



XLIX. The absorption of the γ rays of radioactive substances

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Then comparing corresponding terms in the expansion of (11),

$$\frac{1}{\tau_0} \int x \nu_1 y \nu_2 z \nu_3 d\tau = \frac{3 |\nu_1| |\nu_2| |\nu_3|}{(2s+3) |2s+1|} \cdot \frac{K(\nu_1, \nu_2, \nu_3; A)}{\Delta_a^s} \quad (32)$$

The particular cases $s=1$ and 2 were given in *Æ.* p. 443 without proof. Making a similar application to the angular integral (3), the type of an individual term is

$$\frac{1}{2\pi} \int \frac{l \nu_1 m \nu_2 n \nu_3 d\omega}{u_p(u_a + \mu u_p)^{s+\frac{1}{2}}} = \frac{|\nu_1| |\nu_2| |\nu_3|}{|2s \cdot \Delta_a^s|} \int_{\mu}^{\infty} \frac{K(\nu_1, \nu_2, \nu_3; \alpha) d\mu}{\sqrt{\Delta(\mu)}} \quad (33)$$

The special cases $s=1$ and 2 were also given in *Æ.* p. 445 and p. 459.

The calculation of the coefficients K is facilitated by the use of sequence equations, obtained by differentiation of (31). Thus differentiation with regard to x gives the first of

$$\begin{aligned} \nu_1 K(\nu_1, \nu_2, \nu_3; a) &= (\nu_1 + \nu_2 + \nu_3) [a K(\nu_1 - 2, \nu_2, \nu_3) + c' K(\nu_1 - 1, \nu_2 - 1, \nu_3) \\ &\quad + b' K(\nu_1 - 1, \nu_2, \nu_3 - 1)] \\ \nu_2 K(\nu_1, \nu_2, \nu_3; a) &= (\nu_1 + \nu_2 + \nu_3) [c' K(\nu_1 - 1, \nu_2 - 1, \nu_3) + b K(\nu_1, \nu_2 - 2, \nu_3) \\ &\quad + a' K(\nu_1, \nu_2 - 1, \nu_3 - 1)] \\ \nu_3 K(\nu_1, \nu_2, \nu_3; a) &= (\nu_1 + \nu_2 + \nu_3) [b' K(\nu_1 - 1, \nu_2, \nu_3 - 1) + a' K(\nu_1, \nu_2 - 1, \nu_3 - 1) \\ &\quad + c K(\nu_1, \nu_2, \nu_3 - 2)] \end{aligned}$$

If in $K(\nu_1, \nu_2, \nu_3)$ one of the indices is negative $K=0$. There is a second group of relations of which the type is

$$\begin{aligned} A(\nu_1 + 1)K(\nu_1 + 1, \nu_2, \nu_3; a) &+ C'(\nu_2 + 1)K(\nu_1, \nu_2 + 1, \nu_3; a) \\ &+ B'(\nu_3 + 1)K(\nu_1, \nu_2, \nu_3 + 1; a) \\ &= (\nu_1 + \nu_2 + \nu_3 + 1)K(\nu_1 - 1, \nu_2, \nu_3; a), \end{aligned}$$

got either by inverting the first group, or independently by the use of

$$\left(A \frac{d}{dx} + C' \frac{d}{dy} + B' \frac{d}{dz} \right) u_a^s = 2s \Delta_a \cdot x u_a^{s-1}.$$

XLIX. *The Absorption of the γ Rays of Radioactive Substances.*
By A. S. EVE, M.A., Lecturer in Mathematics, McGill University, Montreal*.

THE following investigations were made in order to ascertain whether the γ rays could be taken as an accurate measure of the total amount of radioactive matter present in a given substance. It was, therefore, necessary to ascertain whether the γ rays of various substances were absorbed to an equal degree under the same conditions.

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

When the activity of a substance is measured by the α or β rays, the effect observed depends on the density of the active substance. In the case of β rays it is necessary to cut off the α rays by screens of aluminium or some light material, and these screens absorb the β rays of the different active substances to an unequal extent, so that the β rays are not satisfactory as a test of activity.

