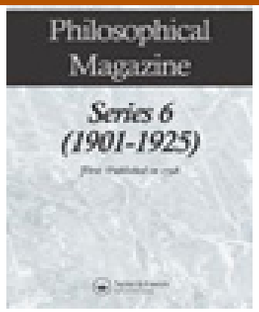

Philosophical Magazine Series 6

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

LV. The quality of the secondary ionization due to β rays

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To cite this article: W.H. Bragg M.A. F.R.S. & J.P.V. Madsen B.Sc. B.E. (1908) LV. The quality of the secondary ionization due to β rays , Philosophical Magazine Series 6, 16:94, 692-697, DOI: 10.1080/14786441008636544

To link to this article: http://dx.doi.org/10.1080/14786441008636544

Published online: 21 Apr 2009.

LV. *The Quality of the Secondary Ionization due to β Rays.* *By* W. H. Bragg, *M.A., F.R.S., Elder Professor of Mathematics and Physics in the University of Adelaide, and* J. P. V. Madsen, *B.Sc., B.E., Lecturer on Electrical Engineering* *.

THE so-called secondary radiation due to β rays has been studied by many observers. Quite recently McClelland and H. W. Schmidt have contributed important sets of papers upon the subject.

It is usual to estimate the amount or the energy of the primary and secondary streams by measuring the ionization produced within an ordinary ionization-chamber placed in the path of the rays, the principal reason being that such measurements can be made with convenience and accuracy.

But it is only under very special conditions that this procedure is legitimate, because the β particle produces more ions in traversing a given space when its velocity is small than when it is great; in other words, the ionization increases as the speed diminishes. If two streams of β radiation are to be compared by this method, it is one of the essential conditions of success that the velocities of the two streams shall be the same, or similarly distributed. This would not be necessary if the ionization-chamber were made so large that even the fastest β particles spent their ionizing powers within it, and if the whole ionization produced by a β particle might be taken as a measure of its energy. But it is usual to employ a small chamber, placed comparatively near to the source of the rays; and in this way an unfair advantage is given to the particles of smaller velocity.

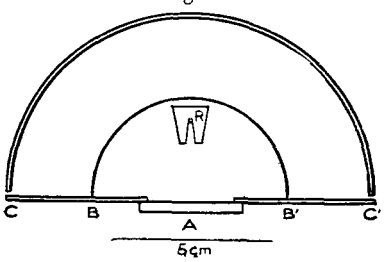
The experiments to be described in this paper show that the secondary radiations returned by different substances struck by the same primary stream are not uniform in quality, but vary from substance to substance. When the atomic weight of the substance is small, the radiation is relatively soft; it contains a larger proportion of less penetrating rays. If, therefore, the constants of secondary ionization are measured in the usual way, they are exaggerated in the case of substances of low atomic weight, as compared with those the atoms of which are heavier.

For the purpose of observing the secondary ionization due

* From the Transactions of the Royal Society of South Australia, vol. xxxi. 1907. Communicated by the Authors.

to β rays we have adopted the form of apparatus shown in the figure. The plate at A scatters in all directions the radiation which it receives from the radium at R. Nearly all the returned particles strike the hemispherical wall BB′ of the ionization-chamber, the larger hemisphere CC′ being connected to the electrometer. The usual shielding devices are used, but not shown in the figure. This arrangement gathers in the effects of all the secondary rays, so that a measurable effect is obtained, even when only a small quantity of radium is used.

Fig. 1.



When the cup or dome BB′ is made of very thin Al foil, stretched on a frame of a few fine wires, the effects obtained by placing plates of different metals at A approximate to those given by McClelland—that is to say, the curve which shows the relation between secondary ionization and atomic weight is of the same general form as McClelland's, though somewhat flatter. But when the dome is thickened by the addition of layers of tinfoil, there is a considerable alteration. The addition of tinfoil of a tenth of a millimetre in thickness is sufficient to make the curve almost linear, and the ionization is then nearly proportional to the atomic weight of the radiator.

