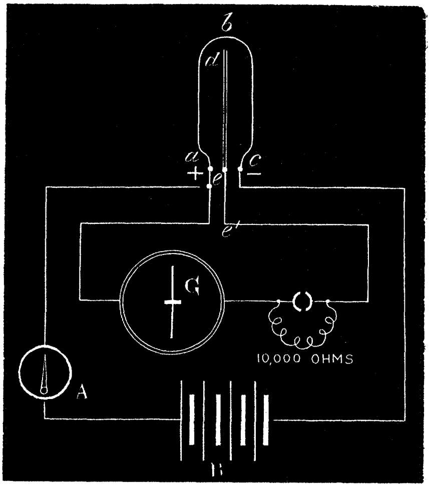
II. "On a Peculiar Behaviour of Glow-Lamps when raised to High Incandescence." By William Henry Preece, F.R.S.

Received March 18, 1885.

1. During my recent visit to America (October, 1884) Mr. Edison showed me a very striking experiment with glow-lamps, the principle of which he had not threshed out, although he had attempted to apply it practically to the regulation of the current flowing in electric light circuits.

Fig. 1.



If *abc* be the incandescent filament of a glow-lamp, *de* a thin narrow platinum plate fixed between the limbs of the filament with an independent wire connexion *ee′* sealed in the glass globe, then, if a galvanometer G be connected between *a*, the positive electrode, and *e*, a derived current will be observed to pass through G, and through the rarefied space *ec* when the main current is increased to a certain strength, and the filament reaches a certain degree of incandescence. The strength of this derived current will increase with the increased brilliancy of the glowing filament. Mr. Edison made for me several lamps of different forms and character to enable me to investigate the phenomenon more carefully in England, and I have the pleasure of submitting the results of those experiments to the Society.

2. I used 60 Faure-Sellon-Volckmar cells freshly and fully charged up at each series of experiments. The current through the filament was measured by a specially constructed and calibrated Ayrton and Perry direct-reading spring ammeter. The galvanometer in the shunt circuit was a sensitive tangent galvanometer of the Post-office pattern. The current through the filament was regulated by varying the number of cells. The current and electromotive force through the shunt *aec* were calculated by the following method:—The resistance of the galvanometer G was 1070 ohms, and a variable resistance R was inserted in its circuit. When the current from a standard Daniell cell (1·07 volt) is sent through the galvanometer, we get a tangent reading *d*, which, since $\frac{1\cdot07}{1070} = \cdot001$, is the deflection, or tangent reading corresponding to 1 milliampère of current. The deflection (d_1) given by the shunt current was first read without any resistance being inserted.

Hence

$$C = \frac{d_1}{d} \text{ milliampères.}$$

Resistance was then added and a second reading d_2 taken; then the resistance r of the shunt is obtained from the formula

$$r = R \cdot \frac{d_2}{d_1 - d_2} - G.$$

The electromotive force producing the current is

$$E = Cr.$$

The shunt circuit includes the rarefied space *ec*, and it is the resistance of this space that we desire to know.

All the observations were simultaneously made by different observers. While one observed the behaviour of the lamp, another read the current flowing through the filament, a third read the currents in the shunt, a fourth varied the electromotive force, and a fifth recorded the results. The electromotive force of the cells was carefully measured before and after the experiments. No photometric measurements were attempted.

3. *Experiment* 1.—The connexions were made as shown in fig. 1. The lamp (No. 4) was a short (75 mm.) filament lamp, with a platinum plate 30 mm. long and 5 mm. broad.

The variation of the current and the increase in the resistance of the filament towards the end of the experiment, together with the behaviour of the shunt, are very noticeable. It is quite clear that when the electromotive force attained 82 volts, a critical point was

Experiment 1.

