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XXI. *The Absorption of γ -Rays by Gases and Light Substances.**By J. CHADWICK, B.Sc.*

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At the present time all information on the absorption of the γ -rays by gases is indirect, for the absorption coefficients are deduced either by assuming the density law or from the observed absorption coefficients of gases for β -rays. Values obtained in this way are, however, rather indefinite, and vary among themselves by about 50 per cent. For example, the experiments of Russell and Soddy indicate an absorption coefficient for air of about $0.000056 \text{ (cm.)}^{-1}$, while Eve,* from the absorption of the β -rays in air, obtains the value $0.000032 \text{ (cm.)}^{-1}$. As a fairly accurate knowledge of the absorption coefficient of air was required in the method of comparison of radium standards described in a previous Paper, a special series of experiments was made to determine the absorption of γ -rays by the gases hydrogen, air, and carbon dioxide. The investigation was extended to include the absorption of γ -rays by a few light solids and by some solutions. As is well known, the value of the absorption coefficients for most bodies depends on the thickness of lead traversed by the γ -rays before passing into the ionisation chamber. The absorption coefficients are given for two thicknesses of lead in common use—viz., 3 mm. and 1 cm.

Absorption by Air.—In determining the absorption by air two methods were employed. In the first liquid air was used, and the absorption produced was measured by means of the balance method described in the previous Paper. In most of the experiments the liquid air was contained in a $\frac{1}{2}$ litre flask of about 10 cm. diameter, and in others in a cylinder of 3 cm. diameter. The diameters of the cylinder and flask were determined by finding the absorption of γ -rays produced when full of water. The vessel containing the liquid air was placed immediately in front of the radium tube. The density of the liquid air was determined by taking a sample of the saturated vapour just above the surface of the liquid and analysing it. The density of the liquid air can then be found from the data given by Behn and Kiebitz ("Ann. d. Physik," 1903). The percentage of oxygen in the vapour varied from 20 per cent.

*Eve, "Phil Mag.," July, 1911.

to 70 per cent., corresponding to a range of density between 0.98 and 1.11. A large number of measurements were made and consistent values were obtained. With a thickness of 3 mm., the values found for μ/D , where μ is the absorption coefficient measured in the usual way and D the density, varied between 0.047 and 0.050, with a mean of 0.0484 (cm.)⁻¹. This is probably correct to within 0.5 per cent. With a thickness of lead of 1 cm., the mean value of μ/D was found to be 0.0465 (cm.)⁻¹.

In the second method air compressed into a long iron cylinder was used. As it would have been very inconvenient to move the iron cylinder for each reading, the balance method was abandoned and the ordinary rate method was used. The change consisted simply in disconnecting the vessel B. The radium tube was placed at one end of the cylinder and the ionisation chamber was at the other end.

The rate of movement of the electrometer needle was observed when the air in the cylinder was at atmospheric pressure, at 60 atmospheres and at 90 atmospheres. The cylinder used was 120 cm. long, and the iron walls were nearly 3 cm. thick. The pressure gauge used in these experiments was carefully calibrated with a standard gauge made by Schäffer and Budenberg. For a thickness of lead of 3 mm. the value obtained for μ/D was 0.048, and for a thickness of 1 cm. μ/D was 0.046. The error in these experiments is probably within 2 per cent. It will be seen that the above values agree very well with those obtained for liquid air.

Absorption by Carbon Dioxide.—The absorption coefficient of carbon dioxide was determined in the same manner. The pressures used were 23, 33 and 50 atmospheres, and the temperature varied from 13°C. to 17°C. The density of the gas at a temperature of 15°C. and pressure of 50.4 atmospheres was found from a table given by Amagat ("Comptes Rendus," 1892). With a thickness of lead of 3 mm., μ/D is 0.051, and with a thickness of 1 cm. is 0.047.

It will readily be seen that the measurement of the absorption coefficient of carbon dioxide at different pressures would afford a very simple and convenient method of determining the isothermals. All the necessary data can be obtained quickly and accurately, and the only difficulty is to keep the temperature constant.

An attempt was made to determine the absorption coefficient of solid carbon dioxide, but serious difficulties were encountered.

The carbon dioxide snow was put in a large liquid air cylinder and pressed together as tightly as possible, but the density under these conditions was about 0.8, while Behn ("Ann. d. Phys.," 1900) found that the real density of the snow is 1.53. Further, the snow evaporates rapidly from the sides of the cylinder, and thus the thickness of the carbon dioxide is continually decreasing. Such results as were obtained confirmed the values given above.

Absorption in Hydrogen.—As the absorption of the γ -rays by hydrogen is extremely small, a slight modification of the balance method was employed. The ionisation chamber A of the previous Paper was replaced by a cubical lead box, whose sides were 3 mm. thick. The cylinder containing the hydrogen and the radium tube were placed against one face of the box in the same way as before, and a balance was obtained by moving a tube containing a small amount of radium along a scale placed against another face. The cylinder used was an ordinary hydrogen cylinder 150 cm. long, with walls nearly 4 cm. thick. The pressure of the hydrogen was 127 atmospheres. Several measurements were made, and the value of μ/D was found to be 0.047. This is for a thickness of lead of 3 mm. This is probably correct to 5 per cent., allowing for possible error of 2 to 3 per cent. in the measurement of the higher pressures, for the pressure gauge was not standardised above 60 atmospheres. The absorption coefficient for a thickness of lead of 1 cm. was not determined, as the effect to be measured was too small. Even with a thickness of 3 mm. the ionisation contributed by the fixed radium tube was only about a third of the total ionisation, and with 1 cm. of lead would only be about a fifth.

