Print) 1941-5990 (Online) Journal homepage: http://www.tandfonline.com/loi/tphm17

LXXIV. On the ionization curves of radium

W.H. Bragg M.A. & R. Kleeman

To cite this article: W.H. Bragg M.A. & R. Kleeman (1904) LXXIV. On the ionization curves of radium , Philosophical Magazine Series 6, 8:48, 726-738, DOI: 10.1080/14786440409463246

To link to this article: http://dx.doi.org/10.1080/14786440409463246

Published online: 08 Jun 2010.

LXXIV. *On the Ionization Curves of Radium.* *By* W. H. Bragg, *M.A., Professor of Mathematics and Physics in the University of Adelaide, and* R. Kleeman *.

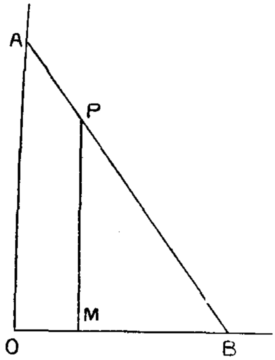
IN a paper "On the Absorption of α Rays, and on the Classification of the α Rays of Radium," contributed by one of us to this Magazine †, a description was given of a method of obtaining curves which represented the ionizing effects of α rays at various distances from their source. It was shown, also, that the general form of the curves supported the hypothesis that the α particle passes, in its flight, through the matter which it traverses, without any appreciable deviation, and only loses its extraordinary velocity when it has expended on ionization the ionizing powers which it possesses by virtue of that velocity. Such a fast moving atom must become positive, as the α atom is known to do, and as perhaps the emanation atom does when it recoils after expelling an α particle. In an experiment on the ionization curve of de-emanated radium, 5 mmg. of radium bromide were dissolved in a little water in a test-tube. Air was bubbled through the solution for many hours. The liquid was then evaporated, and the bottom of the tube on which the radium was deposited was cut off, and placed in the testing apparatus. Although the fragment of glass was of very irregular form, and the curve obtained was distorted by the want of regularity, yet after a few days an effect appeared which could be ascribed with certainty to the fact that the radium layer was thin, and that α rays from even the lowest stratum of it were effective in the ionization chamber. The curve, in fact, had a vertical portion: the interpretation of this being that for some distance of approach of the radium towards the chamber there was no increase in the ionization. A few words of explanation will make this clear.

In the paper referred to, it was shown that when a shallow ionization chamber is gradually brought closer to a source of α rays of uniform initial velocity, the rays being limited by stops to a narrow cone, and the chamber being wide enough to take in the whole cone at all distances, then the ionization increases in proportion to the amount of approach. For as the distance is diminished the curve includes α rays from deeper and deeper strata in the radium. Thus, if ordinates represent distances from radium to chamber, and abscissæ the leaks shown by a quadrant-electrometer in consequence of

* Communicated by the Authors.

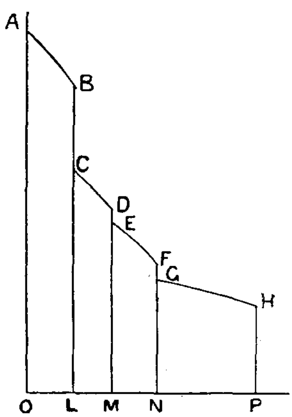
† *Supra*, pp. 719–725.

the ionization currents, then the curve of radioactive material of sufficient depth is simply a straight line such as AB. The α rays are supposed to be all of one kind, *i. e.* of one initial velocity on their expulsion from the parent atom, though not, of course, of uniform velocity when they emerge into the space above the radium. But if the layer is thin, then the ionization curve must take some such form as APM, where PM is the range which the α particles from the lowest layer possess when they emerge. If t is the thickness of the layer and ρ the ratio of its density to that of air, then ρt is equal to the difference between AO and PM. Thus part of the ionization curve is vertical.



