LXVII. The absorption of γ rays

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applicable without further discussion, and here 1 per cent. difference in the atomic weights should produce a difference of $\frac{1}{2}$ per cent. in the diffusion constant.

SUMMARY.

(1) The valency of fifteen radio-elements has been determined by measuring their diffusion constants in acid solution. The valency thus measured directly agrees without exception with what would be expected from the character of the respective radio-elements determined by their non-separability from an element of known properties.

(2) Actinium sends triple charged ions into solution. This fact supports the view that actinium is the subsequent homologue of lanthanum.

(3) In alkaline solutions the short and long lived products of the emanation are present in a colloidal state, in agreement with the views of Paneth and Godlewski. Polonium, in very weakly acid and in neutral solution, is also present in a colloidal condition.

(4) The particles of the radio-colloids contain, in some cases, only two or three atoms.

(5) The possibility of separating chemically identical elements has been discussed.

My best thanks are due to Professor Sir Ernest Rutherford for the continued kind interest which he has taken in this research.

Manchester, August 1913.

LXVII. *The Absorption of γ Rays.* By S. OBA, *Hon. Research Fellow, University of Manchester* *.

IT is well known that with the usual experimental arrangements the absorption coefficient of the γ rays from radium decreases with increased thickness of absorber. This result has generally been ascribed to the heterogeneity of the primary rays. The softer constituents are supposed to suffer a greater amount of absorption and scattering, so that the beam as a whole becomes harder. It has also been observed that the γ rays scattered by matter are softer than the primary rays, and this result was explained by Florance † on the supposition that the softer constituents of the original γ rays are more easily scattered. Gray ‡, however, has

* Communicated by Sir Ernest Rutherford, F.R.S.

† Florance, *Phil. Mag.* xx. p. 921 (1910).

‡ Gray, *Phil. Mag.* xxvi. p. 611 (1913).

concluded that in the scattering of γ rays, the rays undergo a change in quality, becoming softer on scattering. The object of the present experiments was to try to investigate whether or not γ rays are changed in their quality by passing through matter. For this purpose the absorption by aluminium and iron was determined both for the primary γ rays of radium and for the rays after passage through different thicknesses of hardening materials such as copper, tin, and lead, since it is known that these metals apparently decrease the absorption coefficient in aluminium of γ rays which have passed through them.

The experimental arrangement is shown in fig. 1. The

Fig. 1.

γ rays from the source of radium emanation in equilibrium with its products passed through the hardener and the absorber, aluminium or iron, and into the electroscope below. The radium emanation was enclosed in a small glass tube, and was suspended by strings 50 cm. above the middle of the electroscope. It could therefore be considered as a point source, and practically no correction was necessary for the oblique passage of the rays through the absorption-sheets. The absorbers and hardeners consisted of plates of equal size, 20 cm. square, projecting 4 cm. beyond the side walls of the electroscope. The hardeners were placed so as to rest on the absorber. The top of the electroscope was

closed by a thin sheet of the same material as the absorbing sheets. The walls and base, however, were of lead 9.5 mm. thick to keep out soft scattered radiations. The windows consisted of glass plates 8 mm. thick, which were protected by lead cylinders 9 mm. thick. A very small sulphur bead was used for the leaf-suspension, so that constant readings of the leak were obtained. The experiments were carried out in the centre of a large room, all substances from which scattered radiation might possibly arise being at least 2 metres distant from the electroscope.

The results are given in Tables I. and II. and shown in

TABLE I.—Al Absorbers.

Hardeners.	Values of $\frac{\mu}{D} \times 100$.					
None	9.57	4.27	4.23	4.24	4.23	
2.4 cm. Cu	3.58	3.85	4.02	4.03	4.04	
2.5 cm. Sn	3.18	3.51	3.71	3.83	3.81	
.2 cm. Pb	3.54	3.75	3.85	3.96	3.99	
1.1 cm. Pb	2.92	3.21	3.41	3.61	3.64	
2.0 cm. Pb	2.77	3.15	3.23	3.41	3.48	
2.9 cm. Pb	2.67	3.01	3.22	3.30	3.38	
3.8 cm. Pb	2.52	2.92	3.15	3.27	3.35	
Thickness of Absorbers.	.2	3.4	6.6	9.8	13.0	16.2 cm.

TABLE II.—Fe Absorbers.

Hardeners.	Values of $\frac{\mu}{D} \times 100$.							
None	4.53		4.28	4.20	4.13	4.02	3.95	
7.5 cm. Al	4.58		4.21	4.08	4.02	3.97	3.94	
2.4 cm. Cu	4.16		4.11	4.02	4.01	3.93	3.92	
2.5 cm. Sn	3.56		3.84	3.89	3.90	3.89	3.89	
.2 cm. Pb	3.83		3.96	3.98	3.97	3.96	3.92	
1.1 cm. Pb	2.91	3.37	3.53	3.67	3.76	3.78	3.83	
2.0 cm. Pb	2.79	3.15	3.39	3.57	3.70	3.72	3.76	
2.9 cm. Pb	2.75	3.07	3.32	3.51	3.64	3.68	3.72	
3.8 cm. Pb	2.71	3.04	3.29	3.50	3.61	3.67	3.70	
Thickness of Absorbers.	.2	1	2	4	6	8	10	12 cm.

figs. 2, 3, 4, and 5. Table I. refers to aluminium as absorber and Table II. to iron. The aluminium used was of density 2.70 and was practically pure; and for iron, sheets of mild steel of density 7.7 were used. In the first column of either table

Fig. 2.