There seemed good reason to anticipate that the γ rays would afford a most satisfactory measure of the total active matter in a given body, because these rays under the ordinary experimental conditions are but slightly absorbed by the matter from which they are emitted. It is possible to measure the rays of the substance in bulk, also, and this is an advantage when considerable quantities of ore are under investigation. Moreover, previous experiments indicated that the γ rays from thorium, uranium, and radium were absorbed to an equal extent in passing through the same thicknesses of lead. It was found, however, in the course of these experiments, that radium and thorium do emit γ rays which have identical coefficients of absorption, whilst the γ rays from uranium are weak and easily absorbed. Thus the γ ray method can be employed to great advantage in comparing radium and thorium, but uranium and actinium cannot be compared with them, or with one another.

Apparatus.—An electroscope, 30 centimetres high and 20 centimetres in diameter, made of zinc .45 mm. thick, contained the usual gold-leaf system on a long insulated central rod. The fall of potential was measured by the movement of the gold-leaf read by a microscope with a graduated scale in the eyepiece. The radioactive substance under examination was placed on a platform about 7 cm. below the electroscope. Layers of lead were introduced between the active body and the electroscope. Corrections were made in the usual manner for the natural leak of the instrument. In every case lead was used as the absorbing material.

Substances Investigated.

- (1) Radium Bromide.
- (2) Uraninite from Joachimsthal, Bohemia. (1 kilo.)
- (3) Uranium Nitrate, prepared by Eimer and Amend. (1 kilo.)
- (4) Thorium Nitrate, prepared by Eimer and Amend. (2 kilos.)
- (5) Radio-thorium, lent to me by the discoverer, Dr. Hahn, who was working in the McGill Physics Building.
- (6) Actinium, Giesel's preparation, activity about 300.

(7) Actinium, Debierne's preparation, activity about 700.

This substance, belonging to Sir William Ramsay, was kindly lent to me by Dr. Hahn.

Results.—If I_0 be the intensity of radiation on one side of a lead plate, and I be the intensity on the other side after absorption, we have $I = I_0 e^{-\lambda x}$, where x is the thickness of the plate, and λ is the coefficient of absorption. This formula, deduced from $\frac{dI}{dx} = -\lambda I$, assumes that the absorption by a thin layer per unit thickness is proportioned to the intensity. It has been found by McClelland, Wigger, and others, that in the case of radium λ is not constant over wide ranges, but the less penetrating γ rays are first absorbed, and the subsequent values of λ are therefore smaller. In the present experiments, the range of the thicknesses between which the values of λ have been obtained will be stated, without including the minute correction for the air traversed, or for the .45 mm. of zinc which formed the base of the electroscope, or for the glass vessels, such as test-tubes, in which some substances were placed.

Radium.—The results obtained for radium are in fair agreement with those found by McClelland, using the electrometer method (Phil. Mag. July 1904).

γ rays.

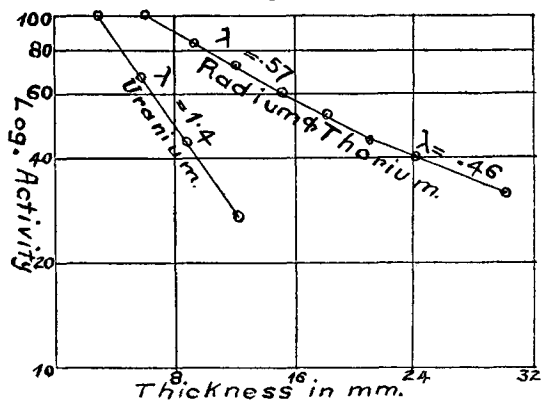
Thickness of lead in cm.	λ (cms.) ⁻¹ .
.64 to 1.21	.57
1.21 to 1.79	.56
1.79 to 2.36	.46
2.4 to 3.0	.46

McClelland found that λ varied from .64 to .44 through the same range. The result is shown in fig. 1, where the abscissæ denote the thickness of lead traversed, and the ordinates give the logarithms of the intensities as measured by the gold-leaf electroscope. It will be seen that the radium line thus plotted is not straight, and that λ has a gradual slight decrease in value.

Uraninite.—The specimen from Joachimsthal gave values of λ almost identical with those obtained from radium bromide, although in one case the radium was concentrated, and in the other was distributed through a kilogram of pitchblende. It will be found later that the γ rays from

uranium are almost absorbed by .64 cm. of lead, so that the γ rays from uraninite are mainly due to radium, and are a measure of the radium present, not more than 20 per cent. being lost by self-absorption.

Fig. 1.