Since this effect was found in the case of the irregular fragment of glass tube on which radium was deposited, it seemed to us probable that layers prepared with greater care would furnish valuable information. This we have found to be the case. The curves are curious and interesting. They fully bear out, so far as we have been able to judge, the hypothesis advanced in the paper already cited. They afford a novel method of examining the phenomena of radioactive change, and a confirmation of the theories and results described by Rutherford and Soddy. They have also brought to light a fact which we believe to have been hitherto unobserved. It is, that the α particle is a more efficient ionizer towards the extreme end of its course.

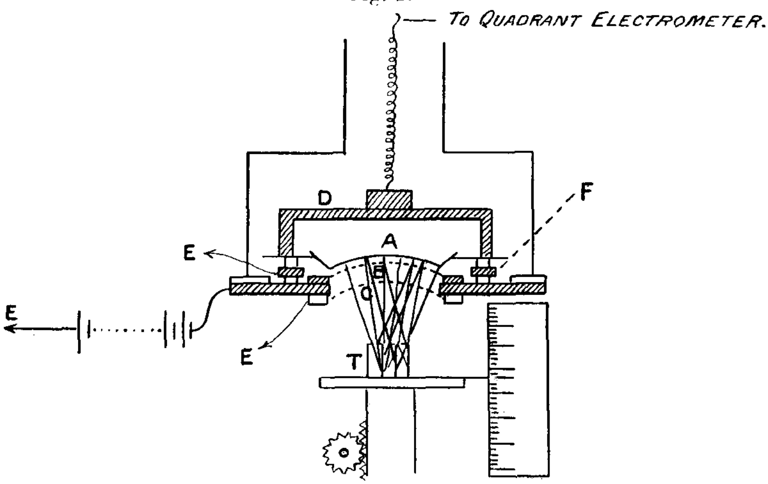
As has been already stated, the curve of a thin layer emitting one set of α rays must be of the form ABLO. But if there are four sets, as Rutherford and Soddy have shown, there should be four such figures, and the ionization curve should be of the form ABCDEFGH. Assuming the lowest part of the curve to represent the α rays emitted at the first change, as was shown to be probable in the paper cited above, then the other three ought to be nearly equal in width. For they represent the emanation and two induced activities, the latter two following so quickly on the emanation that, unless



there is a violent disturbance of radioactive equilibrium, they must emit streams containing nearly equal numbers of particles. They may, however, be much narrower than the quadrilateral GHPN which belongs to the first change. The width of a quadrilateral represents, of course, the number of particles in the stream, relative to the other streams: the longer upright side represents the range in air of particles from the top layer of radioactive material, the shorter upright side the range of the particles from the bottom layer. The sides AB, CD, EF should therefore have the same slope.

In an actual experiment the corners must be rounded off, because the ionization chamber must have an appreciable depth. Moreover, the cones must have an appreciable width. We were, in fact, obliged to use rather wide cones, in order to obtain convenient deflexions in the Kelvin and White electrometer. We bound together various little bundles of tubes of thin copper, and placed them vertically over the flat silver dishes on which we evaporated a few drops of solution of radium bromide. Fig. 1 shows the general arrangement. AB is

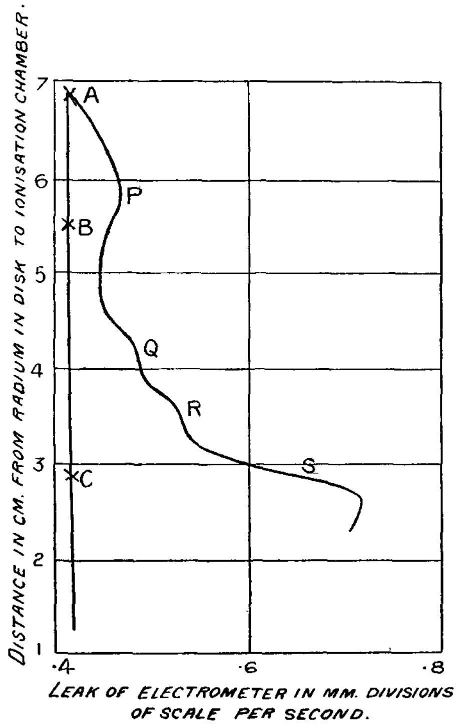
Fig. 1.