Filament.			Shunt.			Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.M.F.	Current in milliampères.	Resistance.	
		ohms.	volts.			
44·40	0·7	63·4				
46·62	0·75	62·17	..	..	..	Normal incandescence, viz., 8 candles.
48·84	0·81	60·30				
51·06	0·86	59·37				
53·28	0·91	58·55	14·7	0·30	49,000	
55·50	0·97	57·21	..	..	..	Diffused blue effect in globe appeared.
57·72	1·02	56·60	16·6	1·15	14,500	
59·94	1·08	55·50	16·2	1·80	9,000	
62·16	1·13	55·01	13·5	2·70	5,000	
64·38	1·20	53·66	11·95	3·85	3,000	
66·60	1·24	53·71	7·45	5·25	1,400	Blue effect brilliant.
68·82	1·24	55·51	10·00	5·00	2,000	
71·04	1·30	54·65	9·10	6·00	1,300	
73·26	1·35	54·28	6·50	5·00	1,300	
75·48	1·35	55·92	9·35	5·50	1,700	
77·70	1·41	55·12	9·60	6·00	1,600	
79·92	1·47	54·38	9·80	7·00	1,400	
82·14	1·60	51·34				Deflection too unsteady for observation. Blue effect very brilliant.
84·36	1·60	52·74	criti	cal poi	nt	
86·58	1·53	56·59				
88·80	1·56	57·00	50·6	2·20	23,000	
91·02	1·53	59·30	62·5	2·50	25,000	
93·24	1·57	59·40	61·0	3·20	19,000	
95·46	1·60	59·51	95·0	3·80	25,000	
97·68	..	..	..	..	..	Filament broke. Interior of globe and faces of plate blackened.

reached. From that point the current in the filament remained very steady, but the resistance gradually increased. The shunt increased in resistance enormously, and the current through it diminished, although the electromotive force increased very largely. It is remarkable how steady the electromotive force in the shunt remained until the critical point was reached, when it suddenly increased and only reached that of the main current at the point of rupture of the filament. Again the current, which steadily increased until the critical point was reached, then diminished, indicating a considerable increase in the resistance of the rarefied space *ec*. In one subsequent experiment, after the critical point was reached, no current could be obtained through the shunt.

The direction of the current is shown in the figure.

Towards the end of the experiment, when the characteristic diffused blue effect in the globe was very marked, a bright arc was observed to be playing about the bottom of the limb at *c*, and it was quite clear that a bridge of conducting material was formed between *e* and *c*, which, together with the galvanometer, made a shunt to the filament.

This experiment was repeated upon different lamps, and the results were so similar that it is not necessary to reproduce the observations.

In all cases an intimate connexion was observed between the blue effect and the appearance of the shunt current.

4. One of Mr. Edison's assistants showed me in Philadelphia that while the effect was very perceptible when the connexions were made as shown in fig. 1, *a* being in connexion with the positive and *e* with the negative pole, no shunt current or a very slight one could be observed when the direction of the current was reversed. I did not find this invariably the case. One lamp (No. 8) only—a long filament lamp (150 mm. long)—which gave a marked shunt current and the blue effect, when the connexions were made as in fig. 1 failed to give any current or blue effect when the current was reversed within the limits of the electromotive force at my command. Doubtless I should have got both effects if I could have raised the electromotive force. In all cases, however, the effects appeared sooner and were more marked when the connexions were as shown in fig. 1 than when the direction of the current was reversed. The effect of placing the galvanometer between *e* and *c* was the same as reversing the current.

5. As the effect might be due in some way to the material of the conducting plate (*de*) inserted between the limbs of the filament, Mr. Edison made for me lamps with copper, iron, and carbon plates.

The following experiments (pp. 223 and 224) were then made, the connexions being the same as fig. 1.

No marked difference was thus observable.

If we examine the shunt current when the faint blue tinge appeared, it was: with carbon, 3·42; with iron, 5·85; and with copper, 3·80 milliampères.

6. It might be affected by the extent of surface of the metal plate, therefore lamps were made with a plate of fine wire, and also of a very broad surface, but no difference was observable between these and the normal plate used.

Experiment 2.—Carbon Centre (single).

Filament.			Shunt.			Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.M.F.	Current in milliampères.	Resistance.	
		ohms.	volts.			
80	0·50	160·0				
84	·57	147·4	..	0·98		
88	·60	146·7	5·44	0·54	99,000	
92	·65	141·6	4·76	1·22	39,000	
96	·70	137·1	27·7	2·20	12,600	
100	·74	135·1	25·4	3·42	7,420	Blue tinge appeared.
104	·79	131·7	21·4	4·88	4,380	
108	·83	130·1	17·5	7·32	2,390	
88	0·60	146·7	08·23	0·46	179,000	Reversed the current through the filament and repeated the experiments.
92	·65	141·6	04·86	0·93	52,300	
96	·70	137·1	26·0	1·76	14,800	
100	·74	135·1	21·1	2·93	7,190	Blue tinge appeared.
104	·79	131·7	19·1	4·45	4,300	
108	·83	130·1	17·5	7·32	2,390	

Experiment 3.—Iron Centre (single).