Thorium.—One kilogram of thorium nitrate was sealed in a flat glass cylinder, 16 cm. in diameter. The values of λ were found to be practically the same as those for radium and for uraninite.

Radio-thorium.—It is important to note that radio-thorium gave values of λ almost identical with those for radium and thorium, but initially the rays from radio-thorium appear to be slightly more penetrating, possibly because the self-absorption is less. Dr. Hahn has shown that radio-thorium has produced Th.X and Th. Emanation, and since radio-thorium gives rays similar to thorium we have another proof, if proof were needed, of the similarity between radio-thorium and thorium. Radio-thorium has not yet been obtained in a pure state, but the eleven milligrams kindly lent me by Dr. Hahn, as measured by the γ rays, were equivalent to 1570 grams of thorium nitrate. This result is of the same order as that found by Hahn, when using γ rays, so that radio-thorium is 143,000 times more active than thorium nitrate. But it will be seen later that the latter, thorium nitrate, loses about 15 per cent. of its γ activity by self-absorption, so that radio-thorium is actually about 12×10^4 more active than an equal weight of thorium nitrate. Now radium bromide was found to be about 15×10^6 times as active as thorium nitrate, when measured by the γ rays; hence the impure radio-thorium had an activity about one-hundredth part of that of pure radium bromide.

It will be convenient to state here the actual figures obtained for the substances which have been considered up to the present point. The differences in the observed intensities are probably within the limits of experimental error, as it is difficult to place such different substances under precisely similar conditions with respect to the electroscope.

γ rays.

Total thickness of lead in cm.	Intensities.			
	Radium.	Uraninite.	Thorium nitrate.	Radio- thorium.
·64	100	100	100	100
1·21	72	73	72	75
1·79	52	53	52	55
2·36	40	41	40	42
3·00	29	30	31	31

Uranium.—The γ ray effect of uranium was found to be surprisingly small. A kilogram of thorium nitrate gave ten times the effect of a kilogram of uranium nitrate, measured through ·64 cm. of lead. The γ rays of uranium were so readily absorbed, that it was not possible to measure λ over a wide range, or with great accuracy. The mean of repeated observations between ·28 and ·57 cm., and also between ·64 and ·92 cm., gave $\lambda = 1·4$; so that the γ rays, like the β rays of this substance, appear to be homogeneous. A specimen of pure uranium gave $\lambda = 1·6$ approximately. In the case of uranium nitrate the loss of γ activity by self-absorption must be large.

The ratio of the activities of uranium nitrate and thorium nitrate was determined by measurement of the α and β ray effect from 12 grams of each substance.

α ray 0·6,

β ray 6·0,

whilst for a kilogram of each,

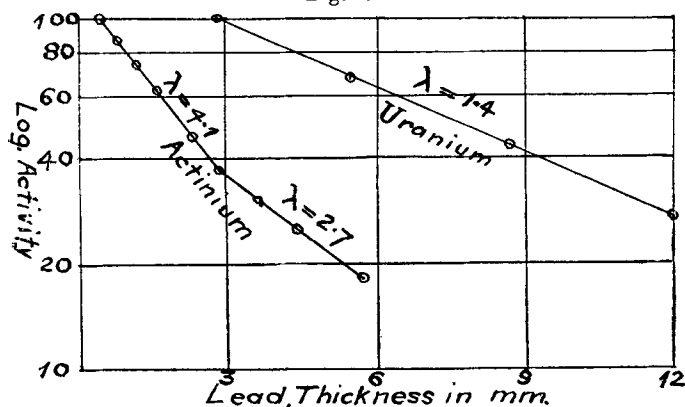
γ ray 0·1.

It will thus be seen that these methods offer no certain test for comparing the total activities of uranium and thorium or of uranium and radium, and the same difficulty will be found in the case of actinium. On the other hand, the

equality of the absorption of the γ rays of thorium and radium makes the γ radiation an accurate comparative measure of the joint quantities of these radioactive substances in two given bodies.

