A DETERMINATION OF e/m AND v BY THE MEASUREMENT OF A HELIX OF WEHNELT CATHODE RAYS.

By J. B. Nathanson.

IN 1904 A. Wehnelt[1] showed that the output of negative carriers of electricity emitted from incandescent Pt, could be enormously increased by coating the Pt with a layer of an alkaline earth metal oxide like CaO. Using this Pt as a cathode, Wehnelt determined e/m and v for the cathode beam issuing from the hot lime. The method employed was the utilization of the potential difference of discharge and the measurement of the diameter of the circle into which the rays were magnetically bent. Wehnelt obtained an average value of 1.48×10^7 for e/m, and for v values ranging from 0.16×10^9 to 1.07×10^9 cm. per second. J. Classen,[2] employing a photographic method for determining the diameter of the circle, obtained a value of 1.773×10^7 for e/m. C. T. Knipp,[3] using the method of electrostatic and magnetic deflections, obtained a value of 1.5×10^7 for e/m and 1.6×10^9 for v.

In the present investigation, the method employed was the utilization of the principle of both magnetic and electrostatic deflections. This avoids the assumption that all of the electric energy of the electric field is converted into kinetic energy of the moving particles. Sir J. J. Thomson[4] has shown that when a moving electron is projected into a uniform magnetic and a uniform electrostatic field, the lines of force of both fields being parallel, that the electron will describe a helical path, the helix being of increasing pitch.

The helical path in the case of the Wehnelt cathode rays was experimentally realized as follows. The rays were projected from a Wehnelt cathode in a direction perpendicular to the lines of force of a uniform magnetic field. The path assumed by the rays was a circle. Upon application of a uniform electrostatic field whose direction coincided with that of the lines of magnetic force, the circle was drawn out into the form of a helix.

[1] Ann. d. Phys., 14, p. 425, 1904.

[2] Phys. Zeit., 9, No. 22, p. 762, 1908.

[3] Trans. A. I. E. E., p. 1883, 1912.

[4] Thomson's Cond. of Elec. through Gases, 2d ed., p. 112.

The circular path of the rays is given by the equation

$$Hev = \frac{mv^2}{r},$$

or

$$v = H\frac{e}{m}r, \tag{1}$$

where H = magnetic intensity, r = radius of the circle.

The negative particles composing the rays, when projected in a direction perpendicular to the electrostatic field of strength Z, will receive a uniform acceleration of Ze/m in the direction of the field, so that in time t the electrostatic deflection z will be

$$z = Z\frac{e}{m}\frac{t^2}{2}. \tag{2}$$

If n is the number of times an electron has passed around the helix in the time t, while experiencing the electrostatic deflection z, then v, the velocity of projection of an electron, is given by

$$v = \frac{2\pi rn}{t}. \tag{3}$$

Evidently the time taken by the electron to go once around the circle with the constant velocity of projection v, is equal to the time taken by the electron to pass once around on its helical path with a resultant velocity v_R. Hence

$$z = \frac{Ze}{m}\frac{2\pi^2r^2n^2}{v^2}. \tag{4}$$

Substituting the value of v from (1) into (4) and solving for e/m, we have,

$$\frac{e}{m} = \frac{Z}{H^2}\frac{2\pi^2n^2}{z}. \tag{5}$$

It was found very early in the investigation that the beam of rays after having passed the first time around on its helical path, would suffer a deflection or distortion when repassing over the cathode, this deflection being due to like sign of both cathode and electrons. As a result of this deflection, the uniformity of increase of pitch was disturbed, and it was therefore deemed advisable to measure the electrostatic deflection for the first one half turn only. Accordingly equation (5) reduces to

$$\frac{e}{m} = \frac{Z}{H^2}\frac{\pi^2}{2z} = \frac{\pi^2V}{2dH^2z}, \tag{6}$$

where V = potential difference of electrostatic plates, d = distance between electrostatic plates.

Eliminating e/m from (1) and (4) and letting $n = 1/2$, we have for v,

$$v = \frac{\pi^2 Vr}{2dHz}. \tag{7}$$

Description of Apparatus.

The discharge chamber consisted of a jar J, lying on its side, 21 cm. in diameter and 18 cm. deep. The mouth of the jar was ground plane to receive a square piece of plate glass P. This was fitted on airtight by means of a mixture of equal parts of beeswax and resin. The plate glass window permitted accurate measurements to be taken on the helix without any accompanying optical distortion.