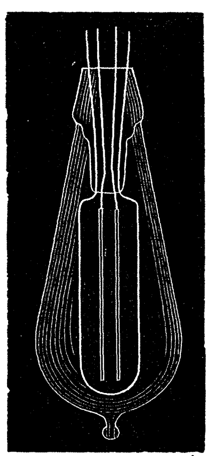
Filament.			Shunt.			Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.M.F.	Current in milliampères.	Resistance.	
		ohms.	volts.			
80	0·50	160·0				
90	·57	157·9				
96	·62	154·8	..	0·25		
100	·66	151·5	..	0·49		
110	·77	142·9	31·4	2·05	15,300	
120	·87	137·9	19·8	5·85	3,380	Faint blue.
90	0·57	157·9	..	0·09	..	Reversed the current through the filament and repeated the experiments.
100	·66	151·5	..	0·49		
110	·77	142·9	27·3	1·95	14,000	
120	·87	137·9	20·0	5·61	3,560	Faint blue.

Experiment 4.—Copper Centre (single).

Filament.			Shunt.			Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.M.F.	Current in milliampères.	Resistance.	
		ohms.	volts.			
80	0·57	140·4	..	0·048		
90	67	134·3	39·2	1·12	35,000	
100	79	126·6	19·0	3·80	5,000	Faint blue.
110	90	122·2	..	needle hard over	..	Strong blue.
90	0·67	134·3	29·9	0·88	34,000	Reversed the current through the filament and repeated the experiments.
100	·79	126·6	17·2	3·32	5,190	Faint blue.
110	·90	122·2	..	needle hard over	..	Strong blue.

7. Lamp No. 9 was made with a double platinum plate, thus:—

Fig. 2



The following experiment shows that no perceptible difference was observable:—

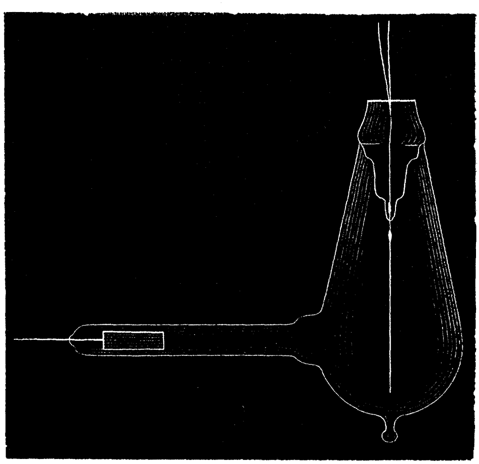
Experiment 5.—No. 9 Lamp (double platinum).

Filament.			Shunt.						Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.M.F. Left.	Calculated E.M.F. Right.	Current in milliampères. Left.	Current in milliampères. Right.	Ohms. Left.	Ohms. Right.	
		ohms.	volts.	volts.					
80	0·56	142·9	5·46	5·46	0·39	0·39	140,000	140,000	
84	·60	140·0	3·8	3·8	0·83	0·83	45,700	45,700	
88	·65	135·4	24·5	24·5	1·56	1·56	15,700	15,700	
90	·68	132·4	20·5	20·5	2·05	2·05	10,000	10,000	
94	·72	130·6	16·2	16·2	3·27	3·27	4,950	4,950	
100	·79	126·6	15·4	15·4	5·85	5·85	2,630	2,630	Slight blue tinge perceptible.
110	·92	119·6			Doubt	ful.			

8. Although the maximum effect was produced by Mr. Edison when the plate was fixed between the limbs, he obtained a current when it was fixed in any part of the rarefied space. If the effect was due primarily to the Crookes effect, or to the projection of molecules from the carbon filament on to the metal plate, since this bombardment takes place in right lines, we ought to have obtained effects when these lines were projected on the plate, but no effects when they could not strike the plate. Several lamps were made, which are shown in the following sketches.

9. The metal plate was taken from between the limbs of the filament, and placed at the end of a tube which had a portion of the filament exposed to the plate.

Fig. 3.



Experiment 6.—No. 5 Lamp.

Filament.			Shunt.			Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.M.F.	Current in milliampères	Ohms.	
		ohms.	volts.			
50	..	..	..	..	..	*a*+, *c*−, Fig. 1.
60						
70	0·55	127·3				
80	0·65	123·1				
84	0·70	120·0				
86	0·73	117·8				
88	0·75	117·3				
90	0·77	116·9				
92	0·80	115·0				
94	0·82	114·6				
96	0·85	113·0	}	No cur	rent.	
98	0·87	112·6	..	..	..	Blue effect visible in bulb.
100	0·89	112·4				
102	0·93	109·7				
104	0·96	108·3				
106	0·99	107·1	..	..	..	Blue effect strong in bulb; none in tube.
108	1·01	106·9				
110	1·05	104·7				

Recommenced Experiment with 100 volts.

