Circular Spark on the Dielectric Plate

By

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I. Introduction.

We have found a peculiar form of spark figure and have published a short abstract about it in the *Proceedings of the Imperial Academy* (*Vol. 3, No. 1*). There we remarked that further investigations would be continued.

In January of this year the *Handbuch der Physik Bd. XIV* dated 1927 arrived. There is a chapter on spark figures, but no figure is described analogous to that which we have found. All the figures described in it are the so called Lichtenberg figures. The radial length of the figure is the principal part of the discussion. The figure taken by Prof. Toepler is somewhat different. Beside the radial figure, there are some polygonal branches. We have noticed already these polygonal branches of the Lichtenberg figures and after various investigations, have reached the conclusion, that this is not the characteristic figure due to the powder or grains on the dielectric plate.

In order to produce these polygonal branches of spark without any powder and grains on the dielectric plate, we have tried various experiments by changing the electric connection, and at last we have found a new figure. This is not the polygonal *branch* of the Lichtenberg figure at all, but some steady circular figure of spark seen on any hard dielectric plate even in day-light. The spark figure is no longer polygonal, but a smooth circle. Moreover the circular spark is quite distinct and the radial spark is rather faint, contrary to the findings of other research workers.

Therefore the diameter of the circular spark is to be investigated, while the radial length is the principal problem of the Lichtenberg figures.

The radial length of the Lichtenberg figure is concluded to be independent of the thickness of the dielectric plate. But now the diameter of the circular spark is found to be a function of thickness. The circular spark on the plate of glass and mica of various thickness are represented in Figs. 1 and 2. It can be concluded at a glance, that the diameter of the circular spark really depends on the thickness.

The investigations by Toepler and others are made by means of a special electrical connection. The radial length of the Lichtenberg figure may vary also with the thickness of the dielectric plate, but from the connection used by Toepler, it may result, that the radial length is independent of the thickness of the dielectric plate. Therefore the electrical connection will be the principal cause to produce such different forms of figure. One of us has studied this problem in detail and we are convinced that our results are rigidly verified.

The object of this essay is to describe the method of producing the circular sparks and to show by photographs the real dependence on the thickness of the dielectric plate. It may be also considered to be an introduction to the further researches made by one of us.

II. Apparatus of experiments.

The electrical connection used for this experiment is shown in the following diagram :

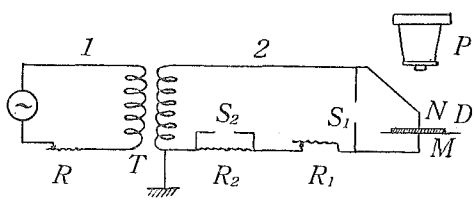

Fig. 3.

1 : Primary circuit,
2 : secondary circuit,
T : transformer,
R : rheostat,
R_1, R_2 : vacuum tubes,
S_1, S_2 : needle spark gaps,
D : dielectric plate,
M : brass plate,
N : needle,
P : photographic camera.

As the high tension producer we used formerly a small induction coil and afterward a high tension transformer and an induction coil having a spark length of 30 cm., both of which are powerful enough to cause the circular spark. In this experiment the high tension transformer which can give a maximum peek potential as high as 200,000 volts is used. The primary current has 60 cycles and is regulated by the resistance R, which will enable giving various potentials to the secondary.

In order to measure the potential difference between the electrodes we use the needle spark gap S_1.

The series spark gap S_2 can be adjusted so as to make the spark perfectly circular. Sometimes this spark gap must be very small, but if none at all is used, we can never have the circular spark. R_1 and R_2 are used in order to make the spark beautiful, though they are not indispensable.

We have tried to insert some capacity in the secondary circuit, but it is proved to be undesirable to have the circular spark. Moreover if the current is rectified by means of kenetron, such circular spark appears no longer.

III. Experiment.

In the earlier part of our experiments, we took photographs of sparks by discharging directly on a photographic plate, but the figure thus taken is not so fine as that taken by discharging on a mere glass plate. Indeed, if the surface of the glass is coated with something, there must exist some irregular effects to disturb the proper motion of the ions or electrons. Therefore it is preferable to use a hard, clean, smooth dielectric plate.