The electrostatic deflections were affected by two parallel Al plates, A and B, resting on an improvised glass support S. These plates were circular, being 15 cm. in diameter. The upper plate A was connected

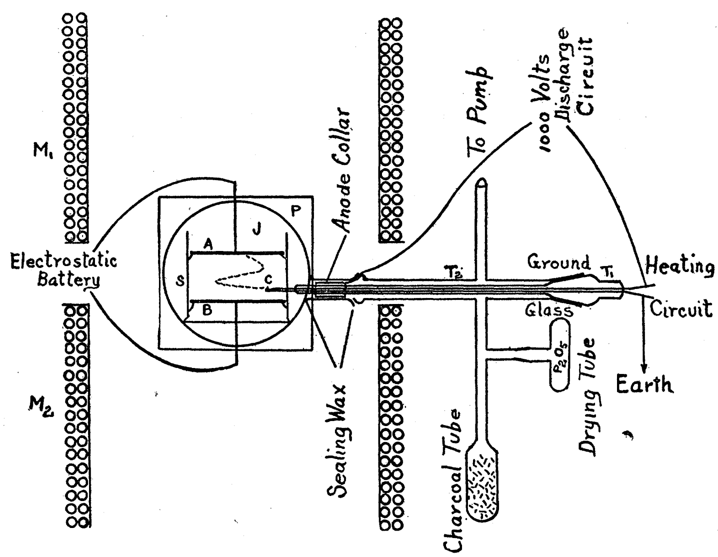

Fig. 1.

through a water resistance to the (+) pole of the battery, the lower plate B, being connected to the (−) pole. With this arrangement the circle could be drawn out into a helix in an upward direction away from the lower plate. The difference of potential between the plates was measured by a Kelvin multicellular voltmeter.

The discharge chamber with its electrostatic plates was surrounded by a uniform magnetic field, furnished by two large coils M_1 and M_2, each 41 cm. in diameter and 30 cm. high. By means of proper supports, they were separated from each other by a distance of 8.5 cm. This admitted the introduction of the Wehnelt cathode C into the discharge chamber, and at the same time allowed observations to be taken on the helix through the plate glass window.

A Grassot flux-meter was employed to determine the magnetic intensity H for any given value of the current I, through the coils. The discharge chamber was removed from within the coils, and the small test coil of the flux-meter was properly supported in the region occupied by the helix. Flux-meter readings were plotted against the values of I in amperes, giving a straight line curve through the origin. From the tangent of the curve, and the dimensions of the test coil, the following relation was found between H and I, where H is in gausses, and I is in amperes,

$$H = 5.7098I.$$

The maximum diameter of the cathode ray circle employed in this investigation was about 12 cm. To test the constancy of the magnetic field over this area, the small test coil was moved outwards from the axis of the magnetic coils, noting the flux-meter readings for various distances of the test coil from the axis, the current through the magnetic coils being kept constant. It was found that the flux-meter deflections were practically constant over a region of 16 cm. diameter. This therefore insured a constant field over the region traversed by the rays.

Since the beam of cathode rays issuing from the small lime speck on the Wehnelt cathode is so compact and well defined, the usual encumbrances of diaphragms, so necessary in the case of ordinary cold cathodes, were done away with, and the Wehnelt cathode was introduced right into the electrostatic field through a hole in the side of the discharge chamber. The manner of mounting the Pt strip on which the lime speck was deposited, was that employed recently by Knipp.[1] The ground glass joint permitted the rotation of the cathode about an axis perpendicular to the lines of magnetic force. The cathode beam could thus be oriented around till its path was perpendicular to the lines of magnetic force. This arrangement therefore admitted of easy adjustment for the obtaining of the beam in the form of a perfect circle.

The small lime surface was obtained by the placing of a minute particle of Bank of England sealing wax on the Pt strip and then electrically heating the strip slowly up to redness. The sealing wax was thereby changed into a small round white speck of lime whose diameter varied from 0.5 to 1 mm.

The discharge potential employed was 1,000 volts and was furnished

[1] PHYS. REV., p. 58, January, 1912.

by a large set of small storage cells. The cathode was grounded and connected to the (−) pole of the battery. The (+) pole was connected through a water resistance to the anode which was in the form of an Al collar on the inside of the tube T_2.

Method of Procedure.

The Wehnelt cathode rays are easily absorbed by any residual gas in the tube and hence are obtainable with distinctness only at a very high vacuum. The vacuum used was therefore the highest obtainable by means of a Gaede pump and charcoal cooled to liquid air temperature.

The cathode beam was started by closing the 1,000-volt discharge circuit, and then slowly heating the Pt cathode to redness. It usually took some time for the cathode beam to appear, the first appearance of the beam being in the form of a whitish flaky cloud. The temperature of the Pt was then slowly increased till the flaky cloud changed into a sharp beam which issued normally from the cathode. This beam was usually not perpendicular to the lines of magnetic force and hence when the magnetic field was applied the beam changed into a helix. By rotating the cathode in the ground glass joint, this helix was readily changed into a perfect circle which lay in a horizontal plane.

The telescope of the cathetometer was then sighted on the plane of the circle, the horizontal cross wire being placed on the horizontal edge of the circle at a, Fig. 2. Upon application of the electrostatic field, the circle was drawn out into a helix whose diameter was usually somewhat less than the diameter of the circle. The horizontal cross wire of the telescope was then sighted at b to obtain the electrostatic deflection for 1/2 turn, the difference in the cathetometer readings between b and a giving the amount of this deflection.

