

ON THE PASSAGE OF CATHODE PARTICLES THROUGH
GASES AT LOW PRESSURE.

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THE work to be described was undertaken primarily to determine whether a very narrow pencil of cathode rays is scattered by traversing a high vacuum. Such an effect may be expected if the electric field of each electron in the atoms composing the walls of the vessel or outside it, is confined to a few narrow tubes or filaments extending to infinity. This structure of the electric field was suggested by Sir J. J. Thomson in his *Electricity and Matter* (p. 63, 1903).

The cathode rays were obtained from a plane aluminium cathode in a spherical bulb about 15 cm. in diameter. They passed into the test chamber through a cylindrical brass tube 5 cm. long and of .02 cm. internal diameter set in a plane anode directly opposite the cathode. The test chamber was about 60 cm. in length and 3 cm. in diameter, and terminated in a transverse tube of larger diameter that served as a photographic camera. All glass to glass, or glass to brass joints were sealed with sealing wax. Diffusion through the hole in the anode was so slow that a good vacuum could be kept in the test chamber without lowering the pressure in the discharge tube to such a value that the photographic effect of the rays would be much reduced. The attainment of exceedingly high vacua was not attempted, since at pressures easily reached by liquid air and cocoanut charcoal (5×10^{-5} cm. of mercury by a MacLeod gauge of about one liter capacity) no scattering was detected.

Proper precautions to prevent any electrostatic fields, or any except axial magnetic fields, were taken by using a brass lining within the test chamber, by cleaning all metal surfaces exposed to rays, and by placing the axis of the apparatus parallel to the magnetic field due to the earth and to the induction coil.

After leaving the hole in the anode the narrow cone of rays traversed about 30 cm. before striking a small aperture or solid obstacle, and the rays not stopped traversed about 30 cm. more before reaching the photographic plate. A series of exposures on the same plate could be taken by the method used by Sir J. J. Thomson for positive rays.¹

¹ Phil. Mag., VI., p. 228, 1911.

The absence of scattering in a high vacuum was shown by the fact that the shadows cast on the photographic plate were geometrically obtainable by drawing straight lines enveloping the obstructions from a point on the axis of the apparatus, which, in case the pressure in the discharge tube was fairly high, was within the anode, but which was near the cathode, in case the pressure in the discharge tube was low enough to make the scattering due to the gas unimportant. The accuracy with which measurements could be made on the photographs was limited by the width of the transition from fully exposed to unaffected areas, about .002 cm. The sharpness of this transition proved that the rays were not uniformly distributed across the aperture in the anode, but were principally axial, as was expected from the necessary obliquity of the electric field close to the anode except along the axis of the aperture.

From the dimensions of the apparatus it was clear that an average angle of scattering exceeding 30 seconds of arc would have been detected with certainty if it had occurred. One series of photographs with rays of varying velocity passing through a slit .029 cm. wide is shown in Fig. 1, exposures 1, 3, 5, 7, and 9, on the center line of the figure. Fig. 2 shows the shadow cast by a cross of copper wire placed in the path of the rays. In exposures 1, 2, and 3 the cross was connected to the anode, which was always to earth, and the geometrical shadow is obtained. In the other exposures the cross was disconnected from the anode, and received a negative charge from the rays which it stopped. These latter photographs (one of which has been intensified in the print) show the shape of the field so clearly that they suggest a method for measuring the electric intensity on a convex surface in a high vacuum.