The series spark gap must be carefully adjusted, so that the circular spark alone appears, and sometimes the vacuum tubes are added also to make the spark exactly circular.

In general, if the width of the series spark gap is less than a certain value, no spark occurs at all and there is only blow discharge from the whole surface of the needle, but for larger distances there appear some radial sparks, some bent and at last they vanish on their way. If we make the spark gap still larger, then the circular spark occurs, and if we make the series spark gap still larger, the circular figure is distorted.

Though we can not find any relation between the width of the series spark gap and the diameter of the circular spark, it can be concluded that there must exist some characteristic values of the series spark gap for producing the steady circular spark.

It can be seen even in day-light that the diameter of the circular spark is the same for a given thickness of dielectric plate and for a given potential difference between the electrodes, so far as the spark is exactly circular.

In order to measure the diameter exactly, we take these circular sparks photographed by using the photographic plate " Ilford Special Rapid ", which is sensitive enough to take a photograph of a single spark in an instant, but we exposed it a few tenths of a second or even several seconds. Thus we have several sets of circles, which enable us to measure the diameter exactly.

The distances of the spark gaps S_1 and S_2 are measured at the same time, when the fine circular sparks are photographed.

Experiments described in the present paper are made with glass and mica.

IV. Results of the Experiments.

The results of the experiments are shown in the following tables I and II.

It is not exact to use the needle spark gap to measure the potential difference between the electrodes, but the oscillating high potential can not by any way be measured accurately. The fourth column of the table denotes the reduced values from the observed values of spark gap by comparing it with the table in Kay's "*X-ray*." Though it can not be reliable, it will serve to approximate the relation between the diameter of the circular spark and the potential difference between the electrodes.

The diameters given in these tables are the mean values of the diameters which are measured by us independently.

We can see in these tables some regular relations among the thickness of the dielectric plate, the potential difference between the electrodes and

the diameter of the circular spark. Fig. 1, Fig. 2, Fig. 4 and Fig. 5 will show these relations distinctly.

TABLE 1.

No.	Thickness of glass in cm.	S_1 Spark Dist. in cm.	Pot. Diff. betw. Electrodes	Dia. of circular Spark in cm.
1	0.145	2.35	26.3	2.99
2	.293	4.05	42.0	3.81
3	.441	5.05	49.2	4.62
4	.625	6.85	60.3	4.74
5	.774	7.40	63.0	5.49
6	.145	2.42	27.0	3.02
7	.290	3.60	38.3	4.04
8	.439	4.90	48.2	4.22
9	.297	3.50	37.5	3.96
10	.320	4.10	42.3	4.12

TABLE 2.

No.	Thickness of Mica in cm.	S_1 Spark Dist. in cm.	Pot. Diff. betw. Electrodes	Dia. of circular Spark in cm.
11	0.0065	0.78	9.0	0.99
12	.012	.90	10.5	1.14
13	.015	1.02	11.6	1.16
14	.020	1.05	12.0	1.66
15	.027	1.30	15.0	1.98
16	.0375	1.45	17.3	2.20
17	.094	1.80	20.8	2.73
18	.145	2.30	26.0	3.05
19	.187	2.40	26.8	3.29
20	.238	3.35	36.2	3.79
21	.004	0.95	10.8	1.03
22	.008	1.10	12.5	1.38
23	.012	1.28	14.3	1.55
24	.015	1.15	13.2	1.33
25	.0155	1.15	13.2	1.45
26	.021	1.25	13.8	1.58
27	.021	1.14	13.0	1.46
28	.022	1.18	13.5	1.91
29	.026	1.20	13.7	1.79
30	.036	1.42	16 3	2.04
31	.047	1.59	18.3	2.27
32	.060	1.61	18.5	2.39

TABLE 2 (Continued).

