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XCI. *The Passage of α Particles through Hydrogen.* By E. MARSDEN, *Lecturer in Physics, University of Manchester**.

ON the nucleus theory of an atom †, Sir Ernest Rutherford and C. G. Darwin have recently discussed the relative motions of an α particle and the nucleus of an atom in an intimate collision. In the case of the encounter of an α particle of velocity V with the nucleus of a hydrogen atom, if the latter is projected in a direction making an angle θ with the original direction of the α particle, then the velocity of the "H" particle is given by $u = 1.6 V \cos \theta$. From Bohr's ‡ formula for the "velocity curve" of a charged particle, it can be deduced that in an end-on collision, i. e. $\theta = 0$, the "H" particle will have about four times the range of the α particle producing it. Consequently, in the passage of α particles through hydrogen the "H" particles may be looked for well beyond the range of the ordinary α particles, and in the experiments to be described evidence of their existence has been found. More detailed experiments are in progress to investigate whether the distribution of their velocities and relative motions with regard to the α particles producing them is in agreement with the calculations from the simple assumptions; but, owing to the probable lengthy series of observations necessary, it appears advisable to publish a preliminary account of the experiments so far made.

Fig. 1.

The apparatus used in the first experiments is shown in fig. 1, and consists of a wide tube about one metre in length and 9 cm. in diameter, closed at one end by a zinc-sulphide screen Z and at the other by a glass plate P on a ground flange. A

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

† E. Rutherford, *Phil. Mag.* xxi. p. 699 (1911); *Phil. Mag.* xxvii. p. 488 (1914). C. G. Darwin, *Phil. Mag.* xxvii. p. 499 (1914).

‡ N. Bohr, *Phil. Mag.* xxv. p. 10 (1913).

source of about 25 millicuries of radium emanation contained in an α -ray tube was mounted inside a sheet-iron cylinder so that it could be moved along the tube by a hand electro-magnet.

The tube was filled with hydrogen at atmospheric pressure, and scintillations counted on the zinc-sulphide screen for different distances between S and Z.

The following numbers were obtained :—

Distance of α -ray tube to screen Z.	Scintillations per minute.
24 cm.	End of range of α particles.
38 „	10.0 per minute.
50 „	5.5 „ „
82 „	0.5 „ „

With air at a pressure adjusted to give the same range of the α particles, *i. e.* about 17 cm. Hg, the number of scintillations decreased very rapidly after the end of the range, falling to 0.5 per minute at 26 cm. The results show that in hydrogen, particles capable of producing scintillations are produced which can travel at least $3\frac{1}{2}$ times as far as the α particles. That these particles are actually generated in the hydrogen is shown by the following experiment :—A similar iron cylinder to the one carrying the source was placed inside the tube between S and Z. Over the end of this cylinder sheets of aluminium equal in stopping power to 8 cm. of air were fastened. The distance SZ was 17 cm., and by manipulation of a hand electromagnet the foils could be placed either near to the source S or the screen Z. In the former case the α particles were altogether absorbed by the aluminium and did not emerge into the gas beyond. The following results were obtained :—

Tube.	Al foils.	No. of Scintillations per minute.
Exhausted to 1.5 cm. Hg ...	Near Z	0.7
Hydrogen at 76 cm. Hg ...	„ „	7.75
„ „	Near S	0.13

A comparison of the numbers shows that practically all the scintillating particles originate in the passage of the α particles through the hydrogen. The small number obtained with the aluminium foils near S only corresponds to one scintillation in 8 minutes, and may be due to natural activity.