The figures in the following table show the results of an experiment of this kind. They give the ionization currents, on an arbitrary scale, for different radiators and different thicknesses of the dome. The smaller figures are only approximate :—

	Pb.	Ag.	Zn.	Fe.	S.	Al.	C.
1. Thin Al leaf	1300	1010	798	679	484	391	166
2. Sn foil ·0065 mm. ...	1124	829	627	519	352	276	141
3. „ ·043 „ ...	414	272	189	145	85	57	21
4. „ ·080 „ ...	210	129	87	65	35	21	8
5. „ ·116 „ ...	125	71	45	32	19	12	5
6. „ ·153 „ ...	76	42	29	21	13	7	5

Assuming that the returned radiation is really due to a scattering of the primary beam, there are two ways of interpreting these results. The β radiation of radium is

heterogeneous, and consists of rays of various velocities. According to H. W. Schmidt there are a certain number of groups, each homogeneous in itself (*Ann. der Phys.* Nov. 1906). It is conceivable that the effect of varying the atomic weight of the radiator might depend on the velocity of the β particle, and that the smaller atomic weights might return a relatively small amount of fast primary rays. Assuming the velocity of the secondary rays to be of the order of that of the primary, it would then follow that the constitution of a heterogeneous primary beam would be altered by scattering, the alteration depending on the atomic weight of the scattering substance or radiator, and being of the nature indicated by experiment. Crowther (Phil. Mag. Oct. 1906) has described an experiment which appears to show a considerable effect of this kind. He found that the secondary ionization due to the β rays of UrX was much more nearly proportional to atomic weight than in the case of radium, as studied by McClelland, and he has suggested that the difference "may be due to to the presence in the radium radiation of comparatively slowly-moving β rays." On the other hand, H. W. Schmidt has recently found (*Ann. der Phys.* Bd. xxiii. 1907) that the behaviour of substances under radiation from the β rays of UrX is not very different to that found by McClelland in the case of radium. As it was important to settle this point, if we were to find the true interpretation of our own experiments, we put together the apparatus of the form used by Crowther, and repeated his experiments with UrX, using also radium and actinium. The apparatus is not very well suited, as Schmidt points out, for obtaining accurately the proportion between secondary and primary; but it gives a ready answer to the question as to whether or no the speed of the β particle has any effect.

Subtracting the effects of the carbon plate from all the others, and setting lead equal to 200, we obtained the following results :—

	Pb.	Sn.	Ag.	Zn.	Cu.	Fe.	Al.	C.
Ac	200	158	147	110	102	91	37	0
UrX	200	160	147	110	102	87·5	36	0
Ra 1	200	155	145	106·5	99·5	86·5	34·5	0
Ra 2	200	152·5	141	101·5	94·5	79	31	0
Ra 3	200	152	145	99	82	68	25·5	0
Ra 4	200	132·5	123	88	82·5	73	27·5	0

The screens used were as follows :—

Ac—Thin mica + thin tinfoil ; the two equivalent to about 10 cm. of air, and enough to cut off all α rays.
UrX—No screen.
Ra 1—Thin mica + tinfoil, the latter ·00366 cm. thick.
Ra 2—Thin mica + tinfoil, the latter ·0293 cm. thick.
Ra 3—Thin mica + tinfoil, the latter ·0586 cm. thick.
Ra 4—Thin mica + lead, the latter equivalent to ·11 cm. of tinfoil.

The figures for Ra 1, Ra 2, Ra 3, are for β rays only, the effects of γ rays having been eliminated. The figures for Ra 4 have not been corrected for γ rays, and must, indeed, refer almost entirely to rays of the latter class.

The velocity of the β rays of Ac is less than in the case of UrX. In the case of radium it varies ; some of the rays are as little penetrating as those of Ac, others more than the rays of UrX. The figures seem to show that there is a certain small dependence on the velocity of the β rays, but it is insufficient to account for the variations in quality which have been described above.

We must therefore fall back upon a second explanation, viz., that the scattered rays possess velocities which are less, on the average, than those of the primary ; and that the difference is greater in the case of the atoms of small atomic weight. This is in general accordance with other experiments and with expectation. It has been shown by Gehrcke (*Ann. der Phys.* viii. p. 81, 1902) that scattered cathode rays possess a variety of velocities, none greater than that of the primary, some, however, being equal to it. And it is not unreasonable to suppose that β rays lose more energy in being scattered by atoms of less weight or of looser building than by those which are heavier or more rigid. If, therefore, a homogeneous beam of β rays fell upon an aluminium plate, there would be found in the scattered secondary rays a larger proportion of particles of much reduced speed than if the plate had been lead.

