ON THE IONIZATION OF GASES BY ALPHA RAYS.

By H. A. Bumstead.

It has long been known that a metal plate struck by α-rays emits electrons, often called δ-rays, whose velocities are such as would be acquired in falling through a potential difference of a few volts. More recently it has been shown[1] that a small proportion of much swifter electrons are present among the slower ones. Velocities as high as 2.7×10^9 cm./sec. (which corresponds to a potential difference of 2,000 volts) have been observed,[2] and electrons of all speeds less than this are present in the stream from the metal. The number having any given velocity is greater as that velocity is less. It is quite plain from the experiments that many of the slower δ-electrons are produced, not directly by the α-rays, but through the intermediate agency of the swifter electrons.

It has been known too that the production of δ-rays by the α-rays is, in some respects at least, analogous to the ionization of a gas by the same agent. Thus, for example, the number of δ-electrons, due to a given pencil of α-rays, varies with the speed or range of the α-rays in the same manner as the number of ions produced in a gas, the variation being given by the well-known Bragg ionization curve.[3] In fact there are many indications that the emission of the slow δ-electrons may properly be regarded as an ionization of the metal or perhaps of a film of adsorbed gas upon its surface.

Since electrons of considerable speed exist among the δ-rays we should, from this point of view, expect to find them also when gaseous molecules are ionized by α-rays; these swifter electrons would, in their progress through the gas, cause further ionization. Thus the column of ions produced by an α-particle "would be made up of the tracks of many secondary electrons radiating irregularly from the axis of the column and extending only a small fraction of a millimeter from it";[4] it would indeed resemble the tracks of X-rays as shown in Wilson's photographs,

[1] Wertenstein, Le Radium, 9, p. 6, 1912. Bumstead and McGougan, Am. Jour. Sci., 34, p. 309, 1912; Phil. Mag., 24, p. 462, 1912.

[2] Bumstead, Am. Jour. Sci., 36, p. 107, 1913. Phil. Mag., 26, p. 250, 1913.

[3] Am. Jour. Sci., 32, p. 410, 1911. Phil. Mag., 22, p. 914, 1911.

[4] Am. Jour. Sci., 34, p. 328, 1912. Phil. Mag., 24, p. 482, 1912.

but on a very minute scale, and with the ions and the electron trails densely crowded together. But, though small compared with X-ray ionization phenomena, the α-ray columns would, on the view explained above, be considerably larger than if all the ions were formed directly by the α-particle itself. In the latter case the radius of the column at the initial instant would be of the order of the mean free path of an ion, say 10^{-5} cm. in air at atmospheric pressure; whereas if the size of the columns is due to the range of the swifter δ-electrons, we might expect initial radii of the order of 10^{-3} cm.; as may be inferred from Lenard's[1] measurements of the absorption by gases of cathode rays whose speeds correspond to 1,000 and 4,000 volts.

So great a difference in the diameter of the columns would cause a very marked difference in the amount of initial recombination to be expected on the two hypotheses. Professor Wellisch and Dr. Woodrow[2] were good enough to investigate this point for me in the course of some experiments on columnar ionization, and their calculation gave for the initial radius of the column 1.6×10^{-3} cm. They were inclined however to attribute this large value to an extremely rapid lateral diffusion of the ions which is practically over before the ions have had time to move sensibly under the action of the electric field.

Soon afterward Jaffé[3] published an elaborate mathematical investigation of columnar ionization in which the effect of diffusion in the column is taken into account. The theory thus developed is compared with experimental results obtained by Moulin, Wheelock and the author himself, and the agreement seems to be satisfactory.[4] Jaffé calculates the mean distance of the ions from the axis of the column at the time zero (*i. e.*, before diffusion has begun) and obtains[5] 1.39×10^{-3} cm. He explains this unexpectedly large value as the result of a rapid preliminary diffusion, before the electrons and positive ions have obtained their normal "loads" and therefore before his equations, with normal values of mobilities, diffusion constants, etc., begin to apply. The "initial state" of his theory is thus later than the formation of the column; and the interval between these events must be supposed to be sufficiently long to permit the column to increase its diameter approximately a hundredfold. Jaffé mentions the possibility of explaining the large diameter of the columns by the hypothesis that the α-rays produce

[1] Lenard, Ann. der Phys., 12, p. 732, 1903. J. J. Thomson, Cond. through Gases, 2d ed., p. 381.

[2] Am. Jour. Sci., 36, p. 229, 1913. Phil. Mag., 26, pp. 526 et seq., 1913.

[3] Ann. der Phys., 42, p. 303, 1913.

[4] See also Jaffé, Phys. Zeits., 15, p. 353, 1914.

[5] Ann. der Phys., loc. cit., p. 341.

primary δ-rays and that these latter ionize the gas; he rejects this explanation however "since nothing is known of δ-rays of such a kind."

