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To cite this article: Harold A. Wilson B.A. D.Sc. (1902) LXVIII. The current-density at the cathode in the electric discharge in air , Philosophical Magazine Series 6, 4:23, 608-614

To link to this article: <http://dx.doi.org/10.1080/14786440209462885>

Published online: 15 Apr 2009.

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LXVIII. *The Current-Density at the Cathode in the Electric Discharge in Air.* By HAROLD A. WILSON, B.A., D.Sc. (Lond.), Clerk-Maxwell Student, Fellow of Trinity College, Cambridge*.

THE experiments described in this paper were undertaken with the object of measuring the current per square centimetre on the cathode, in the electric discharge in air at low pressures. It is well known that the negative glow at pressures of about one millimetre is confined to a definite area on the cathode, and that this area covered by the glow increases with the current through the tube. Wehnelt (*Ann. der Physik*, No. 2, 1902) has shown that the discharge from the cathode is confined to the area covered by the glow and that the current-density is uniform throughout this area. So long as the cathode is not entirely covered by the glow the fall of potential between the glow and the cathode remains independent of the current, but when the cathode is entirely covered the "cathode drop" increases with the current. This fact leads one to expect the area covered by the glow to be proportional to the current through the tube, and the experiments now to be described show that this is the case.

The method employed was very simple; the cathode used consisted of a straight wire fixed along the axis of the discharge-tube and the length of the wire covered by the glow was measured and also the current through the tube.

The discharge-tube used is shown in the figure. It consisted of a glass tube, AB, about 3 cms. in diameter and

Fig. 1.

30 cms. long, having an aluminium disk electrode A sealed in at one end, and a narrow tube BC joined on at the other. This narrow tube served to support a glass tube E which carried the cathode WW. The glass tube E was fastened in with sealing-wax at C, so that it could be easily taken out when it was desired to try a new cathode.

The discharge-tube was connected to a Toepler pump and McLeod gauge and to bulbs containing phosphorus pentoxide.

The discharge was passed from the disk A to the cathode wire, and it was found that the glow appeared on the end of

* Communicated by Prof. J. J. Thomson.

the wire nearest to A and formed a uniform coating over the wire, covering a definite length of it. This length was measured by means of a millimetre-scale placed along the tube and backed by a mirror, so that errors due to parallax could be avoided. The shape of the glow is indicated by the dotted line. It resembled a test-tube. The discharge was produced by means of a battery of small secondary cells, and an adjustable resistance and telephone were included in the circuit.

The Crookes's dark space between the glow and the cathode of course increased in thickness when the pressure was reduced, and ultimately the glow extended to the walls of the tube. When the pressure was so low that this occurred the length of wire covered by the glow was not proportional to the current, and the glow appeared to tend to concentrate itself at the end of the cathode, showing that the walls of the tube impeded it from spreading out uniformly. Measurements were therefore only made when the glow did not reach the walls of the discharge-tube.

Table I. gives the results obtained with a platinum wire

TABLE I.—Platinum wire 1·42 mm. in diameter.

p .	l .	C .	$\frac{C}{lp}$
5·1	5·35	7·36	0·27
"	5·1	·38	0·28
"	1·6	·54	0·31
2·53	8·1	5·16	0·25
"	3·0	·79	0·24
2·04	5·1	2·63	0·25
"	7·55	3·72	0·24
1·40	8·5	2·51	0·21
"	7·6	2·26	0·21
"	4·5	1·32	0·21
0·96	5·55	1·20	0·23
"	9·2	1·69	0·19
"	3·4	0·70	0·21
0·67	4·5	0·69	0·23
"	8·9	1·31	0·22
"	9·1	1·33	0·22
"	3·8	0·61	0·24
Mean			0·236

1.42 mm. in diameter as cathode. p is the pressure in mms. of mercury, l the length of the glow in cms., and C the current in milliamperes.

The quantity $\frac{C}{lp}$ is approximately independent of the current at any one pressure, which shows that the current per unit-length of cathode covered by the glow is a constant.

$\frac{C}{lp}$ is also nearly independent of the pressure, so that the current per unit-length of the cathode is proportional to the pressure.

Tables II. III. and IV. contain the results obtained with other wires as cathodes. In every case $\frac{C}{lp}$ is approximately independent of l and p .