Actinium.—Dr. Godlewski has published in the *Philosophical Magazine* for September 1905 an account of some penetrating rays of actinium, with a coefficient of absorption equal to 4.5. He experimented with a preparation of Giesel's actinium, activity about 300, and he was able to take measurements for thicknesses ranging up to about 3 mms. of lead. Using a stronger preparation of Debierne's actinium, activity about 700, it was possible to carry Godlewski's work further. When the rays passed only through .45 mm. of the zinc which formed the base of the electroscope, the activity was measured by 2.35 scale-divisions per minute. On adding successively .15, .30, .45 mm. of lead, the observed activity fell by an exponential law, with $\lambda=10.5$. These rays probably consist partly of homogeneous β rays, and they are not plotted in the diagram (fig. 2). Further

Fig. 2.



sheets of lead, .15 mm. thick, were added, until a total thickness of 2.85 mm. was reached. The results plotted on logarithm paper gave a straight line, so that the rays are homogeneous between these limits. This result confirms Dr. Godlewski's work with Giesel's actinium, but he found $\lambda=4.5$, and in the present case $\lambda=4.1$. These values are nearly equal, for λ is a sensitive function, and the difference is probably due to experimental conditions. The two preparations of actinium have the same emanation and excited activity, and the same coefficients of absorption are therefore to be expected.

When a thickness of 2.85 mm. of lead was reached a fairly well-marked change occurred, and λ became equal to 2.7, and this value was maintained to a thickness of 4.35 mm., or even to 5.7 mm. Beyond that the effects were small and very difficult to measure, but the mean of repeated observations indicated that λ was equal to about 2 between 5.7 and 8.7 mm.

The results are shown in fig. 2*, but it may be convenient to state them in tabular form also:—

Thickness in mm.			λ (cms.)—1.
Zinc.		Lead.	
.45	+	0	10.5
„	+	.45	
„	+	2.85	4.1
„	+	5.7	2.7
„	+	8.7	2.0?

It appears, then, that actinium has two types of β rays and one or two of γ rays. The two types of β rays are both homogeneous and easily, but not equally, absorbed. It is, of course, possible that there is one type of β rays, and that all the rest are γ rays. The question can only be settled by photographs of actinium rays deflected in a magnetic field. This work is under investigation by Dr. Godlewski.

It is noteworthy that both uranium and actinium have homogeneous β rays, and that these substances give rise to easily absorbed γ rays. But thorium and radium have heterogeneous β rays, and the resulting γ rays are much more penetrating. We may fairly conclude that the high velocity β particles give rise to the more penetrating γ rays, and that low velocity β rays generate easily absorbed γ rays. And we have here a striking similarity with the generation of Röntgen rays by the cathode rays. For in a “hard” bulb, with a good vacuum, the cathode rays have a high velocity, and when these are abruptly stopped a penetrating type of Röntgen rays arises. But in a “soft” bulb, the low velocity cathode rays generate easily absorbed Röntgen rays. So also the abrupt expulsion of high velocity β rays causes

* It was not possible to exhibit all the results of this paper in a single diagram. In fig. 1 radium and thorium are compared with uranium, and in fig. 2 actinium and uranium are contrasted. The horizontal scales in the two diagrams are not the same.

highly penetrating γ rays, and the low velocity β rays produce weak γ rays. In the case of uranium and actinium there appear to be no β rays sufficiently swift to cause the most penetrating type of γ rays, for the β rays are homogeneous, and have a more or less uniform velocity.

Standard of γ Ray Measurement.

The writer suggests that one kilogram of pure thorium nitrate enclosed and tightly sealed in a thin glass vessel, 16 cms. in diameter, would form a convenient standard for testing the amount of radium or thorium in a given ore in bulk. The γ activity could be tested through a centimetre of lead, and the rays of actinium or uranium would then be practically excluded. The results of various experimenters could be readily compared in terms of such a standard.

Concentration and Distance.

If the distance of an active substance from the bottom of the electroscope is varied, the fall of potential of the gold-leaf also alters. In comparing two substances their centres of mass should be made to coincide relatively to the electroscope. The measured activity was found, roughly, to vary inversely as the square of the distance from the active substance to the centre of the electroscope.

In order to see whether the observed effect was dependent on the degree of concentration of the substance under investigation, a few pieces of pitchblende were placed, first at the centre, then at the circumference of a glass dish 16 cms. in diameter. The activity observed was three per cent. stronger when the pitchblende was all near the centre of the dish. If, therefore, the dish were full, the loss owing to the scattering would be about one and a half per cent. This loss is due to the fact that the cone of rays cut by the electroscope is different when an active particle is at the centre, and when it is at the circumference of the glass vessel.

