

The Ionisation produced by an α -Particle.—Part I.

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Using an electrical method, Prof. Rutherford and myself* were recently able to determine accurately the number N of α -particles which are expelled from a gramme of radium per second. The final value of N obtained as an average of a great number of observations was 3.4×10^{10} α -particles per second from a gramme of radium itself, or four times this number if the radium is in equilibrium with its three α -ray products. In another paper† the charge carried by an α -particle was measured by the same authors and found to correspond to 9.3×10^{-10} E.S. unit. Since recent experiments have given conclusive evidence that an α -particle is identical with an helium atom carrying twice the ionic charge, it was necessary to take the ionic charge as 4.65×10^{-10} E.S. unit.

The values of N and e as found from the above experiments enable us to determine the number of ions which are produced by an α -particle along its whole path with a greater accuracy than hitherto. A determination of the number of ions produced by an α -particle emitted from radium itself was made in 1905 by Rutherford‡ in the following way. The ionisation current due to a thin film of radium was measured at its minimum activity, and the total number of α -particles fired off from this film was calculated from the total charge which the α -particles carried with them. Taking the charge on an α -particle as equal to twice the ionic charge e , the number Z of ions produced by an α -particle from radium itself was found to be 1.72×10^5 . This number becomes 1.18×10^5 if for N and e the latest values, referred to above, are introduced.

It was thought advisable in the present experiments to use RaC as the source of α -rays. The advantages of the active deposit of radium as a source of α -rays has been discussed in some detail in a previous paper. About a quarter of an hour after removal from the emanation the active deposit gives off homogeneous α -rays due to the radium C present and the number of α -particles fired off per second at any time after removal from the emanation can be calculated with great accuracy from the γ -ray activity. The simplest way to determine the number Z of ions produced by an α -particle would be

* 'Roy. Soc. Proc.,' A, vol. 81, p. 141, 1908.

† 'Roy. Soc. Proc.,' A, vol. 81, p. 162, 1908.

‡ 'Phil. Mag.,' vol. 10, p. 193, 1905.

to measure the quantity of RaC deposited on a plate, and at the same time to measure the saturation current due to the complete absorption of the whole number of α -particles expelled from the active plate. From these measurements the number Z could at once be deduced.

Preliminary experiments, however, showed that it was impossible to determine Z to the desired accuracy in this way. Bragg and Kleeman* have already drawn attention to the difficulties of obtaining saturation currents when a gas is ionised by α -rays at atmospheric pressure. Under conditions when practically complete saturation for ionisation due to β - or γ -rays is produced, a current of the same intensity, but due to the α -rays, may be 10 or 20 per cent. below the saturation value. To explain the observed effect, Bragg and Kleeman assume that the ions newly formed by an α -particle are especially liable to recombine. A much more intense field is therefore required to separate them. The effect of "initial recombination" is stronger in a complex gas than in air, and it decreases rapidly as the pressure is lowered. Further, it depends upon the velocity of the α -particle which produces the ions. The smaller the velocity of the α -particle, the greater the tendency of the newly formed ions to recombine.†

On account of the difficulties of obtaining complete saturation under the experimental conditions, it was found necessary to adopt an indirect method for the determination of Z . This method is briefly described below.

The ionisation due to the whole number of α -particles expelled from a known quantity of RaC was measured at a low pressure, allowing only a small definite portion of the range of each α -particle to be effective. The ratio of the ionisation produced within that small portion of the range to the ionisation produced along the whole path was then determined by another experiment.

As regards the first part of the experiment, the measurements were carried out in the following way:—The amount of RaC deposited on a small metal plate (about 3 mm. square) was determined carefully by the γ -ray activity.

