IV. *Experimental Researches on the Electric Discharge with the Chloride of Silver Battery.*

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Received August 7,—Read November 20, 1879.

[Plates 8–10.]

Part III.—TUBE-POTENTIAL; POTENTIAL AT A CONSTANT DISTANCE AND VARIOUS PRESSURES; NATURE AND PHENOMENA OF THE ELECTRIC ARC.

Tube-potential.

During the course of the experiments described in Part II.* it could not fail to be noticed that the potential necessary to produce a discharge in partially exhausted tubes diminished with the pressure until a certain minimum pressure had been attained; and that after this minimum had been reached, the potential had to be increased as the rarefaction was carried on, until at last 11,000 cells could no longer produce a discharge. Although Part II. contains many measurements from which it would be possible to calculate the tube-potential (the potential necessary to produce a discharge in a tube) for certain pressures, yet as they would not form a continuous series it was deemed desirable to make a special set of experiments with a constant number of cells, 11,000. This we have done in the case of hydrogen with a new tube, 162, 33 inches long and 2 inches in diameter, the distance between the ring and straight-wire terminals being 29·75 inches. In commencing each set of experiments the deflection of a tangent-galvanometer was observed when the battery was short-circuited; by a table previously calculated, the value of the deflection in ohms of resistance per cell could be read off: this multiplied by 11,000 gave the total resistance of the battery; the tube was then connected with the terminals and the galvanometer again observed, this gave a less deflection and indicated a greater resistance, which, multiplied by 11,000, gave the total resistance of the tube and battery; by subtracting the resistance of the battery the resistance of the tube was ascertained. Calling the total resistance R, the tube-resistance r, the tube-potential V, $V=\frac{r\times 11,000}{R}$. Thus in the first experiment cited, the battery, short-circuited, gave a deflection of 61°, indicating a total battery-resistance of 230,000 ohms; when the

* Phil. Trans. for 1878, Part I. (Vol. 169).

tube was connected a deflection of 7°, indicating a total resistance, tube and battery, of 3,383,000 ohms $=R$, $3,383,000-230,000=3,153,000=r$ the tube resistance, $\frac{3,153,000\times 11,000}{3,383,000}=10,250=V$. The deflection observed was found to be different when the ring was made positive and negative respectively; the following results were obtained in each particular case:—

OBSERVATIONS July 3rd, 1878.—11,000 cells, short-circuit, deflection 61°, total battery-resistance = 230,000 ohms; deflections afterwards taken with the tube connected, the ring being positive.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring + °			cells.
35·5	46,710	7·0	3,383,000	3,153,000	10,250
32·8	43,158	4·5	5,314,000	5,084,000	10,520
31·3	41,184	5·0	4,760,000	4,530,000	10,470
29·2	38,421	5·0	4,760,000	4,530,000	10,470
28·0	36,842	6·5	3,654,000	3,424,000	10,300
26·0	34,211	14·0	1,664,000	1,434,000	9479
25·0	32,895	14·0	1,664,000	1,434,000	9479
23·8	31,316	15·5	1,502,000	1,272,000	9340
21·7	28,553	18·5	1,242,000	1,012,000	8950
20·8	27,368	20·0	1,141,000	911,000	8782
19·8	26,053	21·5	1,054,000	824,000	8592
18·7*	24,605	21·0	1,082,000	852,000	8660
17·8†	23,026	23·0	976,600	746,600	8410
16·0	21,053	25·0	890,600	660,600	8157

JULY 4th.—11,000 cells, short-circuit, deflection 57°, total battery-resistance = 263,600 ohms.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring + °			cells.
13·5	17,763	26·0	851,100	587,500	7593
12·1	15,921	27·0	815,100	551,500	7446
10·7	14,079	29·0	749,200	485,600	7129
9·0‡	11,842	38·0	531,600	268,000	5546
7·9	10,395	37·0	556,200	292,600	5788
6·8	8947	43·0	445,300	181,700	4487
5·3	6974	43·0	445,300	181,700	4487
4·6	6053	48·0	374,000	110,400	3247

* One luminosity like that in Plate 15, fig. 1, Part II.

† Two luminosities like those in Plate 15, fig. 2, Part II.

‡ A phase as 4, fig. 50, Part II., p. 192.

JULY 4th, 4 P.M.—11,000 cells, short-circuit, deflection 58°, total battery-resistance = 253,300 ohms.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring + °			cells.
4·3	5658	46·0	400,300	147,000	4039
3·8	5000	45·0	415,000	161,700	4285
3·41	4487	46·0	400,300	147,000	4039
2·789	3670	51·0	336,200	82,900	2713
2·488	3273	50·0	348,500	95,200	3004
2·327	3062	51·0	336,200	82,900	2713
1·966	2587	51·0	336,200	82,900	2713
1·745	2296	53·0	313,000	59,700	2098

JULY 5th.—11,000 cells, short-circuit, deflection 58°, total battery-resistance = 253,300 ohms.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring + °			cells.
1·023	1346	54·0	302,100	48,800	1776
0·822	1082	51·0	336,200	82,900	2713
0·642	845	57·0	263,600	10,300	430
0·421	554	49·0	360,800	107,500	3278
0·341	449	49·0	360,800	107,500	3278
0·265	349	45·0	413,000	159,700	4254
0·169	222	48·0	374,000	120,700	3550
0·090	126	43·0	445,300	192,000	4742
0·076	100	42·0	461,500	208,200	4963
0·046	61	38·0	531,600	278,300	5758

JULY 6th.—11,000 cells, short-circuit, deflection 60°, total battery-resistance = 239,500 ohms.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring + °			cells.
0·023	30·0	34·0	615,800	376,300	6720
0·013	17·0	32·0	664,600	425,100	7036
0·008	10·5	31·0	691,100	451,600	7171
0·0074	9·7	27·0	815,100	575,600	7769
0·0070	9·2	22·0	1,028,000	788,500	8431
0·0065	8·6	18·0	1,277,000	1,037,500	8937

The following observations were made when the straight wire was made positive; when the contact-key (figs. 2 and 3, Part I., page 59) was in the position fig. 2, this was effected. It was noticed that when in this position the current of the battery itself, when short-circuited, was less than when the key was reversed as for the first series, when the ring was positive, the contact being more perfect in one or other case.

JULY 4th.—11,000 cells, short-circuit, deflection 54°, total battery-resistance = 302,100 ohms.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring − °	ohms.	ohms.	cells.
18·7	24,605	17·0	1,358,000	1,055,900	8531
17·8	23,421	15·0	1,550,000	1,247,900	8837
16·0	21,053	29·0	749,200	447,100	6564

11,000 cells, short-circuit, deflection 50°, total battery-resistance = 348,500 ohms.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring − °	ohms.	ohms.	cells.
13·5	17,763	24·0	932,600	584,100	6890
12·1	15,921	25·0	890,900	542,100	6695
10·7	14,079	29·0	749,200	400,700	5884
9·0	11,842	31·0	691,100	342,600	5453
7·9	10,395	34·0	615,800	267,300	4775
6·8	8947	37·0	556,200	207,700	4109
5·3	6974	42·0	461,500	113,000	2694
4·6	6053	42·0	461,500	113,000	2694

11,000 cells, short-circuit, deflection 51°, total battery-resistance = 336,200 ohms.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring − °	ohms.	ohms.	cells.
4·3	5658	41·0	478,000	141,800	3062
3·8	5000	42·0	461,500	125,300	2986
3·410	4487	43·0	445,300	109,100	2695
2·789	3670	46·0	400,300	64,100	1762
2·488	3273	45·0	415,000	78,800	2088
2·327	3062	46·0	400,300	64,100	1762
1·966	2587	45·0	415,000	78,800	2088
1·745	2296	50·0	348,500	12,300	388

JULY 5th.—11,000 cells, short-circuit, deflection 51°, total battery-resistance = 336,200 ohms.

Pressure.		Deflection with tube.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	ring −	ohms.	ohms.	cells.
1·023	1346	47·0	386,700	50,500	1436
0·822	1082	50·0	348,500	12,300	388
0·642	845	47·0	386,700	50,500	1436
0·421	554	47·0	386,700	50,500	1436
0·341	449	46·0	400,300	64,100	1762
0·265	349	47·0	386,700	50,500	1436
0·169	222	49·0	360,800	24,600	750
0·096	126	47·0	386,700	50,500	1436
0·076	100	45·0	415,000	78,800	2088
0·046	61	44·0	430,700	94,500	2415

The observations point clearly to the resistance of a tube diminishing as the pressure decreases up to a certain point, after which it rapidly increases; the pressure of least resistance in the case of hydrogen, as shown by the experiments when the ring was positive, being about 0·642 m.m., 845 M. The resistance increases very rapidly when a pressure of 0·0076 m.m., 10 M, is reached, and the curve then becomes nearly a vertical to the abscissæ. At a pressure of 0·002 m.m., 3 M, the discharge of 11,000 cells only just passed. (Part II., page 187, footnote.)

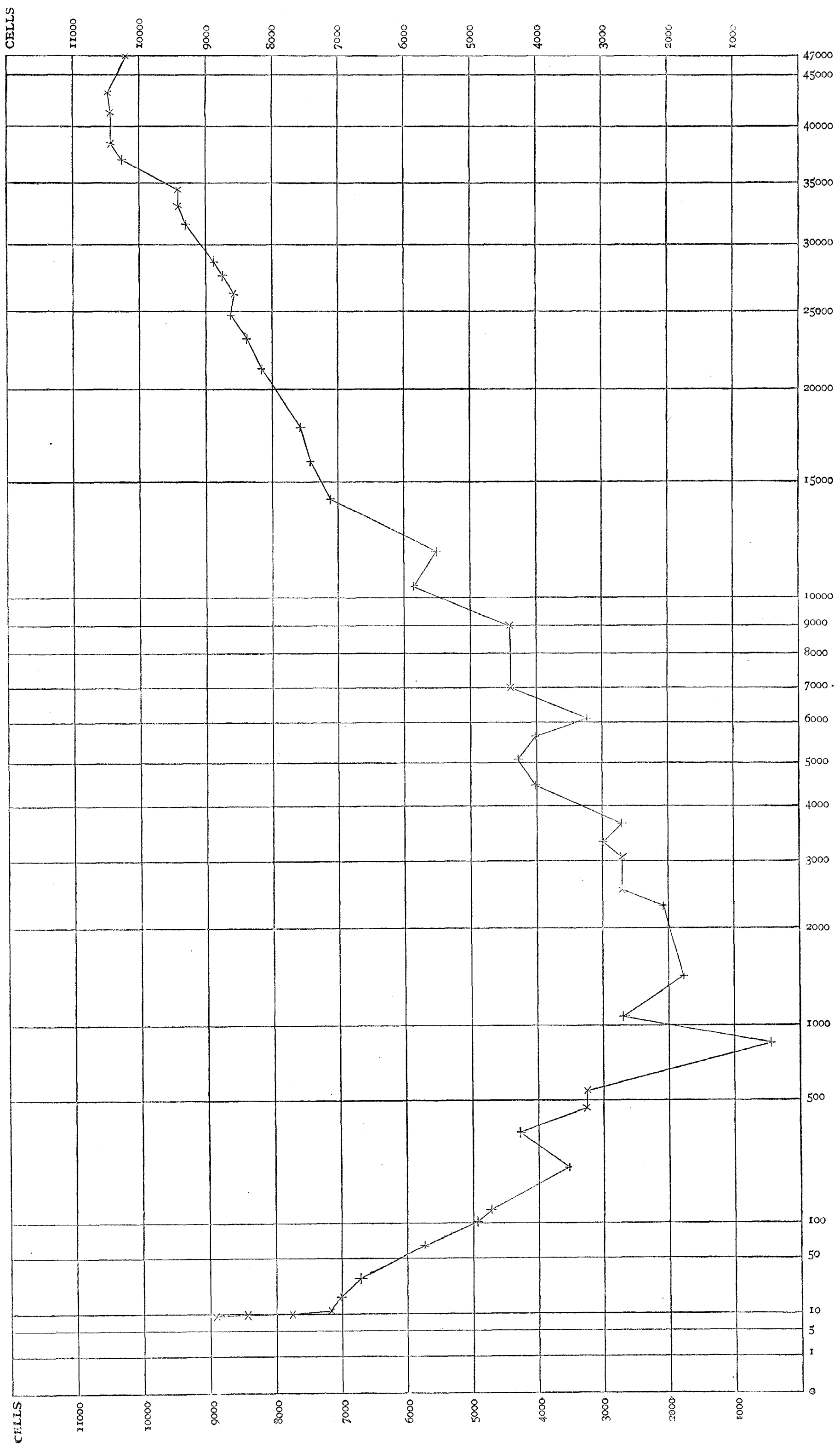
With a pressure of 0·00137 m.m., 1·8 M, 11,000 cells would not pass, and with a pressure of 0·000055 m.m., 0·066 M, even a 1-inch spark from an induction coil would not pass. (Part II., page 215.)

The diagram (fig. 71) laid down from the results when the ring was made positive, shows the curve of the observations as actually obtained without being smoothed. The figure is a reduction to $\frac{1}{3\cdot5}$ of the original; the abscissæ are as the cube-roots of the various pressures in millionths of an atmosphere, and show relatively the number of molecules in a given linear space, the ordinates are as the number of cells.

The life of the battery is so much exhausted by such a series of experiments, in consequence of the length of time the current has to remain on while the galvanometer becomes steady, that it was not deemed desirable to extend them to other gases or to repeat the experiments in order to obtain an average smoother curve for hydrogen. There is, however, no reason to doubt the accuracy of the results as recorded at the moment of each experiment, for the character of a tube is continually altering during a continuous series of experiments, and no precautions can be taken which will render a tube absolutely constant for any length of time. In order to avoid running down the battery, other methods for determining the tube-potential were subsequently adopted; these are described in notes A and B in the Appendix.

When the observations with the ring positive were laid down with the abscissæ representing millionths (not their cube-roots) in order to extend the scale, and a smooth

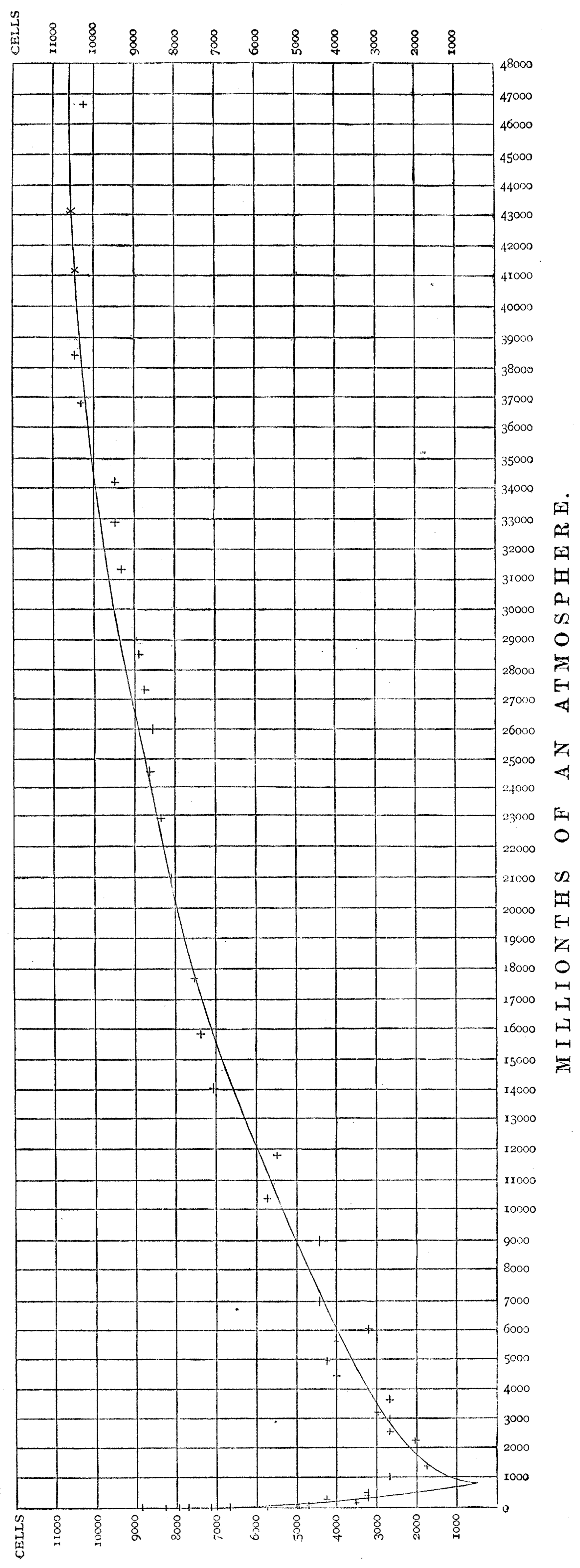
Fig. 71.



ABSCISSÆ AS THE CUBE ROOT OF THE PRESSURE IN MILLIONTHS OF AN ATMOSPHERE.

THE DISTANCES 0 TO 1, 0 TO 100, 0 TO 1000, &c., SHOW RELATIVELY THE NUMBER OF MOLECULES IN A GIVEN LINEAR SPACE.

Fig. 72.


