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

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[PLATES 35, 36.]

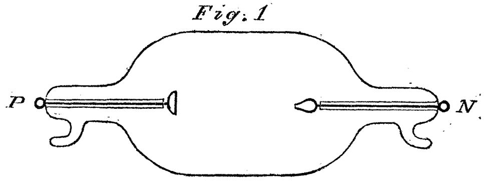
TUBE-POTENTIAL.

Pressure of least resistance dependent on the shape and dimensions of vessel.

WE have already stated that the potential necessary to produce a discharge in partially exhausted tubes diminishes with the pressure until a certain pressure of minimum resistance has been reached, but as the rarefaction is increased beyond this point, then the potential has to be increased in order to produce a discharge.* The experiments on which this result was founded were made with a tube 33 inches (83·8 centims.) long and 2 inches (5·1 centims.) in diameter, and it was found that in a hydrogen partial vacuum the pressure of minimum resistance was 0·642 m.m., 845 M. Professor STOKES suggested the desirability of making experiments with a wide tube, or, still better, with a globe, as it would allow the discharge to spread laterally and diminish the resistance thereby, and, very probably, alter the pressure of minimum resistance. He considers this to be a question of importance with reference to the height of the aurora, for in the atmosphere there is ample space for lateral expansion, and it is conceivable that the least resistance may correspond to a pressure a good deal different from that which gives the least resistance in a tube.

Experiments were made in an air residue contained in a vessel in some measure resembling a prolate spheroid, 7 inches (17·8 centims.) long and 5 inches (12·7 centims.) in diameter, the distance between the terminals, one a cup, positive, the other heart-shaped, negative, was $3\frac{5}{8}$ inches (9·2 centims.) (see fig. 1). The battery employed

Fig. 1



* Part III., Phil. Trans. for 1880, vol. 171, Part I., p. 65 (separate copy, p. 159).

consisted of 11,000 cells, giving a deflection when short-circuited of 49° with a total internal resistance of 360,800 ohms.

On June 17, 1881, the following results were obtained :—

Pressure.			Deflection.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	Cube root of M.	°	ohms.	ohms.	cells.
35·0	46,053	35·84	33·0	639,700	278,900	4796
33·5	44,079	35·32	40·0	495,000	134,200	2982
31·0	40,789	34·42	43·0	445,300	84,500	2089
27·5	36,184	33·08	40·0	495,000	134,200	2982
26·0	34,211	32·46	43·0	445,000	84,500	2089
24·0	31,579	31·61	43·0	..	..	..
21·5	28,290	30·47	43·0	..	..	..
19·5	25,658	29·50	43·0	..	..	..
16·0	21,053	27·61	44·0	430,700	69,900	1784
13·5	17,763	26·09	45·0	415,000	54,200	1435
10·5	13,816	24·00	46·0	400,300	39,500	1085
8·5	11,184	22·36	46·5	393,500	32,700	913
6·5	8553	20·45	46·5	..	..	..
4·5	5921	18·09	48·0	374,000	13,200	388
3·5	4605	16·64	48·5	367,400	6600	194
2·5	3290	14·87	47·0	386,700	25,900	737
2·0	2632	13·81	47·0	..	..	..
1·5	1974	12·54	47·0	..	..	..
1·0	1316	10·96	46·0	400,300	39,500	1085
0·47	618	8·52	44·0	430,700	69,900	1784
0·31	408	7·42	44·0	..	..	..
0·16	211	5·95	44·0	..	..	..
0·06	79	4·29	44·0	..	..	..
0·03	39	3·39	44·0	..	..	..
0·02	26	2·96	38·0	531,600	170,800	3534

On June 22, the following :—

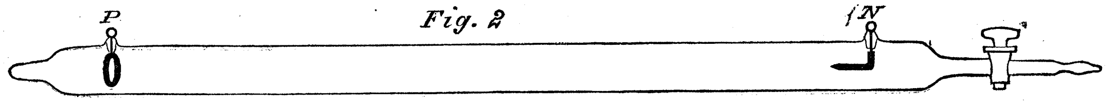
BATTERY 11,000 cells, short circuited, gave a deflection of 65°, and a total internal resistance of 193,600 ohms.

Pressure.			Deflection.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M	Cube root of M.	°	ohms.	ohms.	cells.
21·0	27,634	30·23	60	239,500	45,900	2108
18·0	23,684	28·72	..	..	..	..
15·0	19,737	27·03	61	230,200	36,600	1749
9·0	11,842	22·79	..	..	..	..
7·0	9211	20·96	..	..	..	..
5·0	6579	18·74	62	320,900	27,300	1360
3·0	3947	15·80	63	211,600	18,000	936
2·0	2632	13·80	..	..	..	..
1·1	1447	11·31	62	220,900	27,300	1360
0·67	882	9·59	..	..	..	..
0·17	224	6·07	59	249,500	55,900	2464
0·10	132	5·09	..	..	..	..
0·04	53	3·75	57	263,600	70,000	2920
0·16	21	2·76	51	336,200	142,600	4666

In both of these series of experiments it will be seen that the pressure of minimum resistance for an air partial vacuum in the vessel of spheroidal shape and of the dimensions mentioned is about 3 m.m., 3947 M, corresponding to the pressure of air at an altitude of 27·42 miles, at which height the aurora would from these data have a maximum brilliancy and would be visible at a distance of 499 miles. This result is very different from that before cited, which was obtained with a hydrogen tube from which the pressure of maximum brilliancy was deduced to be for air 0·379 m.m., 499 M.,* at a height of 37·67 miles and visible at a distance of 585 miles.

As no direct experiments had been made for an air residual vacuum in smaller tubes, the following investigations were made with a tube, No. 342, 1·625 inch (4·1 centims.) in diameter and 22·5 inches (57 centims.) between the terminals, one a ring positive, the other a point negative (see fig. 2, on the same scale as fig. 1).

Fig. 2



BATTERY 11,000 cells, deflection when short-circuited 70°, showing a total internal resistance of 151,000 ohms. At a pressure of 19 m.m. there was a glow on each terminal, but the current was not sufficient to deflect the galvanometer used until it had been lowered to 14 m.m.

Pressure.			Deflection.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M	Cube root of M.	°	ohms.	ohms.	cells.
14·0	18,421	26·41	46	400,300	249,200	6848
12·0	15,789	25·09	55	291,200	140,100	5291
11·0	14,474	24·37	55	..	..	..
10·0	13,158	23·59	55	..	..	..
9·0	11,842	22·79	56	280,400	129,300	5072
8·0	10,526	21·58	57	263,600	112,500	4693
7·0	9211	20·96	60	239,500	88,400	4061
5·0	6579	18·74	61	230,200	79,100	3780
3·0	3947	15·80	62	220,900	69,800	3477
2·0	2632	13·81	62	..	..	..
0·69	908	9·68	63	211,600	60,500	3146
0·23	303	6·72	62	220,900	69,800	3477
0·15	197	5·82	60	239,500	88,400	4061
0·05	66	4·04	57	263,600	112,500	4693
0·03	39	3·39	54	302,100	151,000	5499

The pressure of least resistance is therefore 0·69 m.m., 908 M., in the tube in question, and it does not differ materially from 0·642 m.m., the pressure of least resistance in hydrogen.

A pressure of 0·69 m.m. corresponds to an atmospheric height of 34·71 miles, and an aurora at this height would be visible at a distance of 561·4 miles.

* Proc. Roy. Soc., No. 203, 1880.

Another experiment made with a tube (fig. 3, on the same scale as fig. 1) 0·75 inch

(1·9 centim.) in diameter, and 23 inches (58·4 centims.) long between two terminals, both paraboloidal in form, gave the following results :—

Pressure.			Deflection.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	Cube root of M.	°	ohms.	ohms.	cells.
14	18,421	26·41	45	415,000	203,400	5392
13	17,105	25·75	46	400,300	188,700	5186
12	15,789	25·09	47	386,700	175,100	4979
11	14,479	24·37	..	..	..	..
10	13,158	23·59	48	374,000	162,400	4776
9	11,842	22·79	50	348,500	136,900	4321
8	10,526	21·58	53	313,000	101,400	3563
6	7895	19·91	56	280,400	68,800	2699
5	6579	18·74	..	..	..	..
3	3947	15·80	59	249,600	38,000	1674
2	2632	13·81	60	239,500	27,900	1281
1	1316	10·95	61	230,200	18,600	888
0·5	658	8·69	58	253,300	41,700	1811
0·08	105	4·72	47	386,700	175,100	4979
0·04	53	3·76	34	897,300	685,700	8407

The pressure of minimum resistance in this particular case is 1 m.m., 1316 M, which is the same as that of the atmosphere at a height of 32·87 miles, where an auroral display would be visible at a distance of 546·6 miles. It is evident therefore that not only the dimensions of the tube, but possibly also the shape of the terminals, have a marked influence on the pressure of least resistance, and it is very probable that in the atmosphere where the lateral expansion is practically unlimited, the conditions of minimum resistance are different from those which exist even in large tubes.

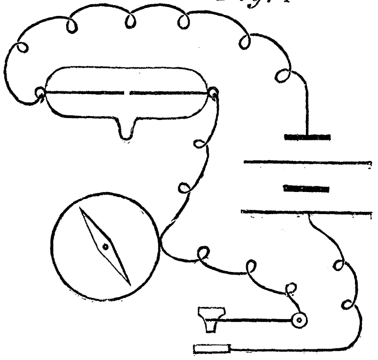
The foregoing experiments, which show that the pressure of minimum resistance is not absolute for any particular gas, but that it varies with the size and form of the vessel containing it, seem to point to the conclusion that the carrier of electricity must be ponderable matter, and not the ether as has been suggested. Professor STOKES considers it most probable "that the presence of ponderable matter is necessary for the transfer of electricity from one place to another. At moderate exhaustions there are plenty of molecules, but they are so close that they hamper one another's motions. As the exhaustion is carried further there are still plenty of molecules, but they hamper one another less, and therefore the facility for the transfer of electricity is increased. But when the exhaustion becomes extreme, there is a loss in the facility of transfer from not having enough molecules; and as the exhaustion is still further continued, it is easily conceived that more may be lost, in point of facility of transfer, than is gained by increasing freedom in their motions. In a wide space the impediment to

free motion is less than in a confined tube, and it is natural, therefore, that the effect of increasing fewness of the molecules should begin to tell at an earlier stage of exhaustion : that is, that the pressure of minimum resistance should be greater than in a tube." Later on we shall quote other experiments on the difference of potential in different parts of a tube in support of this view.

Discharge in miniature tubes.

Experiments on the discharge in miniature tubes gave most unexpected results; for example, in a tube of the dimensions represented of the natural size in fig. 4, which also represents the arrangement of the apparatus. The terminals in this tube so nearly touched, that in order to ascertain that they were not in actual contact, they were connected through a sensitive galvanometer with the opposite poles of a battery of 10 cells. The battery-power was then increased gradually to 2400 cells, when a discharge took place. After this discharge, then a single cell would pass; but if the tube was allowed to stand for a short time (5 minutes) then it required 4800 cells to reproduce a discharge. From the great heat of the discharge the terminals became red-hot and the tube very soon cracked and prevented the repetition of the experiments.

Fig. 4



But in another tube of the size shown in fig. 5 fresh experiments were made, the terminals in this tube were distant about $\frac{1}{1000}$th of an inch (0·00104) (0·0264 m.m.), the points being of the form shown magnified in fig. 6 after a discharge had taken place.

Fig. 5

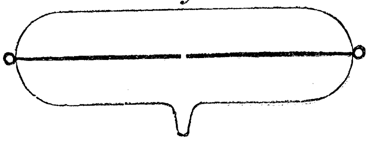
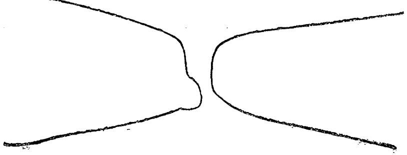


Fig. 6



After the discharge of 2240 cells had passed, then the number of elements had to be increased to 11,240 to produce a discharge, and at last even this number could not cause one except by alternating the current first in one and then in the contrary direction. Ultimately this failed to produce a discharge, but an induction coil did so;

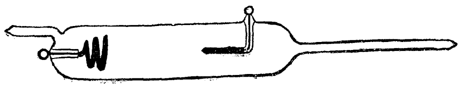
the discharge, however, took place with more facility across the outside of the tube, at ordinary atmospheric pressure, or between the terminals of the coil which were distant $\frac{9}{16}$, 0·5625, inch (1·43 centim.).

The tube was sealed off and laid by for a few days, when it was found that 5100 cells would not pass, but that 8700 did so intermittently, and it required 10,160 to produce a continuous discharge. Subsequently 1200 cells passed, 20 would not do so even immediately after the discharge of the former number; 800 cells, 700, and then 600 passed; but after a while the last number was insufficient to produce a discharge. This tube shared the fate of the first tube and ultimately cracked. It is very possible that the strong discharge volatilized a portion of the terminals, which were of platinum, and that this condensed, or that they absorbed the residual gas so completely as to produce a vacuum too perfect to admit of a discharge taking place, and that, ultimately, sufficient of the occluded gas was again given off to render the discharge again possible.

Occlusion of gas by terminals.

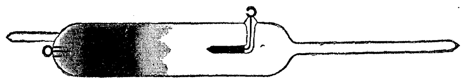
The power of terminals to occlude gas and then under an electric discharge to give it off again is well exemplified by tube 48, the terminals of which are both of palladium. The tube is shown in fig. 7, one terminal is in the form of a helix, the other straight;

Fig. 7.



it is 7 inches (17·8 centims.) long, and $1\frac{1}{2}$ inches (3·8 centims.) in diameter, and contains residual hydrogen. When the tube was new the terminals were bright, but by continued use in consequence of occluding the gas and giving it off again they have become mat or frosted, and porous to a certain depth. We usually cause the spiral to be negative; after the discharge of a battery of 1200 cells has passed for a few seconds the tube which was at first free from deposit, as in fig. 7, becomes coated more especially near the negative, with a mirror-like metallic deposit, as in fig. 8. After the tube has

Fig. 8.