The following experiment was made to throw some light on the direction of projection of the H particles. The source was placed about 38 cm. from the screen, and between them at a distance 16 cm. from the source was placed a cardboard stop with a hole 3.2 cm. diameter at the centre (fig. 1 *a*). With this arrangement 6.5 scintillations per minute were observed on the screen. Replacing this stop by its complement a disk 3.2 cm. diameter suspended centrally by threads (fig. 1 *b*), the number was only 2.5 per minute. When an aluminium foil, equal in stopping power of α particles to 4 cm. of air, was placed near the zinc-sulphide screen, these numbers were reduced to 4.3 and 0.42 scintillations per minute, *i. e.* to 65 and 17 per cent. respectively. In the second case, the relative angles between the H particles and the α particles will be much greater than in the first case; and the experiment shows, in agreement with theory, that they have a considerably smaller average velocity and are consequently more easily absorbed.

Experiments at High Pressure.

The scintillations produced by the H particles differ little from those produced by α particles except that they are not so intense. In the above experiments, however, the luminosity of the screen due to the β and γ rays from the source was considerable. Further, the counting was made more difficult owing to the small rate at which the H particles could be made to strike the screen, due to the large distance of the source necessitated by the long range of the α particles. Experiments were therefore made in hydrogen at high pressure so that the α particles had a smaller range, and by placing the apparatus in a strong magnetic field the β rays were prevented from striking the screen. The apparatus* used is shown in fig. 2.

α particles from the source S were absorbed in the hydrogen filling the apparatus, and the H particles produced passed through a hole in the disk D and impinged on a zinc-sulphide screen Z, where the scintillations were observed by

* The high pressure apparatus was purchased out of part of a grant from the Royal Society.

a microscope M. The source consisted of radium emanation in a conical tube with a thin mica window. The tube was not sealed off, but its end dipped into a small vessel of mercury which also extended into the tube, so as to confine

Fig. 2.

the emanation in a volume at atmospheric pressure about four times the volume of the conical portion of the tube. In this way, when the pressure was raised to about four atmospheres, the emanation just filled the cone and the α particles were fired through the mica window. The disk D had four openings, three of which were covered with foils of the metal whose absorption was under investigation. A piece of soft iron I was soldered to the disk and nearly counterpoised by a piece of lead L. Thus by the attraction of I, any of the four openings could be brought at will over the zinc-sulphide screen by a cycle of operations of short-circuiting in turn the coils A and B of the electromagnet, the successive positions of I being denoted by 1, 2, 3, 4 in the figure.

In an experiment the source and disk were first placed in position and the end plates screwed on to the lead joints. The vessel was then swept clear of air by hydrogen from the high-pressure bottle. The valve was then closed and the hydrogen let in gradually until the pressure was about 4.5 atmospheres, this pressure being nearly 0.75 of an atmosphere greater than was necessary to just prevent the α particles reaching the zinc-sulphide screen.

After four hours the emanation had attained equilibrium with its products on the walls of the conical tube, and observations of the scintillations were commenced. Several hundred scintillations were counted in each of the four positions of the disk, *i. e.* with no foil over the screen and

with foils of different thicknesses over the remaining three openings. The rates at which the scintillations appeared with the different foils were expressed as percentages of the number with no foil, and a curve plotted with these percentages as ordinates and thicknesses of foils as abscissæ. Curves obtained for aluminium, copper, tin, and platinum under the same circumstances are shown in fig. 3.

Fig. 3.

The H particles striking the screen will under the experimental conditions have widely differing velocities, and the foils will act by cutting out the ones with the smallest velocities. It will be noticed, however, that for the same mass per unit area, aluminium shows the greatest percentage absorption of the H particles. This is similar to the law of absorption of α particles, and further, as with α particles, the amounts of the various materials required to produce the same absorption are roughly proportional to the square roots of the atomic weights. This is shown by the figures in the following table. The numbers in Col. IV. are obtained from the curves in fig. 3.