CELLS
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
48000
47000
46000
45000
44000
43000
42000
41000
40000
39000
38000
37000
36000
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16000
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14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
MILLIONTHS OF AN ATMOSPHERE.

curve was drawn through them, as in fig. 72, which is a reduction to one-sixth, the following numbers were read off from measurements on the diagram :—

Pressure.	V.		Pressure.	V.	
	Cells.	Increase per 1000 M.		Cells.	Increase per 1000 M.
M		cells.	M		cells.
845	430		23,000	8490	
					140
1000	1000		24,000	8630	
					170
1500	1780	1190	25,000	8800	
					160
2000	2190		26,000	8960	
		590			140
3000	2780		27,000	9100	
		475			150
4000	3230		28,000	9250	
		430			140
5000	3660		29,000	9390	
		370			140
6000	4030		30,000	9530	
		350			120
7000	4380		31,000	9650	
		370			120
8000	4750		32,000	9770	
		320			110
9000	5070		33,000	9880	
		310			100
10,000	5380		34,000	9980	
		330			90
11,000	5710		35,000	10,070	
		320			80
12,000	6030		36,000	10,150	
		320			80
13,000	6350		37,000	10,230	
		280			70
14,000	6630		38,000	10,300	
		270			60
15,000	6900		39,000	10,360	
		260			60
16,000	7160		40,000	10,420	
		240			55
17,000	7400		41,000	10,475	
		230			45
18,000	7630		42,000	10,520	
		210			30
19,000	7840		43,000	10,550	
		180			30
20,000	8000		44,000	10,580	
		180			10
21,000	8180		45,000	10,590	
		160			10
22,000	8340		46,000	10,600	
		150			0
23,000	8490		47,000	10,600	

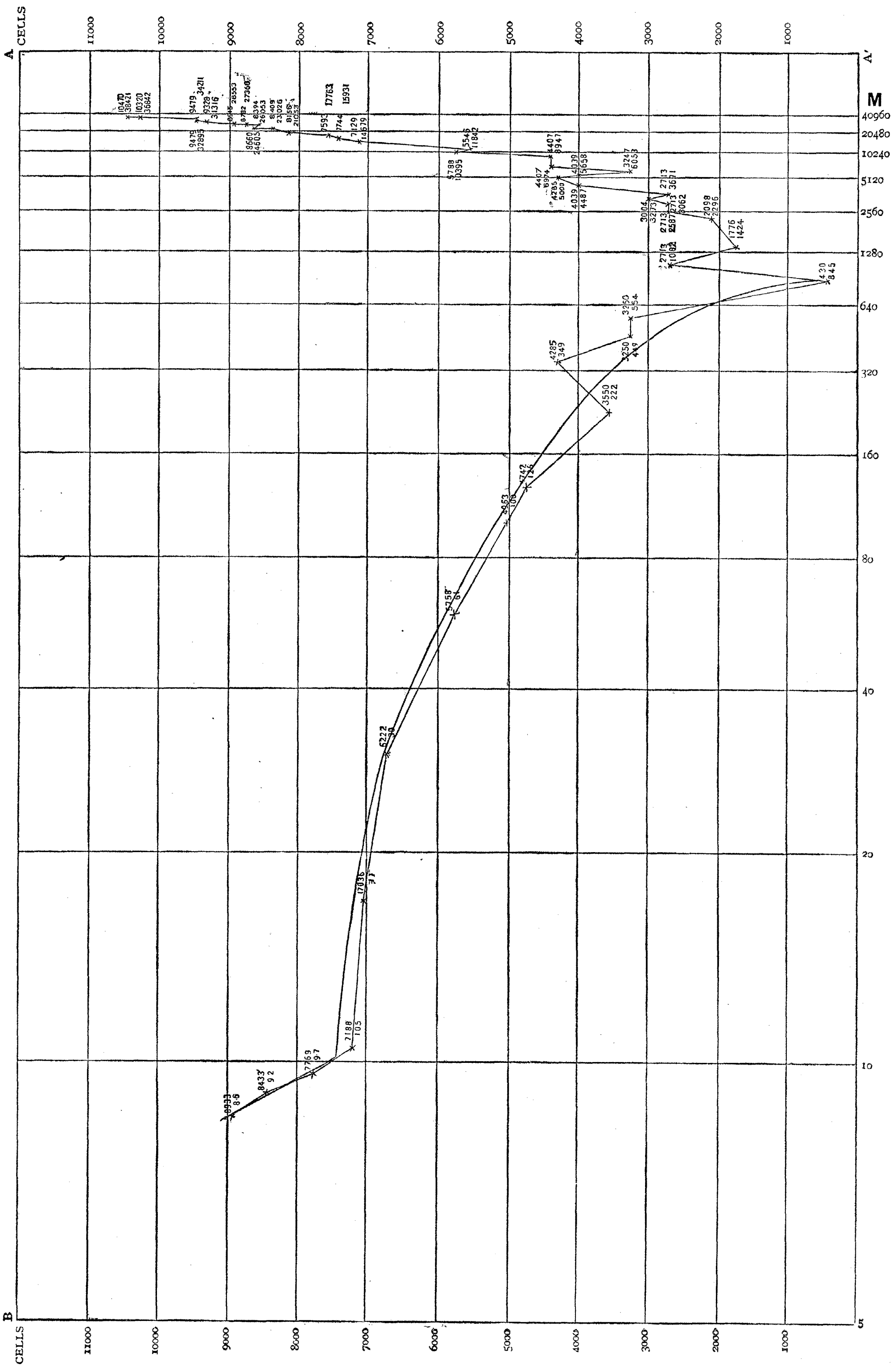
In order to obtain a smooth curve for the observations beyond the minimum of resistance of the tube, they were again plotted down so as to make the abscissæ represent relatively the mean distance of the molecules at the various pressures, as in fig. 73, which is a reduction of the original diagram to one-third; this has the effect of extending the scale for this portion of the curve, while it compresses the scale on the opposite side for increasing pressures.

The following were read off:—

Pressure.	V.		Pressure.	V.	
	Cells.	Decrease per 10 M increase.		Cells.	Decrease per 10 M increase.
M.		cells.	M.		cells.
8	9600		90	5280	
		11,400			135
9	8460		100	5145	
		9600			94·5
10	7500		200	4200	
		420			60
20	7080		300	3600	
		358			48
30	6722		400	3120	
		332			45
40	6390		500	2670	
		300			39
50	6090		600	2280	
		270			45
60	5820		700	1830	
		195			51
70	5625		800	1320	
		180			16
80	5445		900		
		165			
90	5280		1000	1000	

The various phenomena of stratification observed in tube 162 during the course of the preceding series of measurements of tube-potential were very similar to those already described under like conditions in tubes 129 and 139 containing residual hydrogen, in Part II., and represented in plates 15 and 16 of that part. Sketches were made of the various forms of strata, but it would not have been possible to take photographs of these phenomena, as this would have seriously interfered with the continuity of the measurements and have prolonged their duration disadvantageously for the battery. A particular phase worthy of record was, however, observed which had been seen before with tube 145, and which has been described in Part II., experiment 218, page 215. Of this and two preceding phases, photographs were taken and are shown in Plate 9, figs. 1, 2, and 3. The pressure in all three cases was 0·747 m.m., 983 M; the current was not measured, but the potential used was 4800 cells. On making the straight wire negative, the appearance shown in fig. 1 was seen: this is copied from a photograph obtained in 5 seconds.

Fig. 73.



A—B REPRESENTS AN ASSUMED MEAN DISTANCE OF THE MOLECULES AT A PRESSURE OF 5 MILLIONTHS OF AN ATMOSPHERE.

A' TO 10, A' TO 20, ... A' TO 40960 THE CORRESPONDING DISTANCES AT PRESSURES 10, 20, 40960 MILLIONTHS.

On making the straight wire positive the phase was produced which is represented in Plate 9, fig. 2; this is copied from a photograph obtained in 7 seconds. It will be noticed that several of the cup-shaped strata after the first three, counting from the negative terminal, are followed by a secondary series which are tongue-shaped; these latter kept continually disappearing and reappearing precisely in the same position, so that the photograph is in no way indistinct or blurred.

On introducing a resistance of 230,000 ohms, the particular phase to which it is desired to call attention was obtained; it is represented in Plate 9, fig. 3, copied from a photograph obtained in 7 seconds. The somewhat confused discharge near the positive shown in the previous figure has disappeared, and tongue-shaped strata cross each other like the component lines of the letter X: fig. 3 is an exact copy of the perfectly distinct photograph. Such complex phenomena present many difficulties in the way of a theoretical explanation of the forces which concur in their production.

Potential necessary to produce a discharge between discs at a constant distance and at various pressures.

In the first instance, at the suggestion of Professor MASCART, an experiment was made in order to ascertain whether there was either any condensation or dilatation of the gas about the terminals before the actual passage of the discharge. In order to do this an apparatus was constructed as shown in fig. 74.

It consists of a glass cylinder, 4·35 inches inside diameter, the depth of which is accurately the same in every part, 1·6 inch, so as to ensure the parallelism of two glass discs which close its ends. Its cubical content, exclusive of the terminals, was found to be 385 cub. centims.

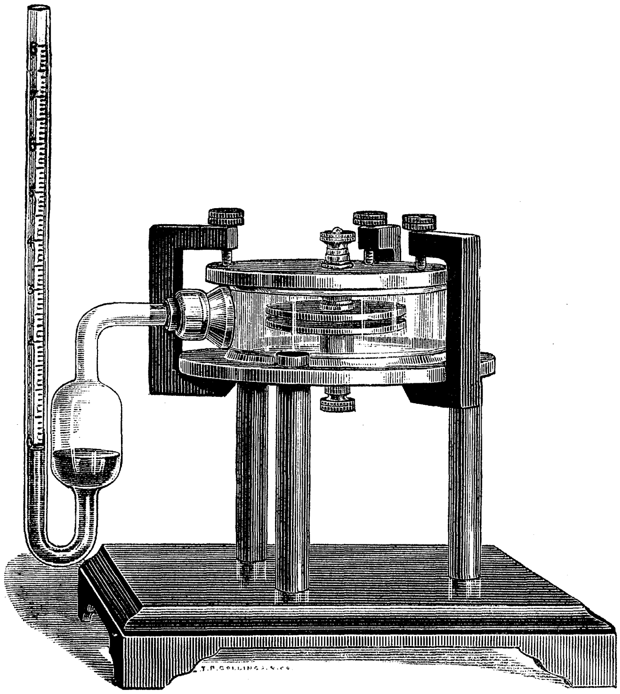
These are held in contact with the ends of the cylinder by means of screw-clamps made of ebonite, and the whole apparatus is supported on a tripod ebonite stand, which is fastened to a square wooden foot. Attached parallel to the top and bottom glass discs, by means of flanged-screw rods, are two brass discs with rounded edges 3·1 inches diameter; these are maintained at a distance of 0·13 inch, at which the discharge of 11,000 cells would only just take place.

The ends which project through the glass discs are furnished with binding-screws for attaching wires from the battery.

On the side of the cylinder is a tubulure in which is fitted a gauge containing strong sulphuric acid, so as to dry the inside of the apparatus, and to indicate whether any condensation or dilatation of the gas contained in the cylinder occurs on connecting the metallic discs with the battery by means of the contact-key. The edges of the cylinder were rubbed with grease, and care was taken to prove that the apparatus was perfectly tight, by causing the fluid in the limb of the gauge to stand for some time higher than that in the bulb. When contact was made with a battery of 9800

cells there was not the slightest indication of any alteration of volume of the contained gas, so that there was neither condensation about the discs which would have caused a

Fig. 74.



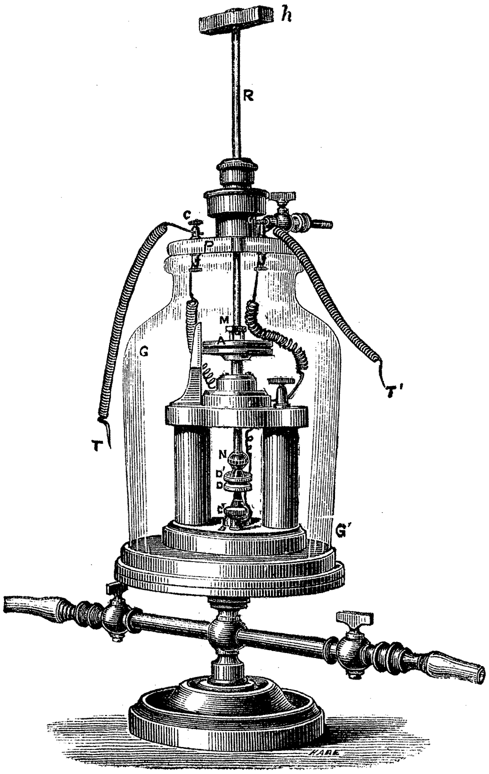
contraction, nor repulsion from the discs which would have caused an expansion of volume. The fluid in the stem, whose internal diameter is 0·185 inch, was observed with a lens, but not the slightest motion of it took place. The same result was noticed even when water was substituted for sulphuric acid. So far, then, as this apparatus, in which the area of the gauge is $\frac{1}{280}$th of that of each disc, would indicate it, the result is entirely negative.

The discharge between two discs 1·5 *inch in diameter.*

The following series of experiments were made by placing the micrometer-discharger under a bell-jar, and in the first instance adjusting the discs to the striking distance at atmospheric pressure for the battery of 11,000 cells. Afterwards a less number of cells was connected with the discs and the bell-jar gradually exhausted until the discharge occurred; the height of the gauge was then read off. Then a less and lesser number of cells was connected with the discs and the operation was repeated. Fig. 75 shows the arrangement of the micrometer discharger under the bell-jar. The

gauge used to indicate the pressure beyond the range of the gauges attached to the pumps is not shown in this figure, but is in fig. 81 to be hereinafter described.

Fig. 75.



AIR.—The discs distant 0·13 inch = 3·3 m.m.

I.			II. Temp. 15°·2 C.				III. Temp. 11°·8 C.			
Cells.	Pressure.		Cells.	Pressure.		Current.	Cells.	Pressure.		Current.
	m.m.	M.		m.m.	M.	W.		m.m.	M.	W.
10,940	761·6	1,002,105	10,980	709·6	933,684	0·03071	10,980	700·3	921,447	0·03259
9900	621·0	817,105	9920	636·5	837,500	0·03259	9780	620·9	816,974	0·03071
8840	537·7	707,500	8840	548·7	721,974	0·03071	8580	537·7	707,500	0·02881
7760	446·4	587,368	7760	456·0	600,000	0·03657	7380	440·8	580,000	0·02693
6300	355·6	467,894	6300	358·7	471,974	0·15470	6180	349·5	459,868	0·02881
4800	254·9	335,395	4800	244·6	321,842	0·16080	4680	243·7	320,658	0·01412
3600	177·6	233,684	3600	188·5	248,026	0·14350	3220	153·9	202,500	0·03071
2400	105·3	138,552	2400	109·1	143,552	0·16080	2140	82·1	108,026	0·02881
1200	38·0	50,000	1200	38·3	50,394	0·13340	1060	31·1	40,921	
600	10·6	13,947	600	9·7	12,763	0·07036				
300*										

It will be observed that although the discharge took place at a pressure beyond 760 m.m. in Series I., it would not do so in II. and III. The greater current in some

* Would not pass at 2·2 m.m., 2631 M.

instances is in a great measure to be attributed to more rod-cells being employed in some of the experiments, as these offer less internal resistance than powder-cells.

HYDROGEN.—Discs distant 0·22 inch = 5·588 m.m.

IV. Temp. 15°·6 C.				V. Temp. 12°·7 C.			VI. Temp. 10°·2 C.		
Cells.	Pressure.		Current.	Cells.	Pressure.		Cells.	Pressure.	
	m.m.	M.	W.		m.m.	M.		m.m.	M.
10,980	760·6	1,000,789	0·03071	1·0980	759·7	999,605	10,980	751·0	988,158
9780	671·8	883,947	0·02881	9780	658·9	866,974	9780	661·0	869,737
8580	564·6	742,895	0·02881	8580	559·6	736,316	8580	576·5	758,553
7380	472·3	621,447	0·02881	7380	483·8	636,579	7380	466·5	613,816
6180	400·6	527,105	0·02693	6180	395·0	519,737	6180	387·6	510,000
4680	271·9	357,763	0·01772	4680	272·8	358,947	4680	258·5	340,132
3220	160·1	210,658	0·03259	3220	173·5	228,289	3220	164·6	216,579
2140	97·4	128,158	0·02505	2140	98·1	129,079	2140	93·6	123,158
1060	37·0	48,684	0·02136	1060	37·8	49,737	1080	38·6	50,789
600	13·9	18,289	0·05801	600	15·4	20,263	600	12·5	16,447

CARBONIC ACID.—Discs distant 0·122 inch = 3·096 m.m.

VII. Temp. 12°·2 C.			VIII. Temp. 14°·5 C.			IX. Temp. 11°·6 C.		
Cells.	Pressure.		Cells.	Pressure.		Cells.	Pressure.	
	m.m.	M.		m.m.	M.		m.m.	M.
10,960	757·9	997,237	10,960	747·2	983,158	10,960	747·6	983,684
9880	693·0	911,842	9880	647·5	851,974	9880	676·7	890,395
8800	602·2	792,368	8800	576·7	758,816	8800	588·9	774,868
7720	492·4	647,894	7720	485·9	639,342	7720	505·1	664,605
6300	370·7	487,763	6300	383·2	504,211	6300	393·3	517,500
4800	277·9	365,658	4800	249·4	328,158	4800	258·6	340,263
3600	186·0	244,737	3600	177·7	233,816	3600	183·8	241,842
2400	104·2	137,105	2400	95·8	126,052	2400	94·9	124,868
1200	31·3	41,184	1200	30·0	39,474	1200	30·0	39,474
			600	5·1	6,710	600	5·3	6974

The numbers obtained for air, hydrogen, and carbonic acid respectively were plotted down on millimetre scale paper, the abscissæ being 1 m.m. = 2500 M, the ordinates 1 m.m. = 25 cells, and curves drawn to give a mean of the several observations. These appeared to resemble hyperbolic curves so closely that true hyperbolic curves were found (partly by a geometric construction,* partly by computation) which would intersect the mean experimental curves in two points. The results of experiment

* The following, suggested to us by Professor STOKES, is the convenient method employed. The experimental curve is laid down on squared paper, as shown by the dotted line in fig. 75[a], and two points, g' and h', for the intersection of the proposed hyperbola are selected, and two corresponding points g, h at the same distances respectively on the opposite side of the vertical axis are marked; through g' and h and through g and h' lines are drawn intersecting in A, lines are also drawn through h' and g', and h and g intersecting in B; a line is drawn through A and B and prolonged on each side in the direction of the axis. The distances of VB and VA are ascertained in terms of the squared paper, their reciprocals taken

were again laid down on these new curves, and it will be seen from fig. 76 that they do not differ more from the experimental results than the experimental numbers from each other.