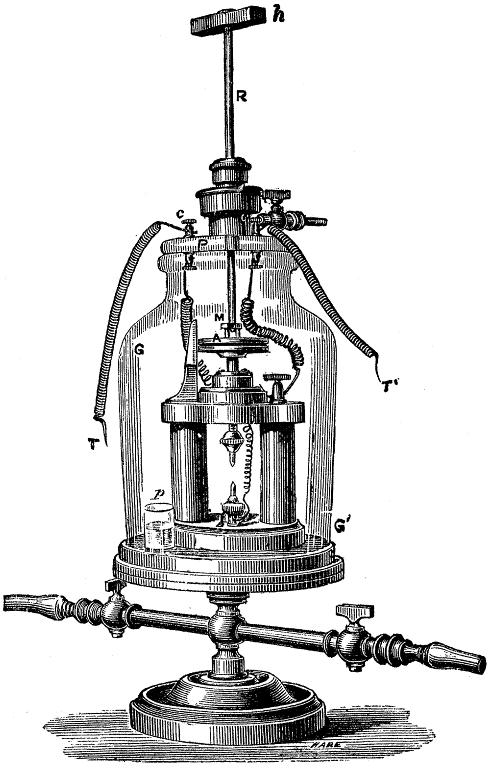
remained at rest for a few days, seven in one instance, this metallic mirror disappears entirely, being absorbed by the terminals; this shows not only that the terminals give off occluded gas and reocclude it, but that there is formed in this particular case a volatile hydrogen-palladium compound. Moreover, the vacuum appears to alter considerably during the discharge, for a stratification which is produced in the first instance ceases in a short time, but the tube regains its original condition by standing for a few days, and stratification is again produced.

The phenomena described have been produced very many times and shown repeatedly to friends who have visited our laboratory since March 13th, 1875.

Length of spark in dry and in moist air.

Many experiments were made to ascertain the effect of saturation with aqueous vapour on the length of the striking distance; for this purpose the bell-jar and micrometer-discharger, as shown in fig. 9, were used.

Fig. 9.



The terminals employed were two paraboloidal points. The striking distance with 10,860 cells was found to be in air dried with phosphoric anhydride at a pressure of 30·345 inches (77·1 centims.) 0·57 inch (1·45 centim.).

The bell-jar was now removed and after having stood for a little while over a dish of water, was then replaced on the plate of the air-pump; in the bell-jar was placed a beaker, *p*, containing water to keep up the saturation, under these circumstances the striking distance was then found to be

		Inch.	
		0·58	(1·5 centim.)
after the lapse of	30 min.	0·58	(1·5 ,,)
,, ,,	4 hours	0·55	(1·4 ,,)
,, ,,	5 ,,	0·54	(1·4 ,,)

In another series of experiments with 8700 cells, the striking distance in dry air was found to be

	Inch.
	0·44
	0·45
	0·46
Mean . .	0·45 (1·1 centim.)
In air saturated with moisture	0·45
" " "	0·445
Mean . .	0·447 (1·1 centim.)

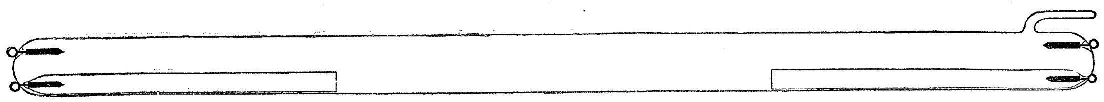
From these experiments we arrive at the conclusion that the striking distance is the same in dry air as in air saturated with moisture.

Two separate currents in the same tube.

Several experiments were made in a specially constructed tube with the object of ascertaining the mutual effect of two discharges passing within it first in the same and then in a contrary direction.

Tube 347 consists of an outer tube $1\frac{3}{4}$ inch (4·4 centims.) in diameter, 31 inches (78·7 centims.) long, and $27\frac{1}{2}$ inches (69·8 centims.) between the terminals, two short pieces of tube, 9 inches (22·8 centims.) long and $\frac{1}{2}$ inch (1·27 centims.) in diameter, are fixed one at each end; the distance between the open mouths of the small tubes being 13 inches (33 centims.) (see fig. 10).

Fig. 10.



Two paraboloidal terminals are sealed in the outer tube and two precisely similar ones are sealed in the small tubes and hold them in their places.

When the discharge from a battery of 3600 cells was made to pass through the small tube a close stratification, as in Plate 35, fig. 1, was produced, which stratification was continued in the interval between the open ends of the small tubes, but of an altered form, wider apart as shown in the figure, which is a facsimile of a photograph obtained on a dry plate in one second.

When the same discharge passed through the outer large tube a continuous stratification was obtained throughout, as shown in Plate 35, fig. 2.

When the discharges from two separate batteries, each of 3600 cells, were made to pass in reverse directions, the one in the outer tube having an external resistance of 250,000 ohms inserted, the discharge in the small tubes was the strongest, and an appearance was produced as shown in Plate 35, fig. 3.

It will be noticed that the effect of this stronger discharge is to completely reverse the convexity of the strata in the middle portion of the outer discharge in the large tube, while the convexity on the two extremities of the outer discharge retains its

natural direction. It would appear, therefore, that the *natural* discharge in the intervening space in the outer tube is, as it were, replaced by a non-luminous one. When the batteries were kept on for about twenty seconds, or so, these intervening strata gradually diminished, and at last disappeared entirely, as shown in Plate 35, fig. 4, where they are replaced by a non-luminous space; but it is very evident, from the shape of the strata where visible, that two discharges continued to take place in the direction proper to each from both sets of terminals; the last stratum of the small tube on the positive side curving upwards into the broad space.

On keeping the batteries in connexion for a further period another remarkable change took place, and the discharge in the larger tube appeared to gain the mastery, its strata in the interval between and above the open ends of the small tubes reappearing with a forward movement one by one at the positive side, the convexities being turned towards the negative, which is the natural direction. The strata in the small tubes did not continue beyond their extremities, and a dark space intervened. These phenomena are shown in Plate 35, fig. 5. Keeping on the discharge still longer the strata in the small tube disappeared entirely, as shown in Plate 35, fig. 6.

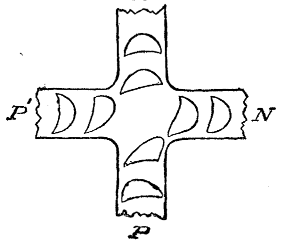
Ultimately, by continuing the discharge, both sets of the strata disappeared, as if one discharge neutralized the other, but these could be reproduced by breaking and remaking the contact with the batteries.

It is very probable when two discharges take place in the same tube in opposite directions that the column of gas becomes divided longitudinally into two layers, one of which conveys the discharge of one battery, while the other conveys that of the other battery.

Two separate currents crossing each other at right angles.

In order to ascertain the effect of two discharges from two distinct batteries crossing each other at right angles, we prepared a tube, No. 344, consisting of two tubes joined at right angles to each other, each tube being 33 inches (83·8 centims.) long and $1\frac{1}{8}$ inches (2·86 centims.) in diameter. The central portion is shown in fig. 11.

Fig. 11.



In the first place the discharge of a battery of 3600 cells was sent through one of the tubes containing air at a pressure 0·428 m.m., 563 M, causing a current of 0·01507 ampère, and producing the stratification which is represented in Plate 35, fig. 10;

which stratification is of the ordinary character, with the exception that, at the crossing of the two tubes, a wider stratum is produced. While the discharge was passing through only one of the tubes a faint illumination was also produced in the two branches of the other, but it was not stratified.

The two component tubes were subsequently connected with two separate batteries, each of 3600 cells, A and B; A with the poles P and N to the vertical component, and B with the poles P′ and N′ to the horizontal one. The effect is represented in Plate 36, fig. 15. It will be seen from the configuration of the strata at the cross, in this case when the currents were equal 0·00833 ampère, that the discharge of A goes from P towards N only as far as the cross, then turns off to the left to N′, the negative of the other battery, B, while on the other hand the discharge of B from P′ goes to the N of A battery.

The case is different if an external resistance is introduced in one of the discharges, as for instance in Plate 36, fig. 16, where, by the insertion of a resistance of 500,000 ohms in the B battery connected with the horizontal tube, the current was reduced to about one-tenth (0·00087 ampère) of that of battery A connected with the vertical tube, the discharge from A battery goes on direct from P to N and the discharge from B from P′ to N′. The different sizes of the two sets of strata render this evident. There is a bending down, however, of the strata of the weaker discharge at the cross in consequence of the action of the stronger one. One cannot but be impressed from this and other experiments before and hereinafter described by the apparent plasticity of the aggregate assemblage of molecules which constitute a stratum, for it evidently yields to external influences which modify its form. For instance, in Plate 36, fig. 17, copied from a photograph taken on a dry plate in half a second, the strata at the cross, produced by two equal batteries of 3600 cells, are so far modified in both tubes that the curvature of one stratum in each branch is made convex towards the positive instead of concave. The vacuum is of air at a pressure of 0·428 m.m., 563 M. The extremities of the vertical tube are both negative, and those of the horizontal tube positive, so that in each tube positive is opposed to positive and negative to negative.

In Plate 36, fig. 18, representing a photograph of the tube when containing hydrogen at a pressure of 0·46 m.m., with a separate discharge of 3600 cells in each tube, a very close stratification is produced. The ends of the vertical tube are both negative, those of the horizontal positive, each set of strata pursues its undisturbed course and produces a beautiful configuration at the cross where the last stratum in the two horizontal branches remains concave towards its own positive, but in the negative branch becomes convex towards the negative, yielding as it were to the influence of pressure of the strata from the positive.

In Plate 36, fig. 19, the two sets of strata follow their proper course leaving a dark interval at the cross between them. The tube contained air at a pressure of 0·428 m.m., 563 M, the batteries used being both 3600 cells, the positive of A battery was connected to the top of the vertical tube, and its negative to the left

end of the horizontal tube. The positive terminal of B was connected to the right end of the horizontal tube, and its negative to the bottom of the vertical tube. The photograph from which this figure is copied was obtained in half a second.

Plate 36, fig. 20, represents the discharge through hydrogen at a pressure of 0·46 m.m., 605 M, batteries A and B, each of 3600 cells, the positive pole of A was connected with the left end of the horizontal tube, its negative to the top of the vertical, 2,600,000 ohms external resistance having been introduced in the discharge; the positive of B battery was connected to the right hand end of the horizontal tube, and its negative to the bottom. In neither set of discharges are distinct strata produced at the positive end, and only after passing the cross are such produced. It would almost seem that the resistance introduced in one pair of branches had offered an impediment to the discharge in the other.

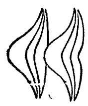
Effect on strata of the shape of the positive terminal.

Experiments were made in order to ascertain whether the *form* of a point used as a positive terminal had any effect on that of the strata. It was found, however, that whether the terminal was carefully shaped as a paraboloid, or was simply cylindrical, the strata took precisely the same form as is shown in Plate 35, where fig. 7 represents the discharge in hydrogen from a paraboloidal point, and fig. 8 that from a cylindrical point.

Complex strata.

The complex configuration of strata in many cases appears to us to present a great difficulty in accounting for their production, and in forming a clear conception of the forces which hold the molecules composing them so persistently together. Usually there is a dark space between the negative terminal and the last stratum on the positive side, but not unfrequently the last stratum or several strata thread themselves on to the negative when it consists of a wire, as, for instance, in tube 346, shown in Plate 35, fig. 9, containing hydrogen at a pressure of 0·5 m.m., 658 M, with a battery of 3600 cells, and an external resistance 200,000 ohms, producing a current of 0·00238 ampère. A beautiful bracket-like series of strata was produced, two or three of which threaded themselves on to the negative, as is distinctly shown in Plate 35, fig. 9. Looked at from the end it could be seen that these strata had circular holes in them larger than the negative wire, so that a small dark space was left. Each stratum consists of an outer bracket convex towards the negative and an inner chord (fig. 12).

Fig. 12.



Discharge in large tubes.

In Part III., pp. 197–201, we described some experiments with a large tube 37 inches (94 centims.) long, and $5\frac{13}{16}$ inches (14·8 centims.) in diameter. We have again taken up the study of the discharge in large tubes 3 feet 2 inches (96·5 centims.) long, and 6 inches (15·24 centims.) in diameter; the resulting phenomena are shown in Plate 35, figs. 11, 12, 13, and 14. In these, which are partly copied from photographs and partly from drawings made at the time in consequence of a to-and-fro movement of the strata preventing well-defined photographs from being obtained:—

Plate 35, fig. 11, exhibits a discharge of 8700 cells with a current of 0·049 ampère in carbonic anhydride at a pressure of about 0·5 m.m., 658 M. The strata near the terminals are not large enough to fill the whole bore of the tube, but they spread and become larger as they recede, and form a sort of conical expansion up to the wall of the tube. A rapid flow was observed from the negative with a still increased velocity, at intervals, producing a gap in the flowing strata of three times the interval between them. The three strata near the negative retained their position but rotated rapidly on their axes, and when looked at obliquely appeared dark in the centre and reminded one of a smoke vortex ring.

Plate 35, fig. 12, represents the appearance in a hydrogen vacuum of about 0·5 m.m., 658 M, with the same number of cells, 8700, producing a current of 0·047 ampère. After a short time the stratification receded towards the positive, leaving a long interval devoid of any towards the negative.

Plate 35, fig. 13, represents the appearance of a vacuum of nitrogen and bromine with the same number of cells, 8700, giving a current of 0·047 ampère. After the discharge had continued for a few seconds the strata, as in the case of hydrogen, receded towards the positive end of the tube as shown in Plate 35, fig. 14.

In all the foregoing cases a very beautiful and distinct stratification was produced, in the first instance, filling the tube just as in those of smaller bore, but near the terminals the strata became gradually smaller in a conical form, the gas itself for a certain distance acting as an enclosing tube.

The dark negative space.