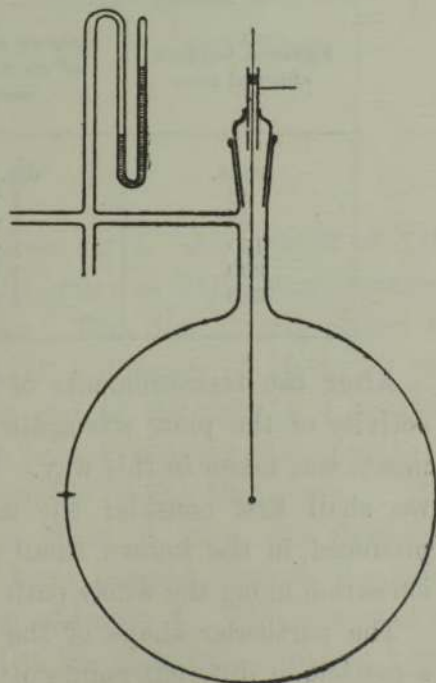


FIG. 1.

* 'Phil. Mag.,' vol. 11, p. 466, 1906.

† Kleeman, 'Phil. Mag.,' vol. 12, p. 273, 1906.

The plate was then suspended by a fine wire exactly in the centre of a glass bulb, as seen in fig. 1. The internal diameter of the bulb was 15.9 cm., and the inside surface was silvered. By means of a thin platinum wire sealed through the glass, the inside could be charged to any desired potential. The wire and the plate attached to it were connected with an electrometer of the Dolezalek type. A condenser of 0.1 microfarad was placed in parallel with the electrometer. As soon as the active plate was fixed in position the pressure inside the bulb was reduced to a few centimetres and accurately measured. In most of the experiments the pressure was adjusted to 3.73 cm. of mercury. Since the range of an α -particle is inversely proportional to the pressure, and each α -particle expelled from the active plate in the centre had to travel through 7.95 cm. of air at a pressure of 3.73 cm., only the first $\frac{7.95}{76} \times 3.73 = 0.390$ cm. of the range of each particle was effective. The ionisation current was measured for different intensities of the electric field in order to test the degree of saturation. At such a low pressure and using only small amounts of active deposit on the plate, saturation was easily obtained. This may be seen from the following figures:—

Silvered surface charged to—	Rate of movement of electrometer needle.	
volts.	div./sec.	} The activity of the plate corresponded to 5.3×10^5 α -particles per sec. Corrections are made for the decay.
40	1.51	
80	1.56	
150	1.64	
330	1.65	
580	1.64	

After the measurements of the ionisation current had been taken, the activity of the plate was again determined as before. A series of measurements was taken in this way. Before, however, giving the numerical results, we shall first consider the method by which the ratio of the ionisation produced in the known small portion of the path of the α -particle to the ionisation along the whole path was determined.

The particular shape of the curve which represents the ionisation of an α -particle at different points of its path is well known from the experiments of Bragg and Kleeman* and Bragg.† Using the α -rays from a film of radium, the authors showed that the ionisation produced by an α -particle, per centi-

* Bragg and Kleeman, 'Phil. Mag.,' vol. 8, p. 726, 1904.

† Bragg, 'Phil. Mag.,' vol. 10, p. 318, 1905.

metre of path, at first increases with the distance traversed, *i.e.* increases with decrease of velocity of the α -particle. After passing through a maximum, the ionisation diminishes rapidly. The same result was obtained by McClung,* who used the active deposit from radium emanation, which gives off homogeneous α -rays. Curves of the same character were obtained by Hahn† for the products of thorium and actinium.

For the present investigation, as has already been pointed out, it was necessary to determine quantitatively the change in ionising power along the path of the α -particle. In devising the experimental arrangement it was thought advisable to attempt to satisfy the following conditions:—

- (1) To use a practically parallel pencil of homogeneous α -rays.
- (2) To use an ionisation chamber of very small depth.
- (3) To obtain saturation by taking the measurements of the ionisation current at reduced pressure.

