ABSORPTION OF THE β-PARTICLES FROM SOME OF THE RADIOACTIVE SUBSTANCES BY AIR AND CARBON DIOXIDE.

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IT is a well-known fact that the absorption of the β-particles from some of the radioactive substances follows an exponential law, at least over a large part of the absorption curve when the ionization method of measurements is used. It was shown by Kovarik and McKeehan[1] by a statistical method that the numbers of β-particles are not diminished exponentially when the β-particles pass through matter, this, however, does not decrease the value of the ionization method because of its simplicity in application in checking up β-radiations of any radioactive material. In the ionization experiments, the absorbing material used is generally solid material, and usually, aluminium or tin foils. The solid foils can never be obtained uniform in thickness, if thin foils are desired, as, for example, in studying soft β-radiations. It would, therefore, seem desirable to devise a method of investigation of the absorption of the β-particles, by the ionization method, in which the absorbing material would be a gas which would permit uniform layers of absorbing molecules and also give possibilities of use in the cases where layers of relatively few absorbing molecules might be desired. This was done and the exponential law was found verified for gases for the rays for which the absorption curve was exponential for aluminium. A determination of the absorption coefficient was then deemed also desirable; likewise an investigation of the relation of activities of the soft and hard radiations in case of some of the radioactive substances.

The first determination of an absorption coefficient in a gas is due to Eve[2] who obtained a value for the coefficient of absorption of the heterogeneous radium *C* rays in air. His method consisted in measuring the ionization produced in a β-ray electroscope when the source of radiation was placed at different distances from the electroscope and applying the inverse square law. This method is readily applicable to strong and penetrating radiation where the distances may be so great that the size

[1] Kovarik, Alois F., and McKeehan, L. W., Phys. ZS., 15, p. 434, 1914.

[2] Eve, A. S., Phil. Mag., S. 6, 22, p. 8, 1911.

of the electroscope and the general disposition will affect the results in only a slight manner. He obtained $\mu = .0045$ cm.$^{-1}$ air. Shortly after that, the writer[1] published abstracts of the preliminary work. Since then, a paper on the absorption of the β-particles of uranium in air by Florance[2] has appeared.

In a former investigation[3] of the β-radiations by the writer, it was first pointed out that the soft radiation of Radium D, E, F is most likely due to radium D. This was soon confirmed by v. Beyer, Hahn, and Meitner[4] by a photographic method applied to the magnetic spectra. They showed in fact that radium D has two line spectra, one corresponding to rays having an absorption coefficient of about 300 cm.$^{-1}$ aluminium and the other very much softer. In the present investigation the method used made it possible to separate these two radiations by studying their absorption curves in air.

METHOD AND APPARATUS.

The method employed is, in fact, the same in principle as that used by Bragg and Kleeman in their study of the ionization curves of the α-particles. An ionization chamber 2 mm. deep (AB, Fig. 1) consisting of a circular brass plate 7.4 cm. in diameter, connected electrically by a pair of quadrants of an electrometer, and a thin aluminium foil, 0.003 cm. thick, connected to one end of a high potential battery, whose other end was to earth, was fixed in position. A guard ring in the same plane as the circular plate of the ionization chamber and held rigidly to it by means of amber bridges with a space of 1 mm., helped to form a uniform field in the ionization chamber. The source of β-rays was placed at D on a central axis perpendicular to A and at any distance not greater than 10 cm. from the ionization chamber. Between the source and the high

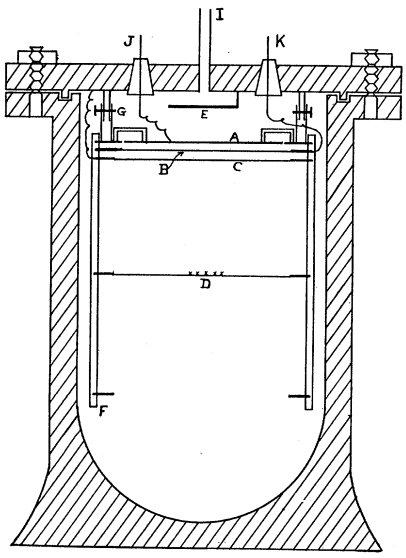

Fig. 1.

[1] Kovarik, Alois F., PHYS. REV., XXXIV., p. 142, 1912; PHYS. REV., N. S., 3, p. 150, 1914.
[2] Florance, D. C. H., Phil. Mag., S. 6, 25, p. 172, 1913.
[3] Kovarik, Alois F., Phil. Mag., S. 6, 20, p. 849, 1910.
[4] v. Beyer, O., Hahn, u. Meitner, Phys. ZS., 12, p. 378, 1911.