Arrangement of experiment:—Spherical ionization chamber. Conductors shaded, insulators plain. The gauze C made with B an external ionization chamber, which prevented any external ionization from entering the measuring chamber AB. It was only used occasionally, and seemed to be unnecessary.

the ionization chamber, A being thin aluminium, B a sheet of gauze. The lead plate to which the latter was soldered was raised to a positive potential of 250 to 400 volts. A was in metallic connexion through the walls of the leaden cover D with the electrometer. A and D were insulated from an earthed brass ring F on which they rested, and F was insulated from the lead plate. No leakage from the high-potential plate could therefore reach the electrometer. The chamber was sometimes flat, sometimes dome-shaped, as will be explained later. A platform supporting the dish and the tubes was placed below, and could be raised to any desired height. The dishes were about 2·4 cms. in diameter, and the tubes 1·5 to 2 cms. in height. Except in one case specially mentioned, the dimensions were so proportioned that the cones, at all distances, fell completely within the chamber. The ionization chamber was usually about 3 mms. deep : in curves shown in any one of the figures given below, it was the same for all the curves of one figure.

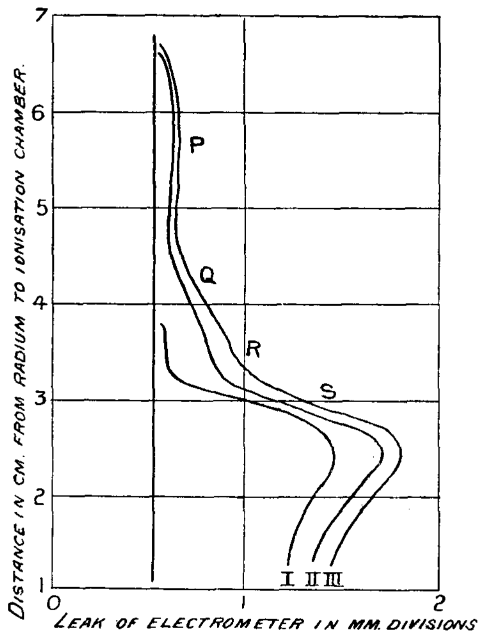
Fig. 2.—Ionization curve of dish prepared seven days before.



In fig. 2 is shown a curve obtained by the use of a dish which had been prepared seven days previously from de-emanated radium. A set of seven tubes was used each 4 mms.

in diameter and 2 cms. high. The readings A, B, and C represent values of the ionization when a piece of paper was placed over the radium so as to cut off all α rays. The most part of the leak when this was done was due to natural leak of the electrometer. This may have been due to very small amounts of induced radioactivity deposited by emanation within the apparatus ; for when we carefully excluded all radioactive material from the working room, and carried out all preparations elsewhere, the leak was greatly diminished. Much of it was of course due to β and γ rays. It will be seen from the set of readings given later and from the curves drawn in the figures that the leak was very constant during any one set of experiments ; and it may be considered as certain that all to the right of the straight line drawn in the figures represents the ionization due to α rays.

Fig. 3.—Ionization curves of dish prepared (I.) 20 hours, (II.) 90 hours, (III.) 140 hours before.



It is plain that the curve PQRS does very fairly approximate to the theoretical form. The gradual approach to this form is shown in fig. 3, where I., II., III. show the ionization of dishes at various times after preparation. In this case the portion P is not fairly represented because we employed tubes which were only 1 cm. high, so that it might be possible to bring the radium close to the chamber: at the longer ranges the curves were therefore too wide to fall completely within the entrance to the chamber. The portion S represents the ionization due to the first change, and is always in excess of the others *. It might appear that after six days P, Q, and R ought to be more nearly of the width of S; but it is probable that the emanation which is formed does not all remain occluded in so thin a layer. We know, in fact, that it is always passing into the atmosphere. When a dish has been made red hot, the radium, as Rutherford has observed, retains its emanation better. In fig. 4 (p. 732) is shown the ionization curve of a dish five days after being so heated; and it will be observed that P, Q, and R are now nearly equal to S.