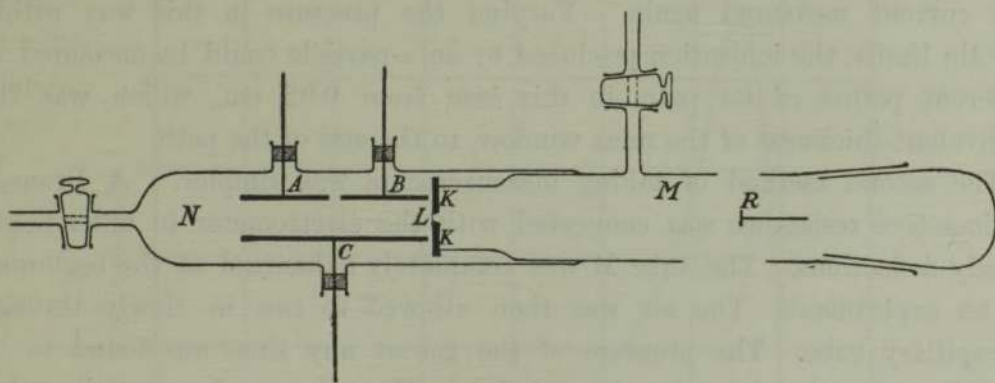


FIG. 2.

The details of the apparatus may be seen from fig. 2. An amount of RaC corresponding in γ -ray activity to about 2 milligrammes RaBr₂ was deposited on a polished glass disc of 0.6 cm. diameter. This disc R was placed in position in the centre of the glass tube M at a distance of 10 to 20 cm. from the lead plate K, which covered the end of the tube. A fraction of the α -particles expelled from the RaC passed through the opening L of 1.5 mm. diameter, bored through the centre of the lead plate. The opening itself was made airtight by a thin sheet of mica, the thickness of which corresponded to 0.92 cm. of air. After passing through the mica window the α -particles entered the ionisation chamber N. This consisted of two insulated plates A and B, both parallel to the plate C and distant 1 cm. from it. The plate C and the lead plate K were charged to the same potential by means of a battery, the plate B being connected to the electro-

* McClung, 'Phil. Mag.,' vol. 11, p. 131, 1906.

† Hahn, 'Phil. Mag.,' vol. 11, p. 793, 1906, and vol. 12, pp. 83 and 244, 1906.

meter, while A served as guard plate to ensure that the current reaching B was due only to the ionisation between the plates B and C. In a few experiments the ionisation vessel was filled with air at a low pressure, but in most of the experiments hydrogen was used at a pressure varying from 10 to 20 cm., since saturation is obtained most easily in this gas. Under these conditions a potential difference of 25 volts was sufficient for saturation. The depth of the ionisation vessel corresponded to 0.07 to 0.14 cm. of air at atmospheric pressure.

Measurements were taken in two different ways.

In some experiments the pressure in the tube M was adjusted to a certain noted value. Knowing this pressure and the distance of the disc R from the opening L, the exact portion of the path of the α -particles, which was producing ions between B and C, could easily be calculated. After the ionisation current had been measured the pressure in M was changed and the current measured again. Varying the pressure in this way within certain limits, the ionisation produced by an α -particle could be measured at different points of its path, in this case from 0.92 cm., which was the equivalent thickness of the mica window, to the end of the path.

The second method of taking measurements was simpler. A Bronson radio-active resistance was connected with the electrometer in order to get steady deflections. The tube M was completely exhausted at the beginning of an experiment. The air was then allowed to run in slowly through a capillary tube. The pressure of the gas at any time was found to be exactly proportional to the time of flow. Thus the gas between B and C was ionised by successive parts of the path of the α -particles and the deflection of the electrometer needle varied as the ionising power of the particles. In fact, the spot of light from the electrometer would trace out the ionisation curve on a photographic plate when moved with uniform velocity at right angles to the path of the light.