The value $\mu/D=0.0484$ found above for air gives $\mu=0.0000624$ (cm.)⁻¹ for air at 0°C. and 760 mm. pressure, and $\mu=0.000059$ (cm.)⁻¹ at 15°C. and 760 mm. pressure.

After these measurements were completed, a Paper by Hess appeared ("Phys. Zeit.," November, 1911), in which he finds μ for air to be 0.000045 at 22°C. and 750 mm. pressure. His method consists in measuring the relative ionisation produced by a quantity of radium placed at different distances from a Wulf's electroscope, and assuming that the deviations from the inverse square law were due to absorption of the γ -rays by air. He used distances varying from 10 metres to 90 metres, and obtained results varying by about 20 per cent. He ascribes these differences to variations in the natural leak of

the electroscope during the observations. The method is not very suitable for an accurate determination, as the effect to be measured is rather small, and the ratio of the ionisation currents measured is about 100 to 1.

In his Paper on the number of ions produced by the γ -rays of radium C, Eve ("Phil. Mag.," October, 1911) has taken the value of μ for air as 0.000044. Taking the value found in this Paper—viz., $\mu=0.000059$ —the number of ions produced by the γ -rays is 8×10^{14} , or about 30 per cent. less than Eve's number.

If we assume that the atmosphere is at a uniform temperature of 15°C ., and that the pressure at the surface of the earth is 76 cm., then, taking into account the variation of density with height, it can be simply calculated that the γ -rays will pass through 817 metres of air before being reduced to 1 per cent. of their value at the surface. Experiments show, however, that the number of ions per cubic centimetre is the same at a height of 1,000 metres as on the surface. It follows, therefore, that the ions in the air cannot be wholly due to the γ radiation from radioactive material in the earth.

Absorption by Light Substances.—The absorption coefficients of a few solids and some solutions of salts in water were determined by the balance method, and are given in the table below, as they are often useful in radioactive measurements. Two thicknesses of lead were used—viz., 3 mm. and 1 cm.

Substance.	Thickness of lead = 3 mm.			1 cm.	
	Density D.	μ in (cm.) ⁻¹	$100 \times \mu/D$.	μ in (cm.) ⁻¹	$100 \times \mu/D$.
Hydrogen.....	...	...	4.7	...	...
Air.....	...	...	4.84	...	4.65
Carbon dioxide...	...	...	5.1	...	4.7
Wood	0.730	0.0380	5.21	0.0320	4.38
Aluminium	2.94	0.133	4.51	0.118	4.01
Iron	7.75	0.350	4.52	0.312	4.03
Lead	11.4	1.029	9.03	0.683	5.99
Water	1.000	0.0558	5.58	0.0472	4.72
CuSO ₄ solution	1.141	0.0631	5.53	0.0512	4.49
NaCl ..	1.145	0.0626	5.47	0.0512	4.47
CaCl ₂ ..	1.164	0.0611	5.25	0.0544	4.67
Pb(NO ₃) ₂ ..	1.156	0.0671	5.80	0.0662	5.72

The solutions used in the experiments were contained in a rectangular vessel of thin glass 5 cm. across. The absorption coefficient of lead was obtained with a sheet 4 mm. thick. If thicker plates are used, the absorption coefficient is much

less—*e.g.*, the absorption coefficient deduced from the absorption by 2 cm. of lead when the thickness of lead over the ionisation chamber is 1 cm. is 0.593.

It will be seen from the table that the value of μ/D is a minimum for substances like aluminium and iron, and the minimum is more pronounced the softer the γ -rays used. This also appears from the absorption experiments of Russell and Soddy.

In conclusion, I have great pleasure in thanking Prof. Rutherford for his help and interest throughout the experiments.

ABSTRACT.

The absorption coefficients of air, carbon dioxide and hydrogen for the γ -rays from radium, have been measured after the rays have traversed 3 mm. and 1 cm. of lead. The gases were contained in an iron cylinder and were under considerable pressure. The values found for the absorption coefficients are, at normal temperature and pressure, 0.000062, 0.000102, and 0.000042 (cm.)⁻¹ for air carbon dioxide, and hydrogen respectively, the thickness of lead being 3 mm. When the thickness of lead is 1 cm. the absorption coefficients of air and carbon dioxide are 0.000059, 0.000092 (cm.)⁻¹ respectively.

The absorption coefficient of air has also been determined by using liquid air. The absorption coefficients found in this way are in good agreement with the values found for air under pressure showing that the absorption of γ -rays is not affected by temperature.

The absorption coefficients of a number of light substances have also been found.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Prof. H. L. CALLENDAR fully appreciated the difficulty of accurately comparing quantities of radium by the electroscopic method. He had a year or two ago made some measurements of the heat given out by radium, and found that with only two or three milligrammes the heat could be measured to 1 part in 1000.

Dr. J. H. VINCENT commented on the value of the new method for the accurate comparison of quantities of radium. It was also valuable to have further tables of the absorption of γ -rays by different substances.

Dr. S. RUSS asked whether Prof. Rutherford attributed the diminution of the coefficient of absorption for γ -rays with increase of distance traversed to the lack of homogeneity of the rays themselves.

Dr. G. W. C. KAYE remarked that the Röntgen Ray Society several years ago considered the question of a Radium Standard. He hoped that when prepared the standard would be placed so that other workers could standardise their radium by it.

Prof. A. W. BICKERTON asked whether it was now regarded as finally established that the α -rays are nothing but helium.

Prof. C. H. LEES asked concerning the preparation of the Primary Standard.

The PRESIDENT remarked on the advantages of being able to get accurate quantitative measurements in any science. The early workers on vacuum tube discharges experienced the same difficulty as the early