On the diagram the results for each series are distinguished by no dot, one dot or two dots on the crosses marking the position of the observations (fig. 77). It would appear, therefore, that the hyperbola fairly represents the law of discharge between planes.*

and the difference of these reciprocals obtained; the reciprocal of this difference gives the distance VC the semi-axis major $=a$, C being the centre; the ordinates $y, y^1 \ldots y^{15} \ldots$, are obtained by the formula

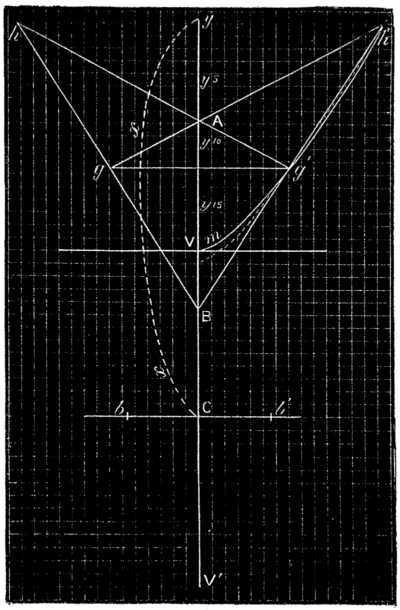
$$y=\frac{b\sqrt{(x+a)(x-a)}}{a};$$

the value of $b=\mathrm{C}b$, the semi-axis minor, is calculated from the measured ordinate y for both the points of intersection g' and h' of the experimental curve and the proposed hyperbola, and their mean taken for the value of b.

$$b=\frac{ya}{\sqrt{(x+a)(x-a)}}.$$

The calculations are simplified by taking $2a=\mathrm{VV}'$ and adding it to Vy to give $=x+a=\alpha$, taking Vy as $=x-a=\beta$ and making $\frac{b}{a}=\delta$, the formula then is $y=\sqrt{\alpha\beta}\,.\,\delta$.

Fig. 75^a.



* Dr. ALEXANDER MACFARLANE has published in the Transactions of the Royal Society of Edinburgh, 1878, vol. xxvii., an elaborate and careful research of the "Disruptive Discharge of Electricity" in air and different gases, and between terminals of various forms. An abstract of this paper will be found in 'Nature,' December 26, 1878, pp. 184, 185. Dr. MACFARLANE used a HOLTZ machine and employed higher potentials than those used by us; he found that the results for the discharge between two discs 4 inches in diameter at various distances up to 1·2 centims. and with various pressures were satisfactorily represented by the hyperbola.

Fig. 76.

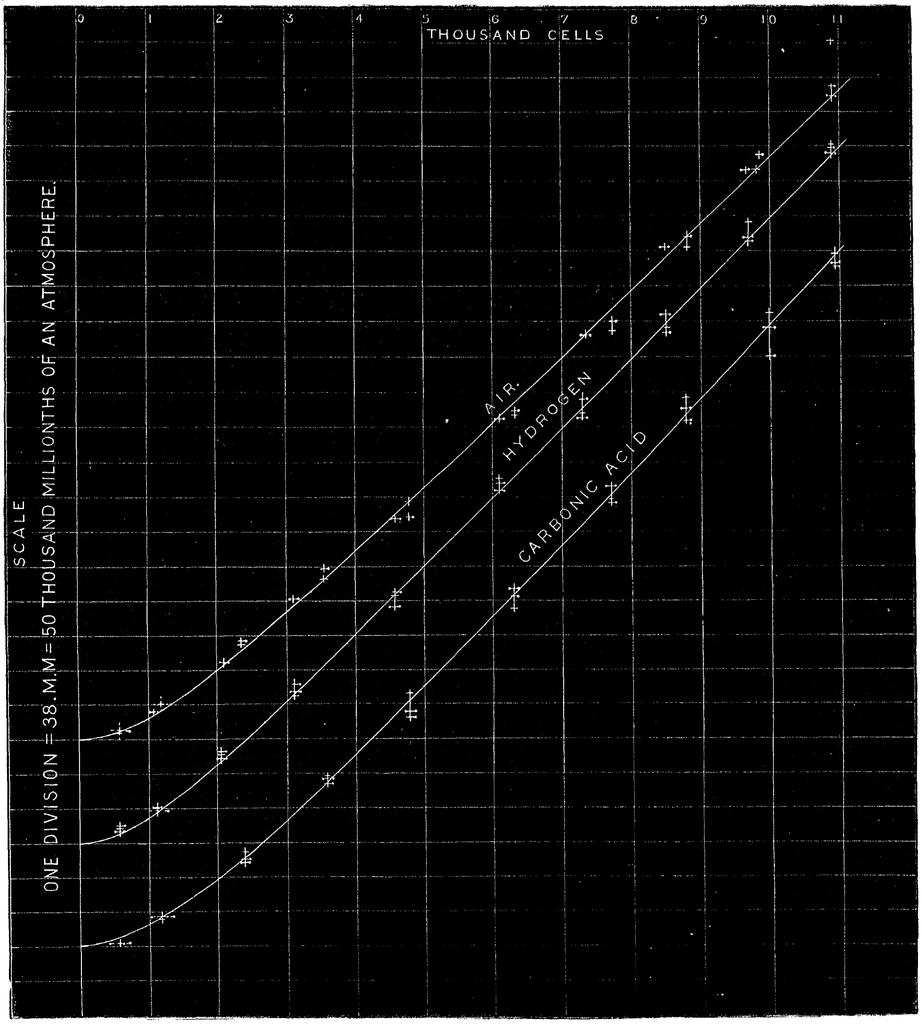
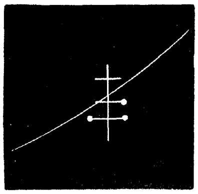

0
1
2
3
4
5
6
7
8
9
10
11
THOUSAND CELLS
SCALE
ONE DIVISION = 38. M.M. = 50 THOUSAND MILLIONTHS OF AN ATMOSPHERE.
AIR.
HYDROGEN
CARBONIC ACID

Fig. 77.



The ratios of the sides of the parallelogram between the assymptotes of these hyperbolas differ somewhat, but not much, from each other, thus—calling CV the transverse axis, CB the conjugate axis.

For air . . . . $\frac{CV=28{\cdot}16}{CB=29{\cdot}13}=0{\cdot}9665$

„ hydrogen . $\frac{CV=25{\cdot}56}{CB=25{\cdot}13}=1{\cdot}017$ } Mean 1·0175.

„ carbonic acid $\frac{CV=38{\cdot}6}{CB=36{\cdot}11}=1{\cdot}069$

Measurements of the hyperbolic curve gave the results shown in the following tables. The greatest discordances between the numbers derived from the mean experimental curves and those from the hyperbolic curves are in the lowest pressures up to about 19 m.m., 25,000 M ; the potential necessary for a discharge to take place being less than that required by the law of the hyperbola.

NUMBERS obtained from curves.

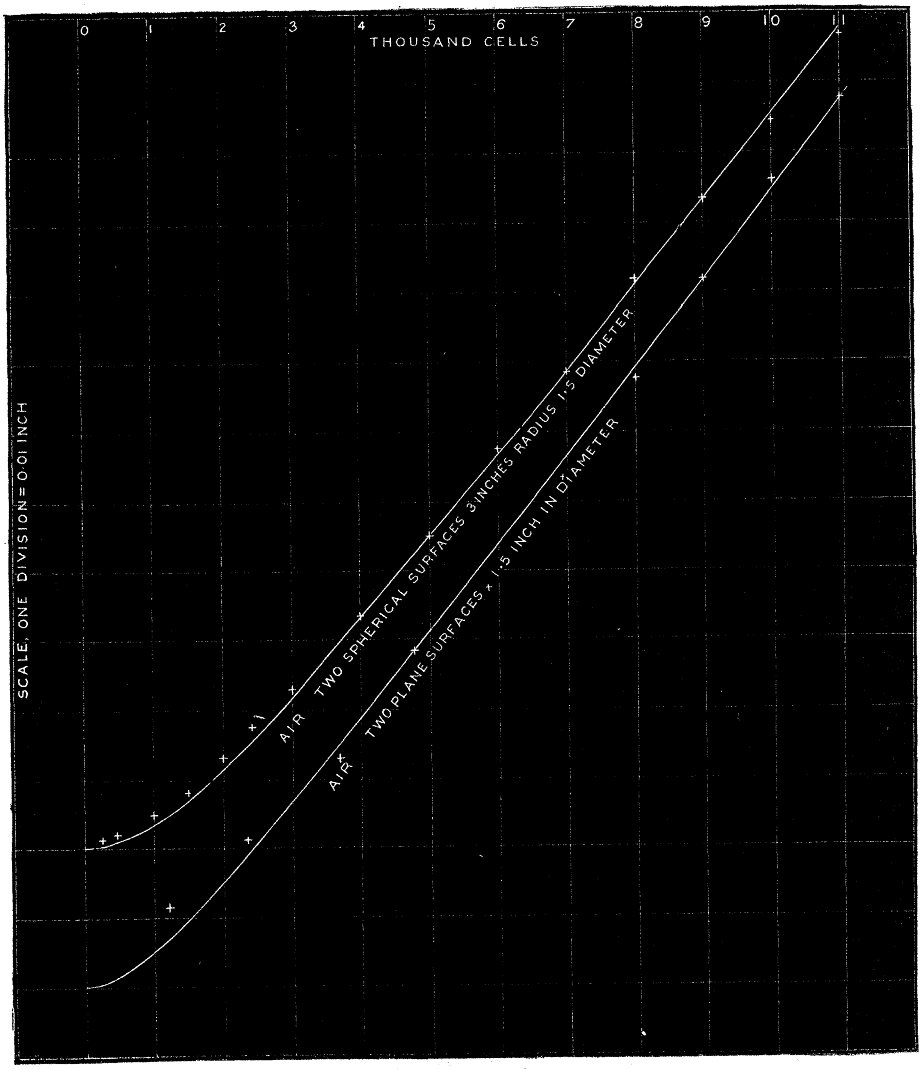
Pressure.	Air.		Hydrogen.		Carbonic acid.	
	Hyperbolic curve.	Experimental curve.	Hyperbolic curve.	Experimental curve.	Hyperbolic curve.	Experimental curve.
M.	cells.	cells.	cells.	cells.	cells.	cells.
5000	391·5	250	355	250	413·5	275
15,000	690	575	626·5	525	722·5	625
25,000	905·5	825	823·5	750	949	850
50,000	1332	1275	1215·5	1200	1381	1300
75,000	1692	1625	1549	1575	1739·5	1700
100,000	2021	2000	1854	1925	2062·5	2025
150,000	2632·5	2650	2425	2525	2652·5	2650
200,000	3211	3250	2967·5	3075	3202·5	3200
250,000	3771·5	3825	3495·5	3625	3730	3725
300,000	4321·5	4400	4014	4150	4244	4250
400,000	5402	5475	5035	5175	5246	5275
500,000	6467·5	6550	6043	6125	6226·5	6275
600,000	7523	7600	7044·5	7100	7195	7225
700,000	8575·5	8625	8041	8050	8156·5	8200
800,000	9623·5	9625	9035	9000	9112	9150
900,000	10,670	10,600	10,026·5	9975	10,064·5	10,100
1,000,000	11,712	11,600	11,017	10,925	11,013·5	11,100

The striking distances at atmospheric pressure and various potentials for spherical surfaces 3 inches radius and 1·5 inch diameter, as given in page 68, curve VIII., and at page 118, also those for nearly flat surfaces in pages 73 and 118, Part I., were reduced to millimetres distance and plotted down in the same way, but not on precisely the same scale, as the preceding curves for constant distance and various pressures. Hyperbolic curves were also found which intersected the experimental curves in two points. A reduction of the original diagram is given in fig. 78.

It will be seen that in the case of spherical surfaces, the result having been obtained

as the average of a great number of experiments, the hyperbola coincides closely with the observations, while in that of plane surfaces, for which only a few experiments were made, the coincidences are not so perfect. Nevertheless, it would appear that

Fig. 78.



the law of the hyperbola holds equally well for a constant pressure and varying distance as it does for a constant distance and varying pressure; the obstacle in the way of a discharge being as the number of molecules intervening between the terminals up to a certain point.

In the two cases of spherical and plane surfaces the ratio between the transverse and conjugate axes of the respective hyperbolas laid down on the scale adopted—

For spherical surfaces $\frac{CV=38{\cdot}87}{CB=32{\cdot}16}=1{\cdot}240$

,, discs . . . . . $\frac{CV=28{\cdot}4}{CB=22{\cdot}1}=1{\cdot}285$

Mean 1·267.

Striking distance between two flat discs.

Since the publication of Part I. we have laid down a fresh smooth curve of the striking distance between two flat discs, on the scale of 5 centims. to 1000 cells and 10 centims. for a millimetre, using the following numbers :—

Cells.	Inch.	Centimetres.	
1200	0·012	0·0305	Taken from Part I., page 73, Curve X.
2400	0·021	0·0533	
3600	0·033	0·0838	
4800	0·049	0·1245	
5880	0·058	0·1473	
6960	0·073	0·1854	
8040	0·088	0·2236	
9540	0·110	0·2794	Actual observation.
11,000	0·133	0·3378	

It is not necessary to give a diagram of the curve, which agrees fairly well with the observations ; it runs—

Below	that for	1200	cells	by 0·0045 centim.
Through	„	2400	„	
„	„	3600	„	
Below	„	4800	„	by 0·0085 centim.
Above	„	5880	„	„ 0·0015 „
Through	„	6960	„	
Above	„	8040	„	by 0·0010 centim.
„	„	9540	„	„ 0·0010 „
Through	„	11,000	„	

From the curve thus laid down the following numbers were deduced :—*

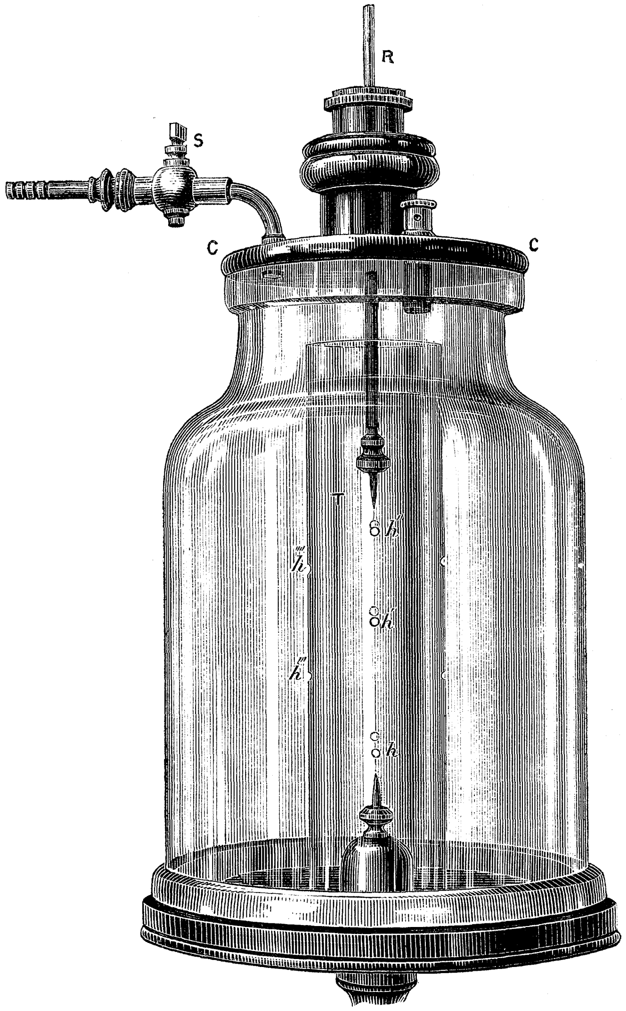
EMF in volts.	Striking distance in centimetres.	Difference of potential per centimetre.	Intensity of force.	
			Electromagnetic.	Electrostatic.
		volts.		
1000	0·0205	48,770	$4·88 \times 10^{12}$	163
2000	0·0430	46,500	4·65 „	155
3000	0·0660	45,450	4·55 „	152
4000	0·0914	43,770	4·38 „	146
5000	0·1176	42,510	4·25 „	142
6000	0·1473	40,740	4·07 „	136
7000	0·1800	38,890	3·89 „	130
8000	0·2146	37,280	3·73 „	124
9000	0·2495	36,070	3·61 „	120
10,000	0·2863	34,920	3·49 „	116
11,000	0·3245	33,900	3·39 „	113
11,309	0·3378	33,460	3·35 „	112

* These were communicated, in April, 1878, to Professor EVERETT, for his 'Units and Physical Constants,' 1879, pp. 141, 142.

The electric arc.

We have already stated* that "*the discharge in a vacuum tube does not differ essentially from that in air and other gases at ordinary atmospheric pressures; it cannot be considered as a current in the ordinary acceptation of the term.*" . . . We had a strong conviction while writing the above that the stratified discharge in a vacuum tube was simply a magnified form of arc, and in consequence we planned out a series of experiments to test the correctness of this supposition; these were com-

Fig. 79.



menced in October, 1878, and although not yet concluded, we venture to lay before the Society an account of the results hitherto obtained, as they seem to support the view that the arc and the stratified discharge are merely modifications of the same phenomenon.

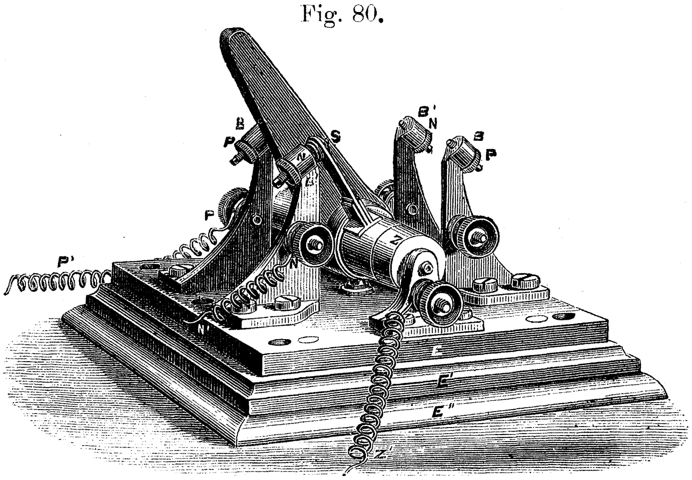
The experiments were made in a bell-jar, containing the terminals, which could be gradually exhausted after having been filled with air or other gas. One of the terminals

* Part II., page 230.

was fixed to the bottom plate, the other could be adjusted to any distance from it by a rod sliding through a stuffing-box in the glass cover. The foot of the stand was insulated by a disc of ebonite, on which it stands. One such bell-jar is represented in fig. 79. It is $9\frac{1}{4}$ inches (23·4 centims.) high and $5\frac{7}{8}$ inches (14·9 centims.) in diameter; its cubical content, obtained by covering the open ends with glass plates and filling with water from a graduated measure, was found to be 3787 cubic centims. This jar was destroyed in the course of the experiments, and was replaced by others. In the figure an inner tube is shown with a series of holes in it, which was not used on this occasion, but will be spoken of hereafter.

