



## XX. The retardation of $\alpha$ particles by metals

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To cite this article: E. Marsden M.Sc. & H. Richardson B.Sc. (1913) XX. The retardation of  $\alpha$  particles by metals , Philosophical Magazine Series 6, 25:145, 184-193, DOI: [10.1080/14786440108634323](https://doi.org/10.1080/14786440108634323)

To link to this article: <http://dx.doi.org/10.1080/14786440108634323>



Published online: 20 Apr 2009.



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XX. *The Retardation of  $\alpha$  Particles by Metals.* By  
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ONE of the most characteristic properties of the  $\alpha$  particles is the existence of a definite range or distance through which they can travel in air or other material. This range differs for  $\alpha$  particles from different radioactive products, but is characteristic of the product. Bragg and others have shown that in the case of  $\alpha$  particles from a single product the length of the range depends not only on the density of the material penetrated but also on its chemical nature. Thus, if different gases be taken and adjusted by temperature or pressure until they are of the same density, it is found that they absorb  $\alpha$  particles by different amounts, the absorption being apparently a function of the atomic weights only. Further, Bragg has shown that if a thin sheet of metal foil is interposed in the path of a homogeneous pencil of  $\alpha$  particles in air, the range of each  $\alpha$  particle is approximately reduced by the same amount, depending on the thickness and material of the foil interposed. In other words, the individual  $\alpha$  particles are not stopped by the foil but have their velocities reduced by the same amount. In this way Bragg has determined the amounts of various substances necessary to cut down the range of  $\alpha$  particles by one centimetre in air, and has noticed that the weights per unit area necessary for different materials are approximately proportional to the square roots of the atomic weights.

It was observed, however, that in the case of  $\alpha$  particles from Ra C, for example, the air-equivalent of a metal foil, or the amount by which the foil cuts down the range in air at atmospheric pressure, is not quite the same when the foil is placed directly over the Ra C as when it is placed a few centimetres from the source †. Taylor ‡ has investigated this question more fully, and has shown that for layers of material of atomic weight greater than the average atomic weight of air, the air-equivalent decreases with decreasing velocity, or range, of the entering  $\alpha$  particles, while in the case of hydrogen, whose atomic weight is less than that of air, the air-equivalent increases with decreasing velocity.

\* Communicated by Prof. E. Rutherford, F.R.S.

† Bragg, *Phil. Mag.* vol. xiii. p. 511 (1907).

‡ Taylor, *Amer. Journ. Sci.* vol. xxvii. p. 357 (1909); *Phil. Mag.* vol. xviii. p. 604 (1909).

The results also showed that the rates at which the air-equivalents varied with the velocity of the  $\alpha$  particles were functions of the atomic weight—the rate of variation for gold, for example, being greater than the variation for aluminium.

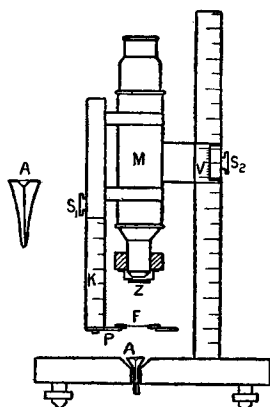
The method employed in these experiments consisted in the observation of the ionization current between two parallel sheets of gauze placed normal to a pencil of  $\alpha$  particles and near the end of the range. It is known that the ionization changes rapidly with distance near the end of the range; and the alteration in air-equivalent of a foil when it was moved between the source and the ionization-chamber was deduced from the change in the ionization current. In these experiments, however, the amount by which the foil could be moved between the source and the end of the range was limited by mechanical difficulties, and the measurements were not made at the beginning or end of the range. In particular, they were not extended to cases where the range of the particles left after traversing the foil under investigation was greater than about 9 mm. Moreover, it is known that the velocity of an  $\alpha$  particle falls very rapidly in the last centimetre of range, so that observations in this portion are important. Further, the ionization method of measuring ranges is somewhat affected by the scattering of  $\alpha$  particles, which becomes very pronounced for low velocities.

It seemed to us, therefore, that the scintillation method, by which the individual  $\alpha$  particles themselves are observed, is in some respects more direct for such measurements. Further, the scintillation method is often more convenient for determining the air-equivalents of metal foils, and it seemed of value to determine absolutely the connexion between mass per unit area and air-equivalent for different foils and different velocities of  $\alpha$  particles.