Fig. 3.

the material and thickness of the hardener are given. The thicknesses of 2.4 cm. copper, 2.5 cm. tin, 1.1 cm. lead were chosen, because they have about the same total absorption.

The remaining columns give the values of $\frac{\mu}{D} \times 100$, where D is the density of the absorber and μ is the absorption coefficient calculated by the equation

$$I_1/I_2 = e^{\mu(x_2 - x_1)}.$$

In this equation I_1/I_2 is the ratio of ionizations in the electro-scope when thicknesses x_1 and x_2 are used. The thicknesses are given in the bottom row of the tables.

Fig. 4.

Fig. 5.

As will be seen from the curves, the results may be summarized as follows:—

(1) The absorption coefficient in aluminium for the primary γ rays decreases gradually with increasing thickness up to 6.6 cm. aluminium, and is then practically constant up to 16 cm., while that in iron continually decreases with increasing thickness.

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(2) The material through which γ rays were first passed acts always to harden the rays. This is seen by the fact that the values for μ/D given in the first row are always greater than those in the same column in any other row. The case of aluminium hardener for thicknesses of iron between .2 and 2 cm. appears an exception, but the difference in this case is almost within the experimental error.

(3) The decrease of the value of μ/D becomes more pronounced for larger thicknesses of the absorber, but the decrease appears to tend to a limiting value. This result is seen from the value of μ/D in the same column for different thicknesses of lead as hardener. This effect becomes more marked with increasing difference of atomic weights of the hardener and the absorber.

(4) The γ rays which have been hardened become gradually softer by passing through increased thickness of absorber. Moreover, particularly in the case of iron, it is possible that the hardened γ rays may tend with large thickness of absorber to the same penetrating power as that to which primary γ rays tend.

As has already been stated, the hardening of γ rays may be ascribed to the heterogeneity of the primary γ rays and a greater amount of absorption and scattering of the softer constituents. According to the analysis of Rutherford and Richardson*, the γ rays dealt with in these experiments will be the easily absorbed rays from RaB with $\mu = .51 \text{ cm.}^{-1}$ aluminium, and the penetrating rays from RaC with $\mu = .115 \text{ cm.}^{-1}$ aluminium. After either 8.5 cm. aluminium, 1.5 cm. lead, 3.0 cm. iron, 2.7 cm. copper, or 3.3 cm. tin, the ionization due to RaB γ rays will be less than 1 per cent. of that due to the rays from RaC. We may consequently take these thicknesses as a measure of the range over which we may expect that hardening will be evident.

It will be seen, however, that the various effects cannot be completely explained as due to the soft radiations from RaB. For in the first place this will not explain the softening effect referred to in (4) above. Further, on such an hypothesis it follows that when the soft RaB rays are removed by absorption, the absorption coefficient of the remaining radiation should be the same and independent of the, so-called, hardener.

It must be remembered that the absorption coefficient μ being calculated from the equation

$$I_1/I_2 = e^{\mu(x_2 - x_1)},$$

* Rutherford & Richardson, *Phil. Mag.* xxv. p. 721 (1913).

the effects of both true absorption and scattering are superposed. However, it is generally supposed * that the softer constituents of γ rays are more easily scattered than the harder ones, so that scattering gives no ready explanation of the softening obtained in these experiments.

It is possible that softening may be due in some way to the effect of excited γ rays in the absorption-sheets—*i. e.*, a transformation of part of the original γ rays. Such excited rays will be in all cases softer than the rays producing them, and the issuing rays will reach a state of equilibrium when the proportion of primary rays and of softer excited rays has a certain definite value. In the case of aluminium absorber, for example, when the rays have previously passed through a hardener of high atomic weight, they will have been robbed of the greater part of the soft constituents, so that as they pass through the aluminium more and more soft radiation will be excited until equilibrium is established. The absorption coefficient should therefore increase to a constant value. The numbers given in the tables tend to support this conclusion.

The question next arises as to whether, when this supposed equilibrium has been established, the absorption coefficient has the same value independent of the hardener. Leaving out of consideration the rays from RaB, this obviously ought to be the case if the rays from RaC are strictly homogeneous, *i. e.* consist of rays of one wave-length only. If the rays, for example, consist of two homogeneous beams of nearly equal wave-length, as the experiments of Moseley † suggest, the hardeners might be expected to show some selective effect which would permanently alter the absorption properties of the beam. The range of thickness used in these experiments is not large enough to decide the question definitely, although the results with At appear to be in favour of the latter hypothesis.

In conclusion I desire to express my best thanks to Professor Sir Ernest Rutherford, at whose suggestion these experiments were carried out.

* Florance, *loc. cit.*

† Moseley, *Phil. Mag.* xxvi. p. 1024 (1913).