A remarkable phenomenon was observed on making connexion between the terminals and the battery by means of the discharging key, fig. 80 (already described in Part I., page 58), namely, that within certain limits of pressure in the bell-jar a sudden expansion of the gas took place, and that as soon as the connexion was broken the gas then as suddenly resumed almost exactly its original volume, showing only a small increase due to a slight elevation of temperature. The effect was similar to that which would have been produced if an empty bladder suspended between the terminals had been suddenly inflated and as suddenly emptied.* We communicated this observation unofficially to our friend Professor STOKES in October, 1878.

Fig. 80.



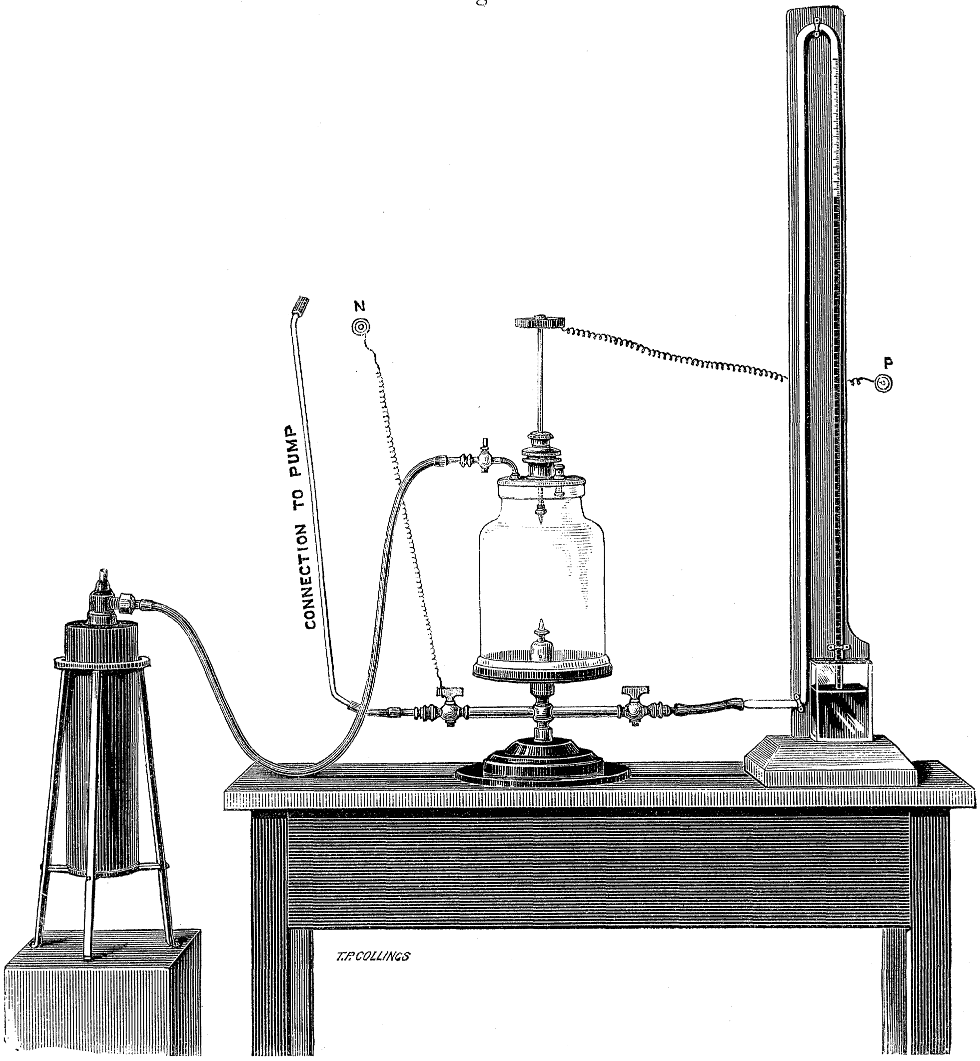
This phenomenon was quite unexpected, and being difficult to account for, was made the object of special study by means of an arrangement of apparatus as shown in fig. 81.

The glass cover of the bell-jar is furnished with a stop-cock which communicates with a gas-holder, and in the bottom plate there is a T-tube connected to two other stop-cocks, one of which communicates with the pumps, the other with a gauge about 3 feet high. The right hand limb of the gauge dips into a rectangular glass cistern, the front face of which is polished to facilitate the reading; this limb is graduated from a zero well below the level of the mercury in the cistern, so that the height

* This was first noticed by my former assistant, Mr. SEATON.

of the column of mercury may be determined with facility. P and N are screw terminals connected with the battery.

Fig. 81.



The following experiment in rarefied air will give an idea of the amount of instantaneous expansion which occurs when the terminals are connected with the poles of the battery.

	Pressure. m.m.	Pressure. M.
Distance of the terminals, 6 inches, the top one a point, the lower a disc	56	73,684
On making contact the arc passed and the column of mercury was depressed	15·8	20,789
Pressure on connexion	71·8 =	94,473

11,000 cells, current 0·01102 W; the resistance of the bell-jar was reproduced by substituting 600,000 ohms wire resistance.

The volume of the bell-jar is 3787 cub. centims., the temperature at the time of the

experiment 17°·5 C., and if the gas had been allowed to expand, its volume would have been $\frac{3787 \times 71 \cdot 8}{56} = 4855$ cub. centims., or an increase of 1068 cub. centims.; as the gas was kept at a constant volume the pressure increased in the ratio 1·282 to 1. Supposing the expansion to be due to an increase of temperature, it would follow that as the volume was kept constant the pressure would vary as the absolute temperature,* therefore $\frac{T'}{T} = \frac{71 \cdot 8}{56} = 1 \cdot 282$, whence $T' = 1 \cdot 282 \times 291 \cdot 2 = 373^{\circ} \cdot 3$ C. The temperature while the discharge was passing would be (373·3−273·7)=99°·6 C., consequently the rise of temperature (99·6−17·5)=82°·1. The temperature of the bell-jar as determined by a thermometer enclosed in it with its bulb uppermost only rose 0°·64 C. per second, taking into account the rate of cooling. It is evident, therefore, that the increase of pressure cannot be ascribed to the instantaneous heating of the bell-jar 82° C.

A photograph of the discharge obtained in 60 seconds, and copied in Plate 9, fig. 8, shows that the central spindle or arc-proper could not have been so much as half-an-inch, 1·27 centims., in diameter, and its length we know was 6 inches, 15·24 centims.; the cubical content of a cylinder of these dimensions is 19·3 cub. centims. If we assume that this volume increased 1068 cub. centims., or to 19·3+1068=1087·3, then $\frac{1087 \cdot 3}{19 \cdot 3} = 56 \cdot 337$ represents the number of times it increased, and accordingly $T' = 56 \cdot 337\, T = 56 \cdot 337 \times 291 \cdot 2 = 16{,}405^{\circ}$ C., and 16,405−291·2=16,114° C. would therefore be the temperature of the arc.

Experiments were made to ascertain roughly the temperature of different parts of the arc, and for this purpose wires were supported by one end being twisted round a vertical glass rod, the other end being made to project into the arc at different heights, or else wires were strained through opposite holes h, h', h'', &c., drilled at different heights in the side of a glass tube 1·75 inch diameter, which was placed inside the bell-jar, as shown in fig. 81. Platinum wires 0·0125 inch diameter were not fused in any part of the arc; they were heated to a white heat in the luminous but not in the non-luminous part. But platinum wires 0·001 inch in diameter, supported by wire 0·0125 inch, in various parts of the arc were immediately fused; the temperature of the arc was therefore as high as the fusion-point of platinum, and possibly considerably higher (Plate 9, figs. 9, 10).

The whole of the heat evolved by a current of 0·01102 W through a resistance of 600,000 ohms would raise 73·1 grammes of air 1° C. per second; and if communicated to the air in the bell-jar, weighing 0·339 gramme, would have raised its temperature to $\frac{73 \cdot 1}{0 \cdot 339} = 215^{\circ} \cdot 6$ C. in that time. We know from direct experiment that such an enormous evolution of heat was not communicated to the air in the bell-jar, because its temperature only increased about 0°·64 C. per second; and it would have to be assumed that the rest of the heat escaped almost instantaneously by radiation. It is difficult con-

* Absolute zero=273·7 C., 273·7+17·5=291·2.

sequently to realise the conjecture that the enormous dilatation which occurred instantaneously could have been caused by increase of temperature. On the other hand the ascertained facts appear rather to point to the phenomenon being caused by the projection of the gas-molecules by electrification against the walls of the glass vessel, producing thereby effects of pressure, which, however, are distinct from the molecular motion induced by heat.

Recently (July 5th, 1879), Professor DEWAR called our attention to a similar phenomenon, which confirms this view. He was working in the chemical laboratory of the Royal Institution on the Electric Arc, the source of electricity being a SIEMENS' dynamo-machine driven by a gas engine. The carbon electrodes were, for the purposes of his experiments, enclosed in a metallic cylinder open at the bottom but closed at the top; the bottom was kept air-tight by immersion in mercury.

The total radiant force was being accurately measured by carrying a stream of water through the cylinder into a separate vessel at a known rate, and measuring its increase of temperature by very sensitive thermometers, which could be read to a hundredth of a degree centigrade; their rapid pulsations were easily seen as the radiant force varied. Suddenly, from time to time, there was an increase of current and a great expansion of the volume of the air in the cylinder took place, and, although there were apertures in this vessel, the mercury joint was forced by the sudden expansion, and yet no sudden rise of the thermometer was noticed when these expansions occurred.*

The arc under various circumstances.

We now proceed to describe the appearance of the arc with terminals of various forms at different distances and with various pressures. It will be seen that the light emitted by different parts of the arc is not of the same intensity throughout, and that under most circumstances there is a tendency to break up into distinct entities, and ultimately to take a stratified appearance.

The appearance of the arc, between discs in hydrogen at the various pressures used in determining the potential necessary to produce a discharge, is represented in Plate 8, figs. 11–19.

		M.		cells.			seconds.
Fig. 11,	at pressure of	18,684,	with	600,	from a photograph	taken in	50
,, 12	,,	58,684	,,	1200	,,	,,	50
,, 13	,,	141,974	,,	2400	,,	,,	50
,, 14	,,	252,368	,,	3600	,,	,,	50
,, 15	,,	386,316	,,	4800	,,	,,	20
,, 16	,,	558,816	,,	6300	,,	,,	4
,, 17	,,	558,816	,,	6300	,,	,,	1
,, 18	,,	651,316	,,	7760	,,	,,	5
,, 19	,,	1,008,421	,,	10,920	,,	,,	5

* DE LA RIVE noticed that oscillations occurred in the mercury of a gauge attached to an exhausted tube as soon as the current passed. In the second and third paragraphs of Note C, in the Appendix, is the account of his experiments.

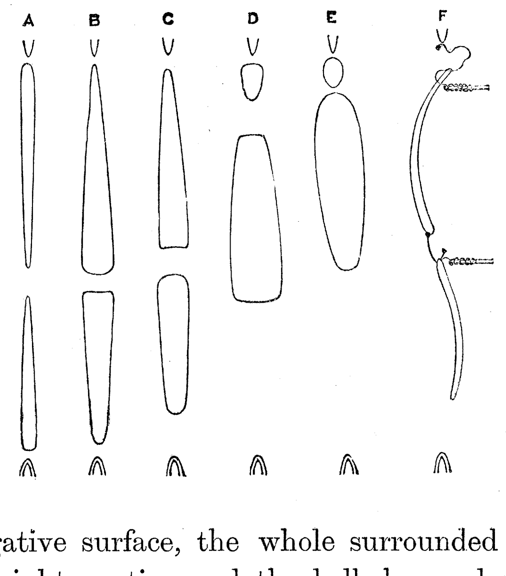
As the pressure was diminished the arc widened out until at last the entire surface of the negative disc was covered with a luminous discharge. From the first it will be seen that the central spindle did not extend quite up to the negative, as shown in fig. 19, at atmospheric pressure; that in fig. 18 the central bright part detached itself so as to form an entity; in figs. 17, 16, and 15 distinct strata were formed; then that, as is shown in figs. 14 and 15, the central bright portion diminished, the dark discharge near the negative increasing; while at the lower pressures, represented in figs. 12 and 11, there existed no central spindle, and that with the exception of the luminosity on the terminals the rest of the discharge was dark. It should be mentioned that part of the details have, in some instances, been supplied from sketches made when the photographs were obtained, for there was sometimes a movement in the discharge which produced a confused picture. No observations of the expansion of the gas were attempted.

The appearance of the discharge in carbonic acid is shown twice the original size in Plate 10, figs. 20, 21, 22, and 23; in all but the last will be observed the peculiar bell-shape form which is characteristic of the arc in carbonic acid (Part I., page 96, 3 of fig. 23).

Fig.	M.	cells.	
20	983,158	10,960	from a drawing.
21	504,211	6300	,, ,,
22	126,052	2400	,, ,,
23	39,474	1200	,, ,,

In fig. 20 is seen a central spindle surrounded by a bell-shape fainter discharge; in fig. 21 the central spindle is composed of well-defined strata; in fig. 22 there is a bright luminosity in contact with the positive disc, then a dark interval with an

Fig. 82.



illumination of the negative surface, the whole surrounded by the bell-shape glow; in fig. 23 the central bright portion and the bell-shape glow have disappeared, and

the surfaces of the positive and negative discs alone are illuminated, the glow, especially on the negative, having become much wider.

The following cases of the discharge between two points in air, illustrated by the outline sketches A, B, C, D, E, F, fig. 82, one-third of the full size, will explain what is meant by the arc breaking up into distinct entities; the outlines represent merely the bright portions of the arc: these are always surrounded with a less bright portion of highly heated gas, as shown in Plate 8, figs. 1 to 33 inclusive.

DISTANCE of terminals, two brass points, 6 inches=152 m.m. in air, 11,000 cells.

Fig.	Pressure.		Current.
	m.m.	M.	W.
A	36	47,369	0·02456
B	14	18,421	0·02456
C	14	18,421	0·02209
D	7	9211	0·02634
E	7	9211	not observed
F	56	73,684	0·01575

The following experiments in air were made with the points still 6 inches distant:—

Pressure 63 m.m., 82,895 M. Two wires, 0·001 inch diameter, had been previously fixed in the direction the arc would take, one at 15 m.m. the other at 80 m.m. from the positive terminal (F, fig. 82); both instantaneously fused and served as new intermediate terminals; the heat appeared to be greatest at the wire most distant 80 m.m. The mean increase of temperature in the jar was at the rate of 0°·485 per second, and the cooling at the rate of 0°·14, so that the real increase would have been 0·485+0·14=0°·625 supposing no cooling had occurred.

Pressure 8 m.m., 10,526 M, 11,000 cells, current 0·01771 W. On making connexion the mercury in the gauge was depressed 2 m.m., so that the volume, or rather the pressure, increased in the ratio 1·25 to 1. The appearance of the arc is represented in Plate 8, fig. 33; the pale portion surrounding the brighter part was quite invisible in subdued daylight. By keeping the current on for about two minutes the air in the bell-jar rose from 17° C. to 95° C.

Pressure 67 m.m., 88,158 M, 11,000 cells, current not measurable with the galvanometer, depression on connecting 22·2 m.m., increase of volume (pressure) in the ratio of 1·331 to 1; the arc is shown in Plate 8, fig. 32. Even at a pressure of 100 m.m., 139,474 M, there was a glow visible on both the terminals.

Pressure 8 m.m., 10,526 M, 11,000 cells, current 0·02634 W, depression on connecting 2·5 m.m., increased pressure as 1·312 to 1. In this experiment wires were placed across the arc; surrounding that one 15 m.m. distant from the positive was a cylindrical brighter glow resembling the glow around a negative terminal; the arc was crossed with close paper-like strata, as in Plate 9, fig. 9.

Pressure 6 m.m., 7895 M, 11,000 cells, current 0·03138 W, depression 1·5 m.m.,

increase of pressure 1·250 to 1. The arc was also in this case crossed with close paper-like strata.

Pressure 7 m.m., 9211 M, 11,000 cells, current 0·03138 W; appearance represented in Plate 9, fig. 9, from a photograph taken in 3 minutes.

Pressure 60 m.m., 78,947 M, current not measured; represented in Plate 9, fig. 10, from a photograph taken in 1 minute.

The arc in air between a point positive and a disc 6 inches distant is shown in Plate 8, fig. 31; pressure 56 m.m., 73,684 M, 11,000 cells, current 0·00993 W. The central spindle is curved and divided near the centre.

INCREASE of pressure on making connexion with the battery of 11,000 cells, and producing a discharge between points 6 inches distant.

Pressure.	Depression.	Ratio of increased to normal pressure.	Current.
M.	m.m.		W.
10,526	2·0	1·25	0·01771
88,158	22·2	1·33	not measured
10,526	2·5	1·31	..
7895	1·5	1·25	0·03138

The arc in air between two points at various distances and pressures with a constant number of cells. Temp. 12°·7 C.

PLATE 8.

11,000 cells, distance 0·54 inch, pressure atmospheric, current 0·02456 W; the total resistance of battery and arc was found to be 461,500 ohms, that of the arc 27,550, by substituting wire resistance; whence the potential between the terminals was 657 cells. The appearance of the arc is shown in fig. 20; it exhibits clearly the tendency to break up into luminous entities; the photograph of which this is a copy is nearly full size and was obtained in 20 seconds. All the other photographs are on a reduced scale. As the batteries were undergoing the annual overhauling, the number of cells, some being removed from time to time, was somewhat less in the following experiments, namely, 10,940.