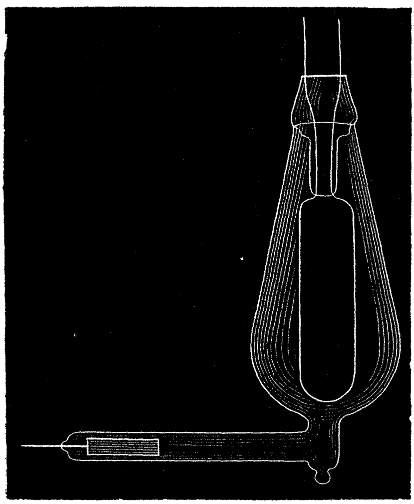
Filament.			Shunt.			Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.M.F.	Current in milliampères.	Ohms.	
		ohms.	volts.			
100	0·89	112·4	..	..	..	*a*+, *c*−, fig. 1.
102	0·93	109·7				
104	0·96	108·3	..	·049		
106	0·99	107·1	..	·049		
108	1·01	106·9	..	..	..	Blue effect entering tube.
110	1·05	104·7	..	·073		
112	1·07	104·7	..	·146		
114	1·11	102·7	..	·195		
116	1·14	101·8	..	·24		
118	1·18	100·0	11·3	·39	29,000?	{ Deflection too low to enable resistance to be properly measured.
120	1·22	98·36	10·9	·49	22,300	

Reversed the current through the filament. Returned to 90 volts, and repeated the experiments. Filament current readings the same as before, and also the blue effects. At 108 volts a slight blue effect was noticed in the open end of the tube.

Doubtless, if I could have increased the electromotive force, the results would have been more marked; but they were sufficient to show that the effects were evident, even though the rarefied space were greatly extended, as in the case of the tube attached to No. 5 lamp.

10. The tube was constructed so that no portion of the filament was opposed by right lines to the metal plate (fig. 4).

FIG. 4.



11. A lamp was constructed with three branches at right angles to each other, as shown in fig. 5, and each metal plate taken in succession, but no results were obtained.

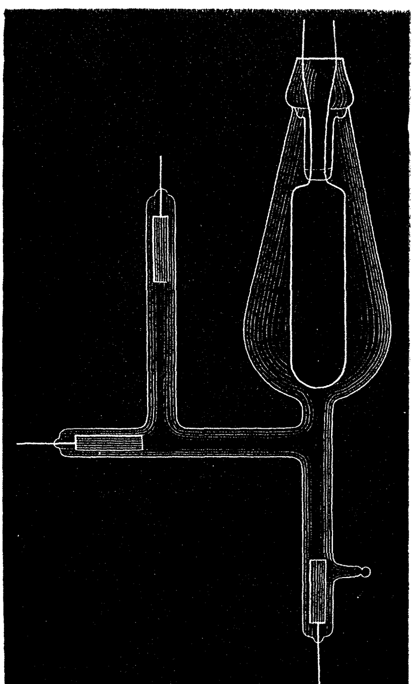
12. Professors Liveing and Dewar ("Proc. Roy. Soc.," March 9, 1882) observed a "sort of flame" during high incandescence, showing by its spectrum the presence of carbonic oxide. It was strongest about the junction of the carbon thread and the positive electrode. It was, according to them, the glow of the positive pole attending a discharge in rarefied gas.

It is a common thing with glow-lamps which have the heels of the filament close together to have an arc forming across when the electromotive force at the terminals is too high. Hence in recent lamps requiring 100 volts, Mr. Swan has considerably increased the distance between the electrodes. Moreover, whenever the incandescence of

Experiment 7.—No. 6 Lamp (long filament).

Filament.			Shunt.			Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.F.M.	Current in milliampères.	Ohms.	
		ohms.				
76						
80	0·57	140·3				
84	0·60	140·0				
88	0·65	135·4				
92	0·71	129·6				
96	0·75	128·0				
100	0·80	125·0	..	..	..	Faint blue in globe.
104	0·84	123·8	..	·049	Deflections too low to enable resistance to be measured.	
108	0·89	121·3	..	·085		
112	0·94	119·1	..	·10		Blue in globe very marked.
116	0·99	117·2	..	·073		
120	1·06	113·2	..	·20		Bulb hot, tube cool.

Fig. 5.



Experiment 8.—No. 7 Lamp.