In the dark space near the negative end of a vacuum tube the electric discharge is undoubtedly always passing, though not evident to the eye; but its passage is rendered apparent by the great heat at times developed within it, as we have already stated in Part II.* It occurred to us to endeavour to obtain a record of its passage by means of photography, and the result shows that it is actinically dark only by comparison. Tube No. 100, containing a residue of carbonic anhydride, gave, with 2400 cells and an

* Phil. Trans. for 1878, Vol. 169, Part I., p. 182, Exp. 47 (separate copy, p. 98).

inserted resistance of 200,000 ohms, a current of 0·00335 ampère, which produced a perfectly steady stratification during more than thirty-five minutes the tube was in connexion with the battery. In two and a-half seconds an impression of the strata was obtained on a dry plate, which is represented in Plate 36, fig. 21. The strata were then carefully covered so as to exclude all their light from the camera and to expose only the dark space; in fifteen minutes an impression was produced on the photographic plate, but it required an exposure of thirty-five minutes to produce an impression as dense as that obtained by an exposure of the strata for two and a-half seconds. The photographic intensity of the dark space is therefore 840 times less than that of the strata. The image of the dark space is shown in Plate 36, fig. 21, below that of the strata; it contains no trace of stratification, although, if any existed, it is fair to presume that it would have been depicted in consequence of the perfect steadiness of the discharge.

Potentials at different nearly aliquot parts of a column of gas, at various pressures.

The following experiments, intended to ascertain the difference of potential in different parts of a vacuum tube,* bring out instructive information, not only in reference to the relative resistances of different lengths of a column of gas at various pressures, but also in regard of the impediment presented by the terminals themselves to the passage of a discharge from gas to terminal or terminal to gas.

They were made by means of an electrometer in connexion with an induction apparatus shown in fig. 13, and described in Part III. of our researches.†

In the present instance, however, certain modifications were adopted to prevent disturbing influences and to ensure concordant results. In the first place, a trap was formed to prevent the creeping down of electricity on the inside and outside, more especially the outside of the cylindrical glass shade enclosing the induction plates. This trap consists of two hoops of tin foil,‡ half an inch in width, pasted inside and outside respectively, about 4 inches below the flat top. Both these hoops communicate to earth by means of two vertical strips of tin foil pasted on the cylinder. Before this arrangement was adopted the cylinder became slowly charged, especially in damp weather, and unduly increased the deflection of the needle of the electrometer, by acting inductively on the induction plates.

It was found very advantageous to connect the needle with a small Leyden-jar§ (L, fig. 14), presenting a coated surface of 57 square inches (3·68 square decims.), and having a capacity of 0·0016 microfarad. The jar, by increasing the capacity of the apparatus, in a great measure obviates the disturbing influence of leakage during the

* Tube 149 with 12 aluminium rings, and tube 150 with 17 rings already described. Phil. Trans. for 1878 (vol. 169), p. 165; Part II. (separate copy, p. 81).

† Phil. Trans. for 1880, vol. 171, p. 112 (separate copy, p. 206).

‡ These are not shown in the engraving.

§ Part I. of our researches, Phil. Trans. for 1878, vol. 169, p. 99 (separate copy, p. 45).

Fig. 13.

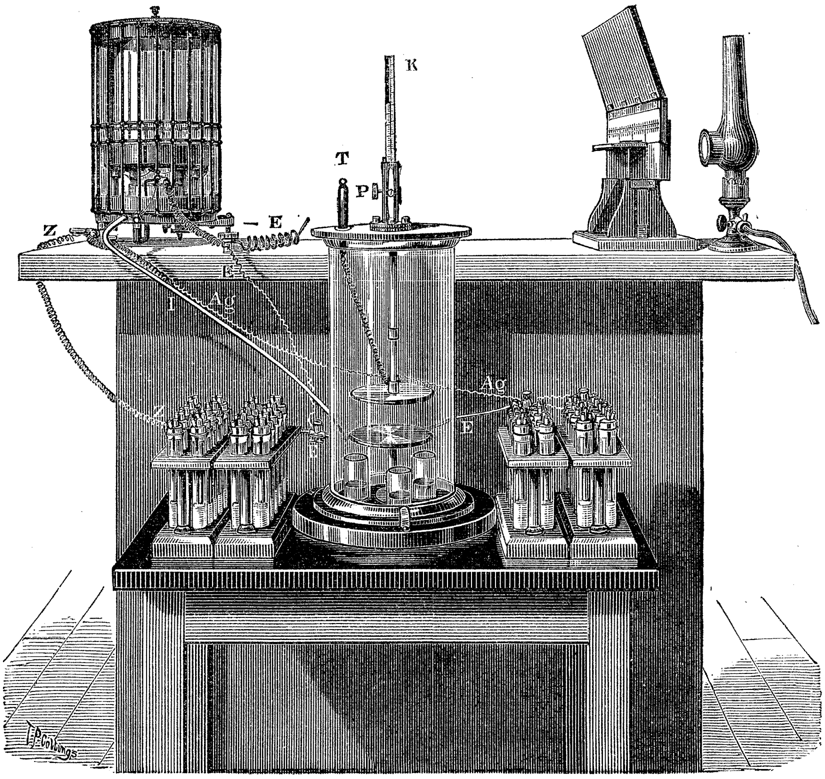
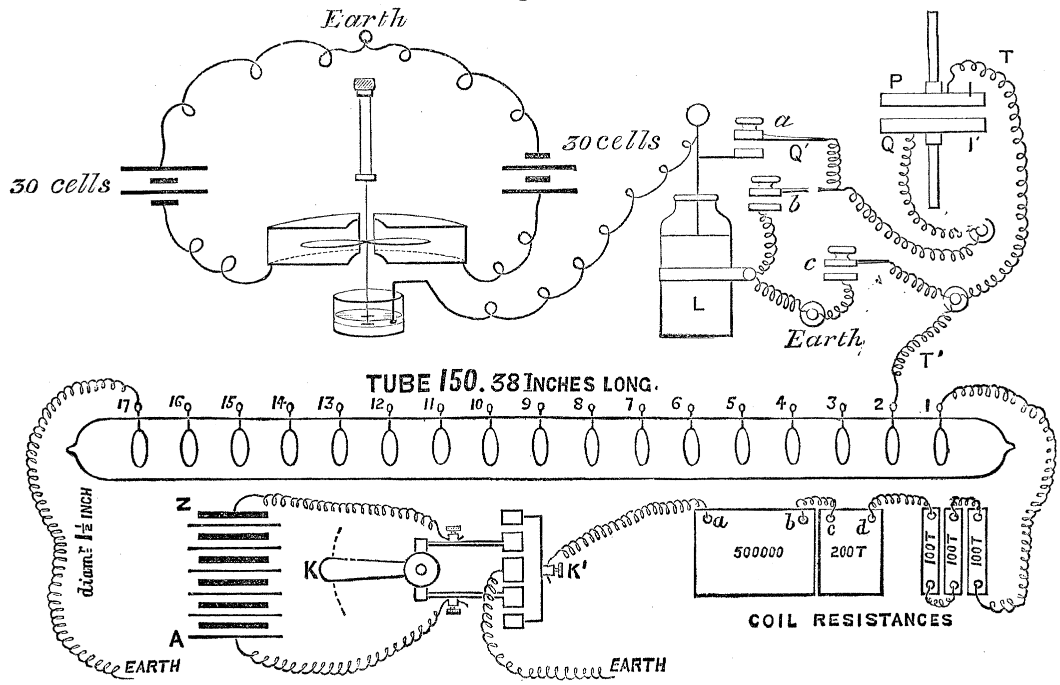

K
T
P
Z
E
I
Ag
E
Ag
Z
E
E

Fig. 14.


Earth
30 cells
30 cells
a
Q'
b
P
T
Q
J'
c
L
Earth
T'
TUBE 150. 38 INCHES LONG.
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Z
K
K'
A
diam.r 1½ INCH
EARTH
EARTH
a
b
c
d
500000
200T
100T
100T
100T
COIL RESISTANCES

observations. For the suggestion of the Leyden-jar and the plan of observation about to be described we are indebted to Professor STOKES, by whose advice we have often profited. The arrangement of the apparatus is shown in fig. 14.

It will be seen on reference to fig. 14 that a battery of chloride of silver cells, the centre to earth, is used to charge up the opposite quadrants of the electrometer with electricity of opposite names. The number of cells is generally varied from 10 up to 60 in order to regulate the deflection, which can also be varied by varying the distance between the plates P and Q of the induction apparatus.

The needle is connected to the inside of the Leyden-jar L, the outside being permanently connected to earth. By pressing down the key *a* (which is supposed to represent a mercury connexion, as do also the keys *b* and *c*) the inside of the jar is connected with the induced plate Q; before, however, connecting the source of electricity with P, the key *b* is pressed down so as to connect the inside of the jar, the needle, and the induced plate Q to earth; this may be designated the Q system.

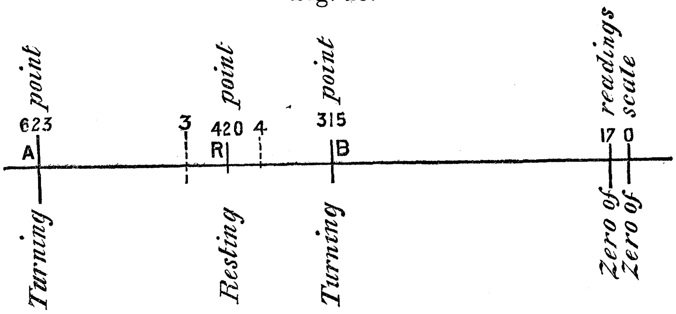
The source of electricity is now connected by means of T. T′ to the inducing plate P; this may be designated the P system. No charge under this arrangement is possible in the system Q which is to earth, consequently the needle remains undisturbed.

The wire T′ is now disconnected, *b* raised to disconnect the Q system from earth; up to this point there is no deflection, but the instant that the P system is discharged to earth by pressing down the key *c* then there occurs a negative deflection; in order to decrease the leakage to a minimum the key *a* is raised so as to disconnect Q from the Leyden-jar.

In order to avoid waste of time, and disturbances of the readings by possible leakage by waiting for the needle to come to rest, the resting point was determined by means of a formula from two consecutive turning points.

The diagram fig. 15 represents the zero of the scale, the zero 17 of the readings, the first turning point A, the second turning point B, and the resting point R; 3 represents the third turning point, and 4 the fourth.

Fig. 15.



$$R = B + c(A - B)$$

c is a factor determined once for all, by causing the needle to swing by means of an electric charge and then discharging; so that the subsequent swings are due solely to the torsion of the bifilar suspension. Four sets of observations were made

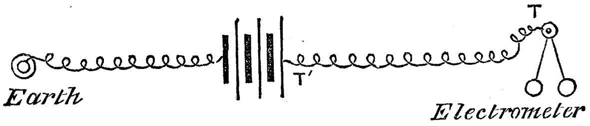
and the needle allowed to come to rest at R in each series. These were very concordant, and c came out $\frac{1}{2\cdot 92}=0\cdot 3425$ by the formula $c=\frac{r}{1+r}$, where $1:r$ is the ratio of the length of one swing to the next, the swings being found to decrease very accurately in geometric progression. By waiting till the needle comes to rest, c may of course be determined directly, by means of the ratio in which any swing is divided by the observed resting point. Thus in fig. 16, AB : RB : : 1 : c. These two methods of determining c agreed perfectly.

The following results were obtained by making the observations on the plan just described.

TUBE 149 CO^2 (12 aluminium rings).

8540 cells. The full potential determined as in diagram fig. 16 was 251 divisions.

Fig. 16.



The positive pole of the battery was connected to No. 1 ring; the negative pole and No. 12 ring to earth, and each third ring in succession from 1 to 12 was connected with the electrometer.

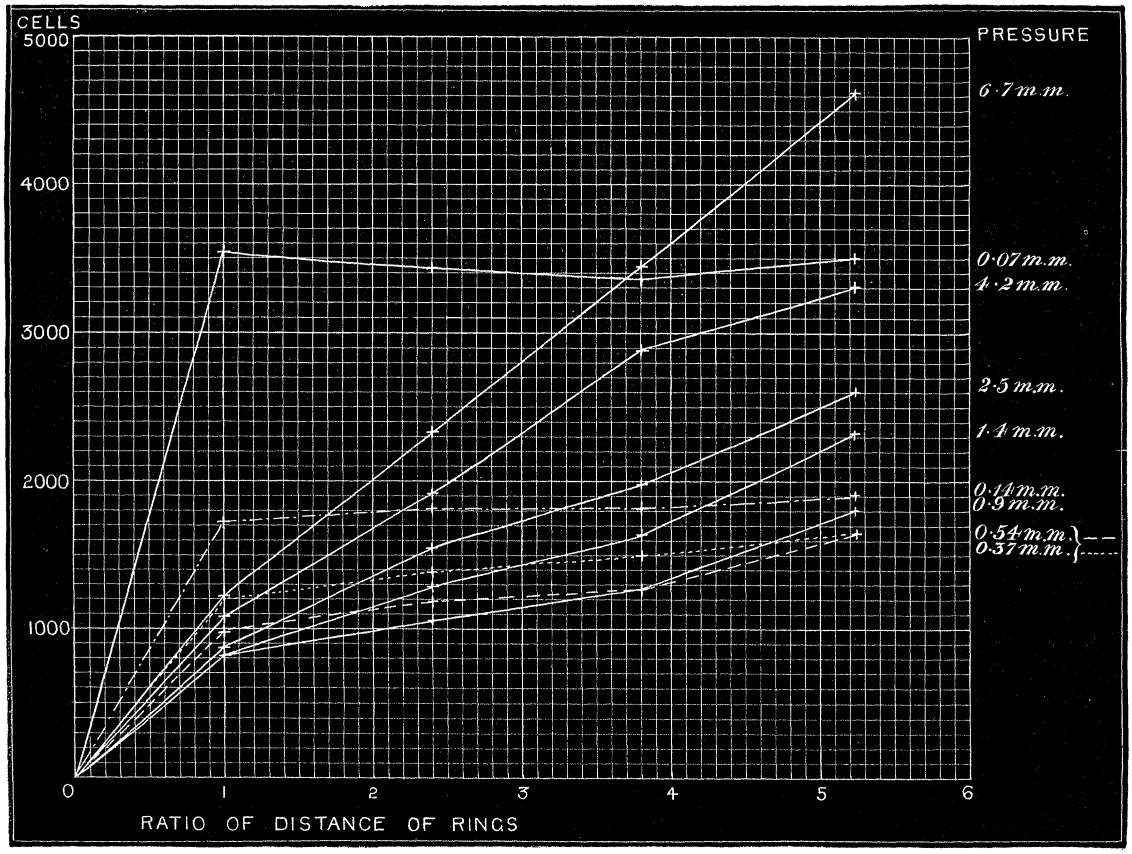
Ring.	Pressure 6·7 millimetres. Potential.			Pressure 4·2 millimetres. Potential.			Pressure 2·5 millimetres. Potential.			Pressure 1·4 millimetre. Potential.			Pressure 0·9 millimetre. Potential.		
	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.
1	136	4267	3·78	97	3301	3·03	76	2586	3·04	68	2314	2·83	53	1803	2·21
4	101	3437	2·80	85	2892	2·66	58	1973	2·32	48	1633	2·00	37	1259	1·54
7	68	2314	1·89	56	1905	1·75	45	1531	1·80	37	1259	1·54	31	1054	1·29
10	36	1225	1·00	32	1088	1·00	25	851	1·00	24	817	1·00	24	817	1·00

Ring.	Pressure 0·54 millimetre. Potential.*			Pressure 0·37 millimetre. Potential.			Pressure 0·14 millimetre. Potential.			Pressure 0·07 millimetre. Potential.			Distance between 12th and the following rings.		
	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Inches.	Centims.	Ratio.
1	49	1667	1·75	49	1667	1·40	56	1905	1·12	103	3504	0·99	22·25	57·1	5·24
4	37	1259	1·32	44	1497	1·26	51	1818	1·02	98	3334	0·94	16·20	41·1	3·81
7	35	1191	1·25	40	1361	1·14	51	1818	1·02	101	3437	0·97	10·20	25·9	2·40
10	28	953	1·00	35	1191	1·00	50	1701	1·00	104	3538	1·00	4·25	10·8	1·00

* Pressure of minimum resistance 0·54 millimetre.

