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

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[Plates 15–18.]

Part II.—THE DISCHARGE IN EXHAUSTED TUBES.

We cannot flatter ourselves that we have done more during our three-and-a-half years' work than contribute a few facts towards the data necessary for the solution of the problem, "What is the cause of the beautiful phenomenon of stratification produced by electric discharges in vacuum tubes?" which, having been first noticed by M. Abria in 1843, was independently re-observed by Mr. (now Sir William) Grove in 1852,†

* These researches have been prosecuted independently and without the knowledge of much that has been done by other workers in the same field. Subsequently to the communication of this memoir we have diligently searched the papers of other physicists, and have extracted from them many interesting passages which, by permission of the Council of the Royal Society, we have added in the form of foot-notes at various parts of the paper. As it is quite possible that some papers may have escaped our notice, a list of those consulted is given in the Appendix, note A.

Mascart, in his valuable 'Traité d'Electricité Statique,' t. ii., pp. 128–141, 1876, has given a succinct account of the phenomena of the discharge in vacuum tubes, and the various hypotheses which have been proposed to account for them.

† Gassiot (Bakerian Lecture, Phil. Trans., 1858, pp. 1–16) gives the following history of the stratified discharge:—

"The striated condition of the electric discharge in vacuo which takes place when the terminal wires are inserted in a well exhausted receiver in which a small piece of phosphorus has been previously placed, was first announced by Mr. Grove in his communication to the Royal Society, 7th January, 1852; his paper is printed in the first part of the Transactions for that year, and was subsequently published in the Phil. Mag., December, 1852, with a supplementary note, dated 9th June, wherein Mr. Grove states 'that he found the transverse dark bands could be produced in other gases when much attenuated, probably in all.'

"The phenomena of stratification in the discharge in vacuo were subsequently observed in Paris by Ruhmkorff, who obtained the effect by using the vapour of alcohol; they were again noticed by Masson, Du Moncel, Quet, and other continental electricians, who all describe the *intense white light without stratification* produced in the barometrical vacuum."

It appears, however, that Grove was anticipated by Abria (Ann. de Chim. vii., 1843, pp. 477–478), who, experimenting with the secondary current of an induction coil, obtained in air at a pressure of 2 m.m., in an exhausted receiver, a brush-discharge from the positive (a ball) which did not quite reach the and has since engaged the attention of so many physicists. Our excellent and highly esteemed friend the late Mr. GASSIOT, working at first with an induction coil, but more recently on the same lines as ourselves (voltaic batteries of high potential *), has published results of great interest, many of which are confirmed by our own experience; while, on the other hand, we have enjoyed pleasurable intercourse and exchange of thought with our contemporary, Mr. W. SPOTTISWOODE, who is still pursuing with great acumen and originality a similar investigation, both with the induction coil and the HOLTZ machine, with which he has recently used condensers of great capacity, like those we employ and have described in Part I. If we arrive at the same results by different paths, the one investigation will support the other, and for each may be claimed more reliance than if unconfirmed.

Throughout our labours we have felt so strongly the necessity of obtaining numerical results as data for the foundation of a theory, that we have not hesitated to risk much in this cause. By the fusion of terminals, or the sudden discharge of the condenser, we have lost a vast number of very beautiful tubes; but gradually, by the adoption of various devices, and by the employment of instruments specially constructed and insulated to suit the high potentials we deal with, we have succeeded in overcoming the various impediments, so that we can now readily obtain values for the physical quantities that enter into consideration in our experiments.

There is a serious trouble connected with the study of the discharge in rarefied gases, for, after a very short time, the tubes completely and permanently change, so as no longer to present the splendid stratifications witnessed on a first trial. We believe these changes occur much more rapidly with the battery, in consequence of the greater amount of current, than with the induction coil; but the fact appears to be well known to Dr. GEISSLER, of Bonn, who, on the occasion of a visit to our laboratory, brought with him some tubes through which no current had previously passed (virgin tubes, as he calls them), which presented most beautiful phenomena lost for ever after too brief a period.