The apparatus used is shown in fig. 1. It consisted essentially of a travelling microscope M, with a zinc-sulphide screen Z, attached rigidly to the objective, so as to be in focus. As source of  $\alpha$  particles a conical tube A containing about 1 millicurie of radium emanation was used. The end of the tube was closed air-tight by a thin mica window fused on to the tube by AgCl. The air-equivalent of the mica was about .8 cm., so that a pencil of the Ra C  $\alpha$  particles emerging from the tube had a range of about 6.3 cm. A metal foil F, whose air-equivalent was under investigation, could be placed on a

platform P and adjusted to any required distance from the zinc-sulphide screen Z by means of a ratchet-screw,  $S_1$ .

Fig. 1.



The experiments were carried out in a dark room. The microscope, along with the zinc-sulphide screen, was raised until the screen was just outside the range of the  $\alpha$  particles, this adjustment being made by observation of the scintillations. Only the  $\alpha$  particles given off from the RaC deposited on the inner surface of the mica were used in this adjustment, as they have the longest range. Owing to their large number and homogeneity, however, the adjustment could be made rapidly and accurately and the position afterwards read on the vernier and scale, V. After the readings corresponding to several adjustments had been taken, the metal foil was placed in position and the end of the range again determined. The difference between the readings then gave the air-equivalent of the foil in the particular position. The position of the foil was then altered and recorded on the scale K, and the adjustment to the end of the range repeated. In this way a series of values of the air-equivalent was obtained for different positions of the foil. To obtain an average value in any position, the foil was moved in a horizontal plane and readings taken for different positions.

The following table gives an example of a set of readings:—

TABLE I.—Gold No. 5.

Weight per unit area =  $\cdot 002186$  grm. per sq. cm.  
 Pressure 774 mm. Temp.  $17^{\circ}$  C.

Reading on scale K.	Emergent range.	Mean reading on V for end of range.	Air- equivalent.
	cm.		cm.
Zero.	...	8.845	...
0.58	0.08	8.525	.320
1.00	0.50	8.460	.385
1.50	1.00	8.422	.423
2.00	1.50	8.400	.445
3.00	2.50	8.367	.478
4.00	3.50	8.335	.510
4.74	4.24	8.326	.519

The first column gives the readings on scale K. From these readings the values of the distance between the foil F and the zinc-sulphide screen Z are deduced and entered in column 2 under the heading of emergent range. The emergent range is thus the distance through which the  $\alpha$  particles have to travel after leaving the foil before completing their range. Column 3 gives the means of readings on vernier V for several determinations of the end of the range. From these, the values of the air-equivalents are calculated and entered in column 4. Two or three sets of observations were made for each foil, and the means obtained from a smooth curve drawn through the actual observations. In some cases a source was used consisting of RaC deposited on a small metal disk, so that the observations could be extended to higher ranges. The mean values obtained are given in the following table (p. 188) and shown diagrammatically in fig. 2 (p. 189). The results are expressed throughout in terms of the emergent range as defined above. The incident range can be obtained by adding to this the air-equivalent in the particular position. The air-equivalents and emergent ranges are reduced in all cases to 76 cm. pressure and  $15^{\circ}$  C.; for it has been well established by many observers that the range of an  $\alpha$  particle in any gas is proportional to the density.

It will be at once seen from the curves that the variations of air-equivalent are quite considerable and specially noticeable for low ranges. In particular, the variation of air value in the cases of aluminium and mica is almost entirely confined to the last two centimetres of emergent range. It may be noted in passing, that this variation is

of great importance in many experiments in which these substances have been used in experiments on  $\alpha$  particles. The alteration of air-equivalent tends to diminish for high ranges in all cases, although there is no indication of the values becoming constant\*.

TABLE II.

Emergent Range.	Gold.			Aluminium.		
	A.	B.	C.	A.	B.	C.
0.0	.299	.750	1.310	.769	.918	1.344
0.5	.384	.895	1.487	.820	1.015	1.422
1.0	.426	.972	1.613	.851	1.051	1.473
1.5	.452	1.021	1.681	.869	1.073	1.499
2.0	.471	1.066	1.733	.880	1.086	1.514
3.0	.502	1.118	1.822	.888	1.102	1.525
4.0	.522	1.161	1.899	.892	1.110	1.528
5.0	.533	1.195	...	.895	1.116	1.530
6.0	.547	...	...	...	...	...