No.	Thickness of Mica in cm.	S_1 Spark Dist. in cm.	Pot. Diff. betw. Electrodes	Dia. of circular Spark in cm.
33	.080	1.87	21.6	2.85
34	.092	1.90	21.8	2.47
35	.092	1.82	21.0	2.77
36	.145	2.10	23.8	2.76
37	.212	2.65	29.3	3.13
38	.171	2.27	25.7	3.14
39	.212	2.81	31.0	3.37
40	.2975	4.03	41.7	3.95

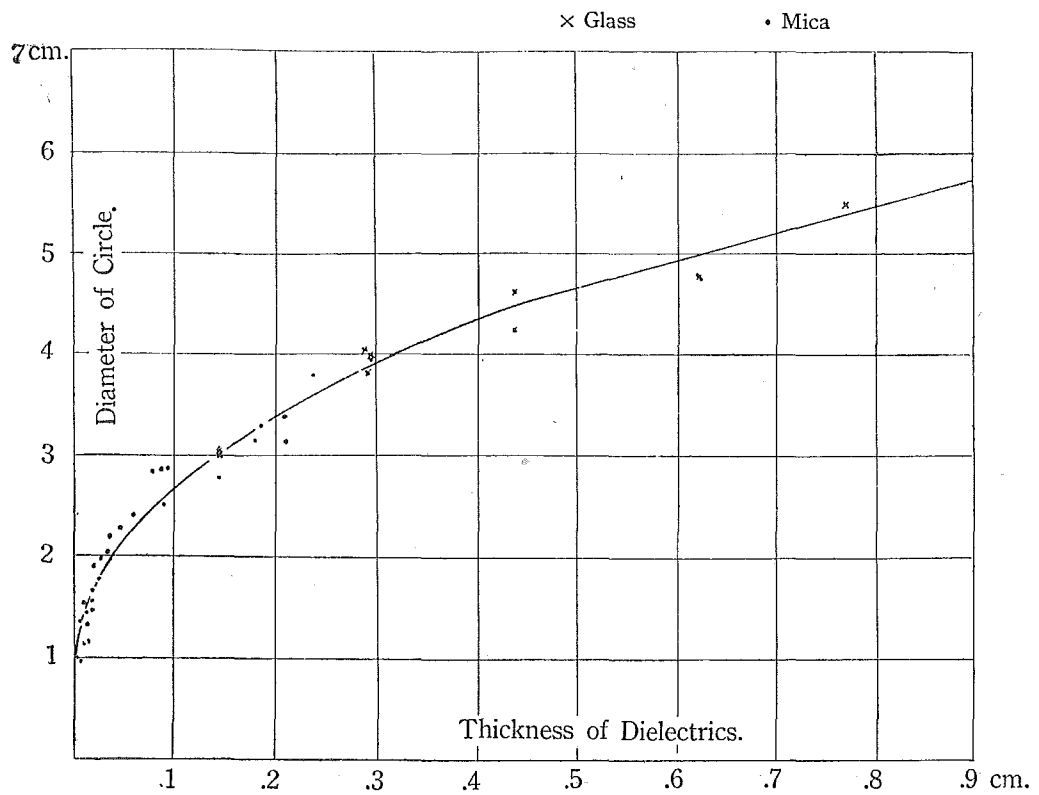

Fig. 4.

TABLE 3.

No.	Thickness of Mica in cm.	S_1 Spark Dist. in cm.	Dia. of circular Spark in cm.
41	0.0018	0.55	0.56
42	.0018	.22	.55
43	.0014	.20	.46
44	.0014	.70	.61
45	.003	.88	.81
46	.005	.96	.93