The rays were not homogeneous in velocity but most of them were of approximately the same speed, as shown in Fig. 1, exposures 1, 3, 5, 7, and 9, and in Fig. 2, where the more diffuse spots at one side of the center line are produced by magnetic deflection between the slit and the photographic plate. The coil for this purpose consisted of a few turns of wire wound on a rectangular frame with semicircular ends. This was placed outside the test chamber with the axes of the two coinciding. If such a coil of length $2l$ and of width a is placed with its center at a distance d from a source of axial cathode rays of velocity v and corresponding e/m the deflection x on a photographic plate at a distance from the source equal to $2d$ corresponding to ni ampere-turns is given to terms of the second order by the equation

$$x = \frac{4nie}{mv} \cdot \frac{d}{a} \left[\frac{(l+d)^2}{\{a^2 + (l+d)^2\}^{\frac{3}{2}}} - \frac{(l-d)^2}{\{a^2 + (l-d)^2\}^{\frac{3}{2}}} \right].$$

The average velocity of the fastest group of rays used, measured in this way, varied from 2.7×10^9 to 8.0×10^9 cm./sec.

Upon raising the pressure in the test chamber the scattering due to the gas became apparent in a reduction of intensity in the photographs at pressures of air as low as 3×10^{-4} cm. of mercury, but even at 1.2×10^{-3} cm., the highest pressure at which photographs were obtainable with an exposure of one hour or less in this apparatus, the geometrical pattern obtained was of the same size, and as clear cut, as at the lower pressures, although very faint, and overlaid by scattered radiation extending with decrease of intensity to more than a centimeter from the center of the photograph. The conclusion to be drawn is that at this pressure a considerable number of these electrons (velocity about 5×10^9 cm./sec.) have free paths in excess of 60 cm., or more than 100 times the mean free path of a molecule of the gas.

Recent experimental work on slow cathode rays by J. Franck and G. Hertz¹ indicates that for such rays the mean free path is $4\sqrt{2}$ times that of a gas molecule, that is, for the case discussed, 3.4 cm. Extrapolation from the values given by Townsend² for negative ions of sub-atomic dimensions gives 6 cm. as the mean path between ionizing collisions under the same set of conditions. The still higher value indicated by these experiments suggests that the high-speed cathode rays must, in many cases, pass completely through the atom without measurable change of direction.

Positive rays could be obtained without alteration of pressure by reversing the discharge current. In Fig. 1, exposures 2, 4, 6 and 8, taken in this way show that the positive rays are much scattered at a pressure that does not affect the cathode rays. The atomic size of the positive rays explains the greater chance of a collision and consequent deflection.

An attempt was made to deduce the law of scattering of cathode rays from the variation of intensity with distance from the center of the photograph, using approximately circular apertures to limit the beam of rays after sorting them magnetically with a solenoid. The hole in the anode was made several millimeters in diameter to permit a greatly increased number of rays to be dealt with, and since discharge tube and test chamber could not be kept at different pressures the average velocity of the rays was altered by Whiddington's method.³ Conditions were held constant for longer periods of time by supplying gas through a very fine capillary tube and removing it continuously with a Gaede mercury pump.

¹ Verh. d. D. Phys. Ges., 15, p. 34, 373, 929 (1913); 16, p. 12 (1914).

² Ionization by Collision, p. 30 (1910).

³ Camb. Phil. Soc. Proc., 17, p. 251, 1913.

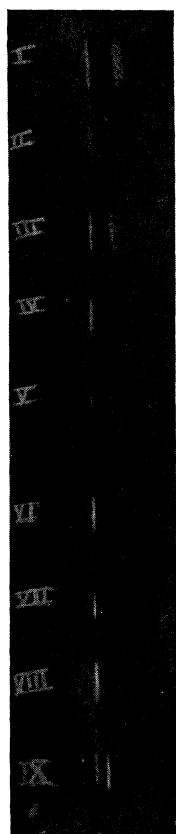


FIG. 1.



FIG. 2.



FIG. 3.

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In each experiment a series of exposures for widely differing times was obtained under conditions kept as nearly constant as possible, but in different experiments the nature of the gas, its pressure, and the velocity of the rays were varied independently. Fig. 3 shows the photographs obtained in oxygen at 4.56×10^{-4} cm. pressure with rays of velocity 6.5×10^9 cm./sec. The time of exposure varies from five seconds to one hour.

