Distribution of Electric Force in the Crookes' Dark Space.

By

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In a previous experiment carried out by T. Takamine and the writer[1], it was observed that the distribution of electric force in the Crookes' dark space in a narrow tube might be expressed by a parabolic equation of the following form,

$$E - E_0 = k(d_0 - d)^2,$$

where d_0 represents the length of the dark space, E_0 the electric force at its end, d the distance of a point in the dark space from the cathode, E the electric force at that point, and k a constant independent of d. Of course, it was already noticed in the former experiment that the glow in the dark space was concentrated as a narrow pencil in the central portion of the tube, the diameter of which was less than 2·4 mm., and consequently the observation was confined to its axial portion.

Now, the diameter of the tubes used in the present experiment was wider than those of the tubes in the former one, their values ranging from 3 mms. to 16 mms. The vacuum tube employed was a spherical glass bulb having four side tubes, as shown in Fig. 1. The side tube 1 served for the introduction of hydrogen gas and the tube 2 for its evacuation. In the side tube 3 and 4 were inserted aluminium electrodes which filled the tubes completely and served either as a cathode or an anode.

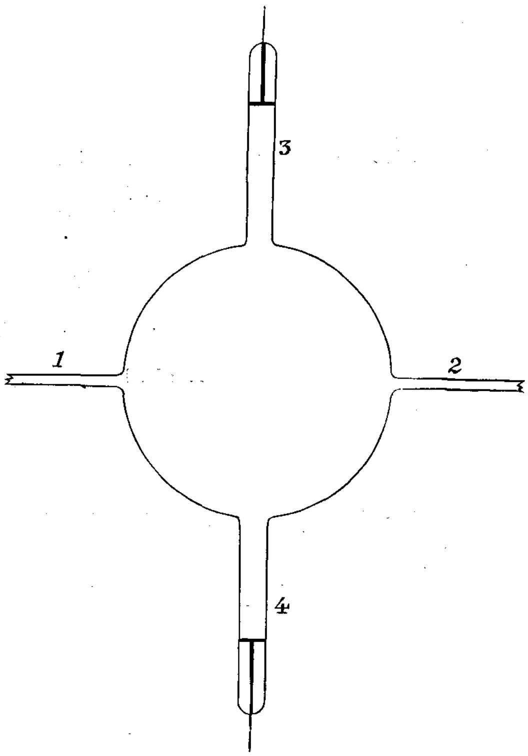
On the outside of the cathode tube, some equidistant lines were marked parallel to the surface of the cathode, so that the length of

1 Mem. Coll. Sci. Kyoto, **2**, 335, (1917).

the dark space and the distance of any point in it from the cathode might be determined correctly from the photographic impression.

For the excitation of the discharge in the vacuum tube an induction coil of spark length 25 cms. was used, its primary current being interrupted by a mercury interrupter of about 30 interruptions per second. The secondary current of the coil was rectified by a valve tube and a spark gap connected in series. Inserting a glow-light oscilloscope in the secondary circuit, and testing the light by a rotating mirror, it was found that the current thus rectified was of a pulsatory form.

Fig. 1.



The experiment was made with the hydrogen vacuum tube. The air in the tube having been evacuated, hydrogen gas was passed several times, and finally it was sealed when the length of the dark space had attained an appropriate value.

In order to measure the electric force in the dark space with the apparatus employed, it was of course necessary that the force should be pretty strong, and therefore the length of the dark space was made comparatively long. When the length of the dark space was increased with a reduction of pressure in the vacuum tube, the glow in the dark space became concentrated more and more in its axial portion. As all the photographs were taken under such conditions, the field-strength measured represents its value in the axial portion of the tube.