TABLE II.—Platinum wire, 0.19 mm. in diameter.

p .	l .	C .	$\frac{C}{lp}$.
2.93	4.4	1.07	0.083
"	12.8	3.66	0.098
"	13.4	3.76	0.096
"	3.4	0.875	0.088
2.18	7.5	1.56	0.095
"	4.4	0.67	0.070
1.475	12.5	1.62	0.088
"	11.25	1.21	0.073
1.36	8.6	0.794	0.068
"	4.8	0.513	0.079
"	4.2	0.47	0.082
"	12.4	1.39	0.082
0.93	7.27	0.622	0.092
"	5.4	0.454	0.090
"	8.95	0.75	0.090
0.65	10.1	0.745	0.110
"	6.9	0.496	0.110
Mean 0.088			

If $\frac{C}{lp}$ is divided by πd (d being the diameter of the wire) we get the current-density at the surface of the cathode.

TABLE III.—Aluminium wire, 2·08 mms. in diameter.

p .	l .	C.	$\frac{C}{lp}$
6·7	1·5	5·8	0·58
3·64	5·3	7·49	0·39
"	1·3	2·16	0·46
3·13	6·3	6·96	0·35
2·37	8·13	5·78	0·30
"	2·6	2·26	0·37
"	2·2	1·97	0·38
"	13·05	11·95	0·39
2·07	7·4	5·96	0·39
"	3·3	2·49	0·37
"	10·8	9·7	0·43
1·46	12·25	5·46	0·31
1·16	7·5	2·30	0·27
"	12·25	4·09	0·29
1·13	7·95	2·35	0·26
0·975	11·4	3·23	0·29
"	4·8	1·18	0·25
0·78	3·1	0·60	0·25
"	8·8	1·63	0·24
"	12·3	2·43	0·25
0·68	12·9	2·35	0·27
0·53	6·1	0·68	0·21
"	12·2	1·75	0·27
0·45	9·2	1·13	0·27
"	13·0	1·79	0·31
"	5·7	0·63	0·25
0·23	5·2	0·54	0·45
Mean			0·323

Table V. contains the values of $\frac{C}{lp\pi d}$ for each of the wires used.

The current-density for the two thickest wires is nearly the same, but for the smaller wires it is much greater. This suggests that the effective diameters of the wires are really greater than their actual diameters, so that if, in calculating the current-density, a small constant quantity was added to the diameter of each wire, then the current-density would be the same in every case. It was found by trial that if 0·5 mm. is added to the diameters the calculated current-

TABLE IV.—Aluminium wire, diameter 0.61 mm.

p .	l .	C.	$\frac{C}{lp}$.
8.5	6.6	8.83	0.16
4.07	13.1	6.92	0.13
2.87	5.3	2.30	0.15
"	5.55	2.36	0.15
"	2.85	1.18	0.14
"	10.45	5.36	0.18
2.43	6.65	2.52	0.16
"	5.8	1.93	0.14
1.94	10.9	3.29	0.16
"	5.1	1.35	0.14
"	3.0	0.81	0.14
1.38	4.75	0.67	0.10
"	6.15	0.97	0.11
"	5.85	0.98	0.12
"	10.85	2.14	0.14
"	11.95	2.40	0.15
0.94	7.4	0.80	0.12
"	9.9	1.01	0.11
0.48	13.9	0.885	0.13
"	9.4	0.57	0.13
Mean			0.139

TABLE V.

Diameter.	$\frac{C}{lp}$.	$\frac{C}{lp\pi d}$.	$\frac{C}{lp\pi(d+0.05)}$.
0.208 cm.	0.323	0.50	0.403
0.142 "	0.236	0.53	0.394
0.061 "	0.139	0.72	0.397
0.019 "	0.088	1.47	0.406

density is the same for all four wires. The results of this calculation are given in the last column of Table V.

It appears, therefore, that the effective area of a cathode is that of a layer 0.25 mm. thick covering it. At the surface of this layer the current-density is given by the formula $i=0.4p$. The above results also show that the current-density is the same for cathodes of platinum as for cathodes of aluminium.

If we suppose that the current at the cathode is entirely

carried by negative ions produced close to its surface, it is easy to calculate what proportion of the air-molecules which strike the cathode must be ionized to give a current-density of $0.4p$ milliamperes per sq. cm.