Tube 123 (Cyanogen), for example, when first connected with the battery, presented strata which completely filled the tube without leaving a dark space near the negative,

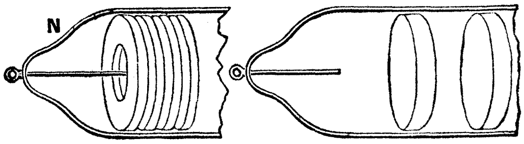
negative (a point), where there was a dark interval: he says, "De plus, cette flamme ou aigrette qui part du pôle positif présente notamment à sa partie supérieure (en supposant la pointe negative en haut) des zones alternativement obscures et lumineuses. Ces zones sont concaves vers la boule quand la pointe (negative) est rapprochée de cette dernière; elles deviennent convexes vers la boule lorsque la pointe en est très-écartée."

* Mr. GASSIOT made several batteries of different kinds in the course of his experiments; on the occasion of a visit to his laboratory, January 26, 1875, the current of his LECLANCHÉ battery was measured by us with a voltameter. The current of 1000 new cells was found to be 0·07464 W; that of the whole 3000 cells, 1000 of which had been a long time in use, 0·04718 W. Taking the LECLANCHÉ as 1·48 volt the internal resistance of the new battery must have been 19·83 ohms per cell; that of the whole 3000, 31·37 ohms per cell. The striking distance of the whole 3000 between a conical point and a disc 0·125 inch diameter was only 0·025 inch; whence the inference is that the insulation was, at that time, imperfect.

some threading themselves on it, as shown on the left of fig. 33; but after a few seconds the strata widened out as on the right-hand figure, then other changes occurred, and the first phases have never been reproduced.

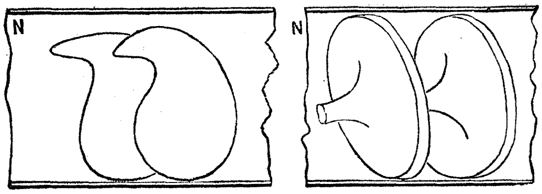
Fig. 33.

TUBE 123.



Another case is presented by the nitrogen tube fig. 34, the right-hand figure showing the first phase, and the left-hand figure a second phase, which in its turn has for ever disappeared, and has been replaced by the ordinary disc-form of strata.

Fig. 34.



After spending much time in experiments with tubes prepared for us by Dr. GEISSLER, Messrs. ALVERGNIAT Frères, of Paris, and Mr. HICKS, of Hatton Garden, with the vexation of finding that we could not often enough repeat our experiments, we ultimately came to the conclusion to have others made, but not exhausted, and to perform ourselves the charging and exhaustion.* The tubes we usually employ have a glass stop-cock fitted to them at each end; they are 32 inches long, and from 1·75 to 2 inches in diameter; the terminals are of aluminium, and about 29 inches apart, one being a ring, the other a wire bent at a right angle, so as to point in the direction of the axis of the tube (see No. 144, fig. 37), for we have found that the phenomena vary according as the ring or wire is made positive. These we exhaust and fill with any gas we may wish to experiment with, and gradually exhaust again, noting the phenomena presented at different pressures, different potentials, and with different amounts of current. We re-fill and exhaust the tube again and again, and mostly obtain, under the same conditions, as nearly as possible the same phenomena, of which we are careful to make sketches and, if possible, to obtain photographic records.