The intensity of the electric field in the Crookes' dark space was determined by the amount of separation of the line H_γ, the apparatus for photographing the spectrum being the same as that in the former experiment[1]. A four-prism-spectrograph was employed for the vacuum tube, having cathodes of 3 and 4.5 mms. in diameter; and a five-prism-spectrograph for the larger ones. With the former spectrograph the dispersion at H_γ was 19 Å.U. per mm., and with the latter 8.6 Å.U. per mm. on the photographic plate. With this latter spectrograph, the intensity of the parallel component was very much reduced, and it was possible to obtain a photograph on which the image of the perpendicular component alone could be observed without any trace of the parallel one. In this case the double image prism was taken off, and the field-strength was calculated from the separation of the perpendicular component of H_γ. With the four-prism-spectrograph, a weak image of the parallel component was visible in most cases in addition to an intense one of the perpendicular component. In this case the field-strength was calculated from both components. Some of the photographs used for measurement are reproduced in Fig. 2, Fig. 3, Fig. 4 and Fig. 5, Plate I.

As stated before, the distribution of the electric force in the Crookes' dark space could be expressed by a simple parabolic equation in the case of a narrow tube. This parabolic equation was tested in the present case, and the result came out positive.

Let d_0 represent length of the dark space, d distance of any point in the dark space from the cathode and E field-strength at that point. Taking $(d_0-d)^2$ and E as the ordinate and abscissa, it was found that observation points thus plotted lie nearly on a straight line passing through the origin, as shown in Fig. 6, Fig. 7, Fig. 8 and Fig. 9, Plate II. This was true in every case examined, and consequently the distribution of the electric force in the Crookes' dark space may be represented by the following formula:

$$E-E_0 = k(d_0-d)^2,$$

where E_0 represents field-strength at the end of the dark space, and k a constant. These constants k and E_0 were determined by the inclination of the straight line before mentioned and by the intersection of this line with the abscissa-axis respectively. Using these values of k and E_0 thus determined and the observed value of d_0, the parabolic curves in Fig. 6, Fig. 7, Fig. 8 and Fig. 9, Plate II, were drawn. From these curves we see a satisfactory agreement between the observed and calculated values. Hence it may be concluded that the

1 loc. cit.

distribution of the electric force in the Crookes' dark space is represented by a parabolic equation, so far as the present experiment is concerned.

Various numerical data observed and calculated in the present experiment are tabulated in Table I. In the seventh column of the table the calculated values of k are given, and in the eighth the calculated values of E_0 are shown, which were in most cases very small

TABLE I.

No. of the plates	Diameter of the tube in mm.	Length of the dark space in mm.	Pressure in mm. of Hg.	Secondary current in m. A.	Maximum E.F. in 10^4 volt/cm. (observed)	$k \times 10^3$	E_0 in 10^4 volt/cm.	Cathode fall in 10^4 volt (calculated)
8	16	17·5	0·1	2·7	1·11	3·70	0	0·661
9	16	19·0	0·07	1·7	1·06	2·98	0	0·682
10	16	20	0·06	0·9	1·01	2·60	0	0·693
25	16	27	—	0·6	1·34	1·65	0	1·08
5	12	13·0	0·19	1·05	1·41	8·40	0	0·614
6	12	14·0	0·16	2·05	1·51	7·80	0	0·715
7	12	14·5	0·15	0·45	1·26	6·05	0	0·616
13	8	4·2	0·91	0·9	0·86	50·2	0	0·124
21	8	9·0	0·30	0·6	1·38	17·1	0	0·418
22	8	9·0	0·30	0·9	1·36	17·2	0	0·418
11	6	4·9	0·67	0·85	1·14	45·5	0	0·178
12	6	4·4	0·86	0·53	1·06	51·5	0	0·146
15	6	7·7	0·38	0·6	1·54	25·3	0	0·386
16	6	7·7	0·38	0·9	1·68	28·0	0	0·426
36	4·5	3·4	1·2	0·85	1·36	103·0	+0·15	0·186
39	4·5	4·7	0·71	0·45	15·5	72·0	0	0·250
40	4·5	4·7	0·71	0·8	1·71	76·5	0	0·265
41	4·5	6·0	0·52	0·45	2·31	62·5	0	0·450
43	4·5	6·0	0·52	0·8	2·65	72·0	0	0·519
34	3	3·3	1·3	0·45	3·06	282	0	0·337
37	3	3·4	1·2	0·7	2·83	290	0	0·380
45	3	4·4	0·86	0·45	5·07	268	0	0·761
46	3	4·4	0·86	0·7	5·60	280	0	0·796

and put equal to zero. Lastly the ninth column represents values of the cathode fall calculated from the parabolic equation.