The foregoing results are plotted in the diagram, fig. 17, where the abscissæ are the relative distances of the rings, as given in the last column of the above table, and the ordinates the potentials in numbers of cells.

Fig. 17.



TUBE 150 CO^2 (17 aluminium rings).

8540 cells; full potential 403 divisions.

The positive pole of the battery connected to No. 1 ring; the negative pole and the 17th ring to earth. Each ring in succession was connected to electrometer.

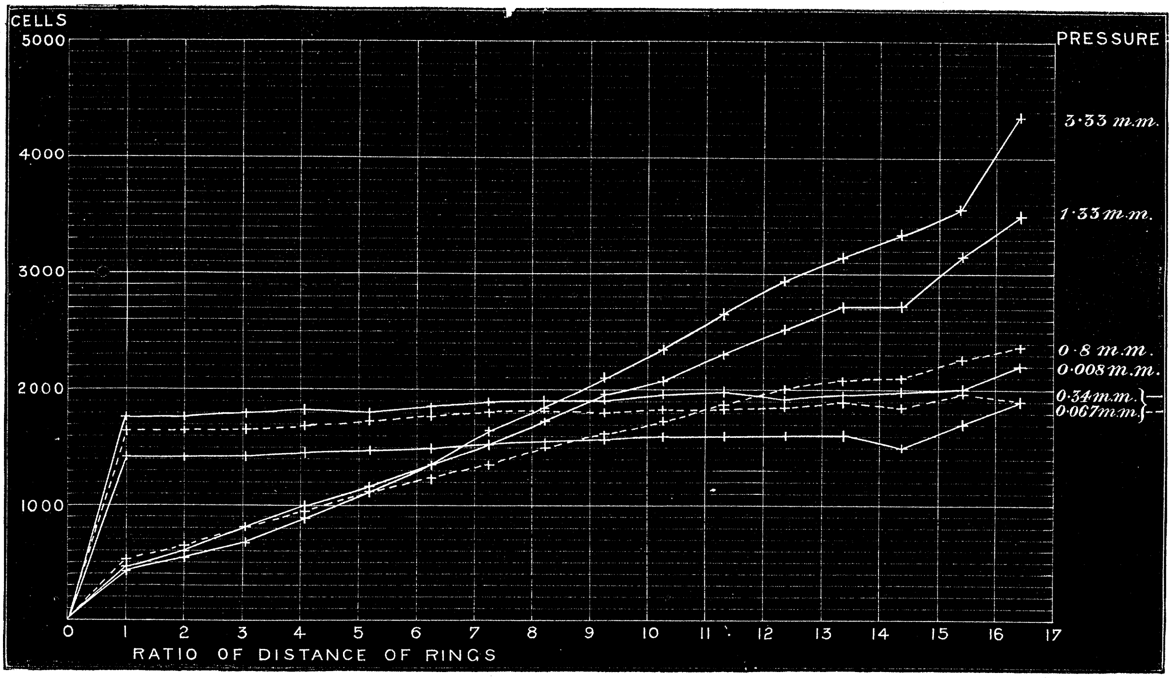
Ring.	Pressure 3·33 millimetres. Potential.			Pressure 1·33 millimetres. Potential.			Pressure 0·8 millimetre. Potential.			Pressure 0·34 millimetre.* Potential.		
	Divisions.	Cells.	Ratio.	Divisions.	Cells.	Ratio.	Divisions.	Cells.	Ratio.	Divisions.	Cells.	Ratio.
1	206	4366	9·8	165	3497	7·5	112	2373	4·5	90	1907	1·3
2	168	3560	8·0	149	3158	6·8	107	2268	4·3	80	1695	1·2
3	158	3349	7·5	128	2713	5·8	99	2098	4·0	70	1484	1·0
4	148	3137	7·0	128	2713	5·8	98	2077	3·9	76	1611	1·1
5	138	2925	6·6	119	2522	5·4	94	1992	3·8	76	1611	1·1
6	124	2628	5·9	109	2310	5·0	88	1865	3·5	75	1590	1·1
7	111	2353	5·2	98	2077	4·5	82	1738	3·3	75	1590	1·1
8	99	2098	4·7	92	1950	4·2	77	1632	3·1	74	1568	1·1
9	87	1844	4·1	82	1738	3·7	71	1505	2·8	73	1547	1·1
10	77	1632	3·7	72	1526	3·3	64	1356	2·6	72	1526	1·1
11	65	1377	3·1	65	1377	2·9	58	1229	2·3	70	1484	1·0
12	53	1123	2·5	55	1166	2·5	52	1103	2·1	69	1462	1·0
13	42	890	2·0	47	996	2·1	45	954	1·8	68	1441	1·0
14	32	678	1·5	38	805	1·7	38	805	1·5	67	1420	1·0
15	26	551	1·2	29	615	1·3	31	657	1·2	67	1420	1·0
16	21	445	1·0	22	466	1·0	25	530	1·0	67	1420	1·0
17	0	..	0·0	0	..	0·0	0	..	0·0	0	..	0·0

Ring.	Pressure 0·067 millimetre. Potential.			Pressure 0·008 millimetre. Potential.			Distance between 17th and the following rings.		
	Divisions.	Cells.	Ratio.	Divisions.	Cells.	Ratio.	Inches.	Centims.	Ratio.
1	90	1907	1·2	104	2204	1·2	32·10	81·5	16·44
2	93	1971	1·2	96	2034	1·2	30·10	76·4	15·41
3	87	1844	1·1	94	1992	1·1	28·20	71·6	14·44
4	89	1887	1·1	92	1950	1·1	26·02	66·1	13·34
5	87	1844	1·1	91	1929	1·1	24·15	61·3	12·37
6	86	1823	1·1	93	1971	1·1	22·05	56·0	11·30
7	86	1823	1·1	92	1950	1·1	20·00	50·6	10·24
8	85	1801	1·1	90	1907	1·1	18·00	45·7	9·22
9	86	1823	1·1	90	1907	1·1	16·10	40·9	8·24
10	85	1801	1·1	89	1887	1·1	14·12	35·8	7·24
11	83	1759	1·1	87	1844	1·0	12·12	30·8	6·22
12	82	1738	1·1	85	1801	1·0	10·02	25·4	5·13
13	79	1674	1·0	86	1823	1·0	7·92	20·1	4·06
14	79	1674	1·0	85	1801	1·0	5·90	15·0	3·03
15	78	1653	1·0	83	1759	1·0	3·90	9·9	2·00
16	78	1653	1·0	83	1759	1·0	1·95	4·9	1·00
17	0	..	0·0	0	..	0·0	..	..	..

* Pressure of minimum resistance 0·34 millimetre.

These results are shown in the diagram, fig. 18, in which the abscissæ are the relative distances of the rings, as given in the last column of the above table, and the ordinates the potentials in numbers of cells.

Fig. 18.



The following experiments were made in order to ascertain the effect produced on the potential of different parts of a vacuum tube connected at the ends with the opposite poles of an insulated battery when the centre of the tube was put in communication with earth, fig. 19.

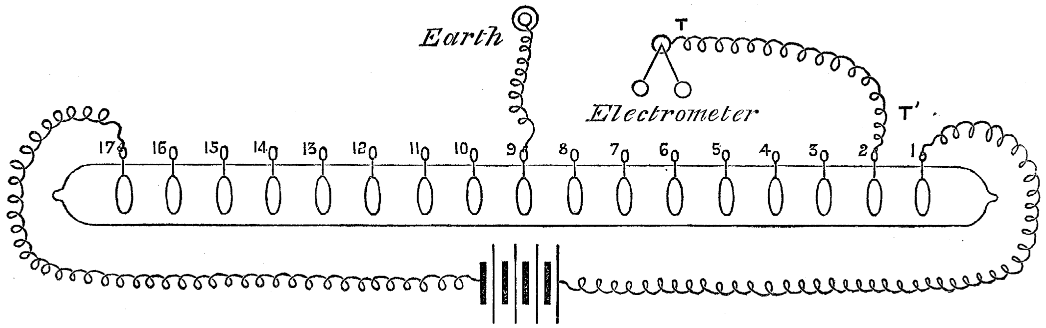
TUBE 150. CO^2.

Battery insulated 8540 cells.

The positive pole was connected to No. 1 ring; the negative to No. 17 ring. The centre ring (No. 9) to earth, and each ring in succession connected with the electrometer. Pressure about 0·5 millimetre*. The deflection was positive between 1 and 9, and negative between 9 and 17.

The diagram, fig. 19, shows the arrangement of the apparatus. The wire T, T′, was connected at T′ to each ring in succession from No. 1 to No. 17.

Fig. 19.

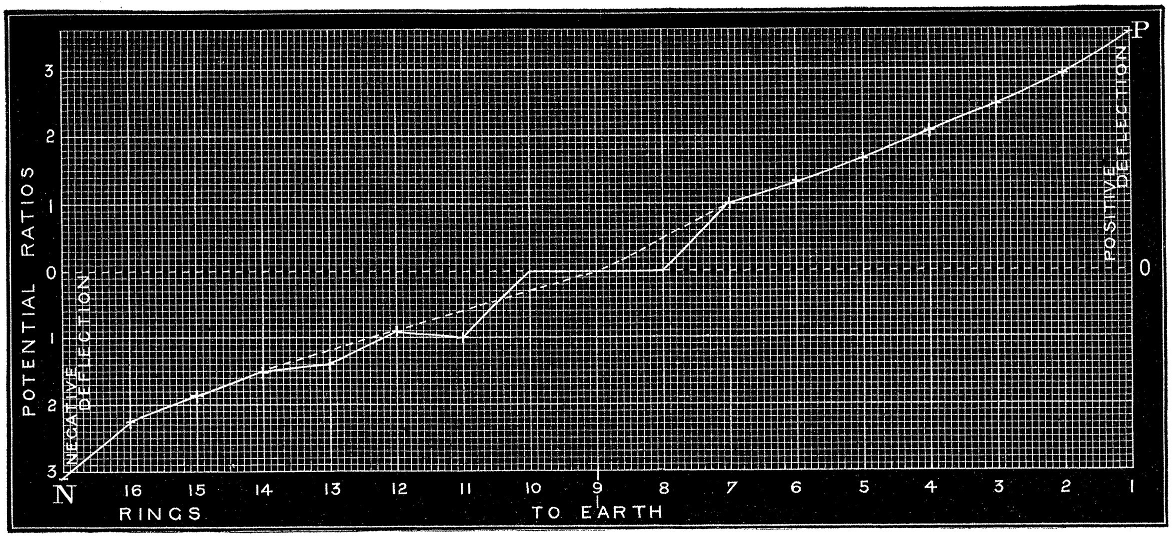


I. Ring.	Potential. II. Divisions.	III. Ratio.	Distance from 9th ring. IV. In inches.	V. Centims.	VI. Ratio of distances.	Column $\frac{VI}{III}$.
1	+114	3·563	15·975	40·5	4·096	1·150
2	+ 93	2·907	14·075	36·0	3·608	1·242
3	+ 79	2·469	11·925	30·2	3·058	1·239
4	+ 66	2·063	10·050	25·5	2·577	1·253
5	+ 53	1·657	7·950	20·2	2·038	1·230
6	+ 42	1·312	5·900	15·0	1·513	1·153
7	+ 32	1·000	3·900	9·9	1·000	1·000
8	..	0·000	2·000	5·1	..	..
9	..	0·000	0·000	0·0	0·000	..
10	..	0·000	1·900	4·8	..	..
11	− 42	1·000	3·850	9·8	1·000	1·000
12	− 38	0·905	5·850	14·9	1·519	1·679
13	− 59	1·405	7·950	20·2	2·065	1·470
14	− 64	1·524	9·975	25·3	2·590	1·700
15	− 78	1·858	11·975	30·4	3·111	1·674
16	− 94	2·239	13·925	35·3	3·616	1·615
17	−132	3·144	15·875	40·3	4·123	1·312

* The tube not being attached to the pump connected with the McLEOD gauge, the pressure could not be exactly determined.

The foregoing results are plotted down in fig. 20, in which abscissæ are the distances of the rings and the ordinates the potentials in scale divisions of the electrometer.

Fig. 20.



The following table contains the results of another experiment also with the opposite poles of the battery to opposite ends of the tube, and the centre ring No. 9 to earth. Fig. 21 represents the results graphically. Tube 150 CO_2, pressure 0·45 m.m., 4620 cells, full potential 227 divisions.