Filament.			Shunt.			Remarks.
Volts.	Ampères.	Calculated resistance (hot).	Calculated E.M.F.	Current in milliampères.	Ohms.	
		ohms.				
80	0·56	142·9				
90	0·66	136·4				
100	0·77	129·9	..	..	..	Blue effect in globe visible.
102	0·79	129·1		No current evident in either section.		
104	0·82	126·8				
106	0·84	126·2				
108	0·86	125·6				
110	0·89	123·6				
112	0·91	123·1				
114	0·94	121·3				
116	0·98	118·4				
118	1·00	118·0				
120	1·02	117·7				

the filament is raised beyond a certain limit the interior of the glass envelope is blackened by a layer of carbon, which has been deposited by a Crookes bombardment effect. When the carbon filament is fixed on copper electrodes, the interior of the glass sometimes becomes coated with copper as well as with carbon, and the line between the two is perfectly marked, showing that the bombardment takes place in right lines. Experiment 1 shows how very high the electromotive force can be carried, if it be steadily and rapidly increased, before the filament is broken; but practice shows that when once the blue effect appears, destruction is only a question of time. Hence the blue effect is an indication of the advent of disintegration, and a very useful warning of danger ahead.

13. Now it is clear that we have a combination of the phenomena above described in the Edison effect. A continuous bridge of molecules is formed between the junction of the carbon filament and the metal plates inserted between its heels. They are found deposited on the metal plate. A shunt is thus formed whose resistance is measurable, and a definite current passes. This shunt is formed just where the negative metallic connexion joins the heel of the carbon filament, as we should expect from the investigations of Mr. Crookes. The current is, however, weak and variable, and it is scarcely reliable enough to be useful for practical purposes as was hoped by its discoverer. When the critical point is reached the blue glow and flame seem to pervade the whole bulb, and the arc-like effect, instead

of playing about the heel, surrounds apparently the whole filament. The result is that the current passes through the galvanometer and through the rarefied space. This is clearly shown in Experiment 1.

14. It is quite clear that the critical point is reached when the filament commences to be disintegrated by the projection of its molecules from its surface. It is here that the resistance of the filament commences to increase, and the law of radiation and light emission ("Proc. Roy. Soc.," No. 229, 1884) commences to be departed from, as was shown by me in a paper read before the British Association at the Montreal meeting.*

15. It is very evident that this Edison effect is due to the formation of an arc between the carbon filament and the metal plate fixed in the vacuous bulb; that this arc is due to the projection of the carbon particles in right lines across the vacuous space; and that it makes its appearance earlier, and is more strongly marked, when the connexions are as shown in Fig. 1 than when they are reversed, because, as Mr. Crookes has pointed out, the projection proceeds from the negative to the positive pole, and it would commence at the point of least resistance. Its presence is detrimental to the life of the lamp, and as its appearance is contemporaneous with the blue effect, the latter is a warning of the approach of the critical point, and a sure indication that the electromotive force is dangerously high. It is also clear that as the Edison effect is only evident when we are "among the breakers," it is not available for practically regulating the conditions of electric light currents as its ingenious discoverer originally proposed.

* In this paper I pointed out from experimental data that the light emitted by a glow-lamp varied apparently as the sixth power of the current. I verified this law, not only by subsequent experiments of my own, but, which is much more satisfactory, by experiments of others. Professor Kittler, of Darmstadt, and Captain Abney made, independently of each other, most careful and exhaustive measurements in this direction. I tabulated and traced them out in curves. They fully confirm the law that

$$L = kC^6,$$

but within limits, and that these limits embrace the ordinary range of a glow-lamp when used for artificial illumination. As long as the resistance and the current vary uniformly together the law holds good; but as the state of incandescence is increased, a point is reached, varying with each kind of lamp, when the resistance ceases to diminish at the same rate, and eventually increases. When this occurs the law is departed from, and the light emitted increases less than the sixth power of the current. The filament speedily breaks. The point of departure from the law indicates a point when a change of state occurs in the carbon filament. Disintegration probably sets in. This point ought to be determined for each kind of lamp, and it should never be allowed to be reached, for it is from this point that decay commences and rupture follows.

The Society then adjourned over the Easter Recess to Thursday, April 16th.

Fig. 1.