The determination of the exact ranges of the swiftest H particles will need more observations than are shown in the figure, but the points where the curves cut the axis of abscissæ give approximate estimates. The most penetrating H particles will be those which are produced by an end-on collision of an α particle of radium C just after emergence from the mica window, for such an α particle will be the swiftest entering the hydrogen. The mica had an equivalent

of 1.9 cm., so that the range in air of the α particle after passing through the window was $6.9 - 1.9 = 5.0$ cm.; and according to theory*, if α particles and H particles of the same velocity are

Foil.	Atomic Weight A.	$\sqrt{A}$.	Wt. per cm ² required to reduce beam to 40 p. c. = W.	$W \div \sqrt{A}$.
Aluminium ...	27.1	5.2	.0108	2.1×10^{-3}
Copper	63.6	8.0	.0132	1.65 „
Tin	119	10.9	.0180	1.65 „
Platinum	195.2	14.0	.0266	1.9 „
			Mean	1.8×10^{-3}

absorbed similarly, the swiftest H particle produced as above ought to have a range equivalent to about $4 \times 5.0 = 20$ cm. of air. The hydrogen between the screen and source was calculated from Taylor's† results to have an air equivalent of 7.0 cm., leaving 13 cm. an equivalent for the swiftest H particle. Although the air equivalent of metal foils varies somewhat with the velocity of α particles and therefore presumably for H particles, we may take for the sake of comparison the weights per unit area per cm. air equivalent given by Richardson‡ and the author for α particles 6 cm. from the end of their range. Multiplying these numbers by 13 we obtain 0.021 gm. Al, 0.029 gm. Cu, 0.041 gm. Sn, 0.055 gm. Pt. As will be seen from fig. 3 these numbers are not very different from the amounts of the various substances required to completely absorb the H particles, and the agreement verifies the fundamental assumptions made.

The foregoing method is somewhat unsuitable for a determination of the number of H particles produced by a given number of α particles of known velocity, since α particles of all velocities are present, and further, the minimum velocity at which a H particle will produce a visible scintillation is a matter of conjecture. However, the number actually observed was about that to be expected from calculations on Darwin's formula, making reasonable assumptions for the difference between the theoretical and experimental conditions.

* Darwin, *loc. cit.*

† T. S. Taylor, *Phil. Mag.* xxvi. p. 402 (1913).

‡ Marsden & Richardson, *Phil. Mag.* xxv. p. 184 (1913).

A more convenient method of making a comparison between theory and experiment is furnished by the use of a thin film of some substance rich in hydrogen, such as paraffin wax or indiarubber. When α particles fall on such films, H particles may be expected to be ejected, and experiments have shown that this is actually the case. The observations are at present being continued so as to study the distribution and number of ejected H particles when a parallel beam of α particles of known velocity passes through these films.

In conclusion I beg to express my indebtedness to Mr. W. C. Lantsberry for his very efficient help in many of the observations, and to Sir Ernest Rutherford for his many kind suggestions.

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XCII. *The Magnetic Properties of a Graded Series of Chrome Steels at Ordinary and Low Temperatures.* By MARGARET B. MOIR, M.A., B.Sc., Carnegie Research Fellow in the University of Glasgow*.

THE influence of temperature upon the magnetic properties of iron, steel, nickel, and cobalt has been investigated by numerous experimenters, perhaps the most notable work being that carried out by Rowland †, Baur ‡, and Hopkinson §.

It is now well known that the effect of raising the temperature of a specimen of iron or steel is to increase its susceptibility to magnetism for low values of the magnetizing force and to diminish it for high values. It is to be expected then that, if the temperature of a test-piece be lowered, the effect should be exactly reversed, and the susceptibility should be diminished for low and augmented for high fields. That such is actually the case has been shown for various magnetic materials by Honda and Shimizu ||, and more recently by Gray and Ross ¶, who have all used the temperature of liquid air, -190° C., as the low temperature at which they have made their investigations. They have shown also that, while alike in this one respect, different materials differ very considerably both in the amount of

* Communicated by Professor A. Gray, F.R.S.

† Phil. Mag. xlvii. p. 321 (1874).

‡ Wied. Ann. xi. p. 394 (1880).

§ Proc. Roy. Soc. xlv. p. 318 (1889).

|| Phil. Mag. x. p. 548 (1905).

¶ Trans. Faraday Soc. vol. viii. part i. (1912).