The portions P and S are easily separable from the rest of the curve, and clearly represent different sets of rays. The portions Q and R are not so clearly distinguishable from each other. When the cones of rays are wide, as in the case of the experiments represented in fig. 2, the break between the two portions is not at all clear; but when the curves are narrower, as was the case in fig. 1, the break is better shown. We have been over this portion of the curve many times, using different dishes and different sets of tubes, and we have always found the dip more or less pronounced.

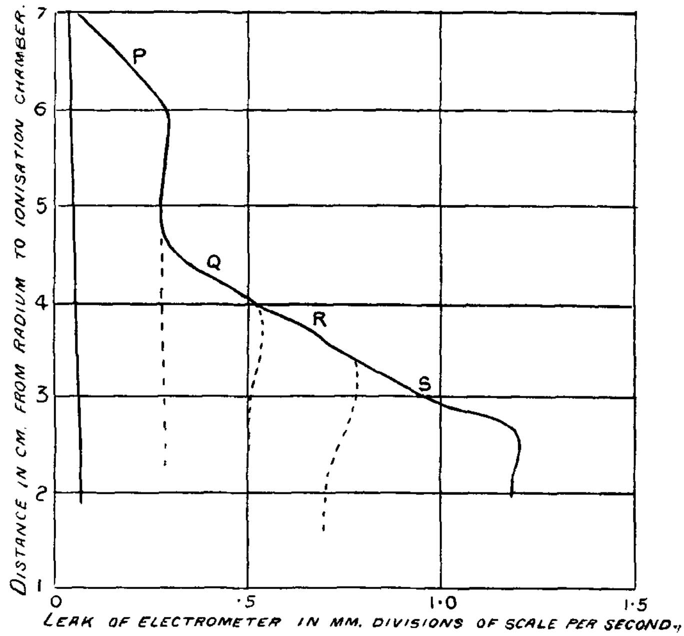
When a dish is raised to a red heat the portions Q and R disappear, whilst P subsequently decays in great part. This is what should occur supposing that Q and R represent the rays from the emanation and the first induced activity,

* We give a table of the figures from which one of the curves in fig. 3 was plotted: it would be tedious to give the figures in every case.

Distance from Radium to Chamber.	Leak per second.	Distance from Radium to Chamber.	Leak per second.
6·85	·535	Paper	·520
Paper	·520	3·65	·880
6·65	·546	3·45	·930
6·45	·560	3·25	·975
6·25	·615	3·05	1·125
6·05	·630	2·85	1·435
5·85	·630	......	1·425
Paper	·520	2·65	1·665
5·65	·640	2·45	1·770
5·45	·640	Paper	·540
5·05	·640	2·25	1·765
4·65	·620	2·05	1·690
4·45	·650	1·85	1·600
4·25	·700	1·65	1·535
4·05	·755	1·45	1·470
3·85	800	1·25	1·430

whilst P represents the rays from the last induced activity. Rutherford has shown that the rays from induced activities are more penetrating than those from the radium itself. Moreover, the rays that are represented by P go twice as far as those represented by Q or R, and do twice as much ionization. In the figure given on p. 262 of Rutherford's book, it is seen that

Fig. 4.—Ionization curve of dish five days after being raised to a red heat.

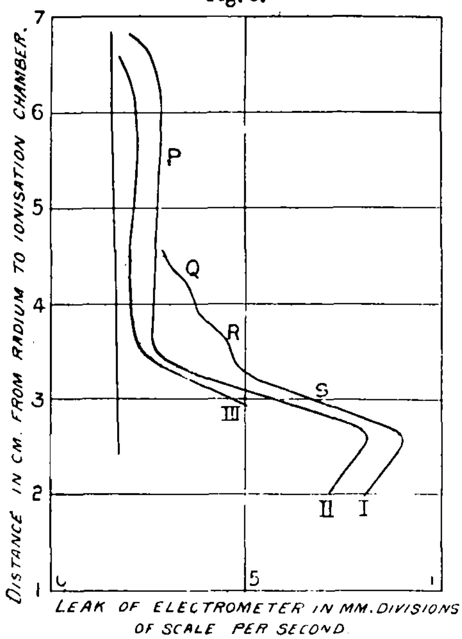


the area of the curve representing the total activity of the second induced activity is much greater than that belonging to the first. In fig. 5, I. represents the curve of a dish thirty hours before heating: it must have moved somewhat to the right before the operation. Curve II. shows the result of heating; readings were taken downwards, and occupied twenty minutes. Curve III. was obtained on going up again, and the decay of P is clearly shown.