Generally speaking, the parabolic constant k decreases as the diameter of the tube and the length of the dark space increase respectively, but it increases as the current increases. The maximum electric force just in front of the cathode decreases as the diameter of the tube increases, but it increases with the length of the dark space and with the current.

Aston[1] and Harris[2] measured the distribution of the electric force in the Crookes' dark space by deflections of cathode rays, and the latter observer obtained somewhat similar curves as those in the present experiment. Here it is desirable to note that the values of the field-strength obtained by these observers represent the mean value of the electric force at any cross-section of the tube parallel to the surface of the cathode, and it may not necessarily mean the same one as that obtained in the present experiment, where the electric force is measured in the axial portion of the tube as stated before.

Lo Surdo[3] also attacked this problem by the same method as that used in the present experiment, and concluded that the electric force decreases linearly from the portion just in front of the cathode to the end of the dark space. This result agrees with that of Aston, but not with that of the present writer. In the present experiment the excitation of the discharge in the vacuum tube was effected by means of a pulsatory current, while other observers adopted the continuous ones. Whether the distribution of the electric force in the dark space depends upon the mode of excitation or not is to be decided by a further investigation.

Summary.

The distribution of the electric force in the Crookes' dark space in a hydrogen vacuum tube was determined, and a parabolic equation was found to hold true, so far as the present experiment is concerned.

In conclusion, the writer wishes to express his hearty thanks to Prof. T. Mizuno for his kindly interest in the research. And the writer's thanks are also due to Prof. M. Kimura for his criticism.

1 Proc. Roy. Soc., **84**, 526, (1910).

2 Phil. Mag., **30**, 182, (1915).

3 Rendiconti d. Lincei, **23**, 117, (1914).

Plate I

Fig. 2.
(No. 10)

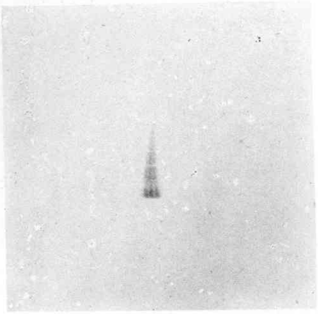


Fig. 3.
(No. 5)

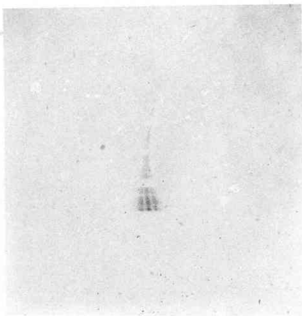


Fig. 4.
(No. 16)

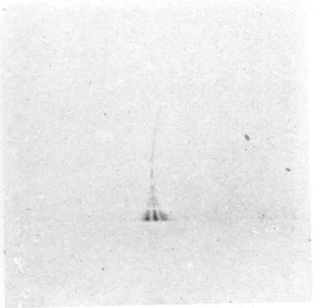


Fig. 5.
(No. 46)

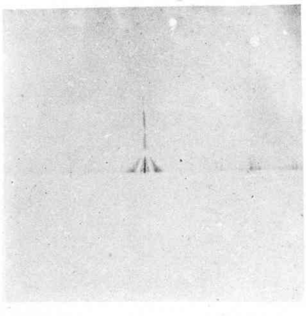


Plate II.