If e is the charge carried by one ion, and n the number of molecules striking the surface of the cathode per sq. cm., then if every molecule striking the surface were ionized there the current would be ne . Now $n = \frac{1}{6}NG$ where N is the number of molecules in a cubic centimetre of the gas, and G the square root of the mean square of their velocities. For air at the ordinary temperature $G = 5 \times 10^4 \frac{\text{cms}}{\text{sec.}}$. Also for a gas at 760 mms. pressure $2Ne = \frac{1}{0.115}$ coulombs.

Hence

$$\begin{aligned} ne &= \frac{p \times 5 \times 10^4}{760 \times 6 \times 2 \times 0.115} \\ &= 47.7p \text{ amperes per sq. cm.} \end{aligned}$$

The actual current observed is $0.4p$ milliamperes per sq. cm. so that the fraction of the molecules striking the cathode which would have to be ionized to carry the current is

$$\frac{0.40}{47.7 \times 1000} = \frac{1}{120,000}.$$

It is therefore clear that the amount of gas present in the tube is amply sufficient to account for the observed current-density at the cathode. J. Stark (*Physikalische Zeitschrift*, 2 Jahrgang, No. 5) has given a formula which represents the variation of the cathode fall of potential with the current-density. This formula is $K = K_n + \frac{k}{pf^{\frac{1}{2}}} (C - xpf)^{\frac{1}{2}}$ where K

is the cathode drop, K_n the "normal" drop when the cathode is only partly covered by the glow, p the gas pressure, f the area of the cathode, C the current, and k and x constants. When the cathode is only partly covered, as in the present experiments, $K = K_n$, so that Stark's formula becomes $C = xpf$. This equation becomes identical with that which my experi-

ments have led to, viz., $\iota = 0.4p$ on putting $\frac{C}{f} = \iota$. Stark

does not give the value of his constant x and his experiments do not appear to be well adapted for its determination since he was mainly concerned with the variation of the cathode drop with the current-density when the cathode is entirely covered by the glow.

Skinner (Phil. Mag. Dec. 1901) has also given a formula for the variation of K with C . It is $K = K_n + \frac{b}{p}(C - a)$ where b and a are constants. This gives $C = a$ when $K = K_n$ and is therefore evidently incorrect, for a should certainly depend on p .

That Skinner's formula will not do has been pointed out by Stark (*Physikalische Zeitschrift*, 3 Jahrgang, No. 13). The results described in this paper therefore confirm Stark's formula in so far as it applies to the current-density when the cathode is only partially covered by the glow.

The fact that the glow only covers a definite area on the cathode is evidently a consequence of the existence of a minimum value for the cathode drop. As the current-density falls the drop falls until it reaches the minimum value. Any further diminution of the current-density would then involve an increase in the drop, so instead of the current-density diminishing, the area of the glow diminishes.

In conclusion I wish to say that my best thanks are due to Prof. J. J. Thomson for his kindly interest and advice during the carrying out of these experiments in the Cavendish laboratory.

LXIX. Notices respecting New Books.

VECTOR ANALYSIS, a Text-book for the use of Students of Mathematics and Physics, founded upon the Lectures of Professor J. WILLARD GIBBS. By DR. EDWIN BIDWELL WILSON. (New York, Scribner's; London, Arnold, 1901.)

THIS is one of the Yale Bicentennial Publications, and in some respects a very remarkable treatise. It is essentially an expansion of a short pamphlet circulated privately by Professor Gibbs some twenty years ago, and forms a goodly volume of fully 400 pages. As in that pamphlet, so in this book, the feature which distinguishes the vector methods elaborated by Professor Gibbs from the vector methods associated with the names of Hamilton, O'Brien, and Grassmann (to name only the *originators* of distinct methods) is the treatment of the linear vector function in terms of the so-called "dyad." It is this which gives significance to the notation adopted for the scalar and vector parts of vector products. So far as these important quantities are concerned, the substitution of $a \cdot \beta$ for $-Sa\beta$ and of $a \times \beta$ for $Va\beta$ is a trifle, for which there could be absolutely no excuse unless the dot-cross notation is based upon some fundamental principle more important than anything which occurs in quaternion vector analysis. If then we leave the "dyad" out of account, there seems to be no sufficient reason why the pictorial notation of Hamilton should be discarded in favour of a purely