It is not so easy to separate Q from R, and to find which is emanation and which the first induced change. Either the red heat which drives off one drives off the other also, or the induced activity dies away so fast when the emanation is removed that it is hard to catch it before it is gone. We cannot with our instruments take one reading in less than thirty seconds; and this is too slow. We have, however, received a long expected Dolezalek electrometer by this week's mail, and hope to work more quickly and accurately with its aid. Heating the dish more moderately seems to show that R is the emanation and Q the first induced activity.

It will be observed in most of these curves that there is a curious return towards the vertical axis: it is best shown in the lower portions of P and S. We do not see that there is any other than one possible explanation, viz., that

Fig. 5.



I. Curve 30 hours before heating. II. Curve after raising to red heat. III. Curve about 30 minutes later.

the α particle is more effective at the end of its course. This is not surprising. The disturbing influence of the α particle in its transit through an atom must become greater as the speed diminishes. The diminution is not likely to be great except at the end. This is indeed shown by the curves. Theoretical considerations based on a somewhat insufficient hypothesis show that the effect should be inversely proportional to the energy of the moving particle; but in the case of the β rays Durack has shown that the influence of change of speed is not so great as this. It is possible that it is only at the end, when the change of velocity is very great in proportion to what remains, that the influence of this cause is perceptible. It is also conceivable that the particle, as its speed approaches the critical value below which it loses the power of penetration, may leave its rectilinear path and be buffeted about, causing a considerable amount of ionization without getting much further away from its source.

The experiments here described show, therefore, that the α particles from the first change have a range of about 3·5 cms. in air at ordinary pressures and temperatures: those from the second induced activity have a range of about 6·7 cms. in similar circumstances, whilst the rays from the other two changes have ranges of about 4·5 cms. and 4·0 cms. respectively.

These values may, however, be modified by the state of the air, by the humidity of the radium, and by the distribution of the radioactive products in the radium.

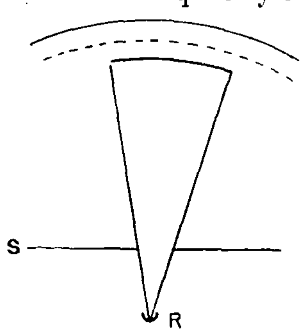
The emanation cannot be uniformly distributed through the radium; it must be somewhat less at the surface than elsewhere, for it is always leaking into the atmosphere. The substances of "induced activity" are formed from the emanation, and their distribution must be affected by the distribution of the emanation.

To this cause we are inclined to attribute small irregularities in the curves which often appear at the heads of the various sections; and which are not experimental errors because the same effects are sometimes found unchanged on going over the curve again.

In the paper referred to previously, a curve was given showing the ionization of a thick layer of radium, in radioactive equilibrium, at various distances from the source. Since the radium was not a thin layer, the curve ought to be a polygon with four corners.

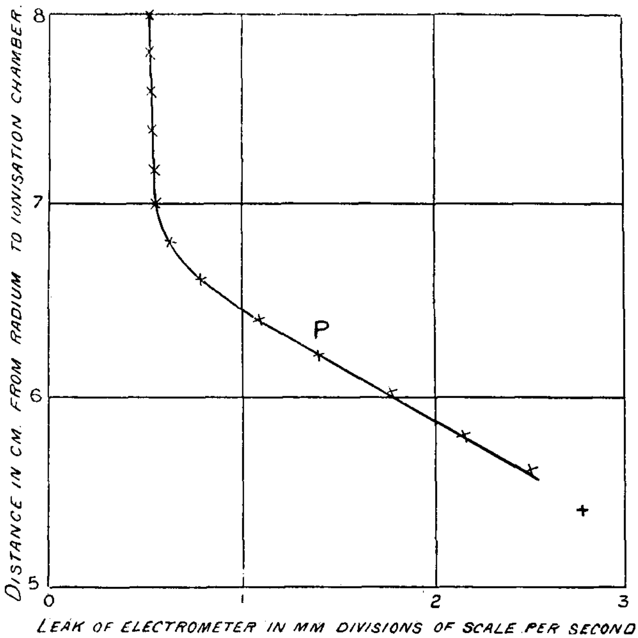
The curve showed two well-marked corners and traces of probably two others.