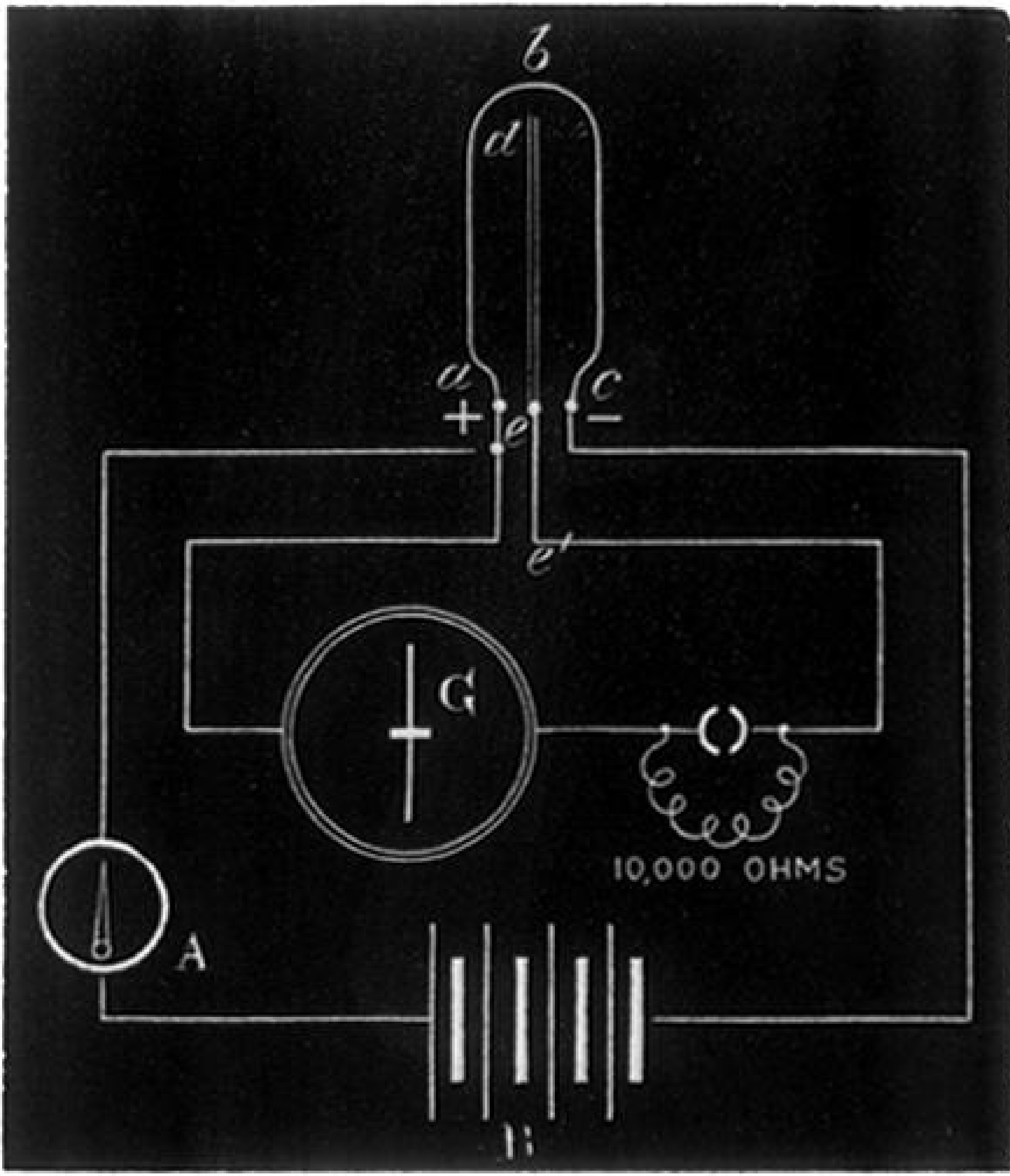


FIG. 2

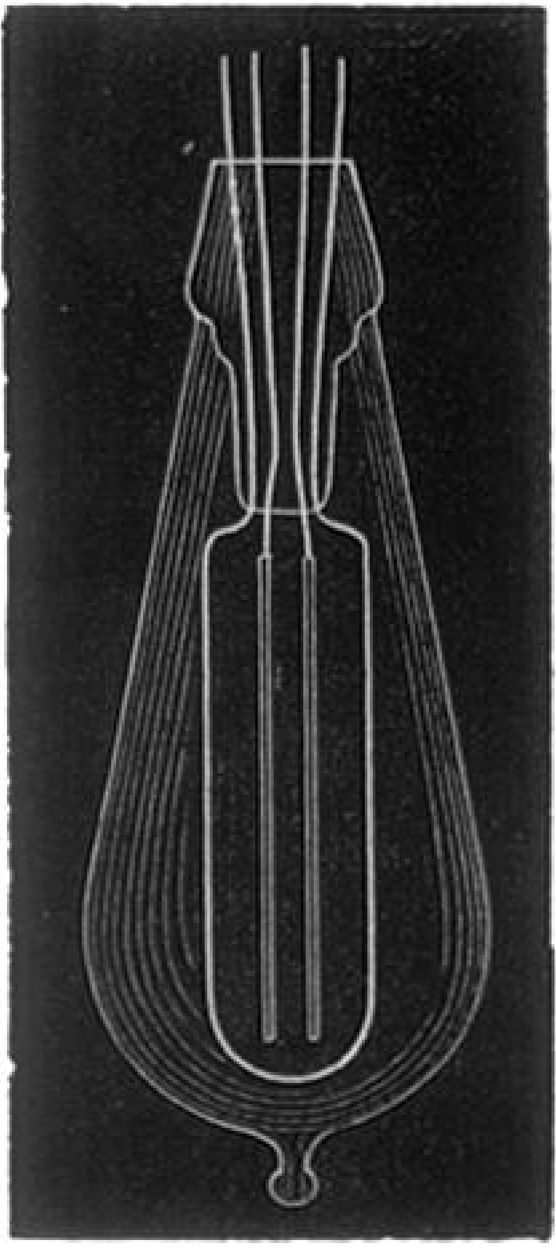