Even with the knowledge of the existence of the swift δ-rays, it is not easy to arrange an ionization experiment which will show in an unambiguous manner whether or not an appreciable fraction of the ions are produced by them; the large value of the initial diameter of the columns obtained by Wellisch and Woodrow and by Jaffé certainly supports this view, but, as we have seen, it may be interpreted as due to other causes. To avoid this possibility of ambiguity in attempting to decide the question I had recourse to C. T. R. Wilson's method of photographing the tracks of α-rays in a supersaturated gas.[1] At atmospheric pressure, even in hydrogen, the diameter of the columns is so small and there are so many ions in a given length that no details of the structure of the columns could be observed. It was therefore necessary to work at reduced pressures.

The expansion apparatus used was that made by the Cambridge Scientific Instrument Co. after Wilson's design. It worked very satisfactorily with initial pressures in the expansion chamber greater than 200 mm. When however the pressure was lowered still further the expansive force of the gas became too small to push the piston down with sufficient promptness. The apparatus was therefore modified to the form shown in Fig. 1, in which the method of causing the expansion

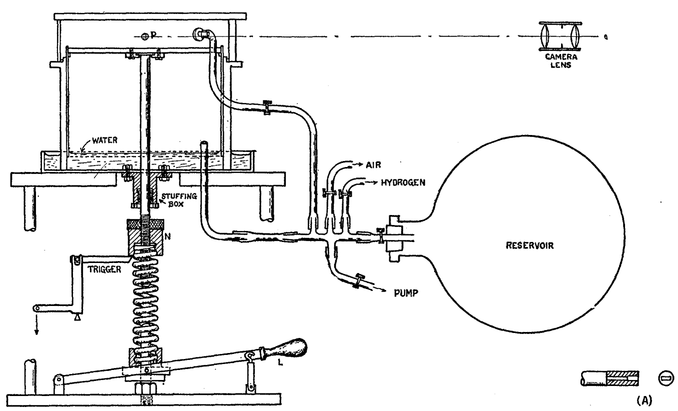

Fig. 1.

is sufficiently obvious. The nut, N, permitted the initial height of the piston to be adjusted so that any desired expansion-ratio could be obtained. The expansion chamber, the space below the piston, and the reservoir, were all filled with air or hydrogen, as the case might be, at the

[1] Proc. Roy. Soc., 87, p. 277, 1912.

desired initial pressure; the purpose of the reservoir (a two-gallon bottle) was to prevent the gas under the piston from attaining a sufficiently high pressure after the expansion to cause an appreciable leak into the expansion chamber around the piston.

It was scarcely practicable and did not seem necessary to have the hydrogen fillings very pure. The entire space to be filled was exhausted with a filter pump to about 20 mm. and hydrogen was then admitted to atmospheric pressure. This process was repeated three or four times, and the hydrogen was finally pumped down to the experimental pressure, usually between 90 and 100 mm. The hydrogen was made by the action of hydrochloric acid upon zinc and was freed from hydrogen sulphide by passing it through a solution of lead acetate.

The position of the source of α-rays is indicated at P. Polonium was deposited upon the end of a little rectangular bar of copper 2 mm. $\times$ 1 mm. in section; to "canalize" the rays a piece of brass with a rectangular channel cut in it was slipped over the copper bar as indicated at (A), Fig. 1. A small vertical piece of brass was attached to the piston so as to cover the source of α-rays except when the piston was nearly in its lowest position. In this way the rays were prevented from crossing the chamber until the expansion was nearly completed. This made it unnecessary to use an electric field in the chamber to clear away ions formed before the expansion.

With this apparatus expansions could be made at any pressures, but there was a limit below which condensation on the ions did not take place readily. In hydrogen this limiting pressure (measured before the expansion) was about 70 mm.; in air, tracks could sometimes be seen when an expansion was made from an initial pressure of 40 mm. In most of the experiments, initial pressures of 90 to 100 mm. were used; the expansion-ratio which gave the best results at these pressures was from 1.35 to 1.40.

Wilson's methods were closely followed in making the photographs. The source of light was a spark in mercury vapor contained in a narrow quartz tube; large Leyden jars charged by a Holtz machine were discharged through two such spark gaps in series. These were arranged on opposite sides of the expansion chamber and a little above it; the light passed obliquely through the top and the tracks were photographed through a plate glass window in the side of the chamber. The light from the sparks was concentrated by large condensing lenses upon the region in the chamber through which the α-rays passed. The sparks were made to occur at definite times after the expansion by means of a falling weight as described in Wilson's paper.