Pressure atmospheric 748·6 m.m., 985,000 M, distance 0·58 inch, current not observed, no depression of the mercury in the gauge was noticed; indeed, it will be seen that at the higher pressures the depression is generally less than at the lower, up to a certain point. The arc is shown in fig. 1 from a photograph obtained in 10 seconds.

Distance $0·58\times2=1·16$ inch, pressure 294·9 m.m., 388,026 M, current 0·02881 W, depression 16 m.m., total pressure $294·9+16=310·9$; ratio of increased to normal pressure as 1·054 to 1. The arc is represented in fig. 2 from a photograph in

15 seconds. It will be seen that the central spindle has become bifurcated about midway.

Distance × 3=1·74 inch, pressure 191·3 m.m., 251,711 M, current 0·04060 W, depression 17 m.m., total pressure 208·3 m.m.; ratio of increased pressure 1·089. The arc is represented in fig. 3 from a photograph in 15 seconds. The bifurcation is apparent in this also.

Distance × 4=2·32 inches, pressure 142·6 m.m., 187,631 M, current 0·04474 W, depression 19 m.m., total pressure 161·6 m.m.; ratio of increased pressure 1·133. The arc is represented in fig. 4, in which the central spindle is broken up into several luminosities.

Distance × 5=2·9 inches, pressure 112·6 m.m., 148,157 M, current 0·03459 W, depression 19 m.m., total pressure 131·6; ratio of increased pressure 1·169. The arc is represented in fig. 5 from a photograph in 15 seconds; in this the central spindle is split up into bright entities connected by less bright portions.

Distance × 6=3·48 inches, pressure 99·4 m.m., 130,789 M, current 0·03071 W, depression 21 m.m., total pressure 120·4 m.m.; ratio of increased pressure 1·211. The arc is represented in fig. 6 from a photograph in 15 seconds. The luminous entities still seen, but are less marked.

Distance × 7=4·06 inches, pressure 85·9 m.m., 113,026 M, current 0·03259 W, depression 22 m.m., total pressure 107·9 m.m.; ratio of increased pressure 1·256. Fig. 7 from a photograph in 15 seconds. The central spindle is divided into two luminosities, with a tendency to form a third near the negative.

Distance × 8=4·64 inches, pressure 71·6 m.m., 94,210 M, current 0·02693 W, depression 22 m.m., total pressure 93·6 m.m.; ratio of increased pressure 1·307. Fig. 8 from a photograph in 15 seconds. The central spindle nearly of the same character as fig. 7.

Distance × 9=5·22 inches, pressure 65·5 m.m., 86,184 M, current 0·02693 W, depression 22 m.m., total pressure 87·5 m.m.; ratio of increased pressure 1·336. Fig. 9 from a photograph in 15 seconds. The bright entities show a tendency to break up into less bright portions.

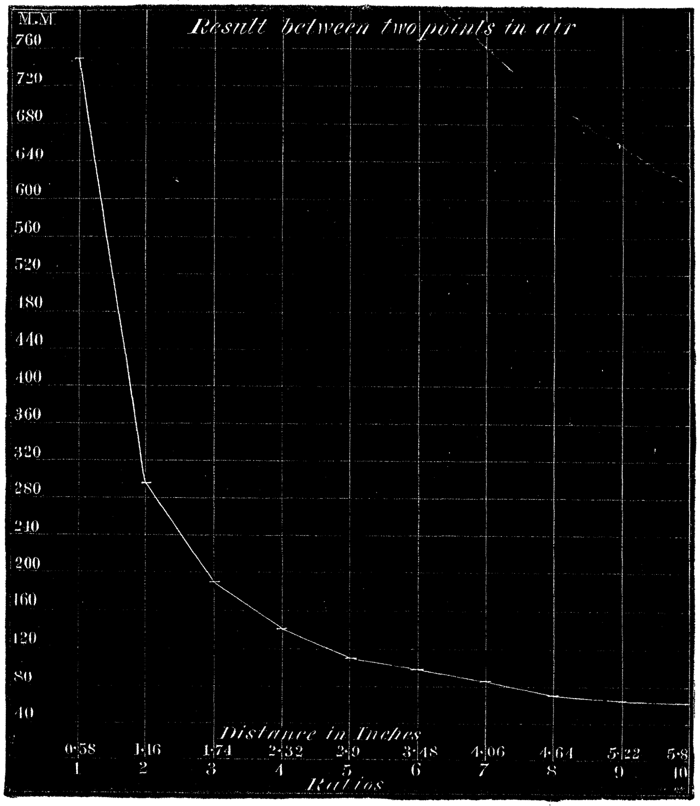
Distance × 10=5·8 inches, pressure 64·4 m.m., 84,737 M, current 0·03071 W, depression 20 m.m., total pressure 84·4 m.m.; ratio of increased pressure 1·310. Fig. 10 from a photograph in 15 seconds. The arc resembles that seen in fig. 9.

Distance 5·8 inches, pressure 4 m.m., 5263 M, current 0·02544, a single nearly globular luminosity about 1 inch in diameter near the positive. The negative terminal completely surrounded with a brilliant purple glow.

Distance 5·8 inches, pressure less than 4 m.m., but could not be exactly observed, current 0·02544. Near the positive three distinct strata had formed.

The curve of the discharge between two points in air, with a constant number of cells, the distance increasing as 1, 2 . . . 10, and the pressures diminishing, is shown in fig. 83.

Fig. 83.



It will be seen by the following table that while the distances increase as 1, 2 . . . 10, the pressures have to decrease in a greater ratio, namely, as 1, 2 . . . 10 multiplied by a factor greater than unity in order to permit a discharge to take place.

Col. I. Ratio of distances.	Col. II. Ratio of diminution of pressure.	Col. III. $\frac{\text{Col. II.}}{\text{Col. I.}}$
1	1	
2	2·54	1·27
3	3·91	1·30
4	5·25	1·31
5	6·65	1·35
6	7·51	1·25
7	8·71	1·24
8	10·45	1·30
9	11·43	1·27
10	11·61	1·16
		1·27 mean

The expansion which arises when a discharge takes place at various distances and pressures :—

Pressure.	Depression.	Ratio of increased to normal pressure.	Current.	
M.	m.m.		W.	ratios.
985,000	None			
388,026	16	1·054	0·02881	1·07
251,711	17	1·089	0·04060	1·51
187,631	19	1·133	0·04474	1·66
148,157	19	1·169	0·03459	1·28
130,789	21	1·211	0·03071	1·14
113,026	22	1·256	0·03258	1·21
94,210	22	1·307	0·02693	1·00
86,184	22	1·336	0·02693	1·00
84,737	20	1·310	0·03071	1·14

The arc in air between two spherical surfaces, 3 *inches radius, and* 1·5 *inch diameter at various distances and pressures, with* 10,960 *cells.* *Temp.* 15°·2 C.

PLATE 10.

(All the representations are from drawings.)

Distance 0·16 inch (the current would not pass at 0·165 inch), pressure 761 m.m., 1,001,317 M, current 0·02371 W, no depression apparent on making connexion with the battery, fig. 1.

Distance × 2=0·32 inch, pressure 272·1 m.m., 358,027 M, current 0·02456 W, no depression, fig. 2 ; the central spindle is broken up into nebulosities.

Distance × 3=0·48 inch, pressure 181·3 m.m., 238,553 M, current 0·02209 W, depression 0·25, total pressure 181·55 m.m., ratio of increased pressure 1·0002, fig. 3, one detached luminosity near negative.

Distance × 4=0·64 inch, pressure 149·8 m.m., 197,111 M, current 0·02131 W, depression 1 m.m., total pressure 150·8 m.m., ratio of increased pressure 1·007, fig. 4 ; the discharge no longer occurred at the shortest distance, and moreover took a curved formation, and was of unequal brightness in the central portion.

Distance × 5=0·80 inch, pressure 140 m.m., 184,211 M, current 0·02209 W, depression 3·5 m.m., total pressure 143·5 m.m., ratio of increased pressure 1·025, fig. 5 ; the discharge was curved, there was a small dark space near the negative on which there was a glow.

Distance × 6=0·96 inch, pressure 117·9 m.m., 155,131 M, current 0·02249 W, depression 2·5 m.m., total pressure 120·4 m.m., ratio of increased pressure 1·021 ; fig. 6. The discharge was pointed towards the negative.

Distance × 7=1·12 inch, pressure 118·4 m.m., 155,789 M, current 0·02209 W,

depression 2 m.m., total pressure 120·4 m.m., ratio of increased pressure 1·016; fig. 7, similar to the preceding.

Distance × 8=1·28 inch, pressure 118·4 m.m., 155,789 M, current 0·02170 W, depression 3 m.m., total pressure 121·4 m.m., ratio of increased pressure 1·025; fig. 8, the luminosity on the negative increasing.

Distance × 9=1·44 inch, pressure 118·4 m.m., 155,789 M, current 0·02170 W, depression 3 m.m., total pressure 121·4 m.m., ratio of increased pressure 1·025, fig. 9. The central bright portion was divided into two luminosities, that nearest the negative being the less bright.

Distance × 10=1·60 inch, pressure 118·4 m.m., 155,789 M, current 0·02056 W, depression 3 m.m., total pressure 121·4 m.m., ratio of increased pressure 1·025, fig. 10. The central portion was divided into two luminosities.

Distance × 11=1·76 inch, pressure 111·3 m.m., 146,448 M (the current would not pass at 118·4 m.m.), current 0·01948 W, depression 4 m.m., total pressure 115·3 m.m., ratio of increased pressure 1·036, fig. 11. The central portion was more decidedly divided into two portions, and assuming an upper-lip like form.

Distance × 20=3·2 inches, pressure 74·6 m.m. 98,158 M, current 0·01840 W., depression 8 m.m, total pressure 82·6 m.m., ratio of increased pressure 1·107, fig. 12. The discharge had formed near the peripheries of the terminals. The luminosity on the negative had increased.

Distance × 40=6·4 inches, pressure 46·6 m.m., 63,947 M, current 0·01390 W, depression 9 m.m., total pressure 55·6 m.m., ratio of increased pressure 1·193, fig. 13. The central bright part reached at first nearly to the negative, then after a short interval retreated first to about 2 inches and then to 3 inches from it.

Distance 6·4 inches, pressure 26·9 m.m., 35,395 M, current 0·01840 W, depression 10 m.m., total pressure 36·9 m.m., ratio of increased pressure 1·372, fig. 14. The central portion reached to the negative and did not divide into entities.

Distance 6·4 inches, pressure 13·7 m.m., 18,026 M, current 0·02056 W, depression 3 m.m., total pressure 16·7 m.m., ratio of increased pressure 1·219, fig. 15. The central portion reached at first to within 2 inches, and then retreated to 3 inches from the negative.

Distance 6·4 inches, pressure 7·1 m.m., 9342 M, current 0·02131 W. The jar-potential was found to be 2069 cells. The discharge had increased in width 1½ inches in diameter, and was 3 inches long. A purple glow on the negative terminal, fig. 17.

Distance 6·4 inches, pressure 5·5 m.m., 7237 M, current not taken, depression not appreciable. There was a barely visible discharge between the terminals, the positive was illuminated all over the surface opposed to the negative, which terminal was completely covered on the top and under surface with a purple glow about a quarter of an inch deep, fig. 16.

Distance 6·4 inches, pressure 4·1 m.m., 5395 M, current 0·02456 W, the jar-potential was 1448 cells, its resistance 70,000 ohms. 2400 rod cells passed, giving

a current of 0·05353 W, and produced thin strata near the positive, the negative being completely covered with a purple glow, fig. 18.

Distance 6·4 inches, pressure 2·6 m.m., 1316 M, 1200 cells, the zinc rods of which had been recently scraped to remove the oxychloride of zinc, gave a current of 0·17230 W, and produced a discharge one and a half inches wide, nearly reaching the negative, which was covered with a purple light, surrounding the top and bottom surfaces to a depth of three-eighths of an inch.

Distance.	Pressure.	Depression.	Ratio of increased to normal pressure.	Current.	
inches.	M.	m.m.		W.	ratios.
0·16	1,001,317	None	..	0·02371	1·71
0·32	358,027	None	..	0·02456	1·77
0·48	238,553	0·25	1·0002	0·02209	1·59
0·64	197,111	1·00	1·007	0·02131	1·54
0·80	184,211	3·5	1·025	0·02209	1·59
0·96	155,131	2·5	1·021	0·02249	1·62
1·12	155,789	2·0	1·016	0·02209	1·59
1·28	155,789	3·0	1·025	0·02170	1·56
1·44	155,789	3·0	1·025	0·02170	1·56
1·60	155,789	3·0	1·025	0·02056	1·48
1·76	146,448	4·0	1·036	0·01948	1·40
3·20	98,158	8·0	1·107	0·01840	1·32
6·40	63,947	9·0	1·193	0·01390	1·00
6·40	35,395	10·0	1·372	0·01840	1·32
6·40	18,026	3·0	1·219	0·02056	1·48
6·40	7237	None	..	Not taken	

The arc in hydrogen between two spherical surfaces, 3 *inches radius, and* 1·5 *inch diameter, at various distances and pressures, chiefly with* 10,960 *cells. Temp.* 13°·3 C.

Distance 0·225 inch (the current would not pass at 0·23 inch), pressure 762·8 m.m., 1,003,685 M, current 0·02456 W, no depression apparent on making connexion with the battery. The central spindle did not quite reach the negative terminal. A, fig. 84; C and F lines visible with the spectroscope.

Distance × 2=0·45 inch, pressure 339 m.m., 446,053 M, current 0·02371 W, depression 0·1 m.m., total pressure 339·1 m.m., ratio of increased pressure 1·0002. The central spindle did not quite reach the negative terminal. The arc appeared to be crossed by very close lines; at the positive, winged appendages were formed B, fig. 84.

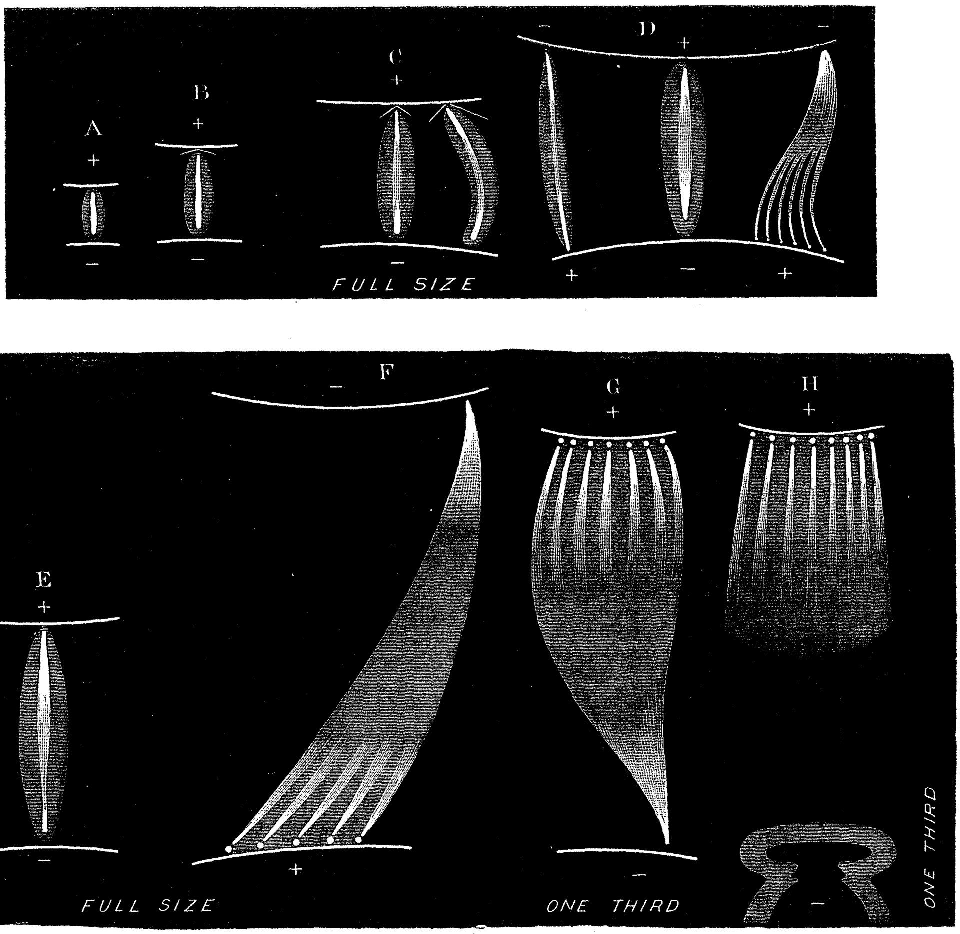
Distance × 3=0·675 inch, pressure 256 m.m., 336,842 M, current 0·02456 W, depression 0·5 m.m., total pressure 256·5 m.m., ratio of increased pressure 1·002. The arc at first formed in the centre as on the left of C, fig. 84, then moved towards the periphery, as on the right of the same figure. Winged appendages were formed as represented.

Distance × 4=0·90 inch, pressure 255 m.m., 335,526 M, current 0·02544 W,

depression 0·5 m.m., total pressure 255·5 m.m., ratio of increased pressure 1·002. The appearance as shown in D, fig. 84, the arc first formed in the centre, then ran all over the surfaces of the terminals, lastly becoming steady, as seen in edge view on the left, and side view on the right.

Distance × 5=1·125 inch, pressure 200·8 m.m., 264,211 M, current 0·02634 W, depression not observed. The arc at first formed in the centre, as seen in E, fig. 84, and then ran all over the surface, as in D.

Fig. 84.



Distance × 10=2·250 inches, pressure 164·1 m.m., 215,921 M, current 0·02056 W. The discharge as in F, fig. 84; on the positive there formed a number of beads of light.

Distance × 25=5·62 inches, pressure 61·8 m.m., 81,316 M, current 0·01272 W. The discharge in form like a fig; a number of beads of light forming on the positive, and the arc ending in a rounded point (the stem of the fig) on the negative G, fig. 84, reduced to one-third.