Self-Absorption.

Two methods were employed to form an estimate of the loss of activity due to self-absorption by thorium nitrate. In the first case the electroscope was placed on a platform of lead .64 cm. thick. A kilogram of thorium nitrate was then placed beneath, and the activity measured 2.3. A small quantity of radium was placed at the centre of the mass, and the total activity was 84.4. Next the activity of the radium

without the thorium was found to be 98.9. Hence the activity of the radium was reduced from 98.9 to 82.1, by the absorption of half the thickness of the thorium nitrate. But λ for thorium and radium has the same value, and in the thorium nitrate the central layers are absorbed to an average extent. Hence the actual reading of the activity of thorium nitrate being 100, the corrected reading would be about 122.

A second method of finding the self-absorption was by the measurement of layer after layer, superadded to one another, in a circular dish, 16 cms. in diameter, adjusted so that the centre layer was at a constant distance from the electroscope. The rise of activity was indicated by a straight line when the masses were taken as abscissæ and the activities as ordinates. The absorption of a thin layer of 200 grams could not be large, and by successive approximations the self-absorption was found to be about 15 per cent. for 1 kilogram of the material placed beneath .64 cm. of lead.

These two results are in rough agreement. Moreover, the intensities found for 1 kilogram of thorium nitrate, 1 kilogram of pitchblende, 2 mg. of radium bromide, and 11 mg. of radio-thorium, followed the same curve for various thicknesses of lead. It is fair to conclude that the loss of activity of a kilogram of pitchblende, due to self-absorption and to lack of concentration, can be fully corrected by an addition of twenty per cent. to the observed value, when .64 cm. of lead cut off the β rays.

Summary.

- (1) Radium, uraninite, thorium, and radio-thorium emit γ rays which are absorbed at the same rate by lead.
- (2) For thicknesses of lead between .64 and 3.0 cms. the values of λ range from .57 to .46 for all these substances.
- (3) Uranium nitrate is weak in γ rays, and these are readily absorbed; $\lambda=1.4$ between 2.8 and 12.1 mm. of lead.
- (4) Actinium emits four types of rays:—
 1. α rays.
 2. β rays which are homogeneous.
 $\lambda=163$ (Godlewski).
 3. More penetrating rays, either β or γ .
 $\lambda=4.5$ (Godlewski).
 $\lambda=4.1$ (Eve), between .45 and 2.8 mm.

4. Most penetrating rays, probably γ rays.
 $\lambda = 2.7$ to 2.0 , from 2.8 to 8.7 mm.
- (5) A kilogram of thorium nitrate sealed in a thin glass vessel 16 cms. in diameter, placed under a layer of lead 1 cm. thick, might be adopted as a convenient standard for measuring the quantity of radium or thorium contained in a given mass of ore.
- (6) The self-absorption of the γ rays from 1 kilogram of thorium nitrate in a vessel 16 cms. in diameter and about 3.4 cms. deep, is such that about 18 per cent. should be added to the results actually obtained. When used as a standard no such correction should be made.

In conclusion I take pleasure in expressing my gratitude to Professor Rutherford for proposing the experiment, and for his usual kind interest and ever ready assistance.

McGill University, Montreal,
December 19, 1905.

L. *The Osmotic Pressures of Alcoholic Solutions.*
By P. S. BARLOW, B.A., *St. John's College, Cambridge*.*

THE earlier experimental work of this paper dealt with the use of the ordinary copper-ferrocyanide membrane for solutions in which the solvent was ethyl alcohol. Tammann† showed that ethyl alcohol could get through this membrane against the osmotic current, but did not itself seem capable of setting up an osmotic current. As there did not seem to be sufficient evidence on this point to justify the assumption that all copper-ferrocyanide membranes, however prepared, could not be used with alcoholic solutions, it was considered necessary to try the cells which had already been in use. The substance of the membrane is precipitated in the colloidal state; and the outward passage of the alcohol would appear to point to the absorption, under pressure, of the alcohol by the membrane. A large number of experiments were made. All the results were negative and in agreement with Tammann's work; but the work done seemed justified by the limited knowledge we have of the detailed properties of colloids. The inevitable small differences of preparation of the membranes might very well have produced some change in the

* Communicated by Prof. J. J. Thomson.

† *Annal. Phys. und Chem.* Neue Folge, xxxiv. p. 309.