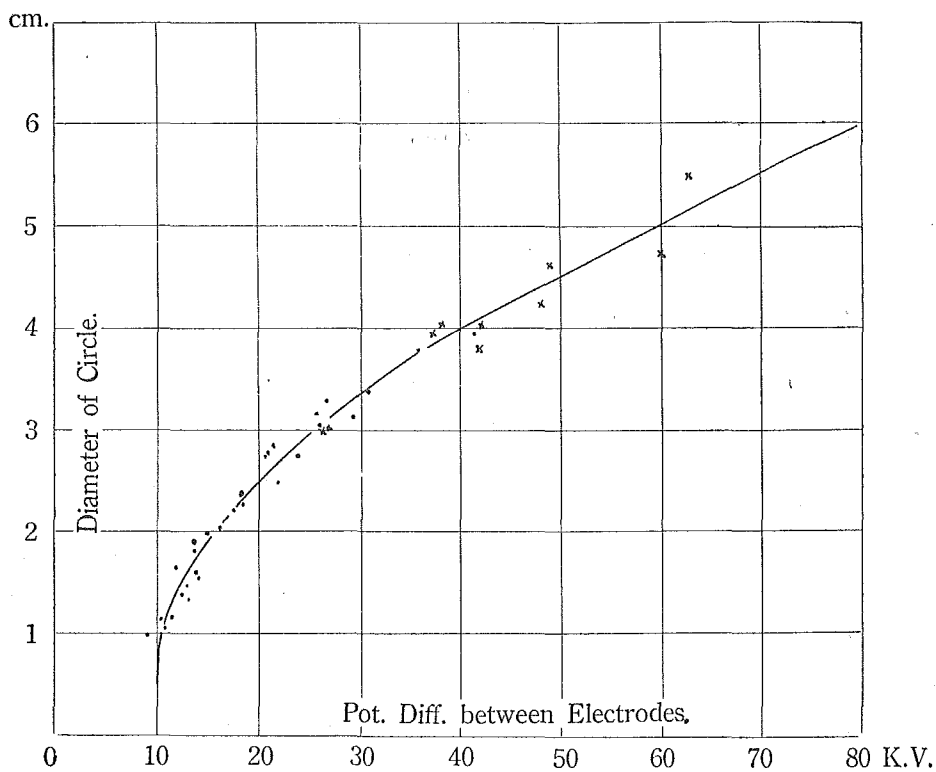

Fig. 5.

It is clear from the tables and figures that the diameter of the circle depends distinctly on the thickness of the dielectric plate and when the thickness of the dielectric plate is given, there exists a characteristic potential difference between the electrodes for making spark circular.

V. Discussion.

From the above tables we have deduced experimental formulae for the relationship between the diameter of the circular spark and the thickness of the dielectric plate and also between the diameter of the circular spark and the potential difference between the electrodes.

Let D be the diameter of the circle, l the thickness of the dielectric plate and V the potential difference of the electrodes, then

$$(D-1.1)^2=25.6\ l,$$
$$(D-0.5)^2=0.4\ (V-10).$$

From these equations we can have D and V, if we measure the thickness l.

When the spark takes a circular form, and when the thickness of the dielectric plate is given, the diameter of the circular spark depends only upon the potential difference between the electrodes. But for producing the exactly circular spark the series spark gap plays an indispensable service. Therefore the circular spark may be considered as a particular phenomenon of the discharge produced by some effects of resonance in the circuit. The regulation of the gap may vary the small capacity in the circuit, with which the large induction in the circuit may perhaps cause some proper oscillations by which oscillations some field may be excited to produce the circular spark. As is shown in Figs. 4 and 5, the effects with glass and mica coincide with one another, but this may be a peculiar coincidence showing, at least, the existence of some similarities between the two.

We express our thanks to our friend Prof. K. Ogushi, for by his advise, we have begun with the investigation on the spark figures.