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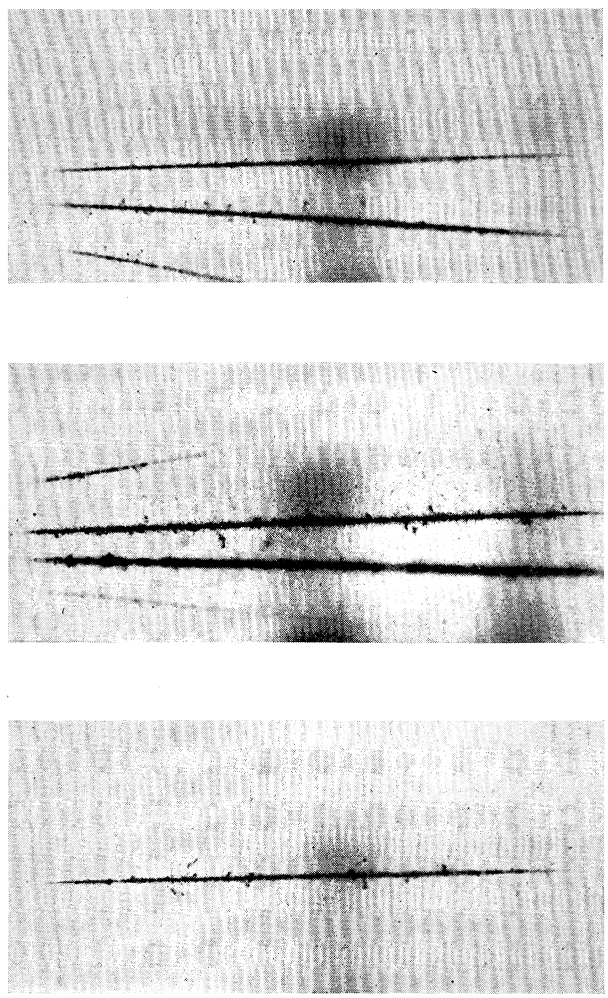

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A Dallmeyer lens of approximately 35 cm. focal length was used with its full aperture, 4 cm. It was mounted on the front of a long copying camera and focused so as to give a magnification of about 1.5.

Many difficulties were encountered not all of which need be detailed here. Considerably more light is needed than for photographing α-ray tracks at ordinary pressures; it was only under favorable weather conditions and with Holtz machine, jars and spark gaps working perfectly that fairly good pictures could be obtained. Precautions had to be taken to prevent brushing as far as possible in all parts of the electric circuit. Although the α-rays were partially canalized, the fan-shaped sheaf had a considerable depth in the line of sight and many of the tracks photographed were out of focus. At the low pressures used, the diffusion of the ions is rapid so that only the rays which passed through the gas after the requisite degree of supersaturation was attained could possibly show any structure. Even after condensation the droplets were sufficiently mobile to make it necessary to illuminate very promptly after the track was formed; and often no ray crossed the field in this brief interval. On the other hand it was undesirable to use a very active source since the water vapor was exhausted and the picture confused by the older and more or less diffuse trails. Much patience and many plates had to be expended in repeated trials before satisfactory results were obtained.

Fig. 2 contains reproductions of negatives obtained in this way.[1] They could doubtless be much improved by a sufficient expenditure of time and labor. But they show with sufficient distinctness (at least in the original negatives) projections from the main trail which resemble in all respects the ends of β-ray trails as observed by Wilson. It does not seem possible that diffusion of the ions could produce columns of this appearance.

Wilson's photographs of X-ray beams make it reasonable to suppose that all the β-ray trails are of approximately equal length when due allowance is made for the foreshortening of oblique trails; this impression is strengthened on looking at the beautiful stereoscopic pictures which were exhibited by Mr. Wilson about two years and a half ago at a meeting of the London Physical Society held in Cambridge. This equality was of course to be expected from the known fact that homogeneous X-rays give rise to secondary electronic rays of a definite velocity. There is however no reason to expect a similar result with the α-rays; my own experiments on δ-rays from metals have shown that electrons of all

[1] The vertical "smudge" on each of the photographs is due to an imperfection of the window of the expansion chamber caused by scraping off some dried alcoholic shellac which had been accidently allowed to flow on it in the process of cementing it on.

velocities up to 2,000 volts are present, and there is no reason to doubt that this upper limit would have been exceeded if a sufficiently strong source of α-rays had been available. The photographs are in complete accord with these facts. Only exceptional electrons start with sufficient velocity to get clear of the crowd and form distinct β-ray trails; a larger number have smaller velocities, but still great enough to produce distinct knobs and projections from the main track; and I think there is little reason to doubt that the ragged edges of these tracks are caused in the same manner by δ-electrons of still smaller velocities.

RESULTS.

Photographs of α-ray tracks in hydrogen at a pressure (before expansion) of 90–100 mm. have been obtained by a slight modification of C. T. R. Wilson's method. They show distinct evidence of the existence of electronic trails radiating from the column, due doubtless to ionization of the gas by swift δ-rays. Such swift rays are known to be produced when metals are struck by α-rays but their existence in the process of gas-ionization by α-rays though suspected has not previously been demonstrated.

The photographs give decided support to the view that a considerable part of the ionization in the α-ray column is produced in this indirect way. The large values of the initial diameter of the columns which have been deduced from experiments on recombination find thus a ready explanation.