FIG. 3.

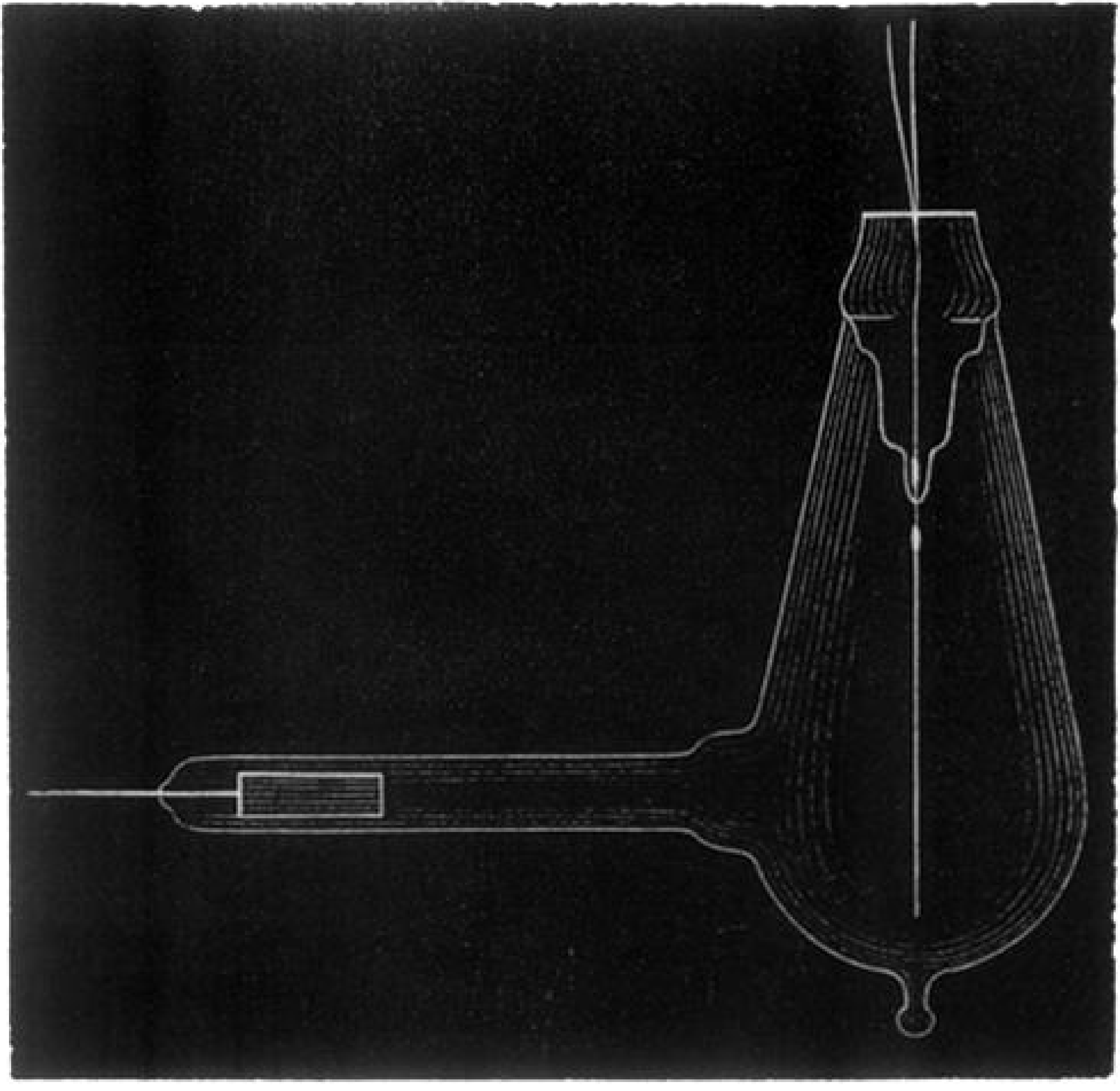


FIG. 4.