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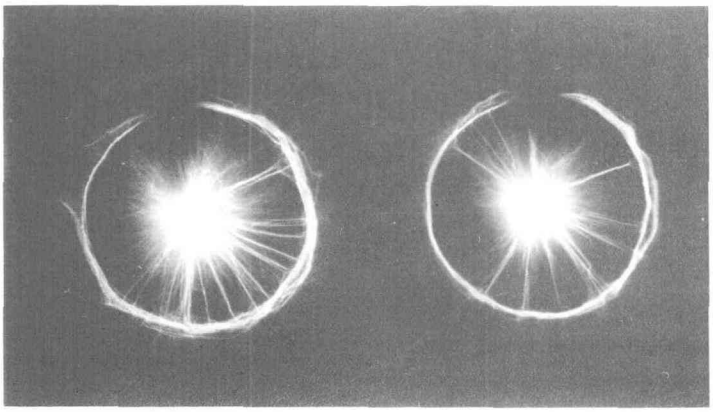
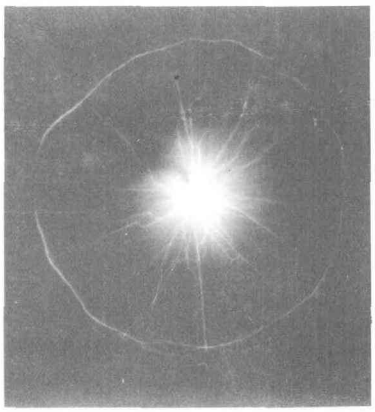
Fig. 1. Circular spark on glass plate of various thicknesses.

(a) ×1



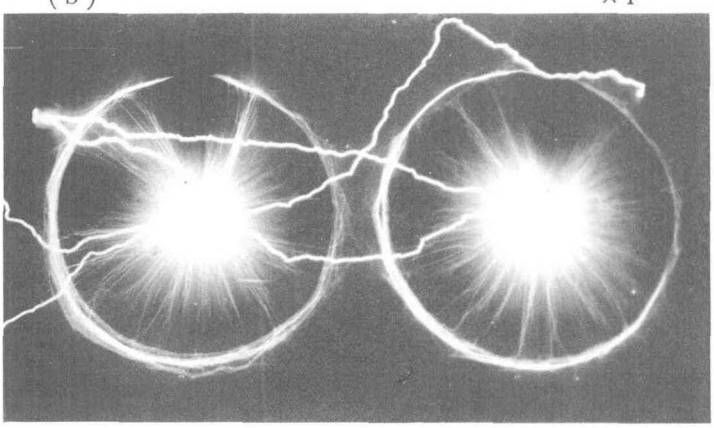
l=0.145 cm.

(d) ×1



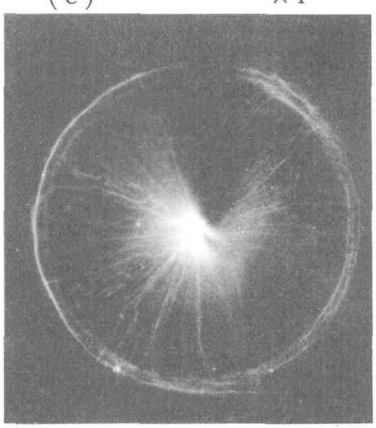
l=0.297 cm.

(b) ×1



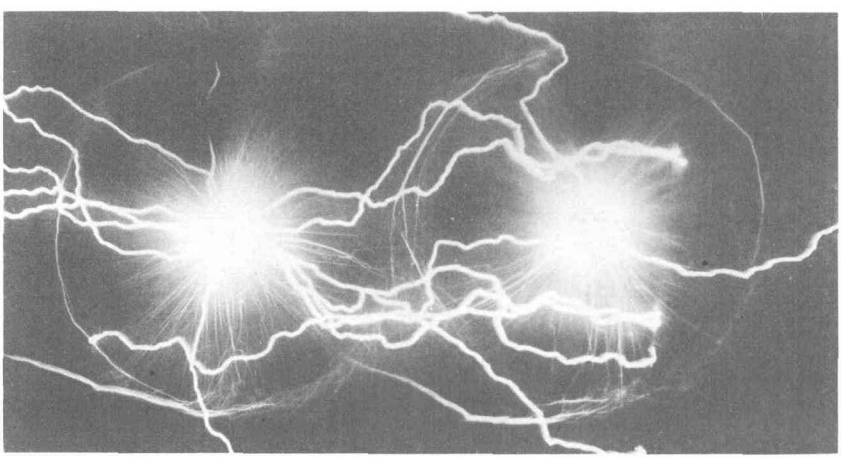
l=0.293 cm.