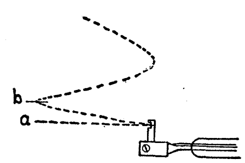

Fig. 2.

The diameter of the circle was measured by placing the leg of a square against the plate glass window, and moving the square along till the edge of the circle at one half turn was in line with the other leg of the square. The same was done for the other side of the circle at the cathode. The difference between the two positions gave the diameter to within 1 per cent., as close a measurement as could be warranted by the slight fuzziness of the boundary of the beam.

It was found that the lime would continually deteriorate and fall off from the hot Pt so that the beam would weaken and fade away with continual use. This necessitated the raising of the temperature of the Pt to bring the beam back again to distinctness. Thus during the course of an experiment, the temperature of the Pt was intermittently raised from red to white heat.

Discussion.

The values of e/m vary from 1.27 to 2.07 $\times$ 10^7, giving an average value of 1.61 $\times$ 10^7. This agrees favorably with Wehnelt's value of 1.48 and Knipp's value of 1.5, but is less than Classen's value of 1.773 obtained by a photographic method. The values of v vary from 1.00 to 1.75 $\times$ 10^9 cm. per second, giving an average value of 1.39 $\times$ 10^9. We would of course expect v to vary with the different temperatures employed.

It might be instructive to check this value of v by another method. If V is the potential difference between anode and cathode, then we have from the equivalence of electrical and kinetic energy,

$$v = \sqrt{2\frac{e}{m}V}.$$

Supplying in this equation V = 1,000 volts, and e/m = 1.61 $\times$ 10^7, v is found to be 1.79 $\times$ 10^9 cm. per second. This is somewhat higher, but of the same order, than the value of v experimentally obtained. However the actual difference of potential between anode and cathode had it been carefully examined, by means of a sounder, would have been found less than 1,000 volts.

Table I.

Distance between the electrostatic plates = 6.60 cm.

	Amperes, I.	Gausses, H.	Volts, V.	Cm., z.	Cm., $2r$.	$e/m \times 10^{-7}$.	$v \times 10^{-9}$.
1	3.30	18.84	81.3	1.01	10.1	1.71	1.62
2	3.99	22.78	81.2	0.85	7.7	1.39	1.21
3	3.33	19.01	79.5	1.08	10.0	.56	1.14
4	4.70	26.84	119.5	0.98	6.4	.27	1.09
5	3.20	18.27	80.0	1.10	10.0	.64	1.49
6	3.75	21.41	119.3	1.33	7.7	.46	1.20
7	3.43	19.58	79.5	0.99	9.3	.59	1.44
8	2.90	16.56	120.0	1.94	10.2	.70	1.43
9	3.62	20.67	83.0	1.01	8.1	1.44	1.20
10	2.90	16.56	120.0	1.72	10.3	1.91	1.63
11	3.61	20.61	126.0	1.30	8.7	1.71	1.53
12	3.35	19.13	43.0	0.43	8.9	2.07	1.75
13	4.20	23.98	120.0	1.05	7.2	1.49	1.29
				Mean..........		1.61	1.39

Returning to the values of e/m given in Table I., we notice that they vary somewhat among themselves. It seems that Wehnelt[1] had the same experience, for his table shows e/m to vary from 1.34 to 1.81 $\times$ 10^7.

[1] Ann. d. Phys., 14, p. 425, 1904.

Since the method of this investigation is so different from Wehnelt's method, there seems to be no other conclusion than that the cause of the variation of e/m lies in the nature of the Wehnelt cathode itself. It was previously mentioned that the lime was continually disappearing from the hot Pt necessitating now and then the raising of the temperature of the Pt to obtain a sharper beam. Other recent work in this laboratory on the Wehnelt cathode shows quite conclusively that the activity of the hot lime, when supplied by Bank of England sealing wax, falls off rapidly with use—the current rising to successively lower and lower maxima each succeeding day when heated to the same temperature. It is evident, due to the sputtering of the hot lime cathode together with the probable complex character of the lime obtained from the sealing wax, that the source of the negative carriers of electricity is not a constant one. Slight variations in the heating current made correspondingly very large variations in the density of the cathode beam. This inconstancy must account in a large measure for the variation of e/m.

The disturbing effect of introducing the cathode between the electrostatic field plates was less than the error due to the variations just mentioned. This was shown to be the case by introducing the hot Pt strip carrying the lime up through a slot in the lower plate and adjusting so that the cathode beam, when bent into a circle by the strong magnetic field, just grazed the upper surface of this plate, the electrostatic field being zero.

In addition it might be said that, apart from all quantitative measurements, the helical method is most beautiful in its nature, and the apparatus serves very excellently as a demonstration piece for the magnetic and electrostatic deflection of cathode rays.

In conclusion I take this opportunity of expressing my thanks to Professor A. P. Carman for the facilities that were so kindly placed at my disposal, and to Dr. C. T. Knipp who made this work possible by his kind help and suggestions.

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