potential plate B was another foil (.0003 cm. aluminium) connected to earth, forming an ion trap preventing disturbances should the foils of aluminium have small holes. The foils of B and C were attached to rigid iron rings which along with the guard ring of A were held in position by being set into slits in 3 ebonite rods, F. The whole was attached by means of screw connectors, G, to the removable cover of the apparatus cylinder for the gas. This cylinder was a strong brass holder 18 cm. deep, and 10 cm. in diameter. The gas entered through I from a tank containing the gas at high pressure. A gas manometer consisting of air enclosed in a long (130 cm.) capillary glass tube by a thread of mercury 5 cm. long was in communication. The capillary tube was carefully calibrated and the pressures were deduced by Boyle's law. E was a metal shield protecting the ionization chamber from the stream of gas from I. The air used was dry, whereas the carbon dioxide was the ordinary commercial product and quite moist. The quadrant electrometer used was of the Erikson-Dolezalek type.[1] On account of the weak material available in some cases and on account of the small volume of the ionization chamber a sensitive instrument was necessary. The Erikson method of charging the needle makes it a simple matter to use the finest quartz fibers available without altering their coefficient of torsion. The sensibility of the instrument used was 2,500 mm. per volt, the scale being 150 cm. from the mirror of the instrument.

In some of the experiments the rate method of observation was employed but on account of varying electrical leaks depending on potential of the charge conveyed to the quadrants, the null method of Townsend[2] was substituted and found far more satisfactory.

The β-particles coming from D radiate in all directions and some pass within the frustum of the cone defined by the plane circular source used at D and the ionization chamber. The particles are subject to absorption by the gas between B and D and also by the gas within the ionization chamber itself. If the pressure of the gas in the vessel is increased, the absorbing medium is proportionately increased in quantity but the ionization is also increased. The increase in ionization is, within the pressures used (20 atmospheres), proportional to the pressure. Consequently, the observed ionization currents at the various pressures were reduced to what they would be at one atmosphere. By plotting these values against pressure in atmospheres, one obtains an absorption curve and a coefficient of absorption per atmosphere of the gas used can be deduced for any particular disposition of the source D. To compare

[1] Erikson, H. A., PHYS. REV., N. S. 1, p. 253, 1913.
[2] Townsend, J. S., Phil. Mag., S. 6, 6, p. 598, 1903.

results, it is necessary to know the depth of the absorbing layer of gas, and since the β-rays are not parallel but radiate in all directions, it is necessary to obtain the mean distance traversed by a β-particle through the gas. Disregarding deflections in its path this distance would constitute the mean path of the β-particles. This distance was obtained graphically very readily, the ionization chamber being circular, the source being also circular and symmetrically placed below the chamber. Since the gas in the ionization chamber also absorbs the radiation, the measurements were made to a plane midway between the plates of the ionization chamber. The coefficient of absorption could then be deduced in $cm.^{-1}$ or $(gm.\ per\ cm.^2)^{-1}$ of the gas used.

It is to be noted that the potential difference between A and B must be sufficient for a saturation current. For the distance of 2 mm. between A and B, 2,000 volts is sufficient for the pressures used.

Since the β-particles are readily deflected in their course, and consider-ab'y reflected by brass, some rays might enter the ionization chamber by a roundabout way. To prevent such reflected rays having effect in this manner a cylinder of paper, which reflects[1] only a small percentage of the incident radiation, was wrapped around the ebonite rod F before inserting the apparatus into the vessel. The effect of the incident radiation then became negligible.

With the entrance of a gas into the vessel a charging up of the amber insulation plugs took place and time had to be allowed before consistent readings could be taken. This was, of course, a source of annoyance especially in the case of rapidly disintegrating substances.

The absorbing value of the thin aluminium foil B and C had to be taken into consideration in the case of soft rays. The natural leak of the apparatus at different pressures was obtained and readings with the rays were properly corrected.

RESULTS.

It was first shown that the radiations which are absorbed exponentially by aluminium are also absorbed exponentially by gases. The curves of Fig. 2 show the result for the rays of radium E absorbed by air and carbon dioxide, the mean path being 10.4 cm. These logarithmic curves show perfect resemblance to similar curves with aluminium, which are well known. The same thing was found with the other radiations investigated, all giving a straight line for that part of the logarithmic curve which was found to obey the exponential law with aluminium absorbing foils.

In order to see whether the mean path obtained graphically is correct,

[1] Loc. cit.

observations were made on the absorption coefficient of the β-rays from radium *E* when the source was placed at different distances from the

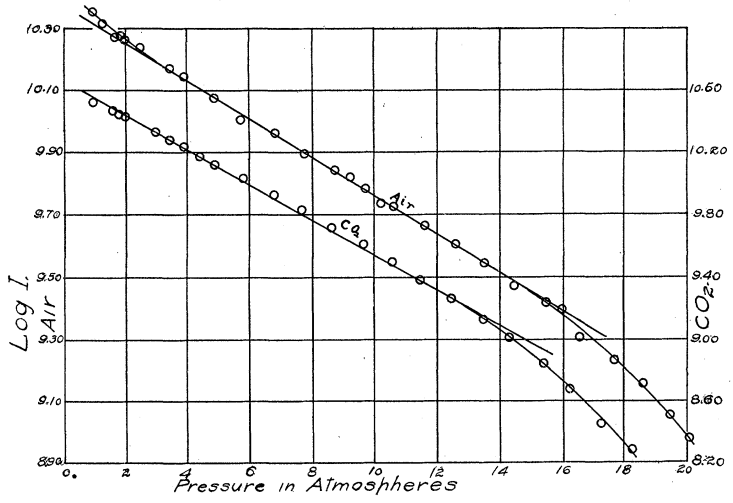

Fig. 2.

ionization chamber. The results are given in Table I., where the coefficients of absorption expressed per cm. of air are entered against the

TABLE I.