Distance 5·62 inches, pressure 2·3 m.m., 3026 M, 2400 cells, current 0·08923 W.

Beads still formed on the positive, the light became so faint an inch or two from the positive as to be barely visible, H, fig. 84, reduced to one-third.

Distance.	Pressure.	Depression.	Ratio of increased to normal pressure.	Current.	
inches.	M.	m.m.		W.	ratios.
0·225	1,003,685	..	..	0·02456	1·93
0·450	446,053	0·1	1·0002	0·02371	1·86
0·675	336,842	0·5	1·002	0·02456	1·93
0·900	335,526	0·5	1·002	0·02544	2·00
1·125	264,211	..	..	0·02634	2·07
2·250	215,921	..	..	0·02056	1·62
5·520	81,316	..	..	0·01272	1·00
5·520	3026	..	(with 2400 rod cells)	0·08933	7·02

The arc in hydrogen between two points. Temp. 16°·2 C., 10,940 *cells.*

Distance 0·75 inch, pressure 745 m.m., 980,263 M, current 0·01575 W, the appearance is represented in Plate 8, figs. 21 and 22, the first copied from a photograph obtained in 5 seconds, the second in 15 seconds. The central spindle breaks into a brush-like form towards the negative, there is then a dark interval between it and the glow on the negative.

Distance 0·9 inch, pressure 745 m.m., 980,263 M, the discharge passed intermittently, so that the current could not be read off on the galvanometer. The appearance is represented full size in Plate 8, fig. 26, from a drawing.

Distance 0·9 × 2, 1·8 inch, pressure 385·6 m.m., 507,368 M, current 0·01575 W, depression 14 m.m., total pressure 399·6 m.m., ratio of increased pressure 1·04. Plate 8, fig. 23, from a photograph in 13 seconds. The distance between the brush-like termination of the central spindle and the glow on the negative has relatively increased. Figs. 27 and 28 are other representations copied from drawings.

Distance × 3, 2·7 inches, pressure 317·8 m.m., 418,158 M, current 0·00580 W, depression 13 m.m., total pressure 330·8 m.m., ratio of increased pressure 1·04. Plate 8, fig. 24, from a photograph in 15 seconds. The central spindle relatively still shorter. At times only the terminals were illuminated, but sometimes strata formed on the positive terminal. Fig. 29 is another representation copied from a drawing.

Distance × 4, 3·6 inches, pressure 170·5 m.m., 224,342 M, 6300 cells, current not measured, the appearance is represented in Plate 8, fig. 25; the central spindle has decreased relatively still more.

Distance × 7, 6·3 inches, pressure 85·8 m.m., 112,895 M, 10,940 cells, current 0·01393 W, only a glow on both terminals, the intermediate discharge being dark.

Distance 6·3 inches, pressure 10 m.m., 13,158 M, 10,940 cells, current 0·02456 W,

depression 14 m.m., total pressure 24, ratio of increased pressure 2·4, only a glow on terminals, the rest of the discharge dark.

Distance 6·3 inches, pressure 3·3 m.m., 4342 M, 2400 cells, current 0·03896 W, strata at the positive extending half way towards the negative, then there is an intervening dark discharge, and the negative point and the whole of its holder is surrounded with a bright violet halo.

Distance 6·3 inches, pressure 3 m.m., 3947 M, 1200 cells, the bottom point positive current 0·03896 W, a splendid stratification though somewhat unsteady; it is represented in Plate 8, fig. 35, partly copied from a photograph, partly from drawings. It was thought at first that well-defined strata would not be formed in a jar of such large diameter, but this experiment shows that this conjecture was unfounded. The negative glow completely fills the neck of the jar.

Distance 6·3 inches, pressure 2·4 m.m., 3158 M, 1200 cells, current 0·02728 W, a very steady stratification when the bottom point was positive; this curious stratification completely overlapped the whole surface of the bottom point and the brass holder, as shown in Plate 10, fig. 26, the glow around the negative completely filling the upper portion of the jar.

Air having leaked into the receiver it was removed from the plate and a tube inserted, as shown in fig. 79, p. 84, in order to ascertain whether the contraction of the space surrounding the discharge would have any effect on the production of strata. It will be remembered that a number of holes had been drilled in opposite sides of the tube, which is 8 inches long and 1·8 inch in diameter. These holes were drilled with the object of straining very fine platinum wires across at different heights for ascertaining the temperature of the arc at these positions, but in the experiments about to be described there were no wires.

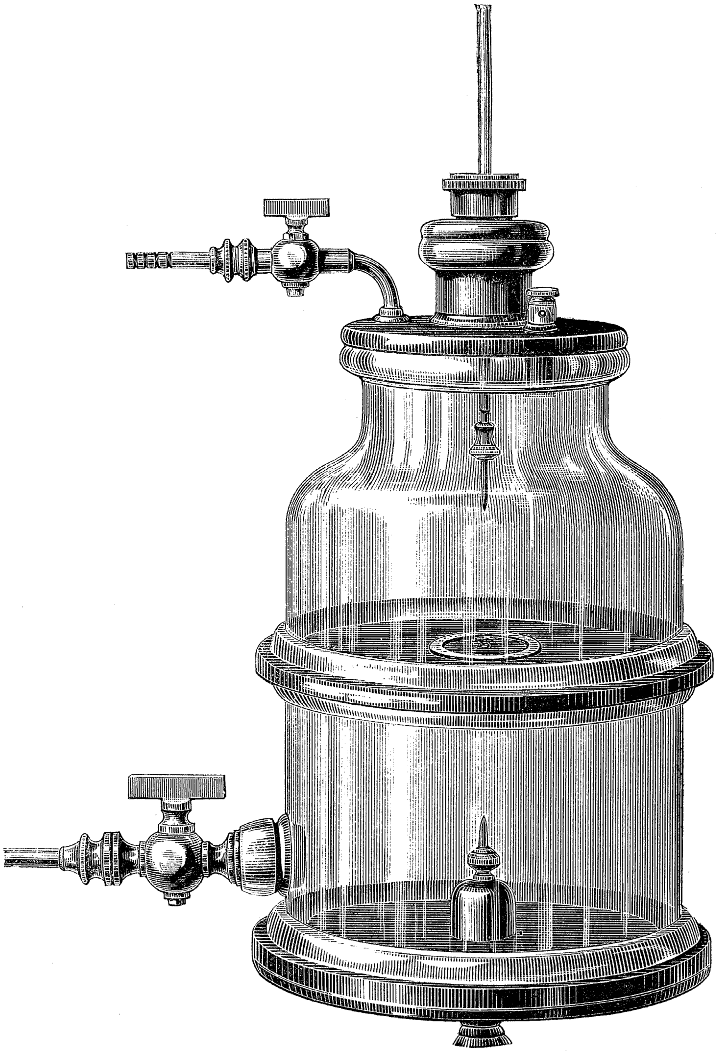
The bell-jar was refilled with hydrogen and exhausted; distance of points 6·3 inches, pressure 5·7 m.m., 7500 M, 2700 cells, current 0·13340 W; notwithstanding this large current no depression of the mercury in the gauge occurred on making connexion. The discharge is mainly cylindrical, with a spherical termination half an inch from the negative, and completely fills the tube; then there is a small dark space, and the negative is completely surrounded with a violet halo.

Pressure 2 m.m., 2632 M, 2400 cells; when the top point was positive there was a production of ordinary strata, as is shown in Plate 8, fig. 35. But when the bottom was positive, a very remarkable phenomenon was observed, namely, the protrusion of strata through the small holes, $\frac{1}{8}$th inch in diameter, in the walls of the inner tube, this being accompanied by an overpouring of negative discharge above the top of it, Plate 8, fig. 34. It seemed as if the positive discharge sought a complete neutralization with negative electricity beyond the confines of the tube, the area of which was too small to permit of complete relief. The close confinement of the discharge at the bottom end of the tube which rests on the glass plate of the pump, may account for the non-oozing out of strata through the holes when the top point was positive,

because in the latter case the negative could not overflow the end of the tube and seek positive neutralization.

Some gas let in, pressure 4 m.m., 5263 M, 2400 cells, current 0·15470 W, a well-defined stratification occurred when the bottom point was positive, but no oozing out through the holes in the tube, Plate 10, fig. 25.

Fig. 85.



In order to ascertain whether there was any difference in the increased pressure on the positive or negative side of the discharge on connecting the terminals with the battery, we had a divided bell-jar constructed as shown in fig. 85, both ends of the two halves being accurately ground, and a glass disc for dividing the chamber into parts was provided; in this there is a hole half an inch in diameter surrounded by a raised rim, in order that plates of mica with holes of different diameters might be cemented with Canada balsam centrally to the diaphragm. The capacity of the

upper half was found to be 1530 cub. centims., that of the lower half 1755, total 3285, or somewhat less than the jar, fig. 79 (3787).

Instead of putting separate gauges in connexion with the two chambers, as was originally contemplated, the lower chamber only was connected to the gauge, as in fig. 81, p. 86, and the lower terminal was made + or − alternately.

Air. Points distant 5 *inches.*

In a preliminary trial with the central hole 0·5 inch diameter, and a pressure which was not recorded, but at which 8840 cells just passed, the depression of the gauge when the lower terminal was negative or positive, was—

LOWER terminal.

	−	+
	m.m.	m.m.
	27	19
	21	19
	23	20
Mean	$23\frac{2}{3}$	$19\frac{1}{3}$

Central hole 0·125 inch diameter, temperature 15° C., pressure 60·9 m.m., 80,132 M, 11,000 cells, current 0·03657 W, the jar-potential was found to be 3550 cells, depression—

LOWER terminal.

	−	+
	m.m.	m.m.
	28	24
	26	23
Mean	27	23·5
Ratio of increased to normal pressure .	1·44	1·39

The appearance of the discharge is shown in Plate 10, fig. 24, which is copied from a drawing.

Pressure 65·2 m.m., 85,789 M, temperature 13°·9 C., 11,000 cells, current 0·04686 W, jar-potential 3188 cells, depression—

LOWER terminal.

	−	+
	m.m.	m.m.
	23	27
	22	26
Mean	22·5	26·5
Ratio of increased pressure .	1·34	1·41

Central hole 0·02 inch, pressure 83·5 m.m., 109,869 M, 11,000 cells, current 0·04686 W, depression—

LOWER terminal.

	−	+
	m.m.	m.m.
	11	17
Ratio of increased pressure .	1·13	1·20

Central hole 0·02 inch, pressure 78 m.m., 102,632 M, 11,000 cells, current 0·05121, jar-potential 3477 cells, depression—

LOWER terminal.

	−	+
	m.m.	m.m.
	17	26
	18	27
Mean	17·5	26·5
Ratio of increased pressure .	1·22	1·34

Central hole 0·02 inch, pressure 68·5 m.m., 90,132 M, 11,000 cells, current when the lower terminal was positive 0·04901 W, when it was negative 0·04686 W ; in order to avoid any errors from reversing with the key, the contacts of which might possibly be more perfect in one or other direction, the connecting wires were reversed and connexion made by moving the key always in one direction ; the jar-potential was 3188 cells, depression—

LOWER terminal.

	−	+
	m.m.	m.m.
	26	28
	26	27
Mean	26	27·5
Ratio of increased pressure .	1·38	1·40

The hole in the centre of the diaphragm was covered with a disc of thin brass cemented on the glass diaphragm. The top point distant 2·5 inches from the brass disc, the bottom point distant from the bottom of the disc 2·55 inches, this makes a total distance between the points of 5·05 inches. The top and bottom cocks were connected together by tubing. Temperature 14° C., pressure 69·2 m.m., 91,053 M, 11,000 cells, current, with 40,000 ohms additional resistance, making a total of 279,000 ohms, 0·04060 W ; the connexion between the top and bottom chambers was left open, depression—

LOWER terminal.

	−	+
	m.m.	m.m.
	11	8
Ratio of increased pressure .	1·16	1·11

The communication between the top and bottom chambers was now closed, pressure 60·2 m.m., 79,210 M, 11,000 cells, current bottom negative 0·04474 W, bottom positive 0·03459 W, jar-potential, both chambers, 4538 cells, depression—

LOWER terminal.

	−	+
	m.m.	m.m.
	12	10
	11	10
Mean	11·5	10
Ratio of increased pressure .	1·19	1·16

The discharge took place when the top was negative in a curved arch from the upper rim of the disc to the point, and from the lower point it was axial to the centre of the underside of the disc; the underside of the disc formed a new negative, while its upper side formed a new positive terminal, Plate 8, fig. 30.

Summary.—Ratio of increased to normal pressure.

LOWER chamber.

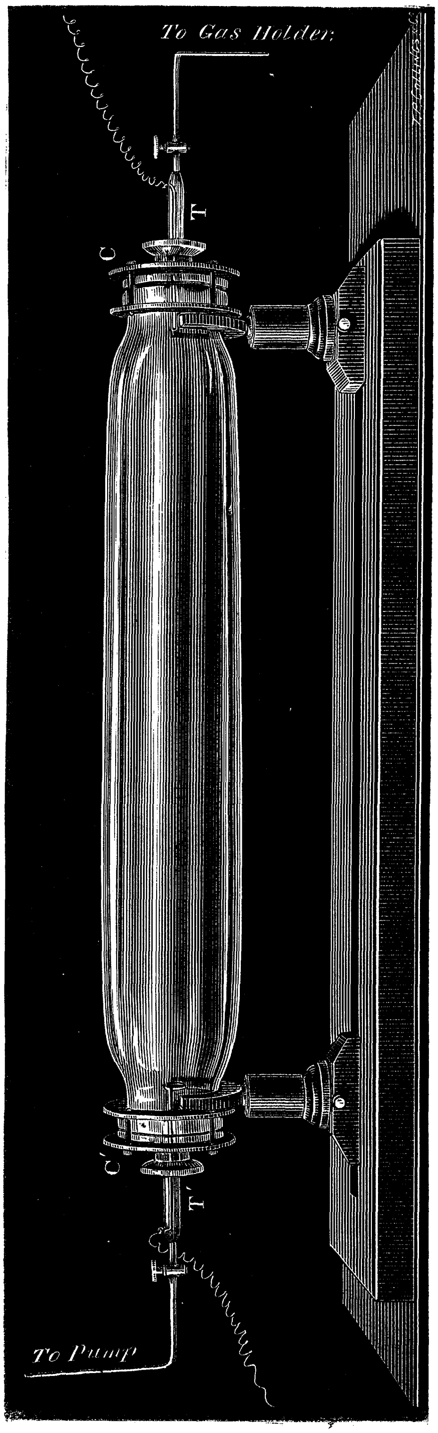
−	+
1·44	1·39
1·34	1·41
1·13	1·20
1·22	1·34
1·38	1·40
1·16	1·11
1·19	1·16
1·266	1·287

It would appear therefore that the dilatation of the gas is the same both in the positive and negative chambers.

In order to prosecute our experiments in a vessel of still greater capacity, we had constructed a larger jar with a neck at each end, or, more properly speaking perhaps, a tube as represented in fig. 86, supported horizontally on ebonite crutches. It is 37 inches, 94 centims., long and $5\frac{13}{16}$ inches, 14·8 centims., in diameter, and its cubical content 14,435 cubic centims., or 3·8 times that of the bell-jar, fig. 79, p. 84. The ends are ground and are closed by caps with necks, C′, C′, also ground flat; the holes in the necks are likewise ground so as to receive two tubes T′, T′; in these tubes are sealed wires on which terminals of any form may be screwed; this has to be done after they have been inserted through the caps and before the caps have been placed in position; by this arrangement terminals nearly as large as the neck of the tube may be used. The tubes which hold the terminals are furnished with glass cocks. The joints are made air-tight by means of grease, and the caps are kept in their places

by ebonite outer rings held by bolts which screw into half-rings at the back of the neck-shaped openings of the tube. This tube is numbered 199; the distance between

Fig. 86.



the terminals, a ring, and a straight wire is 33·5 inches, 85 centims. Another tube, No. 200, 34 inches, 86·4 centims., long and $1\frac{3}{4}$ inch, 4·4 centims., diameter, 30 inches,

76·2 centims., between the terminals, a ring, and a straight wire, is also connected to the pumps in order to permit of the study of the effect of different bores on the phenomena of the discharge when both tubes are at the same pressure.

The experiments with Tube 199 will necessarily occupy a considerable period, partly on account of the long time it takes to exhaust it after each set, partly on account of the variety of experiments it is intended to make with it. We now propose to describe only a few of the first results we have hitherto obtained.

Tube 199, *Air*.

Pressure 3 m.m., 3947 M, 6300 cells. Two luminosities were formed, as shown in Plate 9, fig. 5, the ring negative being surrounded with a nebulosity which completely filled the end of the tube. The tube glowed brilliantly with a blue fluorescent light, which proved to have great actinic power. The figure is copied from a dry-plate photograph obtained in 5 seconds; it records a very curious phenomenon, namely, that the outer boundary of the luminosity appears *darker* than the tube. It is to be remarked that while the discharge was reddish (nitrogen), the fluorescence of the tube was blue; the effect appears to be due to the absorption of a portion of the fluorescent light emanating from the back of the tube in passing through the red luminosity. The effect was quite unexpected, and it was thought at first that it might have arisen from some peculiarity in the development of the dry plate; it was not therefore until the result had been confirmed by other photographs that we ventured on the explanation given.

Tube 199, *Hydrogen*.

Pressure 40 m.m., 56,632 M, 11,000 cells, current 0·00087 W. A mere speck of light both on the positive and negative terminals; in tube No. 200 there was not the slightest glow when the battery was connected with it. The whole of tube 199 glowed with a blue fluorescent light, notwithstanding that there was only a mere speck of illumination on the terminals, and no appearance of light between them.