We have repeated this experiment, using spherical ionization chambers. If a cone of rays from a small quantity of radium R is isolated by a suitable stop S, as in the figure, the upper boundary of the radiation is a portion of a spherical surface. If an ionization chamber of about the same radius is used, it is plain that the entry of the rays into the chamber and the consequent ionization within it will be more sudden and more marked than if the chamber is made of parallel plane sheets.



With a chamber of 6 cms. radius we obtained the curve obtained in fig. 6, which shows well the first corner, at which the ionization due to the second induced activity makes its appearance.

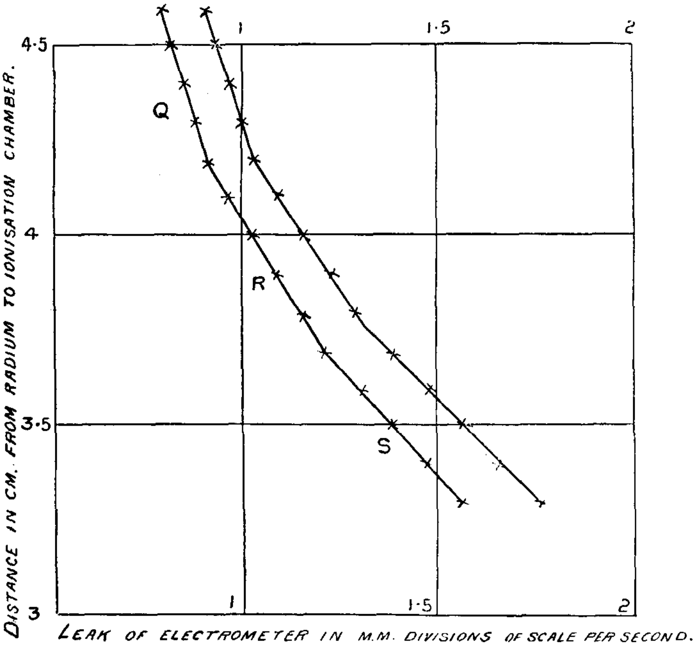
Fig. 6.



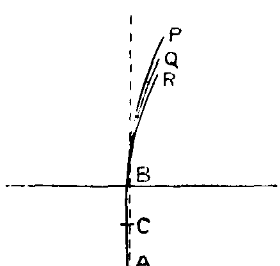
Using a chamber of 4 cms. radius we obtained results represented by the curves in fig. 7 (p. 736). For one of these the ionization chamber was shallower than for the other. These show the two bottom corners, the lowest showing the point where the rays from the first break-down make their appearance, the upper probably representing the commencement of the emanation rays. The use of spherical chambers somewhat raises the points at which the various sets of rays make their appearance, as is to be expected. The higher values should be the more correct.

A very remarkable experiment has been made and described by Becquerel, which showed that the trace of fine sheet of α rays upon a photographic plate possessed less curvature, when deflected by a magnet, at greater distances from the source. If we seek an explanation on the basis of the hypothesis already referred to, we find at once that one side of the trace ought to show this effect.

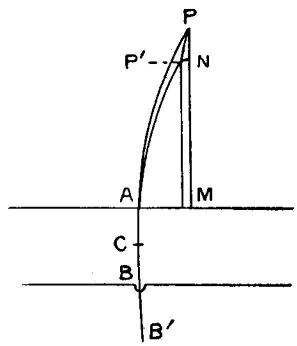
Fig. 7.—Curves showing the two lowest corners: thick layer of radium bromide.