Emergent Range.	Mica.		Copper.	Silver.		Tin.	Platinum.
	A.	B.		A.	B.		
0.0	.536	.575	.668	.750	1.650	1.451	2.968
0.5	.601	.937	.787	.831	1.775	1.561	3.198
1.0	.623	.964	.860	.874	1.851	1.618	3.353
1.5	.631	.977	.896	.900	1.902	1.655	3.460
2.0	.636	.984	.916	.922	1.940	1.681	3.544
3.0	.647	.990	.939	.953	2.000	1.725	...
4.0	.655	.995	.956	.977	2.054	1.760	...
5.0	.663	1.000	.972	1.000	...	...	...
6.0	...	...	...	...	...	...	...

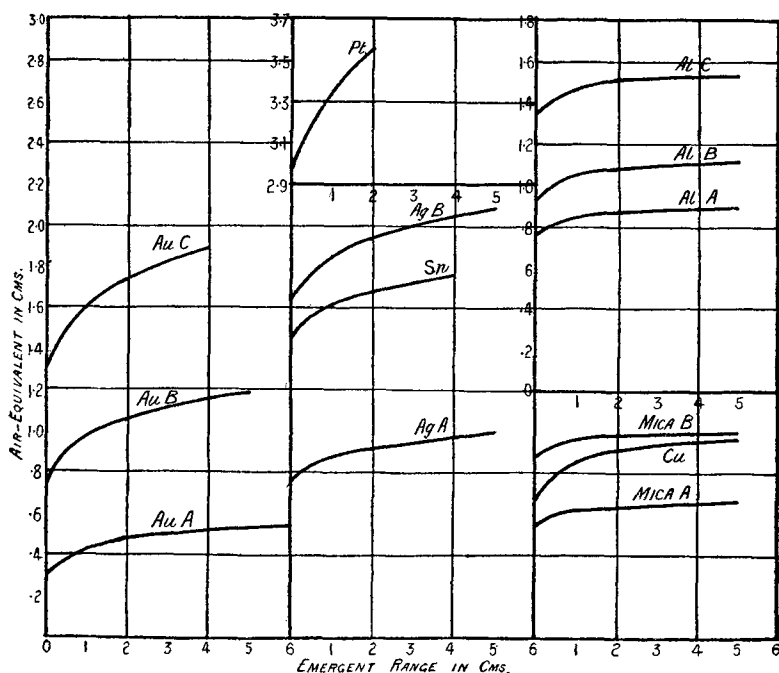
The question arises as to what is the quantity which we have called air-equivalent. As we are measuring in all cases the end of the range of the particles which have not been appreciably deflected from their path, scattering can have little influence on the results. A factor which might come in is the phenomenon which Darwin has† termed "straggling." Darwin states, "In traversing matter some  $\alpha$  particles encounter more atoms than others and go deeper into them. Thus after going a given distance the  $\alpha$  particles will have straggled out and some will be moving faster than

\* Cf. Bragg, 'Studies in Radioactivity,' p. 52.

† C. G. Darwin, Phil. Mag. vol. xxiii. p. 901 (1912).

others." Information on this point might be obtained from a consideration of the number of atoms in a particular foil which come within the sphere of influence of an  $\alpha$  particle traversing the foil. However, no accurate data are available

Fig. 2.

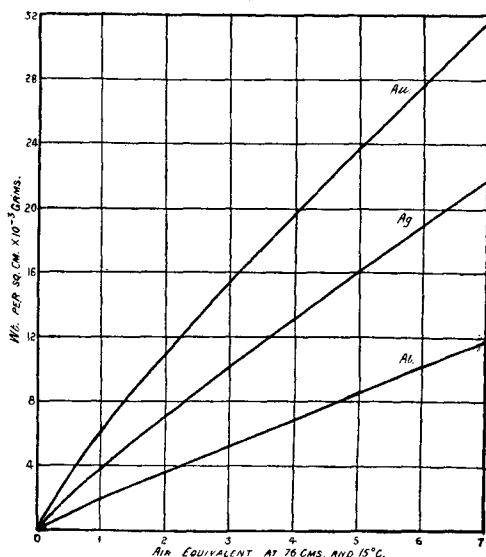


as to the atomic diameter which would of course be required for this calculation. In an experiment we made to throw light on the question, foils of aluminium and gold equivalent to about 1 cm. of air were placed at a definite distance near to the zinc sulphide screen, and their air-equivalents measured (1) when the  $\alpha$  particles previous to traversing the foil had passed entirely through air, and (2) when they had previously traversed a gold foil equivalent to 2 cm. of air. The results for both metals agreed to within  $1\frac{1}{2}$  per cent., showing that longitudinal straggling is either not very serious, or that it varies little from gold to air under the experimental conditions.