Ring.		Potential.			I.	II.	Column $\frac{II}{I}$.
		Divisions.	Cells.		Ratio of potentials.	Ratio of distances.	
Positive	1	23+	468	468	7·767	7·987	1·028
	2	17+	346		5·666	7·037	1·242
	3	15+	305		5·000	5·964	1·192
	4	13+	264		4·333	5·024	1·160
	5	11+	224		3·667	3·976	1·084
	6	7+	142		2·333	2·950	1·264
	7	5+	102		1·666	1·950	1·170
	8	3+	61		1·000	1·000	1·000
to earth	9	0	0		0·000	0·000	0·000 Mean 1·25
	10	3−	61		1·000	1·000	1·000
	11	5−	102		1·666	2·026	1·531
	12	7−	142		2·333	3·079	1·319
	13	8−	163		2·667	4·184	1·569
	14	12−	244		4·000	5·249	1·312
	15	14−	284		4·667	6·302	1·350
	16	14−	284		4·667	7·328	1·570
Negative	17	61−	1242	1242	20·330	8·354	0·411
			Total	1710			

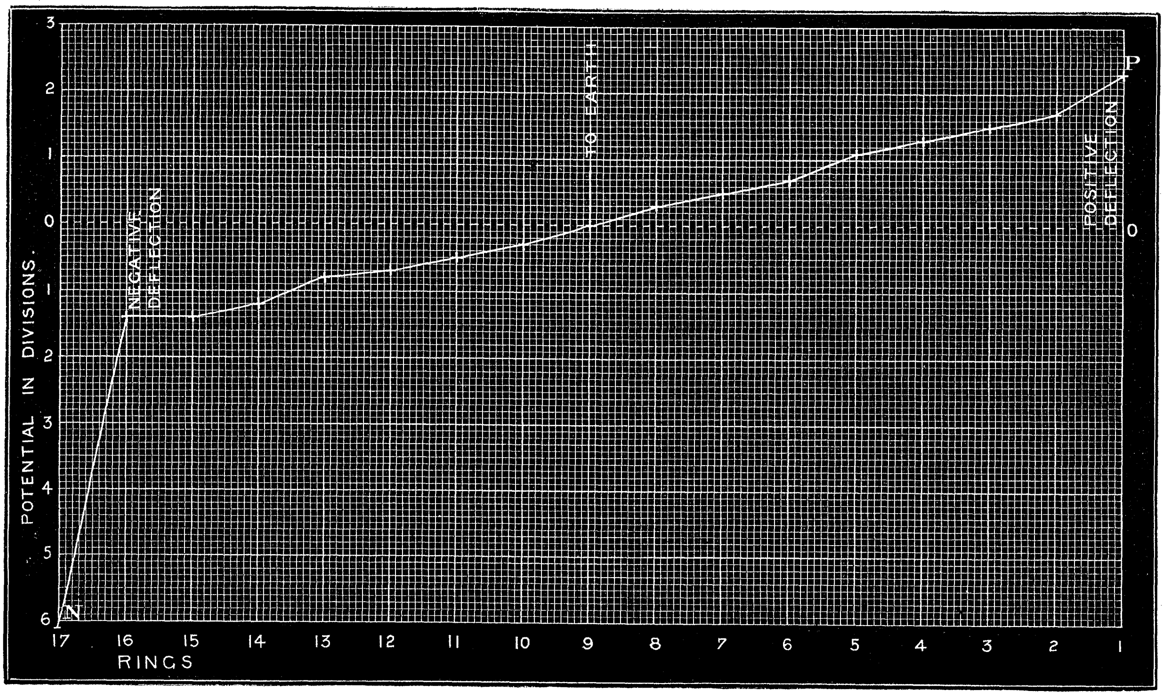
When the opposite poles of the battery were connected to the two end rings and

the centre ring No. 9 to earth, the deflections, as we have before said, were all positive between 1 and 9, and all negative between 9 and 17; if the connexions with the battery were made previous to the connexion of 9 to earth, and a well-formed steady stratification produced, very little change occurred in it when 9 was connected by means of a key to earth; in fact only a slight one in those strata close to the earth ring.

The curves, more especially fig. 21, show that there is no disturbance of the potentials in consequence of the earth connexion in the centre of the tube, but that the whole curve is lifted or depressed so as to cut the axis at that point. The curve (fig. 22) brings out very forcibly how far greater is the obstacle to the passage of the discharge at the negative than at the positive electrode.

We have already called attention in Part III. of our researches to the far greater obstacle presented by the negative terminal to the passage of a discharge than occurs at the positive.* We therein described an experiment with a tube in which the negative terminal was a wire 19 inches long which became more and more illuminated as the current was gradually increased.

Fig. 21.



In order to bring into strong evidence the great resistance to the passage of electricity at the negative as compared to the positive terminal, the same ring was made positive and negative alternately.

* Phil. Trans. for 1880, vol. 171, Part I., p. 108 (separate copy, Part III., p. 202).

Tube 150. CO_2.

4640 cells at pressures 0·45 m.m. and 0·25 m.m.; in the first case battery full potential 242 divisions, in the second 213 divisions.

In the first series, at both pressures, the positive was connected with No. 1 ring; in the second, the negative was connected with No. 1 ring. No. 17 ring and the opposite pole of the battery to earth.

Ring.	Pressure 0·45 millimetre. Potential.						Pressure 0·25 millimetre. Potential.						Distance between 17th and the following rings.
	Positive to No. 1.			Negative to No. 1.			Positive to No. 1.			Negative to No. 1.			
	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Ratio.
1	85	1629	1·77	61	1169	10·16	82	1786	1·34	74	1612	12·34	16·44
3	78	1496	1·62	34	652	5·66	77	1677	1·26	12	261	2·00	14·44
5	73	1400	1·52	30	575	5·00	73	1590	1·20	21	457	3·50	12·37
7	68	1304	1·42	27	518	4·50	71	1546	1·16	10	218	1·67	10·24
9	62	1189	1·29	21	402	3·50	67	1460	1·10	16	348	2·67	8·24
11	58	1112	1·21	23	441	3·83	64	1394	1·05	21	457	3·50	6·22
13	52	997	1·09	14	268	2·33	59	1285	0·97	8	174	1·33	4·06
15	48	920	1·00	7	134	1·16	59	1285	0·97	6	131	1·00	2·00
16	48	920	1·00	6	115	1·00	61	1328	1·00	6	131	1·00	1·00
17	0	0	0·00	0	0	0·00	0	0	0·00	0	0	0·00	0·00

The results are shown in the diagram, fig. 22.

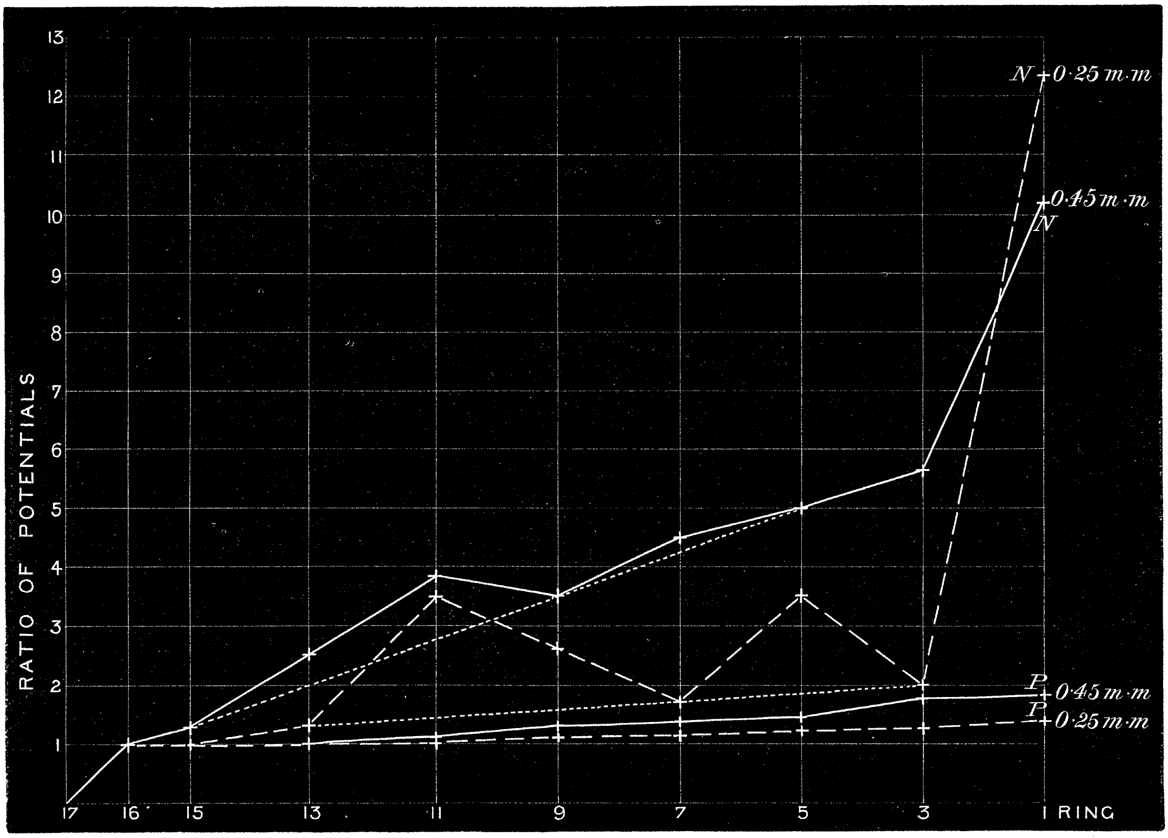
The foregoing experiments "show clearly," as Professor STOKES has pointed out to us, "that at high exhaustions nearly the whole of the energy is spent in the passage of the discharge between the gas and the negative electrode. It seems pretty clear that the electric potential energy is converted into kinetic energy.

"There appears to be no such difficulty as regards the positive. The increase of change of potential near the positive at moderate exhaustions seems fully accounted for by the contraction of the path of the discharge, as the electricity issues at first from little more than a mere point, and the path at first lies within an approximately conical boundary.

"The experiments bear in an important manner on the theoretical height of the aurora. It appears that at high exhaustions gases offer little obstacle to the passage of electricity; only there must be matter enough to carry it. On the whole the experiments tend to considerably increase the theoretical height, which accords with observation, so far as such observations can be trusted.

"How far the first issue of electricity from a charged cirrus cloud resembles the issue from a metallic electrode is a matter of speculation."

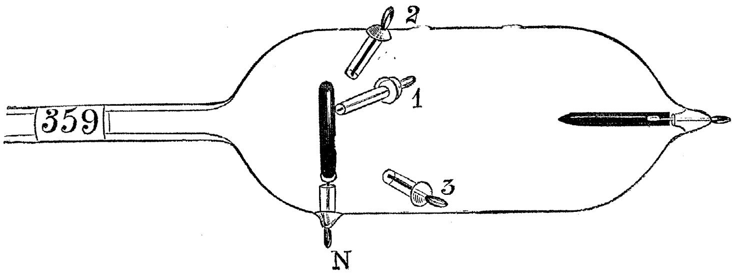
Fig. 22.



Electrical condition of a gas in a vacuum tube in the vicinity of the negative terminal.

The preceding experiments, in relation to potential at different parts of a column of gas, suggested the desirability of probing the electrical condition of a tube in the vicinity of the terminals, more especially the negative. Professor STOKES suggested that this might be conveniently done by means of wires fixed at different distances from it, provided the wires were covered with miniature glass tubes reaching nearly to their extremities. Accordingly a bulb was prepared of the form and construction represented half-size in fig. 23, in which P is a terminal in the shape of a point, to serve as the positive, N, another in the shape of a ring, to serve as the negative, both

Fig. 23.

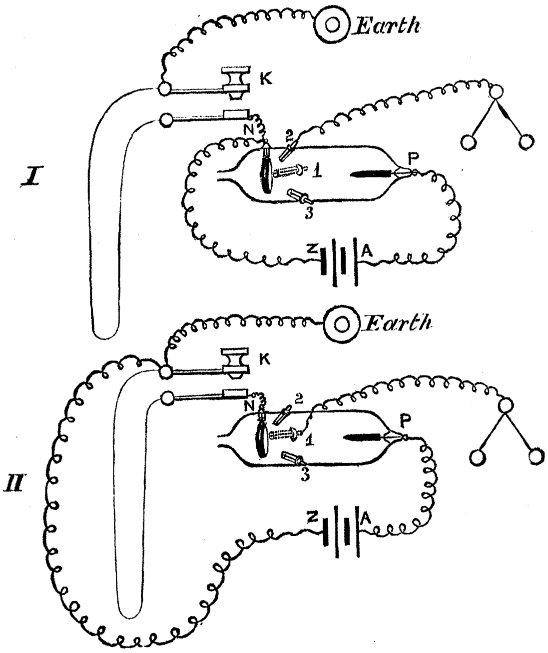


being of aluminium. Nos. 1, 2, and 3 are idle probing wires of platinum, covered with miniature glass tubes, except their extreme ends. The end of No. 1 is about 0·02, No. 2 0·2, and No. 3 0·6 inch from the ring.

In the following experiments variations were made: in one case the battery was insulated and its pole A connected with the point, and its pole Z with the ring; either a stout or a fine wire was then led from the ring, negative, to earth. At other times the battery was uninsulated, the pole A being connected to the point, and the pole Z with earth, and a stout or a fine wire led from the earth connexion to the ring. The stout wire, 0·06 inch diameter, was that ordinarily used in connecting the battery, the fine wire, 3 feet of platinum, 0·002 inch diameter, and having a resistance of 81 ohms at 19°·2 C.

Fig. 24, I. and II., shows the different arrangements.

Fig. 24.



In I. the battery is insulated, the silver end A being connected with the point, and the zinc Z with the ring; from the negative ring a stout wire is led to the lower portion of the key K, and the earth connexion is made with stout wire to the upper part of the key, so that in the position shown in the figure the communication to earth is through the fine wire, but when K is pressed down then the earth communication is through the stout wire.

II. shows the battery uninsulated, the silver end A being connected to the point, and the zinc Z to the upper part of the key. The ring is connected to earth by a stout wire, and also to the lower part of the key. In the position shown in the figure the discharge has to pass through the fine wire to earth, but when the key is pressed down it passes through the stout wire.