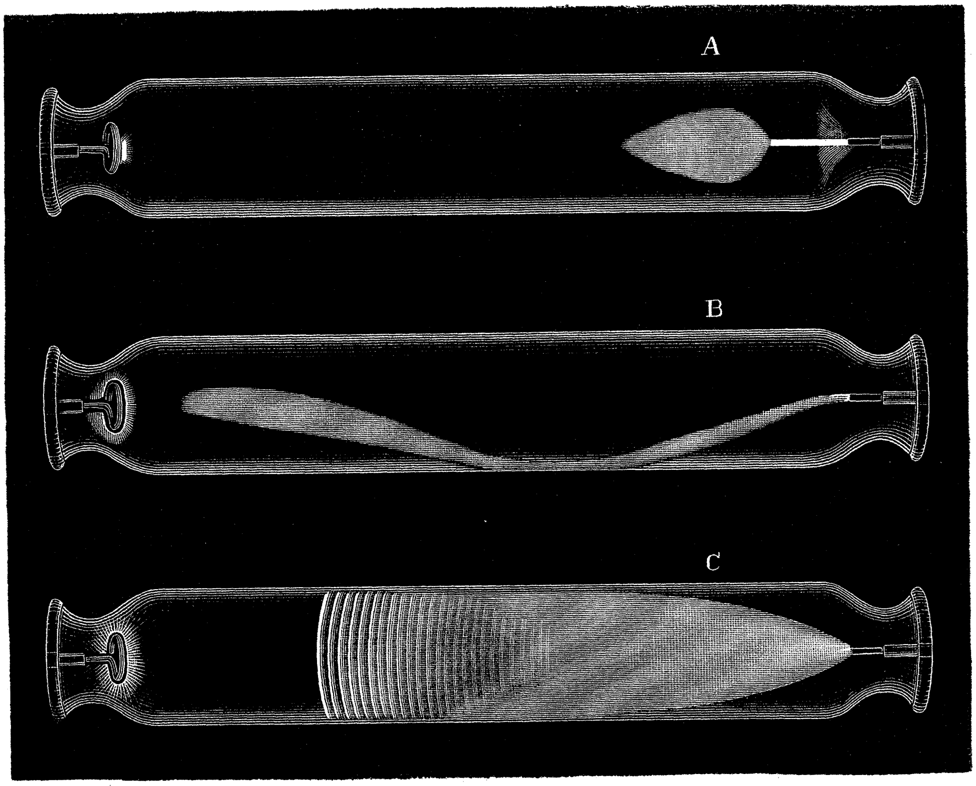
Pressure 28 m.m., 36,842 M, 11,000 cells, current 0·00527 W. A spear-head shaped luminosity about half an inch long on the positive straight terminal, a mere speck of light on the negative ring. No discharge occurred in tube 200 at the same pressure.

Pressure 26 m.m., 34,211 M, 11,000 cells, current 0·00879 W. A fan-shape luminosity about one inch long at the positive, a mere speck of light about one-eighth of an inch in length on the negative ring. The tube glowed with a blue fluorescent light throughout its length. 6300 cells would not pass.

Pressure 22 m.m., 28,948 M, 11,000 cells, current 0·01412 W. The glow on negative extended to three-eighths of an inch, a spear-head luminosity on the positive wire, to which it was attached by a very bright wire-like stem not greater in diameter than the terminal, A, fig. 87.

Pressure 15 m.m., 19,737 M, 11,000 cells, current 0·03071 W. A spindle-shaped luminosity at the positive about $1\frac{1}{2}$ inch long, and the negative ring completely surrounded with a glow which had increased considerably since A. After a short time the spindle on the positive lengthened out and nearly reached the negative, hugging the underside of the tube, as in B, fig. 87. It was not sensitive to the approach of the finger, although close to the glass; 6300 cells produced the same phenomena.

Fig. 87.



Pressure 13 m.m., 17,105 M, 11,000 cells, current 0·01772 W. At the positive, a spear with a staff not greatly exceeding the diameter of the wire, the spear-head reaching to the middle of the tube. The glow on negative less brilliant than the preceding phase in consequence of a less current passing.

Pressure 9 m.m., 11,842 M, 6,300 cells, current 0·02693 W. A well-formed arrow-like luminosity at the positive, the negative ring three parts illuminated. After a while the luminosity shot forward towards the negative and lost its arrow shape, and then retreated to the positive, assuming the form of a long pear.

Pressure 8 m.m., 10,526 M, 6300 cells, current 0·01772 W. A long discharge reaching to the middle of the tube, in the centre of which was a very bright wire-like luminosity like that in A, fig. 87, which in the latter case was attached to the positive.

Pressure 5 m.m., 6579 M, 6300 cells, current 0·02693 W.

Pressure 4·5 m.m., 5921 M, 6300 cells, current 0·03657 W.

Pressure 4 m.m., 5263 M, 6300 cells, current 0·03459 W. The discharge in the latter case was partially stratified.

Pressure 3 m.m., 3947 M, 6300 cells, current 0·04474 W. Similar phenomena to those at a pressure of 4 m.m., except that the negative glow was more extended and terminated in a fringe-like contour composed of filaments of light.

Pressure 3 m.m., 3947 M, 6300 cells, current 0·04901 W. Two stratified luminosities as shown in Plate 9, fig. 6, copied from a dry-plate photograph obtained in 25 seconds, and a drawing made at the time; the negative was completely and very brilliantly illuminated. After a short time the two luminosities coalesced to form one at the positive terminal, and between it and the negative there was a long dark discharge. The outer boundary of the discharge from the positive is less bright than the fluorescent glow of the tube, as was the case with a discharge in air. Plate 10, fig. 19, shows the phenomena of the discharge in tube 200 at the same pressure, with a current of 0·03071 W; this exemplifies well the influence of the diameter of the tube on the phenomena of stratification. In fact, in tube 199 we have not yet succeeded in obtaining a steady stratification, while in tubes of a less diameter perfectly steady strata are always obtained, although their form and number depend partly on the dimensions of the tube, Part II., fig. 62a, p. 209.

Pressure 2 m.m., 2632 M, 6300 cells, current 0·04686 W. Strata for three-fourths of the length of the tube, commencing at the positive in a point and enlarging to about half the diameter of the tube as it approached the negative.

Pressure 1·5 m.m., 1974 M, 6300 cells, current 0·05801 W. The strata completely filling the tube towards the negative in form like C, fig. 87. The negative still more brilliantly illuminated, the glow terminating as a fringe. The resistance of the tube was found to be 63,000 ohms.

Pressure 0·5 m.m., 657 M, 4800 cells, current 0·03657 W. The discharge was as in Plate 9, fig. 7, copied from a dry-plate photograph obtained in 25 seconds. The glow around the negative completely filled the tube as if the discharge experienced difficulty in emanating from that terminal, and that the gas was driven with force against the inner wall of the tube. We have already alluded in Part II. to the projection of matter from the negative terminal in a direction normal to its surface, and not necessarily towards the positive; GASSIOT* has recorded similar phenomena, and CROOKES' remarkable researches have shown in the most convincing manner that this occurs, and that the matter projected may be brought to a focus by curved surfaces.

The great extent of the dark discharge which sometimes obtains is very remarkable and requires special study. We have stated in Part II., p. 157, &c., that the strata sometimes thread themselves completely on the negative terminal, and that after a time they

* Part II., Appendix, Note C.

retreat towards the positive. In the course of our experiments we have frequently observed the stratification extending quite up to the negative, and after a certain time only filling about half of the tube, as, for example, in tube 128, containing hydrogen, the discharge in which, with 2400 cells, the current being 0·01639 W, is shown in Plate 9, fig. 4, copied from a photograph obtained in 5 seconds.

It will have been noticed that the extent of illumination of the negative in tube 199 gradually increased as the exhaustion and the current became greater; it would seem that the negative discharge requires a greater extent of outlet than the positive, especially as the current increases; this is well exemplified by tube 51 containing hydrogen; it is 7 inches long and 2 inches in diameter; it contains a small ring terminal half an inch in diameter, the other being a spiral supported on three glass rods, and formed of a wire 19 inches long, and making four turns. When connected with a battery of 1200 cells, the spiral being negative, it became illuminated to a small extent near the positive, then the luminosity extended backwards as the current was increased, but not in the same ratio.

Through a resistance of	Illumination of negative.		Current.	
ohms.	inches.	ratios.	W.	ratios.
500,000	2·00	1·00	0 00238	1·00
400,000	2·50	1·25	0·00263	1·10
300,000	4·50	2·25	0·00277	1·16
200,000	8·00	4·00	0·00347	1·34
100,000	9·00	4·50	0·00555	2·33
50,000	13·50	6·25	0·01023	4 29
40,000	15·75	7·87	0·01158	4·86
20,000	19·00	9·50	0·01575	6·62
0	19·00 more brilliantly	9·50	0·03138	13·18

The resistance of the tube was found by substitution to be 10,500 ohms.

Plate 10, fig. 27, represents the appearance with 500,000 ohms resistance in circuit; it is copied from a photograph obtained in 10 seconds; fig. 28, the appearance without resistance, from a photograph in 5 seconds.

The experiments described in Part III. lead to the following conclusions:—

1. *For all gases there is a pressure which offers the least resistance to the passage of an electric discharge. After the minimum has been reached, the resistance to a discharge rapidly increases as the pressure of the medium decreases.* With hydrogen the minimum is 0·64 m.m., 842 M; at 0·002 m.m., 3 M, it is as great as at 35 m.m., 46,000 M.
2. *There is neither condensation nor dilatation of a gaseous medium in contiguity with charged terminals.*

3. *When the discharge takes place there is a sudden dilatation of the medium in addition to and distinct from that caused by heat. This dilatation ceases instantaneously when the discharge ceases.*
4. *The potential necessary to produce a discharge between parallel flat surfaces at a constant distance and various pressures, or at a constant pressure and various distances, may be represented by hyperbolic curves. The resistance to the discharge between parallel flat surfaces being as the number of molecules intervening between them.*
5. *This law does not hold with regard to points. In Part I. it has been shown that the potential necessary to produce a discharge at the atmospheric pressure and various distances is as the square root of the distances; while with a constant potential and various distances, the pressure has to be diminished in a greater ratio than that of the increase of distance in order to permit a discharge to take place.*
6. *The electric arc and the stratified discharge in vacuum tubes are modifications of the same phenomenon.*

We propose later on to follow up this communication with an account of some researches on the conditions of the dark discharge and of special phenomena of the negative discharge. We have also made preparations for constructing the terminals of the tubes of very small platinum tube, in order to permit of gas being admitted through them during the discharge.

We have again pleasure in thanking Professor STOKES for his much-valued advice during the course of our investigations. To our assistant, Mr. FRAM, we are indebted for his able co-operation, and we have to thank Mr. H. REYNOLDS for his aid and skill in taking photographs.

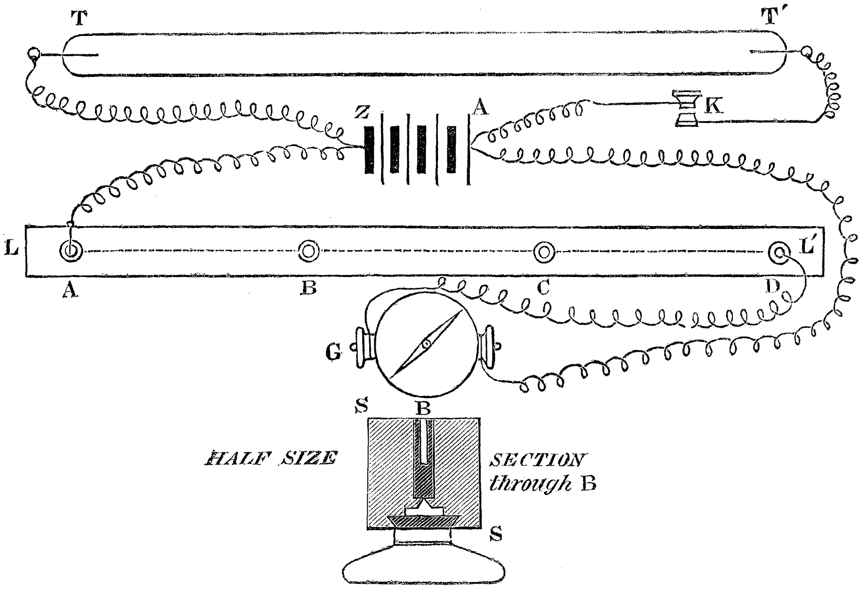
APPENDIX.

NOTE A, RELATING TO PAGE 69.

In order to avoid the injurious running down of the life of the battery in making observations of the tube-potential, two new methods of observation were adopted subsequently to that described in pp. 65–68; one by means of the galvanometer, the other by means of the electrometer. The first method consists in observing, in the first place, the deflection, D, of a THOMSON galvanometer through an adjustable resistance, so high in relation to the internal resistance of the battery that the latter might be neglected, then in observing the deflection, d, when the tube is connected with the terminals; the second deflection d, multiplied by the number of cells employed, B, and divided by the first deflection, D, gives the tube-potential V, $V=\frac{dB}{D}$.

The resistance made use of is a line drawn with a hard (H) blacklead pencil along a **V**-shaped groove in a quadrangular prism of ebonite, one inch square in section, as shown in S S (fig. 88), half size. In the

Fig. 88.



prism, on the under side, a recess is made not quite reaching the ends of the prism, and at the bottom of this recess the **V** groove is formed. A dovetail groove is also made, in which an ebonite cover slides, to completely cover the recess so as to keep out dust. Into the cover two ebonite feet are screwed. Four brass rods, pierced partly through with holes to receive the terminals, are inserted through the upper surface so as to reach the apex of the V, and at the end of each rod, at the level of the apex, a small flat is formed which is rubbed over with blacklead to ensure contact with the pencil line. The length of the pencil line from A to B is 9·1 inches, B to C 9·05 inches, and C to D 9·05 inches.

The resistance of	A to D	was found to be	149,670 megohms.
,,	,,	A ,, C	,,	,,	50,789	,,
,,	,,	A ,, B	,,	,,	8098	,,

The deflection produced by different potentials, per 100 cells, was as follows:—

Number of cells used.	Sections.		
	A to D.	A to C.	A to B.
	divisions.	divisions.	divisions.
10,980	1·226	3·613	22·66
9780	1·339	3·569	19·84
8580	0·9790	3·368	18·53
7380	0·7995	3·035	16·12
6180	0·5825	2·655	14·40
4700	0·2979	2·106	11·68
3240	0·1235	1·666	9·23
2160	0·0000	1·250	7·36
1080	0·0000	0·000	5·64

The deflection is read for the battery without the tube and again when the tube is connected. If the tube-potential approaches that of the whole number of cells it may at once be calculated, but if the tube-potential is much less than that of the battery a shorter length of the line-resistance is taken and a new reading obtained with the tube connected; this new deflection is reproduced approximately by lessening the number of cells and reading the deflection again without the tube; the tube-potential is then calculated from the new data. The pencil-line-resistance has been found to change from time to time, but this is not of the least moment, because, in every observation, the tube-potential is balanced, as it were, at the time it is made.

In fig. 88 T T′, is the tube; Z A, the battery; L L′, the line-resistance; A C, B C, C D, sections of this resistance; G, the galvanometer; K, a key for connecting on the tube when required. The movable wire is shown to be inserted into the hole D so as to include the whole resistance A D, but it may be inserted into either C or B.

NOTE B, RELATING TO PAGE 69.

The second method of obtaining the tube-potential, suggested to us by Professor MASCART, is a modification of that described (Part II., p. 165); the change consisting in detaching the induction apparatus from the electrometer, as shown in fig. 89; for it was found in the former arrangement that the influence of the induction-plate on the pair of quadrants opposed to that over which it was placed was detrimental, especially when much raised. Moreover, it was found to be advantageous to charge the *needle* and not one of the quadrants with the induced charge; and, on the other hand, to connect each pair of quadrants respectively with the + or − terminal of two chloride of silver batteries, each of 20 or more cells. The other terminal of each battery being connected to the earth; each pair of quadrants becomes constantly charged to the same potential, one with positive the other with negative electricity, and their influence on the needle is perfectly symmetrical.

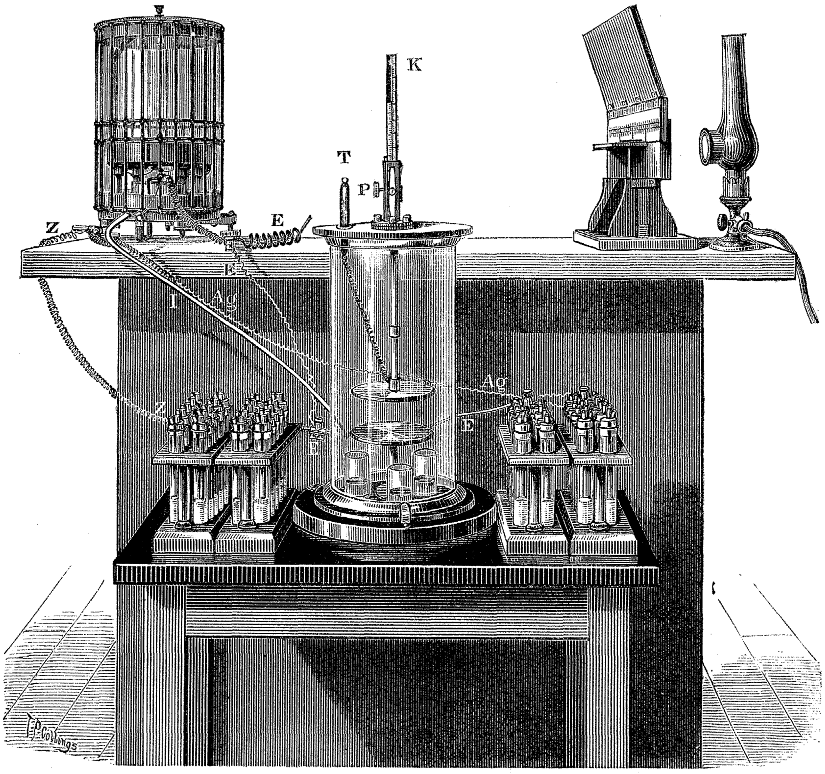
The figure shows clearly the arrangement. The lower plate is in connexion with the needle through the insulated wire I; the Z terminal of one battery, and the *Ag* terminal of the other are connected to their respective quadrants. When an observation has to be made, one terminal of the battery of high potential is brought into connexion with T, which is in metallic communication with the upper or inducing plate of the induction apparatus, the other terminal of the battery being to earth; the swing of the needle is observed and the apparatus is afterwards discharged by connecting the needle and the inducing plate to earth, the tube is then attached to the terminals and the swing observed when T is again touched. The ratio of the latter to the former gives the ratio of the tube-potential to the number of cells used. If the

two deflections are very different, it is advantageous to balance the swing with the tube approximately by a less number of cells, and to calculate the tube-potential with the fresh data.