If the photographic intensity were directly proportional to the number of rays received, a single exposure on each plate would suffice to give the relation between distance from the center and number of rays. This was not the case as experiment showed, for the ratio of intensities at two given distances from the center was not the same on the different exposures. However, if conditions are really constant during an experiment, and if the intensity of the photograph on a small area of the plate depends only on the number of rays of approximately the same velocity received there, although not proportional to it, the law of scattering for a given gas atom and for a given velocity of rays can be found by measuring the distances from the centers of the several exposures in the appropriate experiment to circular zones in which the photographic intensity is identical. Each pair of unequally timed exposures gives the relation between distance from the center and relative number of cathode rays, and all pairs on the same plate should give the same relation. As long as the greater part of the pencil of rays is not diffused, the scattering is single and not compound¹ since the probability of more than one deflection is small.

In the experiments actually performed in this way consistent results were not obtained. The chief reason for this failure lies in the wandering of the beam of rays within the discharge tube, due to surface charges and fluctuations of discharge potential. These alterations of direction were directly observed on fluorescent screens placed within the test chamber, and were so considerable as to vary the intensity of the photograph by as much as one half in consecutive exposures of several minutes duration.

Another difficulty inherent in the method is the small amount of scattered radiation that can be obtained within the limits of single scattering, and the consequent faintness of the photographs. This faintness enhances errors due to fogging by light or by X-rays, to original non-uniformity of the sensibility at different points on the plate, to non-uniform development, and to reversion of the latent image. The layer of the emulsion affected by homogeneous cathode rays is so thin

¹ Sir Ernest Rutherford, *Phil. Mag.*, VI., 21, p. 669, 1911.

that inversion began at low intensity, a second inversion took place at the center in all long exposures, and a third inversion was just detectable in one photograph. The use of sensitized paper in place of dry plates was found to overcome the last mentioned defect, but no better results were obtained.

One of the assumptions made above is open to attack on theoretical grounds. Scattered rays should have smaller velocities than unscattered, and the photographic effect should not therefore be quite proportional to number of rays, but should depend slightly on the angle of deflection. It can be seen that this effect should be small for small angles, but it is inseparable from the photographic method.

A consideration of the number of rays available, and of their ionizing power at the necessary low pressure made it seem inadvisable to attempt an electrical method of counting, especially since the chief defect of the experiments would not be overcome by such a change. The general problem of the deflection of an electron by matter is being attacked in this laboratory by a more direct and powerful method,¹ from which definite results are expected.

In conclusion thanks are due to Sir J. J. Thomson for the suggestion of the original problem, and for the facilities afforded during that part of the work performed in the Cavendish Laboratory.

PHYSICAL LABORATORY,
UNIVERSITY OF MINNESOTA,
April 27, 1914.

¹ A. F. Kovarik and L. W. McKeehan, *PHYS. REV.*, II, 3, p. 149, 1914.



FIG. 1.

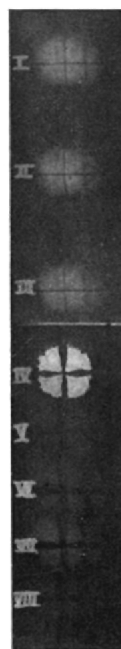


FIG. 2.

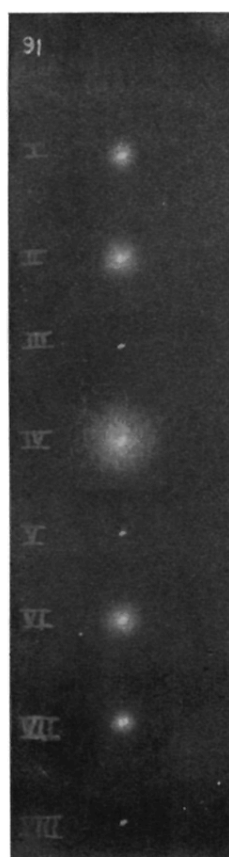


FIG. 3.