If we assume that straggling is not an important factor in the above measurements, we can deduce general expressions for the air-equivalents of any foil at any part of

the range. Starting from the end of the range, let  $x_1$  be the air-equivalent of a foil of mass per unit area  $m$ ; then the incident range is  $x_1$  cm. Let  $x_2$  be the air-equivalent for emergent range  $x_1$ , then the incident range is  $x_1 + x_2$  cm., and the air-equivalent of the combined foil of mass per unit area  $2m$  is also  $x_1 + x_2$ . Thus the air-equivalents for masses per unit area  $m, 2m, 3m$ , etc., are  $x_1, x_1 + x_2, x_1 + x_2 + x_3$ , etc. respectively. In this way by taking the values of  $x$  from the above data (fig. 2), a curve can be plotted connecting mass per unit area and air-equivalent, this being reckoned in all cases from the end of the range. Such curves are given for gold, silver, and aluminium in fig. 3. They were

Fig. 3.



determined as the means of the observations for the various foils of the same material given in Table II. The curves obtained for the different foils of the same material agreed closely, showing the approximate accuracy of the assumptions. From the mean curves given, the air-equivalents of any foil at any part of the range can be obtained. For instance, suppose it is required to find the air-equivalent of a foil of mass per unit area  $m$  for  $\alpha$  particles of incident range  $R$ . Let  $M$  be the mass per unit area necessary to completely absorb  $\alpha$  particles of range  $R$ , and  $R'$  the range for mass per unit area  $M - m$ ; then  $R - R'$  is the air-

equivalent required. The values of  $M$  and  $R'$  can be taken from the curve for the particular material used.

From the curves given above we have determined the mass per unit area per centimetre air-equivalent at different parts of the range. The results are given in Table III., and the values for the other materials for which we have not determined the curves sufficiently accurately are given between 5 and 6 cm. of air. The results are expressed throughout at  $15^\circ\text{C}$ . and 76 cm. pressure. The limits of air value are in each case reckoned from the end of the range and not from the beginning. The reason for this is that the end of the range is the only point common to  $\alpha$  particles of different radioactive products. Moreover, there is some doubt as to the exact range of Ra C. This has generally been assumed to be 7.06 cm. at 76 cm. and  $20^\circ\text{C}$ . Bragg, however, has recently given the value 7.14 cm.\* In our experiments the end of the range at which the zinc-sulphide screen was generally set corresponded to 7.04 cm. from the source (76 cm. and  $20^\circ\text{C}$ .), although an occasional scintillation could be observed up to 7.10 cm. (76 cm. and  $20^\circ\text{C}$ .).

TABLE III.

Material.	Atomic weight	Mass per unit area of foil equivalent to 1 cm. air at $15^\circ\text{C}$ . and 76 cm. ( $=m \times 10^3$ grms.).							Bragg's results.	
		0-1 cm.	1-2	2-3	3-4	4-5	5-6	6-7	Stopping power.	$m \times 10^3$ .
Aluminium...	27.1	190	171	165	164	163	162	162	1.495	1.545
Copper .....	63.6	...	...	...	...	...	2.26	...	2.46	2.21
Silver .....	107.9	3.805	3.28	3.10	3.01	2.93	2.86	2.81	3.28	2.80
Tin .....	119.0	...	...	...	...	...	3.17	...	3.56	2.85
Platinum ...	195.2	...	...	...	...	...	4.4	...	4.14	4.02
Gold .....	197.2	6.10	4.84	4.44	4.25	4.06	3.96	3.91	4.22	3.98
Mica .....	...	...	...	...	...	...	1.43	...		