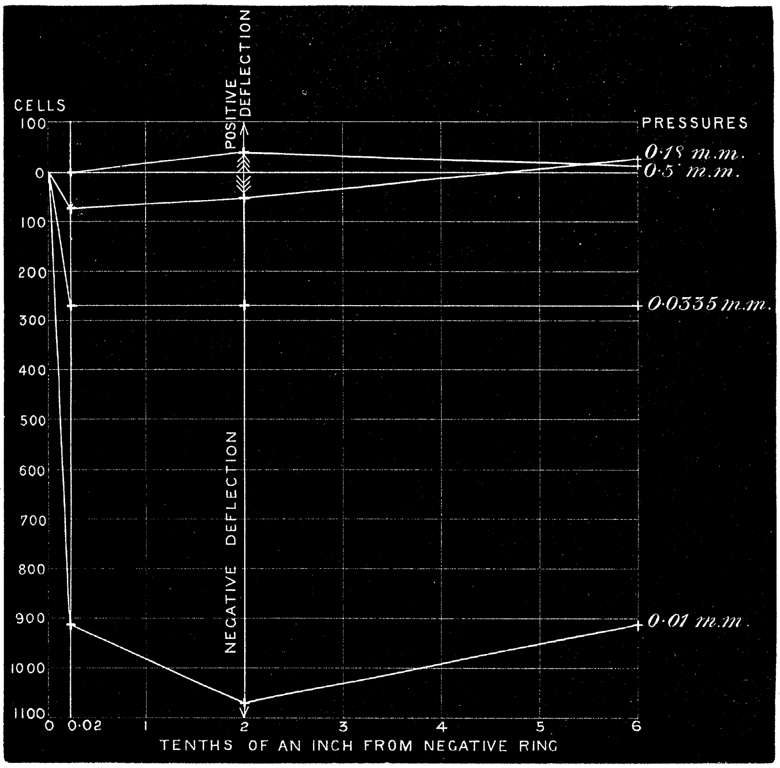
The following results were obtained with tube 359 air :—

Pressure 0·5 millimetre. Battery 1200 cells. Arrangement II. Stout wire. Potential, cells.					Pressure 0·18 millimetre. Battery 1200 cells. Arrangement II. Stout wire. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.	Tube.	No. 3.	No. 2.	No. 1.	Ring.
540	10+	40+	0	0	730	20+	50−	70−	0

Pressure 0·0335 millimetre. Battery 2400 cells. Arrangement II. Stout wire. Potential, cells.					Pressure 0·01 millimetre. Battery 5840 cells. Arrangement II. Stout wire. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.	Tube.	No. 3.	No. 2.	No. 1.	Ring.
496	273−	273−	273−	0	4627	912−	1068−	912−	0

So that in the vicinity of the negative, which was well connected to earth and gave no deflection, there was at pressure 0·18 the remarkable phenomenon of a development of a negative charge on the idle wire No. 2 of a potential equal to 50 cells, and on No. 1 of 70; this negative development increased up to a potential of as high as 1068 cells, at a pressure of 0·01 m.m. These results are shown in the curve (fig. 25).

Fig. 25.



Pressure 0·027 millimetre. Battery 5840 cells. Arrangement II.									
Stout wire. Potential, cells.					Fine wire. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.	Tube.	No. 3.	No. 2.	No. 1.	Ring.
1794	478−	1196−	578−	0	..	120+	120+	100+	0

Pressure 0·027 millimetre. Battery 5840 cells. Arrangement II.									
Stout wire. Potential, cells.					Fine wire. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.	Tube.	No. 3.	No. 2.	No. 1.	Ring.
1734	619−	619−	640−	0	3921	392−	62+	186+	0

The pressure by standing during a night fell to 0·017 m.m., some of the air had evidently become partly absorbed by the terminals, and 5840 cells would no longer pass. In some of the following experiments the inside of a Leyden-jar of the capacity of 0·0049 microfarad was sometimes made to communicate with the ring (negative), the exterior of the jar being connected to earth.

Pressure 0·017 millimetre. Battery 7040 cells. Arrangement II. Stout wire. Potential, cells.							
Tube.	No. 3.		No. 2.		No. 1.		Ring.
		With jar.		With jar.		With jar.	
5134	1040−	1040−	1256−	1018−	1560−	1387−	0
4325	815−	776−	873−	892−	853−	1106−	0

Pressure 0·017 millimetre. Battery 7040 cells. Arrangement II. Fine wire. Potential, cells.							
Tube.	No. 3.		No. 2.		No. 1.		Ring.
		With jar.		With jar.		With jar.	
5134	0	0	173+	108+	195−	195−	0

The signs + and − denote the name of the electrical charge at the idle wires, and it is seen that in many cases the charge is again negative, notwithstanding that the negative ring gives no deflection.

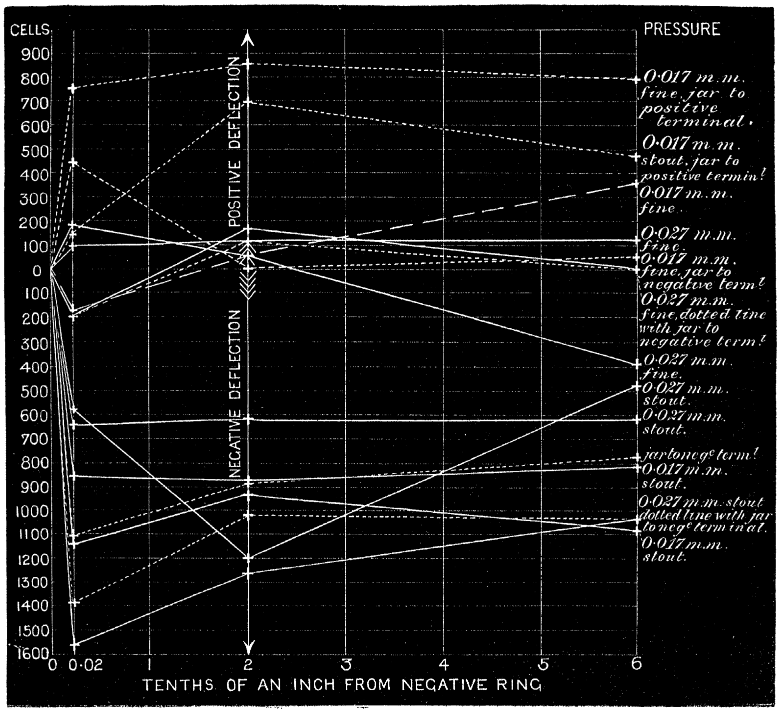
In the following experiments the inside of the Leyden-jar was in contact sometimes with the negative, at others with the positive terminal of the tube.

Pressure 0·017 millimetre. Battery 7040 cells. Arrangement II. Stout wire. Potential, cells.							
Tube.	No. 3.		No. 2.		No. 1.		Ring.
		Jar to P.		Jar to P.		Jar to P.	
4325	1086−	466+	931−	698+	1145−	252+	0

Pressure 0·017 millimetre. Battery 7040 cells. Arrangement II. Fine wire. Potential, cells.										
Tube.	No. 3.			No. 2.			No. 1.			Ring.
		Jar			Jar			Jar		
		To N.	To P.		To N.	To P.		To N.	To P.	
6874	358+	48+	787+	72+	0	859+	167−	453+	763+	0

These results are given in the curve (fig. 26).

Fig. 26.



In the following experiments the arrangement I. was employed, that is to say, the poles of an insulated battery were connected with the terminals of the tube, and an earth connexion made either by means of a stout or fine wire to the negative terminal.

Air was introduced, and at various pressures, with 2400 cells, the following results were obtained :—

Pressure 3·7 millimetres. Battery 2400 cells. Arrangement I. Potential, cells.					Pressure 1·7 millimetre. Battery 2400 cells. Arrangement I. Potential, cells.				
Tube. Stout or fine.	No. 3. Stout or fine.	No. 2. Stout or fine.	No. 1. Stout or fine.	Ring. Stout or fine.	Tube. Stout or fine.	No. 3. Stout or fine.	No. 2. Stout or fine.	No. 1. Stout or fine.	Ring. Stout or fine.
513+	47+	47+	47+	0	513+	466+	466+	466+	0

Pressure 0·18 millimetre. Battery 2400 cells. Arrangement I. Potential, cells.						Pressure 0·1 millimetre. Battery 2400 cells. Arrangement I., mean of six experiments. Potential, cells.				
Tube. Stout or fine.	No. 3. Stout or fine.	No. 2. Stout or fine.	No. 1. Stout.	No. 1. Fine.	Ring. Stout or fine.	Tube. Stout or fine.	No. 3. Stout or fine.	No. 2. Stout or fine.	No. 1. Stout or fine.	Ring. Stout or fine.
1235+	1119+	986+	116−	140+	0	1990+	1784+	1281+	384+	0

The connexion to earth made through a cork (0·5 inch diameter, and 0·5 inch long) saturated with water, and having a resistance of 4,300,000 ohms.

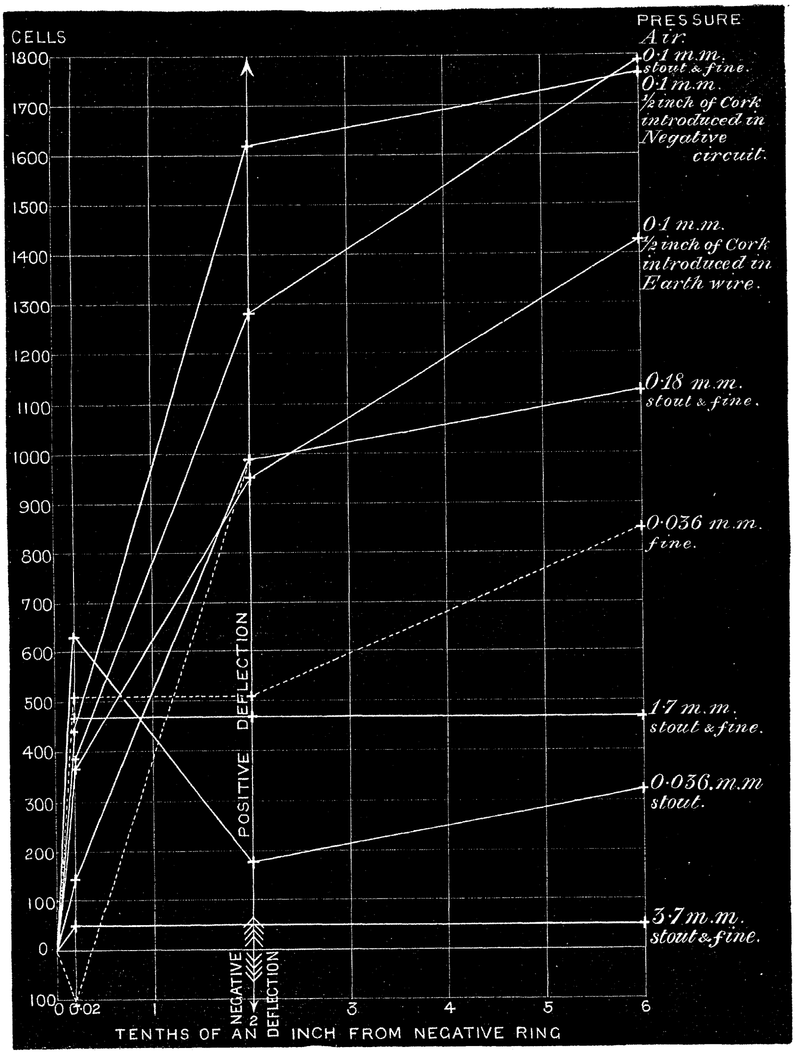
Pressure 0·1 millimetre. Battery 2400 cells. Arrangement I. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.
1179+	1420+	955+	367+	0

Cork introduced into circuit—

Pressure 0·1 millimetre. Battery 2400 cells. Arrangement II. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.
2400	1763	1616	441	2400

These results are shown in the curve (fig. 27).

Fig. 27.



Potential at the centre and periphery of a ring negative terminal.

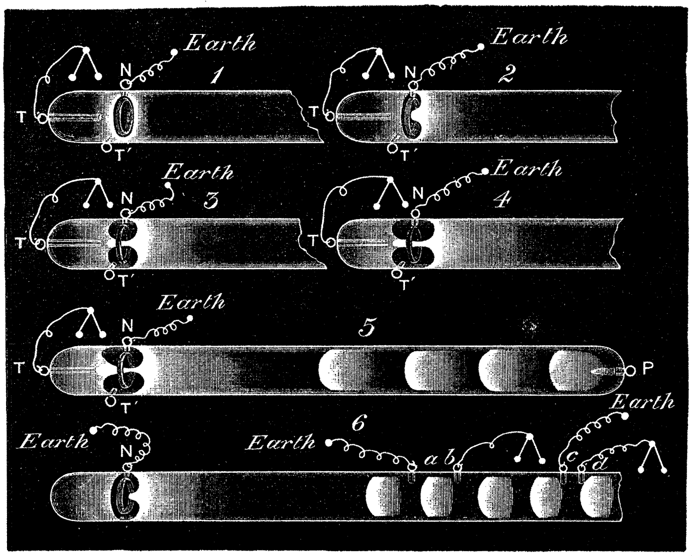
Everyone familiar with the appearance of a stratified discharge will have noticed, when the negative terminal is a ring, that as the exhaust proceeds a spindle of light approaches and at last protrudes through the interior of it, as shown in fig. 28, 5.

This spindle is thus a visible exponent of strong action among the molecules of the gas composing it, and it appeared to be of interest to probe its electrical condition. We therefore prepared a tube, No. 363, for this special object with an idle wire, surrounded by a minute glass tube, except its extremity, in the axis of the tube and projecting to a distance of $\frac{3}{8}$ of an inch (0·95 centim.) from the plane of the ring which was made negative.

The dimensions of the tube are:—Length, 15·5 inches (39·3 centims.), and 1·75 inches (4·44 centims.) in diameter, and the distance between the terminals, a point and a ring, 12 inches (30·5 centims).

A battery of 3600 cells was used, the terminal, in the shape of a point, was connected to the positive pole, and the ring and negative pole of the battery were both connected to earth. The gas used was carbonic anhydride. The full potential of the battery was found to be 313 divisions of the electrometer, that of the idle axial wire at a certain exhaust 142 divisions, equal to 1633 cells.

Fig. 28.



The exhaust was carried further, and it then required 6000 cells to produce a discharge. The tube potential was found to be equal to 2523 cells, and the idle wire, T, 2535 cells, or practically the same as the tube.