Becquerel isolated a very narrow sheet of rays by placing the radium in a narrow groove, and confining the rays by means of a fine slit. Suppose P to be one ray, that is to say the path of one set of particles of uniform speed, coming from the top of the radium. Then Q will represent the path of a similar set from a somewhat lower stratum, R a set from still lower, and so on. These paths are exactly alike in form except that they are shorter. If a wire were bent to the shape of PBA, and pushed downwards



in the direction of its length, and kept always in contact with B and A, then PQR would be successive positions. Now the path of any one particle is more curved towards the end of its course, because its velocity diminishes. In the figure ABP is intended to be more curved at the upper end. But for this very reason the locus PQR is more curved at the lower end, as can be easily realized by means of the idea of the moving wire. The point P moves about an instantaneous centre at the intersection of the normals at B and A: approximately, therefore, about the centre of curvature of the wire at the point C. Thus the curvature of the locus PQR at the point P is therefore the curvature of the path of the ray at the point C, not at P. Hence if the locus is given, it is possible to calculate the curvature at different distances from the end of the path of a ray, which, it must be remembered, is the same for all α rays. Becquerel calculates the radii of the circles through PBA, QBA, RBA, and so on; but this is not exactly what we now require. He gives, however, a table of most careful measurements of the various points on the trace: and it is therefore possible to make an approximate calculation of the curvature at various points of the path.



Let PAB, P′AB be two different paths. Let ρ be the radius of curvature at C, a point midway between A and B. Let s be the distance of C from P, and ψ the angle made with the tangent at any fixed point on the moving wire with the vertical AB. Let PM $=y$, AM $=x$.

Then approximately P′N $=$ CP′. $\delta\psi$,

and $$\rho = \frac{ds}{d\psi} = \frac{\text{PN}}{\text{P}'\text{N}} \cdot \text{CP}' = s\frac{\delta y}{\delta x}.$$

Becquerel states the following results *:—

Values of y.	Corresponding Values of $2x$.
·1	·00719
·2	·01489
·3	·02293
·4	·03160
·5	·04028
·6	·04973
·7	·05928
·9	·07864
1·1	·09854

And AB $=2$ cms.

Hence when $s=1·1$, $\delta x=·0036$ cm., and $\delta y=·1$ cm.

Thus $\rho=1·1\times·1\div·0036=30$ cms. approximately.

* *Comptes Rendus*, cxxxvi. p. 1519 (1903).

The other values are given in the following table.

Distance from end of Path.	Radius of Curvature.
1·1	30
1·2	31
1·3	31
1·4	33
1·5	32
1·6	35
1·8	37
2·0	40

The radius of curvature should be approximately proportional to the square root of the distance from the end of the path: and the agreement is quite as close as we could expect.

This argument applies of course to the outer edge of the trace only. But it may be argued that this edge should have more character than the other because we know that the rays end with precision. The inner edge of the trace is made up of the paths of rays which gradually decrease in intensity as we proceed from right to left in the figure. It is probable also that the photographic action, like the ionizing action, is more intense at the end of the path. The figures drawn greatly exaggerate the actual deflexions; for in Becquerel's trace the length of AP is only 1 cm., and the deflexion at P only ·05 cm.

The University of Adelaide.
Adelaide, Sept. 8, 1904.

LXXV. *The Genesis of Ions by the Motion of Positive Ions, and a Theory of the Sparking Potential.* *By* John S. Townsend, *M.A., F.R.S., Wykeham Professor of Physics, Fellow of New College, Oxford; and* H. E. Hurst, *B.A., Hertford College, Oxford* *.

In a paper on the "Genesis of Ions in a Gas" (Phil. Mag. Nov. 1903) the theory of ionization by collision in a uniform field of force was explained, and a number of experiments with air and hydrogen were given in illustration of the phenomena. The apparatus which was described in that paper was used for a further set of experiments with the same two gases in order to test the theories over a wider range of pressures.

* Communicated by the Authors.