In column 10 of the above table we have entered Bragg's values for the stopping powers of the materials considered. They are taken from p. 44 of his book 'Studies in Radio-activity,' and Prof. Bragg has kindly informed us that they generally refer to an incident range of about 6 cm. and

\* *Loc. cit.* p. 21.

emergent or residue range of about 3 cm. It will be noticed that our values are somewhat the greater. Our values are also in excess of those given by Taylor\*. Further, the variations of air-equivalent for the foils given by both Bragg and Taylor are somewhat more pronounced over the range they examined than are our values. The difference is probably due to the two methods of measurement. It may be convenient here to give a few points comparing the two methods of determining air-equivalents,—ionization and scintillation. In the case of the scintillation method no trouble arises from scattering, as is possible in the ionization method. In the scintillation method a much smaller area of foil, generally only about 2 sq. mm., is used than in the ionization method, where an area ordinarily not less than 0.5 sq. cm. is employed. In the case of foils which are in any way ununiform, a better average is therefore obtained in the ionization method. This can be remedied to some extent by determining the equivalence in several places. However, difficulty arises in the scintillation method when the foils under investigation contain small holes or local irregularities, for in that case there is a tendency to measure the thinnest portion of the foil. These small local irregularities were found in all the foils examined except gold. In our experiments we avoided the error to some extent by using composite sheets of many thicknesses of foils. Any serious irregularities can be instantly noticed by the fact that they allow  $\alpha$  particles of different velocities to fall on the screen, causing scintillations of different brightness.

The scintillation method, as used above, is convenient in that it does not involve any extensive apparatus. The observations are more direct and can be made much quicker than by the ionization method. A source such as we have used is not necessary, for instance a moderately strong preparation of polonium serves very well.

A theoretical investigation of the above results on the variation of air-equivalent is somewhat difficult in the absence of definite information of the change of velocity of the  $\alpha$  particles in passing through the various foils. The velocity is obviously more fundamental than the range, which is of course measured in an arbitrary substance. It appears, therefore, preferable to postpone further discussion until the completion of some experiments on velocity curves in various substances now in progress by Dr. Taylor and one of us.

\* *Loc. cit.*

We are indebted to Prof. Rutherford for his kind encouraging interest in these experiments, and also to the Royal Society Government Grant Committee for a grant to one of us, out of which part of the expenses have been paid.

*Additional Note added Dec. 23, 1912.*

It was noticed in the above experiments that when the zinc sulphide screen was moved so as to gradually approach the source of  $\alpha$  particles, a considerable illumination of the screen appeared just prior to the point where the scintillations began to appear in large numbers on the screen. Near the end of the range the scintillations themselves consist of very faint spots of light, more localized than those due to  $\alpha$  particles of high velocity. The illumination mentioned above appears uniform, and was specially noticeable in the experiments where adjustments of the end of the range were made with a gold or other metal foil placed within 1 mm. of the ZnS screen. The illumination appears to be connected with the  $\alpha$  particles and not to be due to a  $\beta$  or  $\gamma$  radiation emitted from the source. The radiation producing it can penetrate about 1 mm. of air, which seems to exclude the idea of  $\delta$  rays being the cause. A transverse magnetic field of 2500 gaussess had no appreciable influence on the luminosity, and this, in consideration of the recent experiments by Chadwick, suggests that it may be due to  $\gamma$  rays excited by the  $\alpha$  rays. Such  $\gamma$  rays would be of course much softer than any yet investigated by the ionization method, but might conceivably belong to a series similar to those investigated by Barkla.

Experiments with willemite and BaPtCy, which might be expected to give a larger relative illumination of  $\gamma$  to  $\alpha$  rays, were somewhat unsatisfactory owing to the large illumination effect of the  $\beta$  and  $\gamma$  rays given off from the source.

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XXI. *The Excitation of  $\gamma$  Rays by  $\alpha$  Rays.* By J. CHADWICK, M.Sc., Beyer Fellow of the University of Manchester\*.

AT the end of a paper† published recently the writer stated that some evidence had been obtained of the excitation of  $\gamma$  rays when  $\alpha$  rays impinge on matter. This has now been definitely established, and the preliminary part of the experiments will be described.

The source of  $\alpha$  rays used in these experiments was radium emanation with its active deposit contained in a very thin

\* Communicated by Prof. E. Rutherford, F.R.S.

† Chadwick, Phil. Mag. xxiv. p. 594 (1912).