Several curves were taken by the two methods, the gas pressure in the ionisation vessel being varied in the different experiments. The curves, however, differed only slightly up to 6.5 cm. of the range. The maximum current corresponding to 6.5 cm. of the range varied somewhat, being in some experiments 10 to 15 per cent. higher than in others. This difference, however, can only affect the final result to about 0.5 per cent.

Using the experimental arrangements described above, we cannot obtain the ionisation curve at the beginning of the path, since the initial 0.92 cm. of the range was taken up in traversing the mica window. The initial part of the curve, however, could readily be taken by using the vessel employed in the first part of the experiment and shown in fig. 1. A small amount of

active deposit was placed in the centre of the bulb and the ionisation current measured for different pressures. Up to a pressure of about 15 cm. saturation was easily obtained. For low pressures the ionisation current was found to be nearly proportional to the pressure, while for higher pressures the ionisation increased somewhat more rapidly than the pressure. The increase was found to be in agreement with the results obtained by the experimental arrangement as in fig. 2. But from a pressure of about 20 cm. (which is equivalent to about 2 cm. of the range) the ionisation does not increase with the pressure so rapidly as the known ionisation curve would lead us to expect. This is obviously due to the lack of saturation at the higher pressures, even when large potentials are employed.

The curve given in fig. 3 represents the average of all the measurements which have been taken. It can readily be shown that the corrections to be

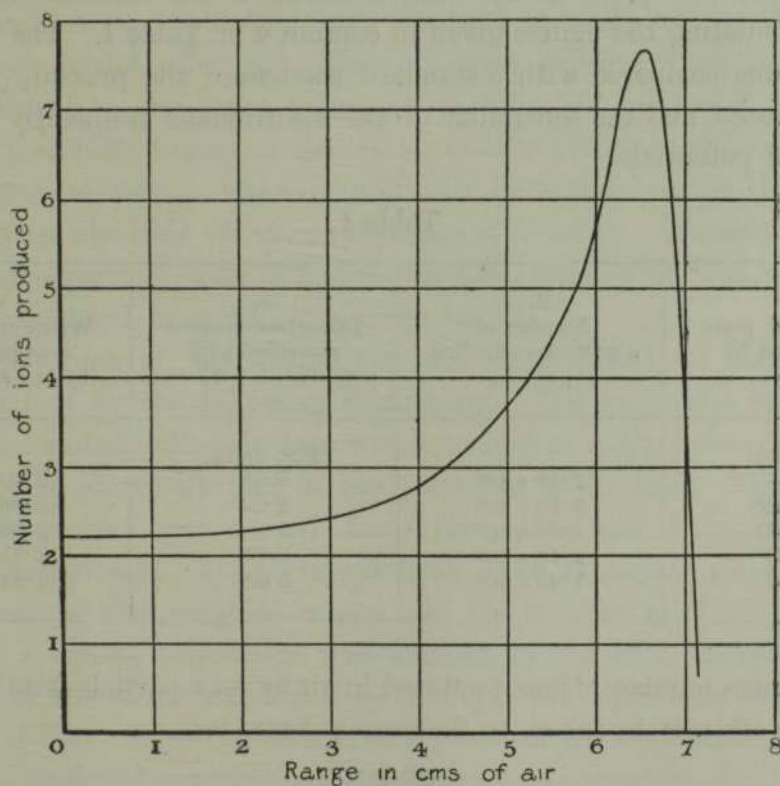


FIG. 3.

applied on account of the angle of the rays and on account of the depth of the ionisation chamber are exceedingly small, and do not appreciably affect the shape of the curve. It is thus clear that the ionisation due to a parallel pencil of α -particles travelling with identical velocity does decrease in the last 5 mm. of the range. Several possible explanations can be put forward to account for this diminution, but a discussion is reserved until some

investigations now in progress are completed. On the whole it appears probable that the effect is really due to the scattering of the α -particles in passing through the gas.