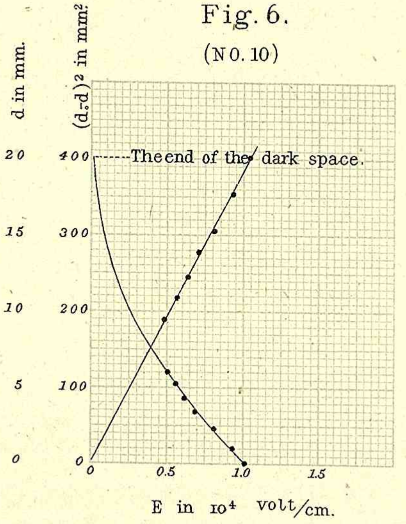


Fig. 6.
(NO. 10)
d in mm.
(d₀-d)² in mm²
The end of the dark space.
20
15
10
5
0
400
300
200
100
0
0
0.5
1.0
1.5
E in 10⁴ volt/cm.

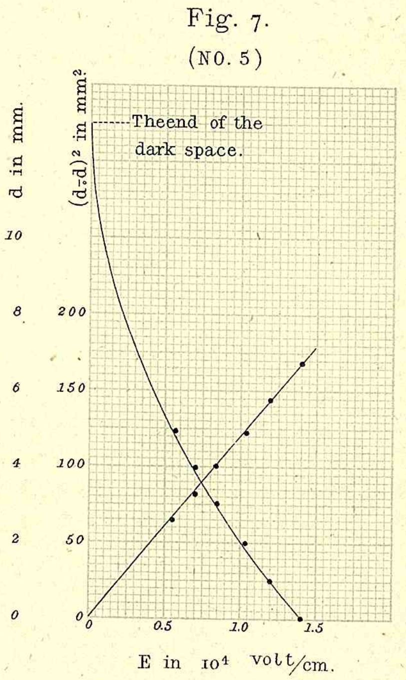


Fig. 7.
(NO. 5)
d in mm.
(d₀-d)² in mm²
The end of the dark space.
10
8
6
4
2
0
200
150
100
50
0
0
0.5
1.0
1.5
E in 10⁴ volt/cm.

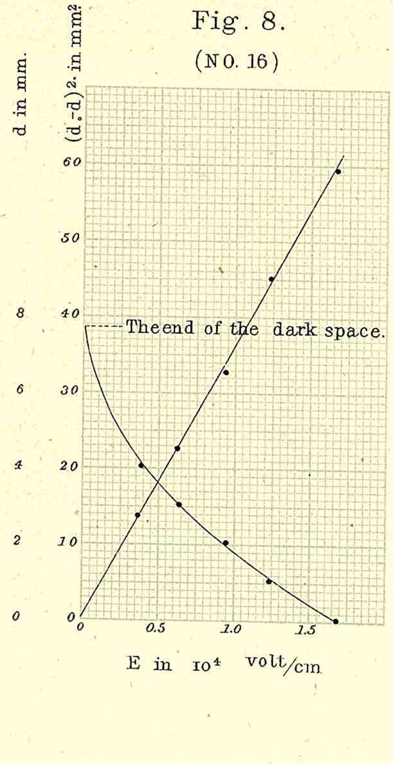


Fig. 8.
(NO. 16)
d in mm.
(d₀-d)² in mm²
The end of the dark space.
8
6
4
2
0
60
50
40
30
20
10
0
0
0.5
1.0
1.5
E in 10⁴ volt/cm

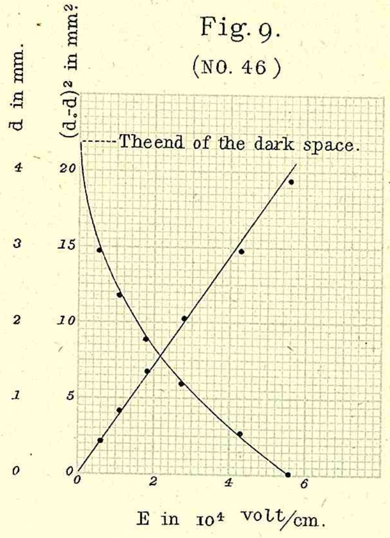


Fig. 9.
(NO. 46)
d in mm.
(d₀-d)² in mm²
The end of the dark space.
4
3
2
1
0
20
15
10
5
0
0
2
4
6
E in 10⁴ volt/cm.