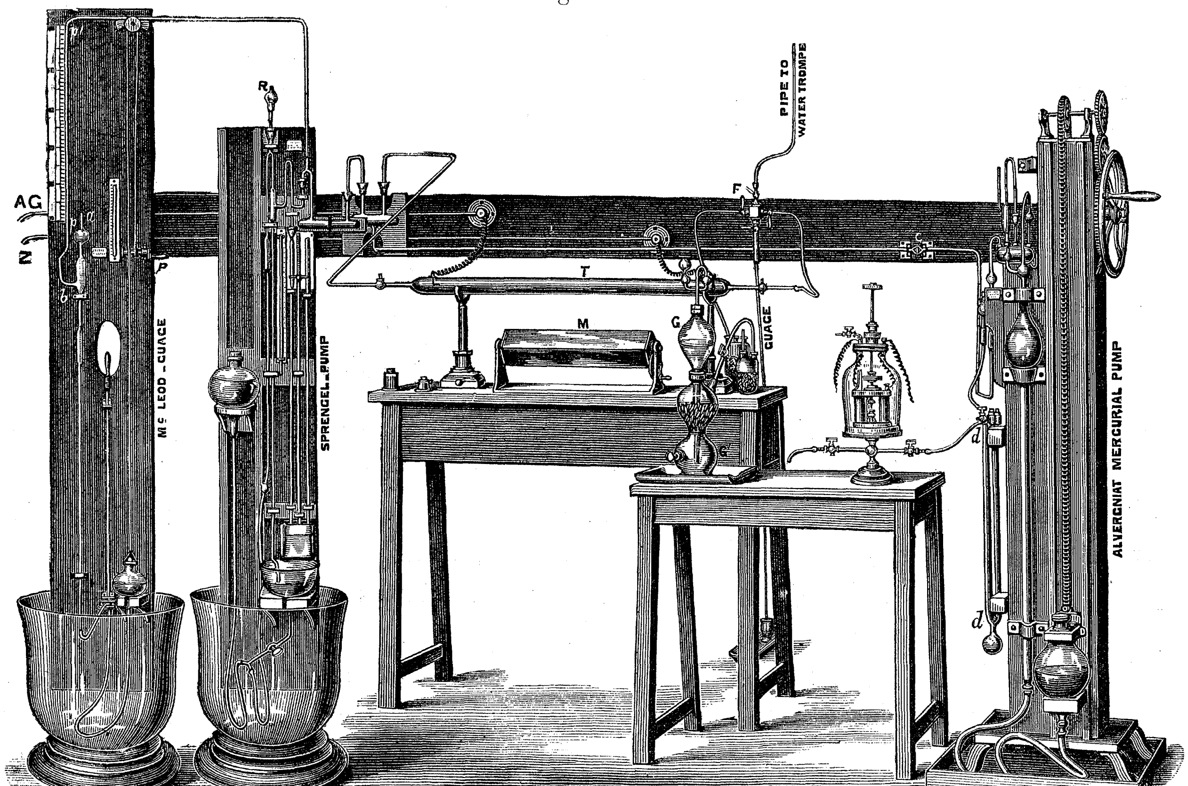
In some cases we make use of tubes provided with a calibrated chamber between two stop-cocks, as *a*—*b*, No. 145, fig. 37, the chamber in this particular case having $\frac{1}{2200}$th of the capacity of the tube. After a tube has been exhausted so as to

* GASSIOT was driven to the same conclusion; he says, in speaking of GEISSLER'S tubes: "I reluctantly laid them aside, and for all experiments I have to describe each tube was charged and exhausted by myself or in my presence."

produce a particular phase, and in the course of the experiment the exhaustion has been carried beyond that degree which permits of the production of that phase, one or more charges of gas may be successively admitted into the tube by filling the calibrated chamber with gas at any particular pressure, and then opening the stop-cock communicating with the tube; the lost phase is thus reproduced.

The apparatus which we have found it advantageous to adopt for the exhaustion of our tubes is shown in fig. 35; it comprises three means of exhaustion which are successively employed as the vacuum becomes more perfect. The first is an ALVERGNIAT

Fig. 35.