From the ionisation curve, fig. 3, the ratio of the total ionisation produced by an average α -particle along the whole path to the ionisation produced within the first 0.390 cm. of the range is found to be 27.1. This value is obtained from the ratio of the whole area of the curve to the area which is enclosed between the ordinates 0 and 0.390. From the ionisation produced within the first 0.390 cm. of the range, as measured in the first experiment, we can now calculate the whole number of ions produced by an α -particle from RaC. Since all the measurements were taken at practically the same room temperature, no correction for temperature was necessary. The correction for the β -ray effect was found to amount to less than 0.5 per cent.

Special care was taken in the determination of the constants which were used in calculating the figures given in column 4 of Table I. The condenser employed was compared with a standard condenser, the pressure gauge was carefully tested, and the sensibility of the electrometer frequently measured for different potentials.

Table I.

1. Activity of plate measured by γ -rays.	2. Number of α -particles expelled per sec.	3. Ionisation current measured at a pressure of 3.73 cm.	4. Whole number of ions produced by one α -particle.
mg. Ra.		E.S. units.	
0.141	2.40×10^6	9.88	2.40×10^5
0.0326	5.53×10^5	2.24	2.36×10^5
0.0151	2.56×10^5	1.04	2.36×10^5
0.128	2.18×10^6	8.83	2.31×10^5
0.083	1.41×10^6	5.88	2.44×10^5

The average number of ions produced in air by an α -particle from RaC along its whole path may be taken, to the nearest figure, as

$$2.37 \times 10^5.$$

The ionising power at different points of the path is illustrated by the following figures, which give the number of ions produced per millimetre at the respective points of the range. All the figures refer to air at atmospheric pressure and temperature of 12° C.

The scale in fig. 3 is such that each square centimetre represents 10^4 ions. The number of ions produced within any part of the range can therefore be found at once.

Table II.

cm.	ions per mm.
At 1	2250
2	2300
3	2400
4	2800
5	3600
6	5500
6.5 (about)	7600
7 "	4000

There appears to be no simple relation between the ionisation and the velocity of an α -particle. Any attempt to connect them by a theoretical consideration must be delayed until further experiments have given an explanation of the end part of the curve.

All the experimental evidence seems to show that the α -particles from the different radio-active substances are identical in mass and charge but differ only in their initial velocity.* They all cease ionising when their velocity has diminished to the same value, *i.e.* to 1.5×10^9 cm./sec.† It seems, therefore, justifiable to assume that all α -particles produce the same ionisation at the same velocity. Consequently the ionisation curves for different α -particles are identical for the same range of velocity. Hence if the whole range of an α -particle in air is known, the total number of ions produced by it can be calculated from the curve given for RaC.

The correctness of the assumption was investigated for the α -particles from polonium by the following experiment. The ionisation current from a small disc coated with polonium was measured at a low pressure (3.73 cm.) in the silvered glass bulb just in the same way as for RaC. The number of α -particles emitted per second from the plate was determined by the scintillation method.‡ The plate was fixed in an exhausted glass tube about 10 cm. from a zinc sulphide screen and the number of scintillations produced on a square millimetre was counted by aid of a microscope. The efficiency of the screen was tested by counting the α -particles from a known quantity of RaC. It was found that 92 per cent. of the α -particles which struck the screen produced scintillations. Applying this correction, the total number of α -particles expelled from the polonium plate per second was 4.6×10^4 .

The ionisation current due to the first 0.390 cm. of the range of all polonium particles was 0.120 E.S.U. The current due to a single polonium

* Rutherford, 'Phil. Mag.', vol. 12, p. 348, 1906; Rutherford and Hahn, 'Phil. Mag.', vol. 12, p. 371, 1906.

† Rutherford, 'Phil. Mag.', vol. 10, p. 163, 1905.