(e) ×1



l=0.320 cm.

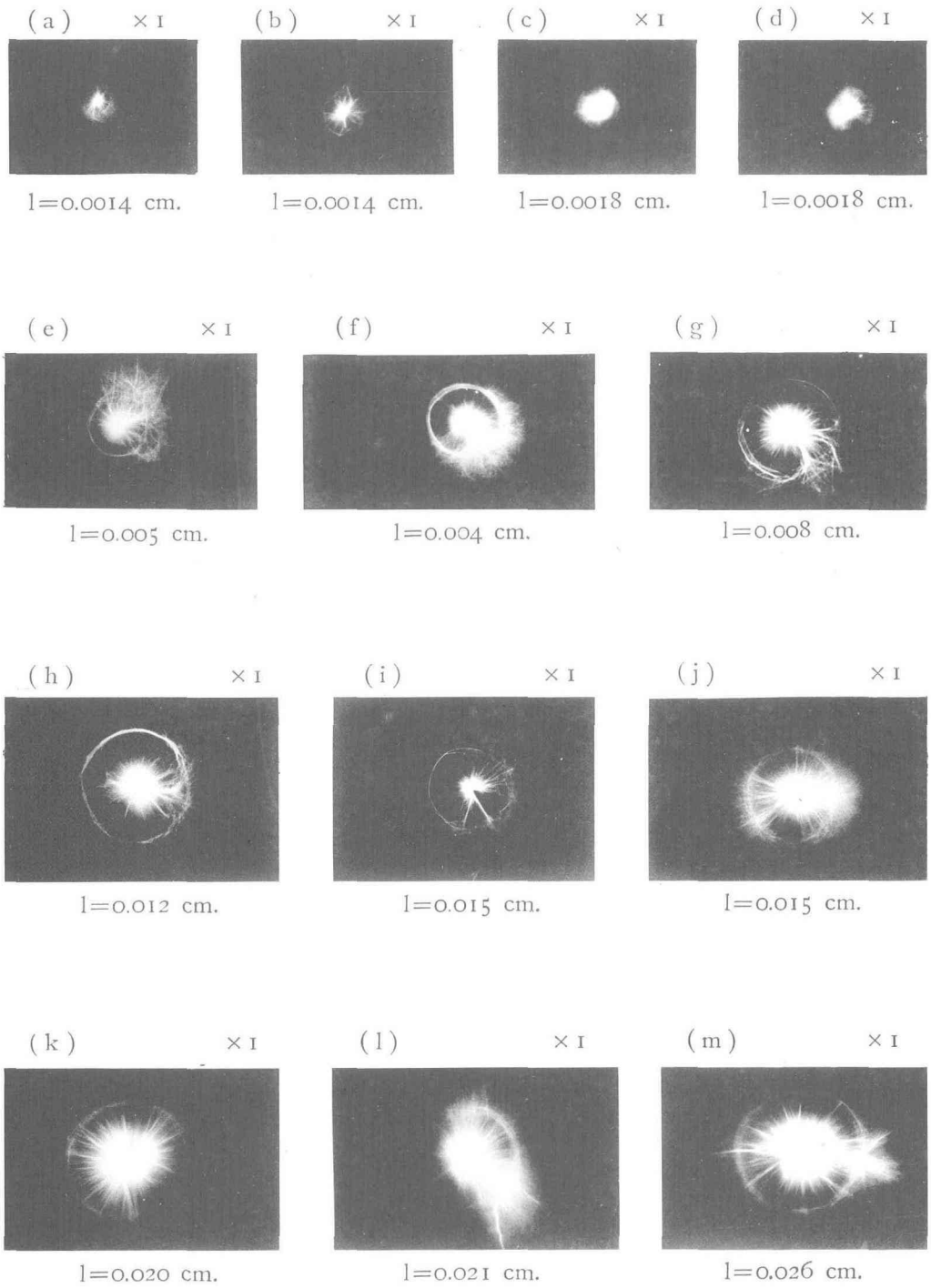
(c)



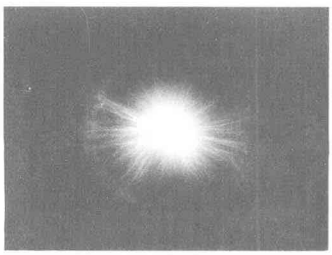
×1

l=0.441 cm.