When we measure the ionization produced in an ionization-chamber, and insert successive thicknesses of absorbing material between the radiating substance and the chamber, placing them in contact with the wall of the latter, the effect is the same as if we gradually removed the chamber to greater distances ; if we may assume that the law of absorption in air and in the given absorbing material is not greatly affected by the alterations in quality which we are considering. We

may, therefore, take the figures in any vertical column of the first table given above as showing the effects of the secondary radiation at various distances from the radiator. If we plot an ionization-distance curve the whole area between the curve and the axes is the true measure of the ionization due to the returned rays. The usual plan is to accept as a measure the one figure at the head of the column.

We find that in each case the curve may be nearly expressed as the sum of two exponentials as $Ae^{-\lambda_1 x}+Be^{-\lambda_2 x}$. Whether this has a physical meaning or not does not concern our immediate argument. Commencing with one thickness of tinfoil on the dome, the actual figures are :—

I.	II.	III.	IV.
Pb	$564e^{-60x}+560e^{-13\cdot6x}$	200	200
Ag	$492e^{-57x}+337e^{-14x}$	125	140
Zn	$409e^{-57x}+218e^{-14x}$	83	98·5
Fe	$365e^{-54x}+154e^{-14x}$	61·5	76·5
S	$264e^{-59x}+78e^{-13\cdot5x}$	35	43
Al	$218e^{-73x}+58e^{-14x}$	19·5	27·5
C	$117e^{-73x}+23e^{-14x}$	0	0

The area of the curve is given by $A/\lambda_1+B/\lambda_2$, and the relative values of the areas are placed in the third column, that of C being first subtracted and that of Pb being set equal to 200. In the last column are the corresponding figures when the amount of radiation is measured by $A+B$, *i. e.*, the ionization found when one layer of tinfoil is placed over the chamber. It is clear that there is a considerable difference.

When tinfoil is placed over the radium itself so as to cut out a large proportion of the slower β rays, the secondary radiation is also hardened correspondingly.

The figures here given are not sufficiently accurate to be taken as absolute. The measurements were made as carefully

as possible, but more numerous and more varied experiments are needed before it will be possible to map out the phenomena with exactness. But the results show clearly that—

(1) The secondary radiation from different substances, due to the β and γ rays of radium, varies in quality, those of lower atomic weight returning a greater proportion of less penetrating rays.

(2) When the less penetrating portion of a primary beam of β rays from radium is sorted out, the secondary rays also become more penetrating.

(3) In view of these considerations the ionization current due to secondary radiation, measured in a chamber of the ordinary form, does not give a simple or accurate determination of the nature of that radiation.

LVI. *Positive Rays.* *By* JOHN TROWBRIDGE*.

MY intention in undertaking this investigation was to endeavour to measure the group velocity of the positive rays by producing a standing wave ; or a stratum of maximum collisions in an exhausted tube in the space between the anode and the cathode. In the case of an oscillating circuit, if we call λ the wave-length, v the velocity of light, t the time of a half oscillation, s the distance between the anode and the cathode, v the velocity of the positive rays, we have

$$\lambda = vt, \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(Eq. 1)}$$

$$s = v't, \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(Eq. 2)}$$

$$t = \frac{\lambda}{v}, \qquad v' = \frac{vs}{\lambda}.$$

If, by tuning a circuit containing a condenser, self-induction, and the exhausted tube, the stratum of maximum collisions could be formed at the orifice in the cathode, it was thought that none of the positive rays would enter the canal region ; if, on the other hand, the positive rays swung, so to speak, with the oscillations of the circuit, a maximum fluorescence could be obtained on a suitably placed willemite screen.

The circuit was arranged as follows : a leyden-jar L, fig. 1, was charged by a storage-battery of ten thousand cells,

* Communicated by the Author.