Radium D, E, F at Different Distances from the Ionization Chamber.

Mean Path of the β-Particles in Cm. of Air.	Absorption Coefficient in Cm.$^{-1}$ Air at 1 Atmosphere and 22° C.
10.60	0.0151
5.36	.0145
3.00	.0149
2.31	.0150
1.64	.0160

mean path obtained graphically. The agreement is good except for the shortest path in which case the rays varied much in the length of path.

The radioactive substances used were radium *D*, *E*, *F*, one specimen chemically separated and another prepared from radium emanation. These gave the radiations from radium *E* and also from radium *D*. The actinium active deposit on thin aluminium was used for actinium *B* and *D*, and thorium active deposit for thorium *B* and *C* + *D*. Uranium *X* chemically separated and also uranium oxide were used for the soft and hard rays of UX_1 and *UX*. The soft radiations were separated from the hard radiations by subtracting the latter from the observed results, calculating their values for low pressures according to the exponential law. There was no difficulty in doing this when observa-

tions were carefully carried through with small pressures and when the mean path was short. The results are given in Table II., in which the values of the coefficients are expressed for air and carbon dioxide both in cm.$^{-1}$ at one atmosphere and 22° C. and also in (gm./cm.^{2})$^{-1}$.

TABLE II.

Coefficient of Absorption.

Source of β-Particles.	Cm.$^{-1}$ Air 1 Atm. and 22° C.	Air (Gm./Cm.^{2})$^{-1}$.	Cm.$^{-1}$ CO_2 1 Atm. and 22° C.	CO_2 (Gm./Cm.^{2})$^{-1}$.
Radium E	.0152	12.70	.0297	16.31
Actinium C+D	.0091	7.60	.0175	9.62
Thorium C+D	.0068	5.68	.0129	7.08
Uranium X_2	.0065	5.43	.0114	6.26
Uranium X_1	.12	100.	.23	126.
Radium D	.097	81.	.183	101.
Radium D (very soft)	.64	535.	1.69	930.
Thorium B	.090	75.	.142	78.
Actinium B	.31	260.		

In order to obtain an idea of the relative ionizations produced by soft and hard rays when both are present, extrapolation exponentially to zero thickness of the absorber was carried out, and the ratio of the ionization produced by the soft rays to that produced by the hard rays in air at one atmosphere was averaged for the particular radiations in the various experiments. These values are given in Table III. It will be noted that

TABLE III.

Relation of Ionizations in One Atmosphere of Air of Soft Radiations to Hard Radiations Reduced by Extrapolation to Zero Absorber.

Sources of β-Particles.	Ratio of Ionizations.
$\frac{\text{Radium D}}{\text{Radium E}}$ (more penetrating)	0.30
$\frac{\text{Radium D}}{\text{Radium E}}$ (very soft)	2.4(?)
$\frac{\text{Actinium active deposit (soft)}}{\text{Actinium active deposit (hard)}}$	1.14
$\frac{\text{Thorium active deposit (soft)}}{\text{Thorium active deposit (hard)}}$	2.86

the value for the soft thorium radiation compared with the hard is higher than that usually given. The value for the very soft radium *D* radiation must be taken with reserve, because the extrapolation was too great, but that for the more penetrating radiation of radium *D* seems satisfactory; the same is true of the relation of the soft to the hard radiation of actinium active deposit.

CONCLUSIONS.

1. A method depending on the change of pressure of a gas was devised for measuring the absorption of the β-particles. This consists of measuring the ionization in a shallow ionization chamber placed at a fixed distance from a source of radiation within a high pressure vessel: reducing the ionization readings at various pressures to that at one atmosphere of pressure, measuring graphically the mean path of the β-particles, and then, in the usual manner, deducing the coefficient of absorption.

2. It was shown that the absorption curves in gases are the same in shape as those obtained with aluminium foils.

3. It was shown that the graphical method of obtaining the mean path is correct.

4. Values of the absorption coefficients in air and carbon dioxide of the β-particles of some of the radioactive substances were obtained.

5. Relation between the ionizations of the soft and the hard radiations were computed by extrapolation to zero absorber. This was done for the two soft radiations of radium *D* compared with the effect of the radiations of radium *E*; soft and hard rays of the actinium active deposit; soft and hard rays of the thorium active deposit; soft and hard rays of uranium *X*.

In conclusion I desire to express my deep gratitude to the committee of the Minnesota Research Fund for allowing funds to procure some of the necessary apparatus and material to carry out this work.

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