In order to prevent worrying oscillations of the needle a slight but important change is made in the attachment of the damper to the needle. Soldered rigidly to the needle is a ⊥-shaped wire, to the horizontal ends of which is hung a Y-shaped wire to form a hinge; to the vertical projection of the Y are attached three cross-wires which dip into the acid, forming in this way a damper as well as a conductor. As the damper is rigidly connected to the needle in the plane of the swing it moves steadily, and its extreme swing may be taken for the reading.

The inducing and induced plate are both 4 inches in diameter, and may be made to touch or be separated a distance of 7 inches.

Fig. 89.



The following readings were obtained with the plates 4 inches apart; the quadrants charged to a potential of 20 cells :—

Cells.	Deflection in scale divisions.	
	Total.	Per 1000 cells.
1200	22	18·3 ⎫
2400	40	16·7 ⎪
3600	64	17·9 ⎪ 17·4 average
4800	79	16·5 ⎪
6300	108	17·1 ⎪
7760	139	17·8 ⎭
8840	185	20·9
9920	234	23·6
11,000	288	26·2
	with the quadrants char	ged to a potential of 30 cells
11,000	338	30·7

By increasing the number of cells in connexion with the quadrants, say to 100, the deflection is considerably augmented; it may also be increased to any requisite extent by bringing the plates of the induction apparatus closer together.

NOTE C, RELATING TO PAGE 88.

DE LA RIVE, Genève, Mem. Soc. Phys. XVII., 1863, pp. 73–74.—"Le phénomène dans les fluides élastiques raréfiés consisterait dans des contractions et dilatations alternatives du milieu gaseux, produites par la série des décharges toujours plus ou moins discontinues dont le jet électrique est formé. En effet, que ce soit par l'appareil RUHMKORFF ou bien par une machine électrique ordinaire, ou une machine hydro-électrique d'ARMSTRONG, et même par une pile voltaique à haute tension, qu'on produise les stratifications, on n'a jamais une décharge continue, mais bien une série de décharges qui peuvent se succéder assez rapidement pour que la discontinuité ne soit pas accusée même par un galvanomètre; mais cette discontinuité n'existe pas moins, comme M. GASSIOT l'a montré en opérant avec une pile de GROVE à haute tension qui, avec les mêmes électrodes et dans le même milieu, peut donner naissance, d'abord à des stratifications, puis plus tard à un arc voltaique, quand le courant est devenu continu.

"Au reste l'action mécanique de la série des décharges sur le fluide élastique raréfié peut être constatée directement par les oscillations très prononcées de la colonne de mercure du manomètre mis en communication avec la fluide élastique qui accompagnent la propagation de l'électricité dans ce fluide. Ces oscillations s'élèvent jusqu'à deux ou trois dixièmes de millimètre dans l'hydrogène sous la pression de 16 millimètres; elles commencent à être sensibles dès que le jet passe, c'est-à-dire à 36 millimètres de pression; elles atteignent leur maximum, qui est de trois dixièmes de millimètre, entre 20 et 12 millimètres de pression; elles diminuent rapidement à partir de 12 jusqu'à 5 millimètres de pression, sous laquelle elles n'ont pas lieu. Avec l'azote et avec l'air atmosphérique, et en se servant du même tube de 16 centimètres de longueur et de 5 de diamètre, les oscillations commencent à se montrer en même temps que le jet passe, sous la pression de 20 millimètres environ; elles atteignent leur maximum de 4 à 5 dixièmes de millimètre entre 12 et 8 millimètres de pression; puis elles vont en diminuant jusqu'à 2 ou 3 millimètres pression, sous laquelle elles ne sont plus sensible.

"Avec le tube d'un mètre de longueur, et même avec celui de 50 centimètres, je n'ai pu observer aucune apparence d'oscillation accompagnant la transmission du jet électrique, quel que fût le gaz renfermé dans ces tubes et quelle que fût la pression à laquelle il fut soumis. Par contre, j'ai obtenu des très prononcées, de 1 à 2 dixièmes de millimètre dans un bocal de 20 centimètres de hauteur (7·8 inches),

sur 16 (3·2 inches) de diamètre rempli d'hydrogène raréfié, et dans lequel le jet électrique passait d'une boule centrale à un anneau concentrique à cette boule, de 12 centimètres (4·68 inches) de diamètre. Ce dernier résultat montre que l'absence d'oscillation dans les longs tubes tient moins au volume de la couche gazeuse, qui est plus faible qu'elle ne l'est dans le bocal de la dernière expérience, qu'à l'influence des parois des tubes qui gênent le mouvement du gaz. C'est aussi une preuve que les oscillations proviennent bien d'une action mécanique, et non d'une élévation de température. Quant à l'intensité des oscillations, elles dépendent évidemment de la résistance plus ou moins grande que le milieu gazeux oppose à la transmission du jet électrique, puisque les oscillations sont plus considérables avec l'azote qu'avec l'hydrogène, et qu'elles diminuent en même temps que la pression à partir d'une certaine pression, qui est celle où la décharge peut s'opérer d'une manière complète et à laquelle l'intensité des oscillations atteint son maximum.

"La stratification de la lumière électrique serait donc un phénomène analogue à la production des ondes sonores, c'est-à-dire un phénomène mécanique provenant d'une succession d'impulsions isochrones excercées sur la colonne gazeuse raréfiée, par la série des décharges électriques se succédant très rapidement les unes aux autres. Nous trouvons une nouvelle preuve en faveur d'envisager le phénomène dans la perturbation qu'apporte aux stratifications un déplacement de la matière gazeuse, et par conséquent dans la disposition du fluide élastique qui permet leur apparition. Il suffit, pour produire cette perturbation d'introduire dans le tube où l'on a un fluide élastique raréfié, pendant que l'électricité s'y propage une quantité additionelle du même gaz qui s'y trouve déjà renfermé de manière à augmenter la pression de $\frac{1}{4}$ ou $\frac{1}{2}$ millimètre ou plus. Voici ce qui se passe avec l'hydrogène, les effets sont les mêmes avec les trois tubes de 15, de 50, et 100 centimètres de longueur." . . . . .

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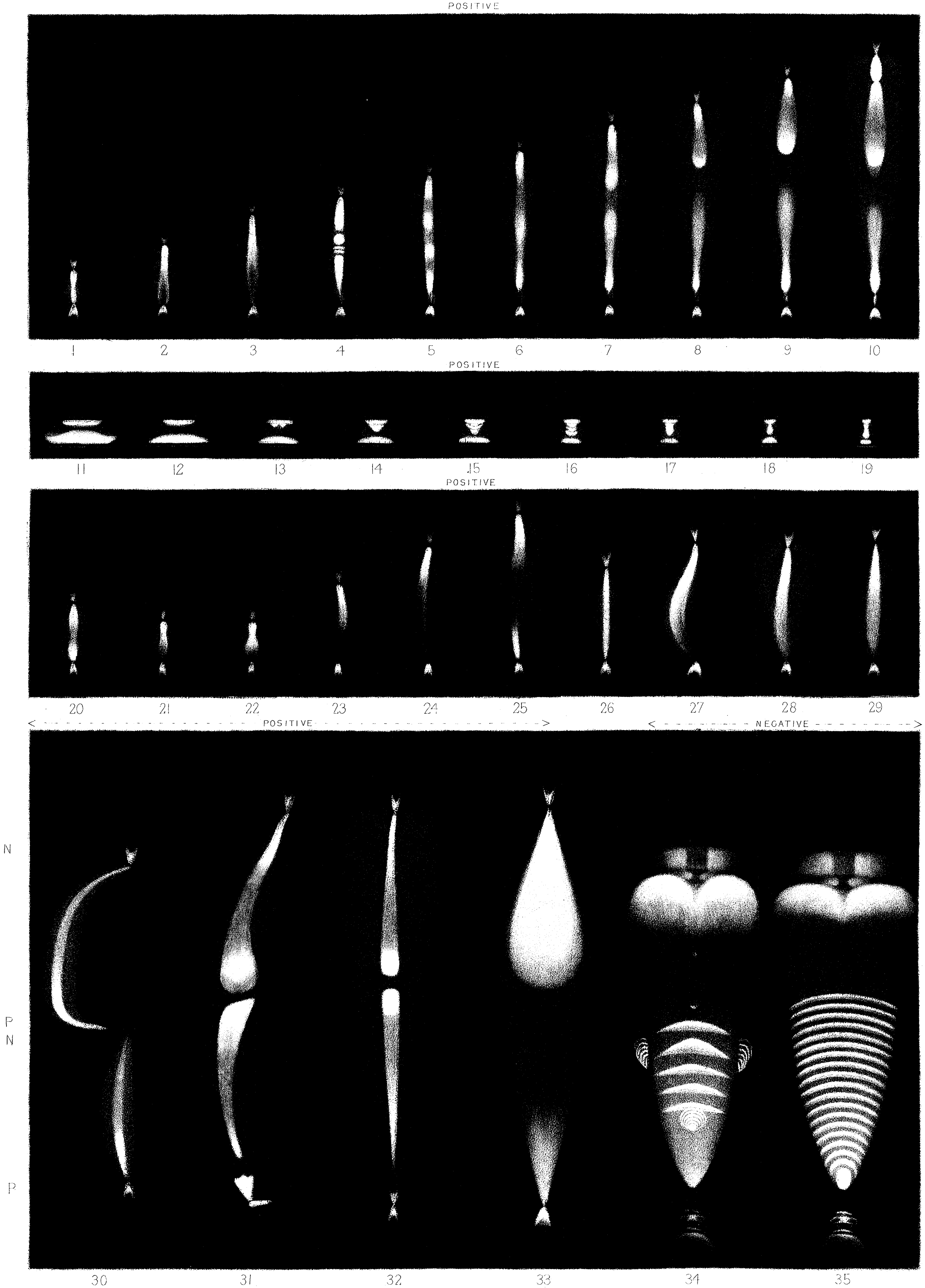

D.J. Pound Sculp.t

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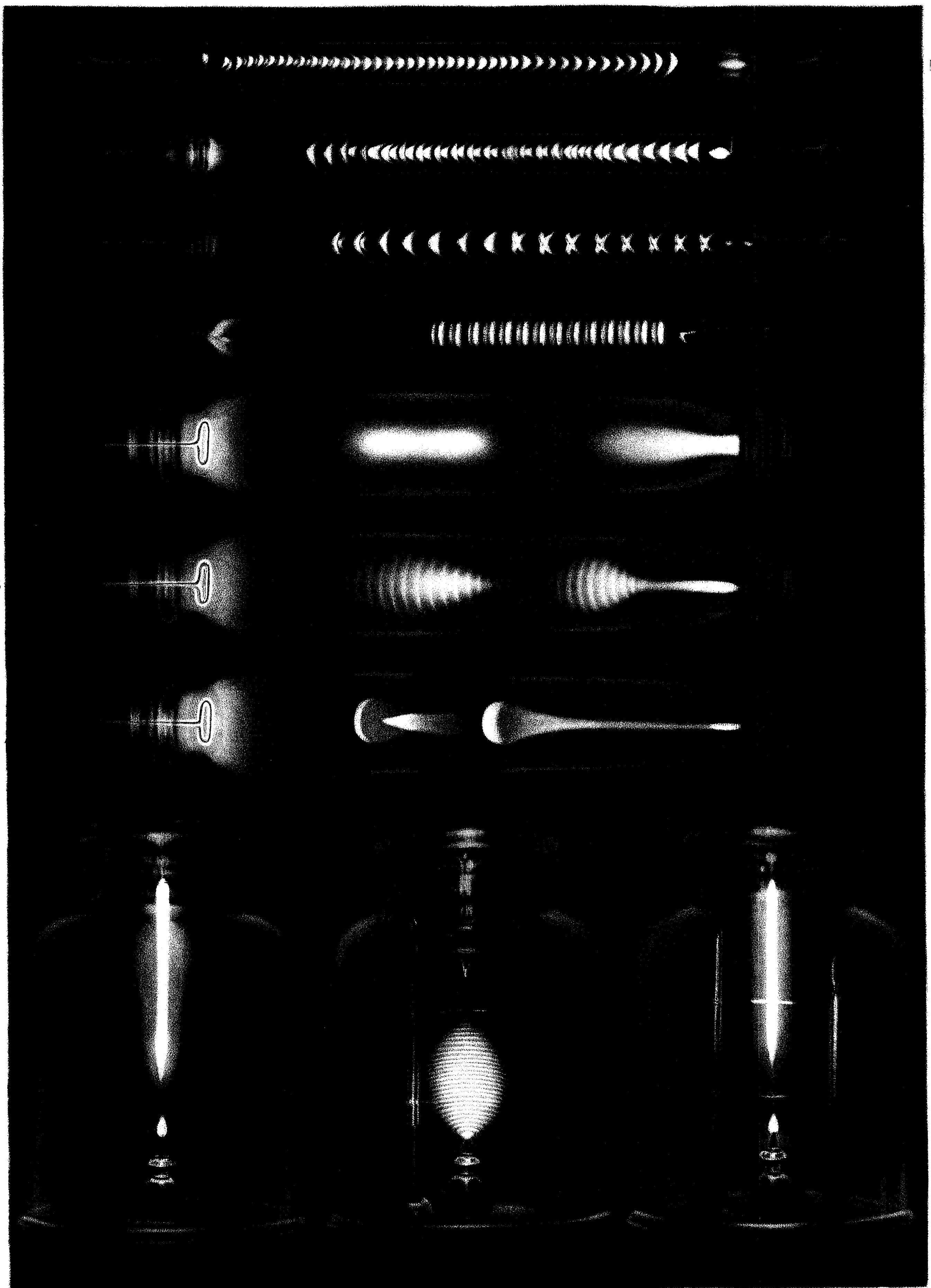
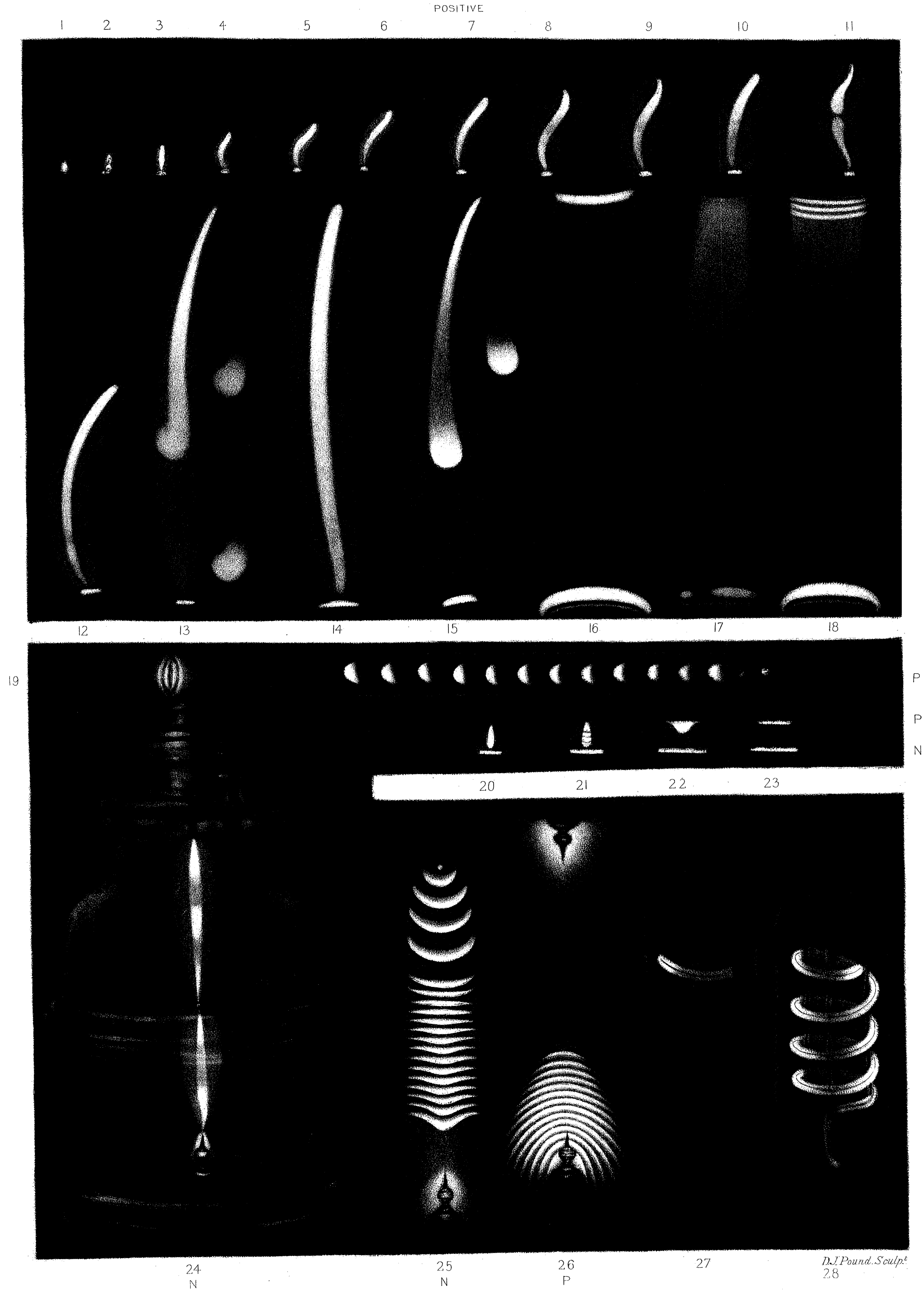


1 N
2 P
3 P
4 P
5 P
6 P
7 P

N 8 P 9 N 10

D. J. Pound, Sculp^t.

1 TO 5, 8 & 10 FROM PHOTOGRAPHS THE REST PARTLY FROM DRAWINGS.



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