Another set of experiments was made with the same tube, and progressively greater and greater exhausts, consequently presenting different appearances of the luminosity at the negative ring as the exhaust was increased. These appearances are shown in fig. 28, Nos. 1, 2, 3, 4, 5, in which the idle wire, T, is connected with the electrometer.

			Divisions.		Ratio to tube potential = 1.
1. Idle wire,	T potential		48 / 92	=	0·52
	Tube	„			
1. A little higher exhaust, T		„	57 / 95	=	0·60
	Tube	„			
2.	T	„	118 / 136	=	0·87
	Tube	„			
2. A little higher exhaust, T		„	134 / 144	=	0·93
	Tube	„			
3.	T	„	143 / 158	=	0·90
	Tube	„			
4.	T	„	170 / 181	=	0·94
	Tube	„			
5.	T	„	163 / 173	=	0·95
	Tube	„			

It is evident, therefore, that as the exhaust increases, and the luminous spindle becomes more developed, the potential of the idle wire, T, augments until it nearly or quite equals that of the whole tube.

In tube No. 363 there was no means of testing the potential on the outside of the negative ring under the same conditions as the centre, so that another tube, No. 364, was made in which an idle wire, T, was in the axis 0·25 inch (0·63 centim.) from the plane of the ring, and another, T′, 0·15 inch (0·38 centim.) from its periphery. The tube is $13\frac{1}{2}$ inches (34·3 centims.) long, $1\frac{3}{4}$ inches (4·44 centims.) in diameter, and $9\frac{1}{2}$ inches (24·1 centims.) between the terminals, and was charged with carbonic anhydride.

When 2400 cells were used, the tube potential was found to be 742 cells; the potential of the axial wire, T, was 158 cells, when that of the exterior wire, T′, was only 40 cells, so that the potential of the central wire, T, was $\frac{158}{40}=3{\cdot}9$ times that of the external wire T′. The potentials in relation to that of the whole tube equal 1, were found to be T wire $=0{\cdot}21$, T′ $=0{\cdot}054$.

Potential across a dark space and a stratum respectively.

At the suggestion of Professor STOKES, experiments were made to ascertain the potential across a dark space and also a stratum, several tubes being constructed for that object. The experiment is an extremely troublesome one, on several accounts; in the first place it is difficult to get a stratum or a space to fall exactly between a pair

of idle wires, and although this may be frequently accomplished, even between the same pair, when there is a steady and slow onward motion of the strata, if the battery is left on for a time and the tube becomes gradually heated; yet even then it requires great dexterity to catch the precise moment at which to make contact with the electrometer. Part of the difficulties may possibly be due to the inherent nature of the discharge itself, which if a pulsating one of a very high order, may be caught at different phases at the instant of contact.

In tube No. 361 charged with carbonic anhydride, 32·5 inches (82·5 centims.) long, and 1·75 inches (4·44 centims.) in diameter, having two terminals, one a point, the other a ring, distant 28·25 inches (71·74 centims.), two idle glass-covered wires were fused into it. No. 1, 11·75 inches (29·84 centims.), and No. 2, 12·75 inches (32·38 centims.) from the plane of the ring which was made negative; the proper position of the idle wires was determined by that of the strata in a preliminary trial.

The battery used was 3600 cells, the negative pole and the ring terminal were connected to earth.

The tube potential was found to be =1945 cells.

When the electrometer was connected with:—

	Cells.
No. 1, touching convex side of a stratum, the potential was No. 2, " concave " " "	= 1862
At another pressure the tube potential.	= 1784
No. 1, touching a dark space . . . . No. 2, " "	= 1339
No. 1, touching concave of stratum . . . . No. 2, " convex "	= 1398

So that when an idle wire either touched the convex or concave side of a stratum, or either side of a dark space, the potential was the same, and approached nearly that of the tube when tested at the positive terminal.

With the same tube when the two points were made to straddle a stratum or a space, one point, No. 2, connected with the electrometer, and the other, No. 1, to earth, the indications differed.

	Cells.	Stratum.	Space.
A stratum intervening, potential	= 282	= 1·32	= 1
A dark space, "	= 215		

Another series gave—

	Cells.	Stratum.	Space.
Stratum intervening, "	= 87	= 1·19	= 1
Dark space, "	= 73		

Another series gave results the reverse of this, namely, a greater potential when a dark space intervened, but it is possible that the connexion with the electrometer was not made precisely at the proper moment.

	Cells.		
Space	102	=	1·05
Stratum . . .	97	=	1

Taking the mean of several other sets, the balance of the results is in favour of the potential being greatest when a stratum intervenes, for example :—

	Stratum.	Space.
	1·243	1
	1·327	1
	1·081	1
Mean	1·243	1

A series of experiments were made with tube No. 362 having a hydrogen charge; a battery of 3600 cells being used, which gave a current of 0·04686 ampère through it.

This tube has four idle wires a, b, c, d, as shown in fig. 28, 6, but only two were used, namely, c and d, 1 inch (2·54 centims.) apart; and a stratum or a space was made to intervene between them. The positive pole was connected to the terminal in the shape of a point, and the negative to the ring which was also connected to earth. The following are the results :—

		Divisions.		Cells.		Divisions.		Cells.
Tube potential	=	192		1443				
Stratum „		111			Space	98		
		137				59		
		84				115		
		132				78		
		133				115		
		129				69		
		74				72		
		146				69		
		102				141		
		132				142		
Mean		118	=	887		96	=	722

These figures may be taken as fairly representing the whole series of observations. $\frac{118}{96}=1{\cdot}229$, which agrees well with the ratio before cited as that of the potential of a stratum to that of a space=1; and we think that it may be fairly assumed that the potential is really greater when a stratum is straddled than when a space is straddled.

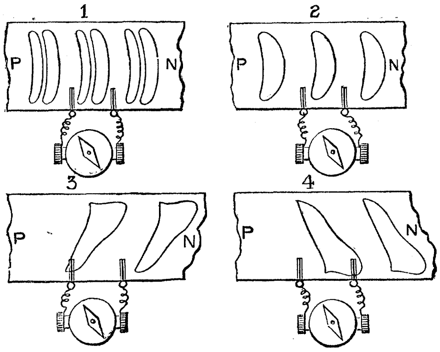
Eddies in an electric discharge through a vacuum tube.

On testing the discharge between two idle wires distant $\frac{5}{8}$ inch (1·6 centim.) with a THOMSON galvanometer, the current was found sometimes to go in the reverse direction to that of the main current. In order to fix with certainty this pheno-

menon in one's mind the current was at first sent through a fine platinum wire 26 inches (66·04 centims.) long, and 0·002 inch (0·005 centim.) in diameter, leading wires from a THOMSON galvanometer were connected $\frac{1}{2}$ inch (1·27 centim.) apart with the middle of the wire, the deflection of the galvanometer to the right showed that the current was as anticipated in the same direction in this fraction as in the whole wire. The deflection through the wire was 162 divisions with $\frac{1}{999}$ shunt, $=161,200$ without shunt, $=\frac{75{\cdot}5 \text{ volts}}{1 \text{ megohm}}$ to the right. When a moistened thread was substituted for the fine wire the effect was the same. When, however, a vacuum tube was employed, then evidence was frequently obtained of a current in a contrary direction.

With tube No. 365, $21\frac{3}{4}$ inches (55·25 centims.) long, with 3600 cells, a series of eleven pairs of beautiful double strata like those in Plate 16, fig. 3, Part III., were obtained, fig. 29, 1; these were perfectly steady. Two idle wires, $9\frac{3}{4}$ inches (24·8

Fig. 29.



centims.) and 10 inches (25·4 centims.) distant from the positive end and embracing the seventh pair of strata, were connected with the THOMSON galvanometer,* when the following numbers were obtained :—

With $\frac{1}{9}$ shunt.			Without shunt.
To left	50—	=	496—
To right	56+	=	559+
To left	50—	=	496—
,,	30—	=	298—
,,	140—	=	1389—
To right	143+	=	1419+

On introducing a resistance of 500,000 ohms in the current, a pink stratification of nineteen strata was obtained like that in Plate 16, fig. 4, Part III., fig. 30, 2. The

* The constant of this galvanometer, with the controlling magnet in the position used in the following experiments, is C $\frac{1 \text{ volt}}{1 \text{ megohm}}=2136$ divisions, or through 2136 ohms $\times 10^6=1$ division. The multiplier for the $\frac{1}{9}$th shunt $=9{\cdot}92$, that for the $\frac{1}{999}$th $=995{\cdot}3$.

idle wires embraced the eleventh stratum from the positive, and deflections were obtained as under with $\frac{1}{9}$ shunt:—

With $\frac{1}{9}$ shunt.			Without shunt.
To left	180—	=	1785—
To right	170+	=	1686+
,,	70+	=	694+
To left	204—	=	2023—*
To right	110+	=	1091+
,,	140+	=	1386+
,,	130+	=	1289+
,,	30+	=	297+
,,	15+	=	149+
To left	20—	=	198—

With tube No. 362 hydrogen charge and a battery of 2400 cells, the strata were tongue-shaped as in Part II.,† Plate 15, fig. 11; two touch points 1 inch (2·54 centims.) apart were connected with a THOMSON galvanometer. It was noticed that there was a strong deflection to the left (the deflection through a wire being to the right) when the base of a stratum touched the idle wire nearest the positive terminal and its apex pointed in the direction of the negative, but rose above it towards the opposite diameter of the tube, fig. 29, 3. When the apex of the tongue pointed in the reverse position so as to touch the idle wire next the negative and the base went to the other side of the tube above the idle wire near the positive, fig. 29, 4, then the deflection was in a contrary direction (that is the same as through a wire). When the tongues crossed the axis of the tube nearly at right angles, then there was an oscillation of the needle, first in one direction then in the other, according as the strata altered their position slightly with regard to the direction of the apex and base of the tongue.

The following are the readings without any shunt:—

140	left	—
20	right	+
15	left	—
210	right	+
200	,,	+
165	,,	+
150	,,	+
210	left	—

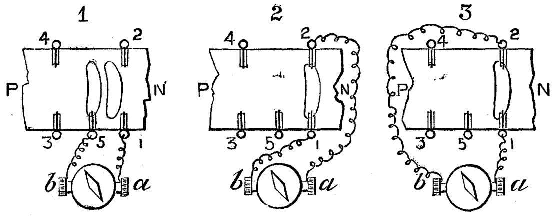
Sometimes when a deflection took place in the same direction as the current through a wire, and had arrived at its maximum, then a slow oscillation was observed in the deflection, the needle moving backwards and forwards for about 20 divisions when the full deflexion was 290, or 0·068 of the total deflection.

* Nearly equal to 1 volt through a megohm.

† Phil. Trans. for 1878, Vol. 169.

Another tube was made to test whether there is a current at right angles to the column of gas; namely No. 366, $21\frac{1}{2}$ inches (54·61 centims.) long, and $1\frac{5}{8}$ inches (4·1 centims.) in diameter, in it are sealed five idle wires, 1, 2, 3, 4, 5. No. 3 is $5\frac{1}{2}$ inches (14 centims.) from the positive. Nos. 3, 5, 1 are all in a longitudinal line on the same side of the tube, 4 and 2 in line on the opposite side; 4 is diametrically opposite to 3, 2 diametrically opposite to 1. The tube with its wires is shown in fig. 30, 1, 2, 3; the opposite wires of the galvanometer are marked *a* and *b*.

Fig. 30.



The charge was hydrogen, and 2400 cells were used. In the first place the galvanometer was connected with two wires in a longitudinal direction, the galvanometer wire *b* to the idle wire 5, the galvanometer wire *a* to the idle wire 1; the idle wires at this time straddled both a stratum and a space. The deflection was to the right, amounting to:—

With $\frac{1}{9}$ shunt.	Without shunt.
202+	2004+
117+	1161+
62+	615+
37+	367+
22+	218+
2+	20+
82+	813+
102+	1012+
132+	1309+

The wires of the galvanometer were now reversed, *a* to 5 and *b* to 1, the deflection was now to the left, but the galvanometer connexion having been reversed, the sign was the same as in the preceding.

With $\frac{1}{9}$ shunt.	Without shunt.
98+	972+
68+	674+
83+	823+
68+	675+
58+	575+
48+	476+
38+	377+
118+	1170+

All these deflections are in the same direction as if the current went through a wire. The wires of the galvanometer were now connected, *b* to 1, *a* to 2, these being

diametrically opposite, a stratum was touched at an opposite end of its diameter by each wire; the readings were:—

With $\frac{1}{9}$ shunt.	Without shunt.	The current was from
To left 3−	30−	1 to 2
,, 8−	79−	,,

The wires were now reversed, *a* to 1 and *b* to 2, and the following observed:—

With $\frac{1}{9}$ shunt.	Without shunt.	The current was from
To the right 12+	119+	1 to 2
,, ,, 2+	20+	,,
To the left 8−	79−	2 to 1
,, ,, 3−	30−	,,
0	0	

It is evident, therefore, that there is a current sometimes in one direction, sometimes in the contrary, across a diameter of the tube, as if the motion of the molecules conveying the discharge was of an epicycloidal character. By way of comparison a tin-plate, 14½ inches (36·8 centims.) long and 5½ inches (14 centims.) wide, with circular ends, was made; a connecting clamp was soldered to each end and two others across a central diameter. The direction of the current was ascertained when the poles of the battery were connected one to each end of the plate, and the opposite wires of the galvanometer also one to each end. Then the two clamps across a central diameter were connected alternately with the opposite ends of the galvanometer, the terminals remaining connected with the ends of the plate, but no deflections occurred even without a shunt.

One of the main objects of the experiments recorded in this paper was to endeavour to discover some of the obscure secrets of the electric discharge through gases. Although many more will undoubtedly have to be made before a theory can be formed which will account even for a few of the complex phenomena presented by this discharge, yet every onward step, however small, brings us nearer to the goal, and we shall consider ourselves well rewarded if we have advanced the frontier in the very smallest degree. We believe that what we have done has secured some advance, and rendered evident that electricity is always conveyed in gases by ponderable matter and not by the so-called ether; moreover, that there are eddies in the discharge in a vacuum tube, and that it is possible that these eddies may be connected with the production of strata whose form would depend on the kind of eddy originally produced. This recalls the phenomena figured in Part III., Plate 8, fig. 34;* in this is seen an eddy of strata through small holes in a tube confining the main discharge.