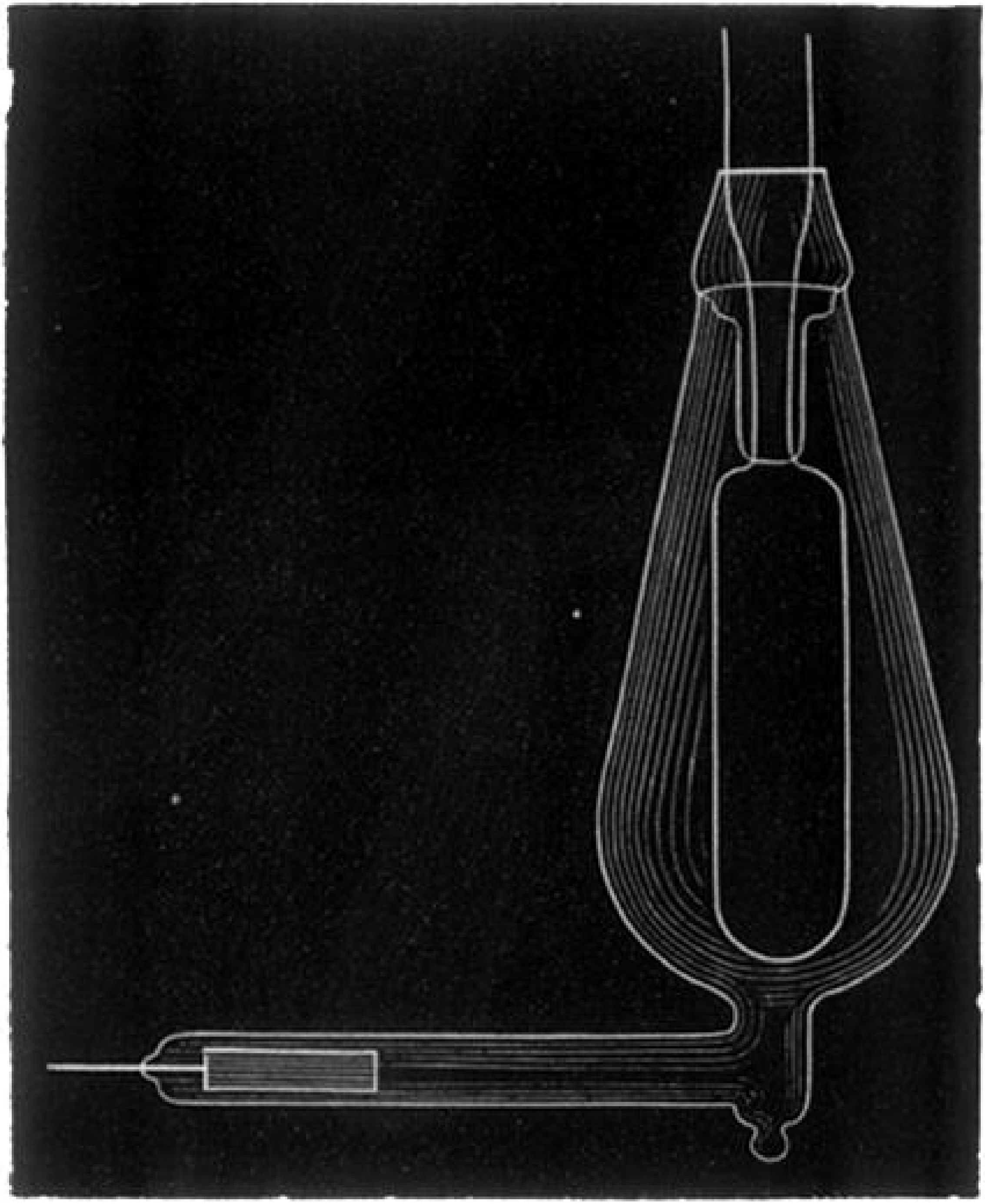


Fig. 5.