Fig. 2. Circular spark on mica plate of various thicknesses.

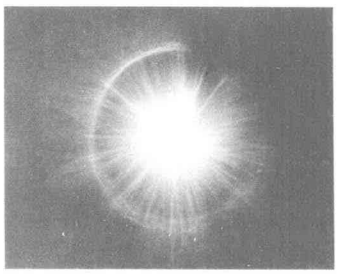


(n) ×1



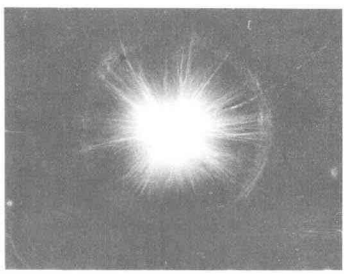
l=0.036 cm.

(o) ×1



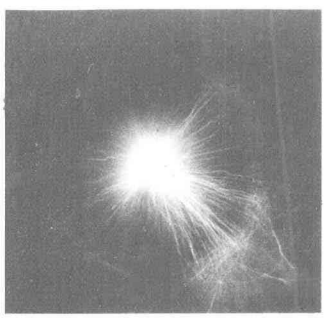
l=0.0375 cm.

(p) ×1



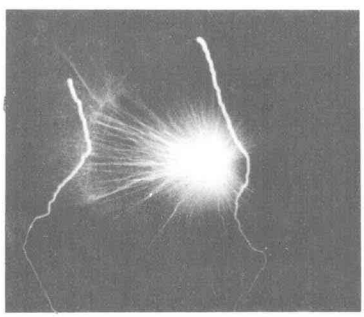
l=0.060 cm.

(q) ×1



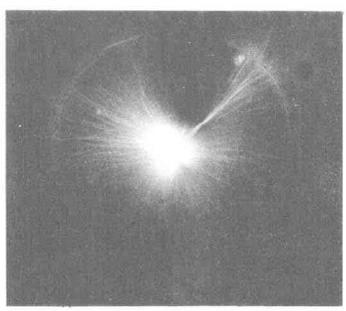
l=0.080 cm.

(r) ×1



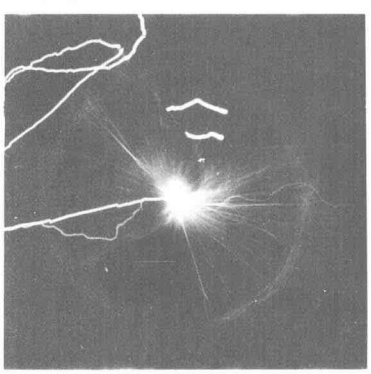
l=0.092 cm.

(s) ×1



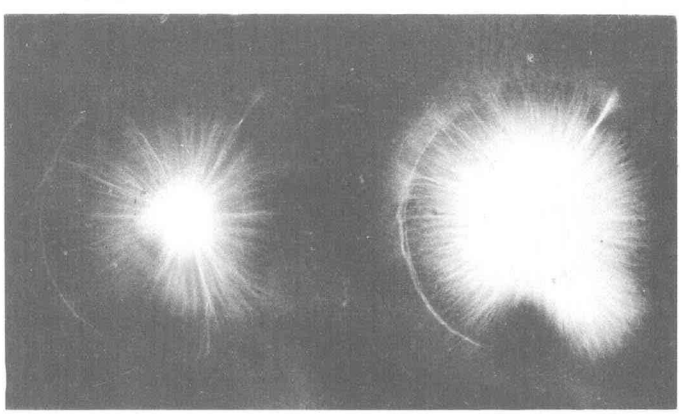
l=0.145 cm.

(t) ×1



l=0.187 cm.

(u) ×1



l=0.238 cm.