We have much pleasure in thanking Professor STOKES for his many valuable suggestions, and for his kind advice generally, during the course of this investigation. To our chief assistant, Mr. JAMES FRAM, we are indebted for able and zealous co-operation, and we wish to place on record the excellent services of our junior assistant, Mr. ERNEST DAVIS. Mr. H. REYNOLDS has, as on former occasions, taken the photographs with his usual skill.

* Phil. Trans. for 1880, Vol. 171.

Postscript.

(Added July 10th, 1883.)

Our battery now consists of 15,000 cells, all of the form in which the chloride of silver is fused into rods on a flattened silver wire.* On the occasion of a lecture given by one of us at the Royal Institution on January 21, 1881, 14,400 cells, partly of the rod form, partly of the chloride in powder form, were used; the length of the spark with this number between paraboloidal points was 0·7 inch (17·8 millims.), and between a point and disc 0·62 inch (15·7 millims.). It will be recollected that in Part I. of our researches,† we obtained with 11,000 cells between two points a spark 0·62 inch long, and between a point and disc one 0·47 inch long. It does not appear, therefore, that the law of the spark being as the square of the number of cells holds good beyond a certain number; the falling off may be in part due, however, to the failure of insulation as the potential is increased.

$$\frac{14400^2 \times 0{\cdot}62 \text{ inch}}{11000^2} = 1{\cdot}060 \text{ inch (27 millims.)}$$

$$\frac{14400^2 \times 0{\cdot}47 \text{ inch}}{11000^2} = 0{\cdot}806 \text{ inch (20 millims.)}$$

Since the removal of the battery from the Royal Institution we have not charged up the whole of it, as the experiments on which we have been engaged did not necessitate more than 11,000 cells.

We have recently (May 10–July 4) repeated the experiments on the question of the polarisation of the terminals on a discharge taking place in gases, and have obtained the same results as those already described;‡ they confirm, therefore, our previously expressed opinion,§ that the experiments point conclusively to the deduction that the small current, which is observed when the terminals of a vacuum tube (in which a discharge has taken place) are disconnected from the battery and instantaneously connected with a galvanometer, is due solely to a static charge and not to *chemical polarisation.*

* Phil. Trans., Part I., Vol. 169, 1878, p. 109, separate copy, p. 55.

† Ibid., p. 118, separate copy, p. 64.

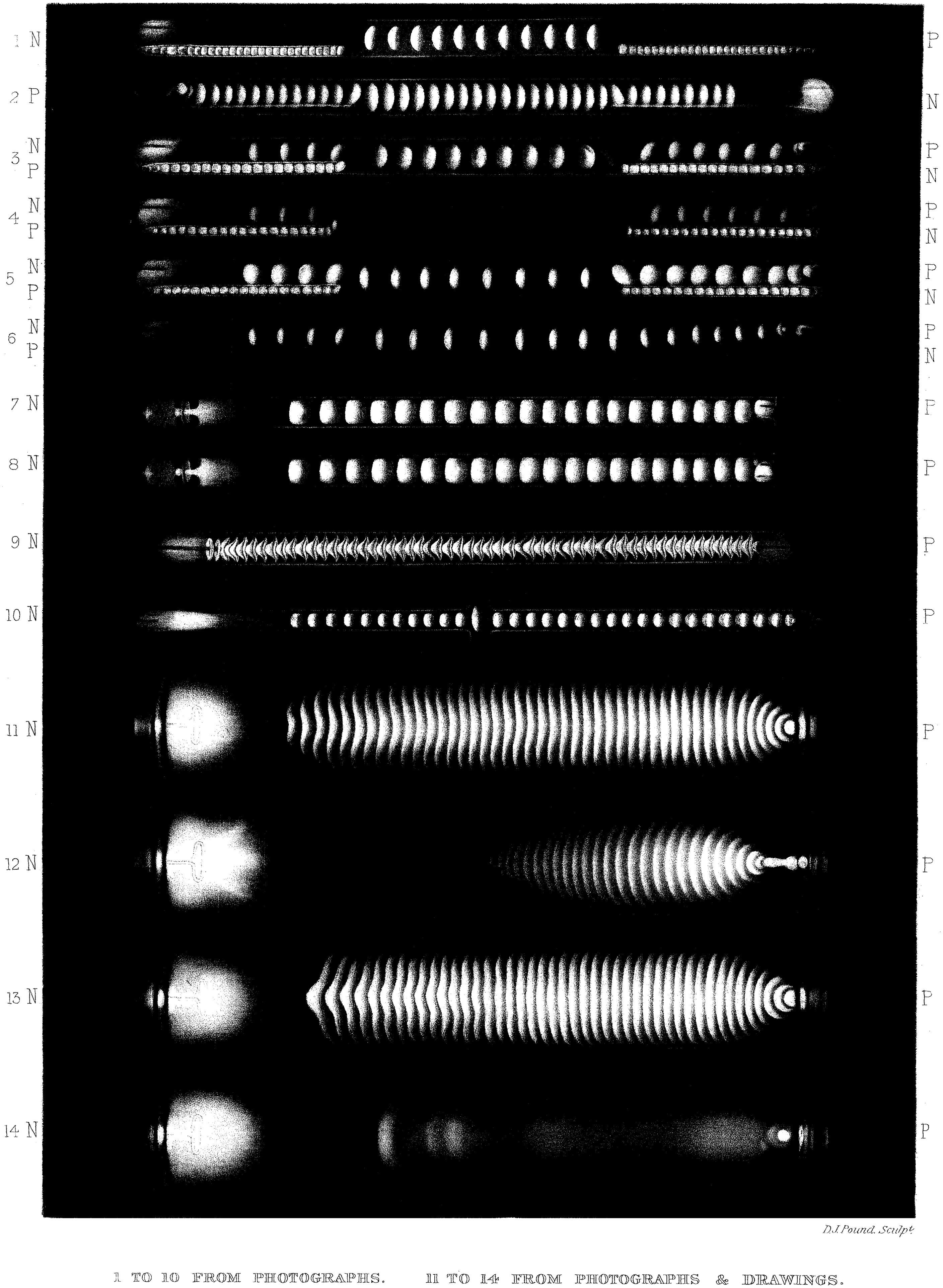
‡ Proc. Roy. Soc., No. 205, 1880, pp. 563–572.

§ Ibid., p. 570.

INDEX TO PART IV.

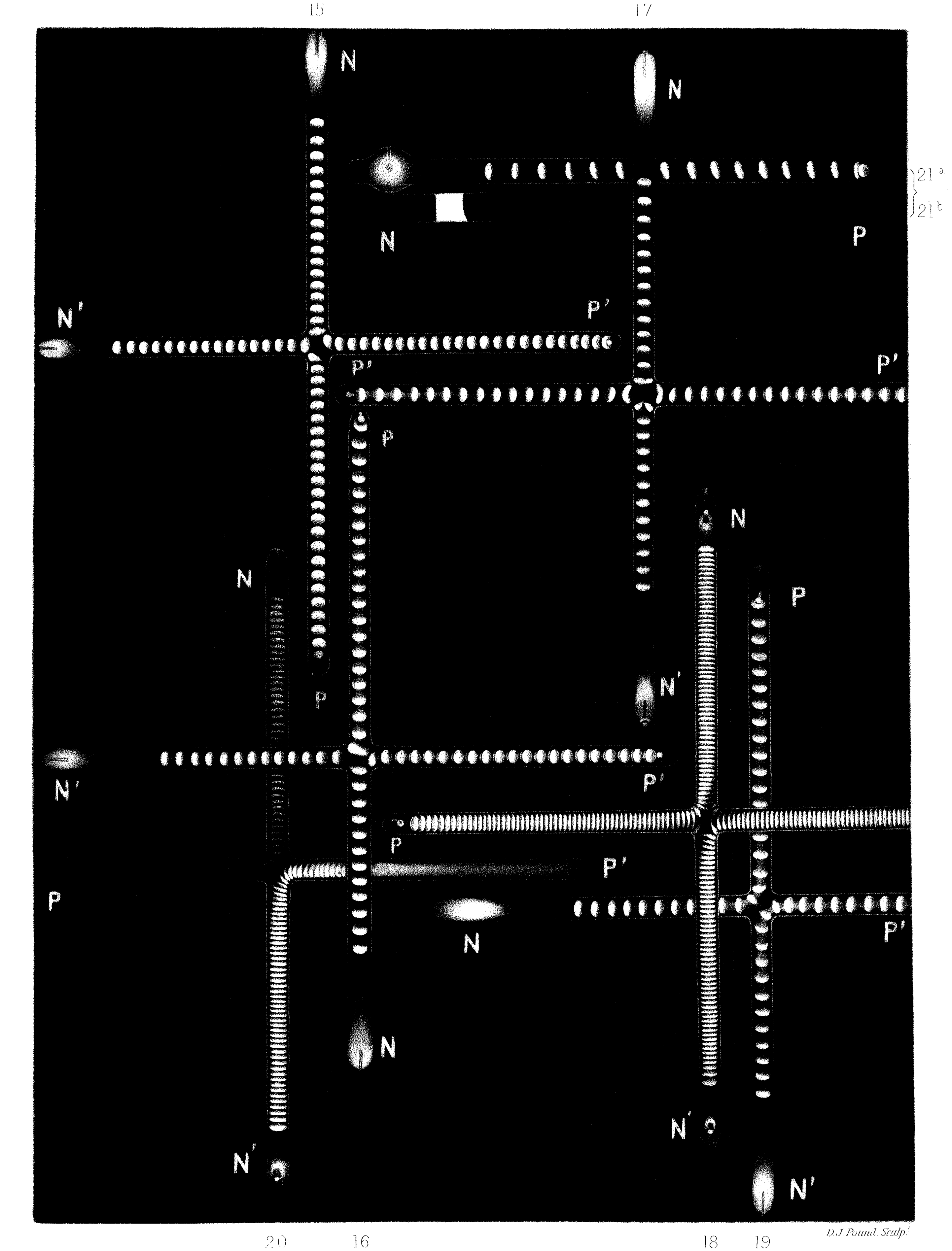
PLATES 35 AND 36, REFERENCES TO TEXT.

CURVES REPRESENTING TABLES, REFERENCES TO TEXT.



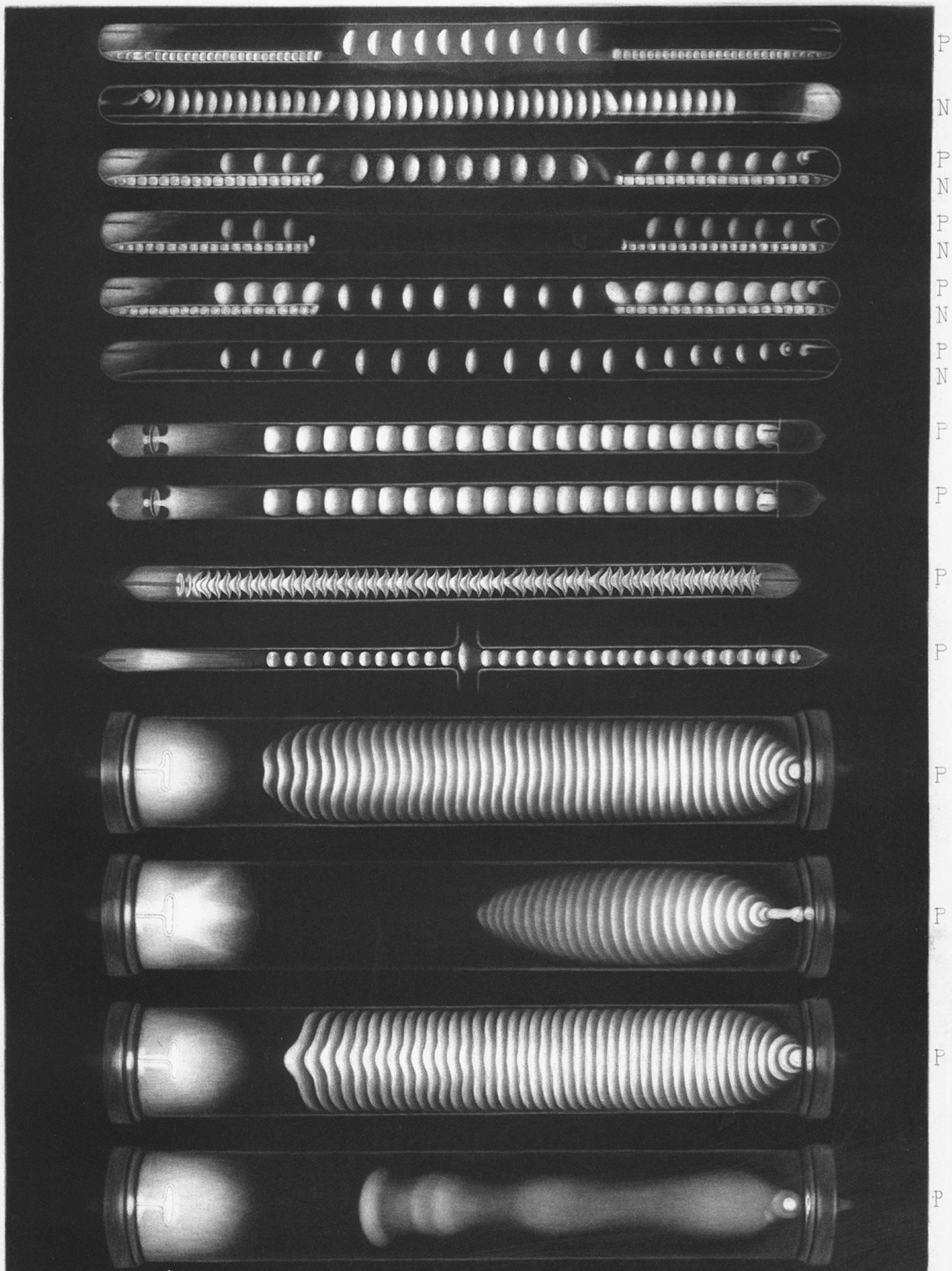
D.J. Pound. Sculpt.

1 TO 10 FROM PHOTOGRAPHS. 11 TO 14 FROM PHOTOGRAPHS & DRAWINGS.



D.J. Pound. Sculpt.

FROM PHOTOGRAPHS.



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