‡ Regener, 'Verhdlg. d. D. Phys. Ges.', vol. 10, p. 78, 1908; Rutherford and Geiger, 'Roy. Soc. Proc., A, vol. 81, p. 141, 1908.

particle was therefore $0.120/2.3 \times 10^4 = 5.2 \times 10^{-6}$ E.S.U. The current produced by an α -particle from RaC measured under the same conditions is 4.07×10^{-6} E.S.U., and therefore the ratio of the two currents equals 1.28. Now from the ionisation curve (fig. 3), this ratio ought to be 1.18, if the range of a polonium particle is taken as 3.86 cm. The difference between the two values is within the experimental error, since the determination of the number of α -particles from the polonium plate by the scintillation method involved an uncertainty of several per cent.

In the following table the number of ions produced by the different α -particles from the radium family is calculated. The calculations are based on the ionisation curve (fig. 3) and the known range of the particles.

Table III.

	Range.	Total number of ions produced.
	cm.	
Radium	3.50	1.53×10^5
Emanation	4.33	1.74×10^5
Radium A	4.83	1.87×10^5
Radium C	7.06	2.37×10^5
Radium F	3.86	1.62×10^5

It must be remembered that in calculating the above figures the charge on an ion is taken as 4.65×10^{-10} E.S.U. If further investigation should lead to a more accurate value, these results can at once be corrected.

The number calculated for radium itself [1.53×10^5] is in good agreement with the value obtained by Rutherford, considering that his number [1.18×10^5] must be increased by at least 10 per cent. owing to the difficulties of obtaining saturation for an intense ionisation at atmospheric pressure.

Note on the Determination of Small Quantities of Radium.

The total ionisation current due to a gramme of radium at its minimum activity and spread out in an infinitely thin film on a plate so that one half of all α -particles are absorbed in ionising is :

$$1.21 \times 10^6 \text{ E.S. units.}$$

This result may prove useful in estimating small quantities of radium. But it must be remembered that the figures given refer to complete saturation.

Small quantities of radium or other radio-active substances may also be determined with great accuracy by measuring the ionisation current at a low pressure in a conducting bulb, which may be of smaller dimensions than the

one employed in these experiments. The number of ions produced by a single α -particle under the special conditions of the experiment is easily found from the curve given in fig. 3. The determination of the ionisation current in the bulb then gives at once the total number of α -particles. Care has to be taken to obtain saturation and to avoid ionisation by collision, which occurs when too large a voltage is applied.

I wish to acknowledge the assistance which Mr. E. Marsden has given me in some of these observations.

In conclusion, I desire to express my gratitude to Prof. Rutherford for his valuable suggestions and his kind interest in the experiments.

On a Diffuse Reflection of the α -Particles.

By H. GEIGER, Ph.D., John Harling Fellow, and E. MARSDEN, Hatfield Scholar, University of Manchester.

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When β -particles fall on a plate, a strong radiation emerges from the same side of the plate as that on which the β -particles fall. This radiation is regarded by many observers as a secondary radiation, but more recent experiments seem to show that it consists mainly of primary β -particles, which have been scattered inside the material to such an extent that they emerge again at the same side of the plate.* For α -particles a similar effect has not previously been observed, and is perhaps not to be expected on account of the relatively small scattering which α -particles suffer in penetrating matter.† In the following experiments, however, conclusive evidence was found of the existence of a diffuse reflection of the α -particles. A small fraction of the α -particles falling upon a metal plate have their directions changed to such an extent that they emerge again at the side of incidence. To form an idea of the way in which this effect takes place, the following three points were investigated:—

- (I) The relative amount of reflection from different metals.
- (II) The relative amount of reflection from a metal of varying thickness.
- (III) The fraction of the incident α -particles which are reflected.

* See Schmidt, 'Jahrbuch der Radioaktivität und Elektronik,' vol. 5, p. 471, 1908.

† Rutherford, 'Phil. Mag.,' vol. 12, p. 143, 1906; H. Geiger, 'Roy. Soc. Proc.,' A, vol. 81, p. 174, 1908.

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