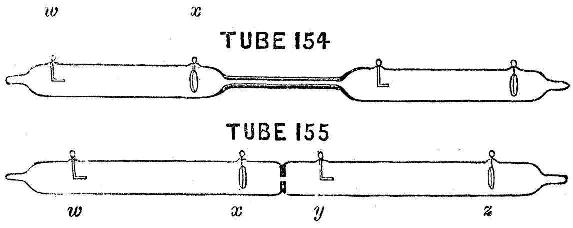


high-pressure water *trompe* in connexion with the high-pressure water-main of the West Middlesex Water Company, the head of water being 106 feet; it produces a vacuum to within half-an-inch (0·47 in. = 12 millims.) of the height of the barometer. The pipe leading to it is so marked in the drawing; it is attached, through a cock, to a four-way-junction-piece F, provided with three more cocks, communicating:— one to one end of the tube T, one to the last drying bottle of the gas generator G G,′ and one to a mercurial gauge. The other end of the vacuum tube T communicates by means of a Y-piece to both, an ALVERGNIAT mercurial pump, on the right of the figure, and a SPRENGEL pump, on the left. After the *trompe* has done its work, the ALVERGNIAT is used for rapid exhaustion, and then shut off by means of the glass cock C, leaving the exhaustion to be completed by the SPRENGEL; we have thus obtained, by the *pumps alone*, in tubes 32 inches long and 2 inches in diameter, vacua of only 0·002 millimetre pressure, equal to 2·6 millionths of an atmosphere—a vacuum so perfect that the current of 8040 cells would not pass. The apparatus is in connexion with a McLEOD gauge,* by means of which pressures to 0·00005 m.m. can be determined. Besides this gauge, the SPRENGEL and ALVERGNIAT pumps have their own gauges, which read to a millimetre. M is a rotating mirror consisting of a four-sided prism mounted on a horizontal axis and provided with a multiplying wheel; on each face of the prism is fastened a piece of looking-glass. The reflection of the tube in the mirror enables one to examine whether an apparently nebulous discharge consists really of strata, also whether and in what direction there is a flow of strata which may appear quite steady to the eye. The observations are facilitated by covering the tube with a half cylinder of cardboard having a slit in the direction of its axis about $\frac{1}{10}$ inch wide. R is a radiometer attached to the SPRENGEL; *d*, *d*, a drying tube containing sticks of potash used when gas is introduced from a reservoir through the ALVERGNIAT.

In fig. 37, to which is attached a scale of feet and inches to enable a judgment to be formed of their dimensions, tubes of various forms are represented. It will presently be seen that the resistances of these tubes bear no exact relation to the distance between the terminals, but that it is affected greatly by the bore of the tube; the small spectrum-analysis tubes, 83, 93, and 95, a portion of which has a capillary bore, offer generally great resistance to the battery current, while much longer tubes, 1 and 2, of larger bore, offer far less.

In order to test how much of this depends on the length of the constriction, we had made two tubes, 154 and 155, fig. 36, of nearly the same length, 16 inches, and internal

Fig. 36.



diameter $\frac{15}{16}$ths of an inch, the residual gas in each case being Carbonic acid, CO_2. The distances between the several terminals of tube 154 are respectively between *w*

* (Phil. Mag., Aug. 1874.) When the mercury cistern is raised, a portion of gas at the same pressure as that in the tube is shut off at *b*, and compressed in the small graduated chamber, *a*, at the top of the bulb, to different degrees, in our gauge, from $\frac{1}{49 \cdot 83}$ to $\frac{1}{18 \cdot 25}$, according as the gas is less or more rarefied; the mercury at the same time rises in the pressure column, *p*, and its height affords the means of determining the pressure of the gas in the tube. Tables have been prepared to give the value of the reading by inspection.

and x 4·375 inches, between x and y 5·75 inches, and between y and z 4·25 inches; the length of the constricted part being 3·75 inches, and its diameter 0·125 inch. The distances for tube 155 are respectively between w and x 5·25 inches, between x and y 2·375 inches, and between y and z 5·25 inches; the constricture in this case is a glass diaphragm 0·03 inch thick with a hole 0·125 inch in diameter.

The following results were obtained from observations made January 25th, 1878 :—

Terminal $z+$; terminal $w-$ (to Earth).

	Tube 154.	Tube 155.
Difference of potential between z and y	75	81
,, ,, y ,, x (the constriction)	138	32
,, ,, x ,, w	118	146
,, ,, z ,, w	331	259

The diaphragm in tube 155 being 0·03 inch in thickness, and in tube 154 the constriction being 3·75 inches long, the one is 125 times longer than the other, but the ratio of the differences of potential between x and y in the two cases is only 4·31. It is evident, therefore, that the main effect is due to the simple constricture of the tube.

Among the tubes depicted in the diagram fig. 37, only the following require any special allusion being made to them in this place :—

Tube 145 has at the right hand a chamber for holding an absorbent substance (spongy palladium, charcoal); the vertical tube is for connexion with the pump, and the left hand small tube for connexion with the supply of gas; by using spongy palladium with hydrogen, a vacuum has been obtained in which 11,000 cells could not produce a current.*

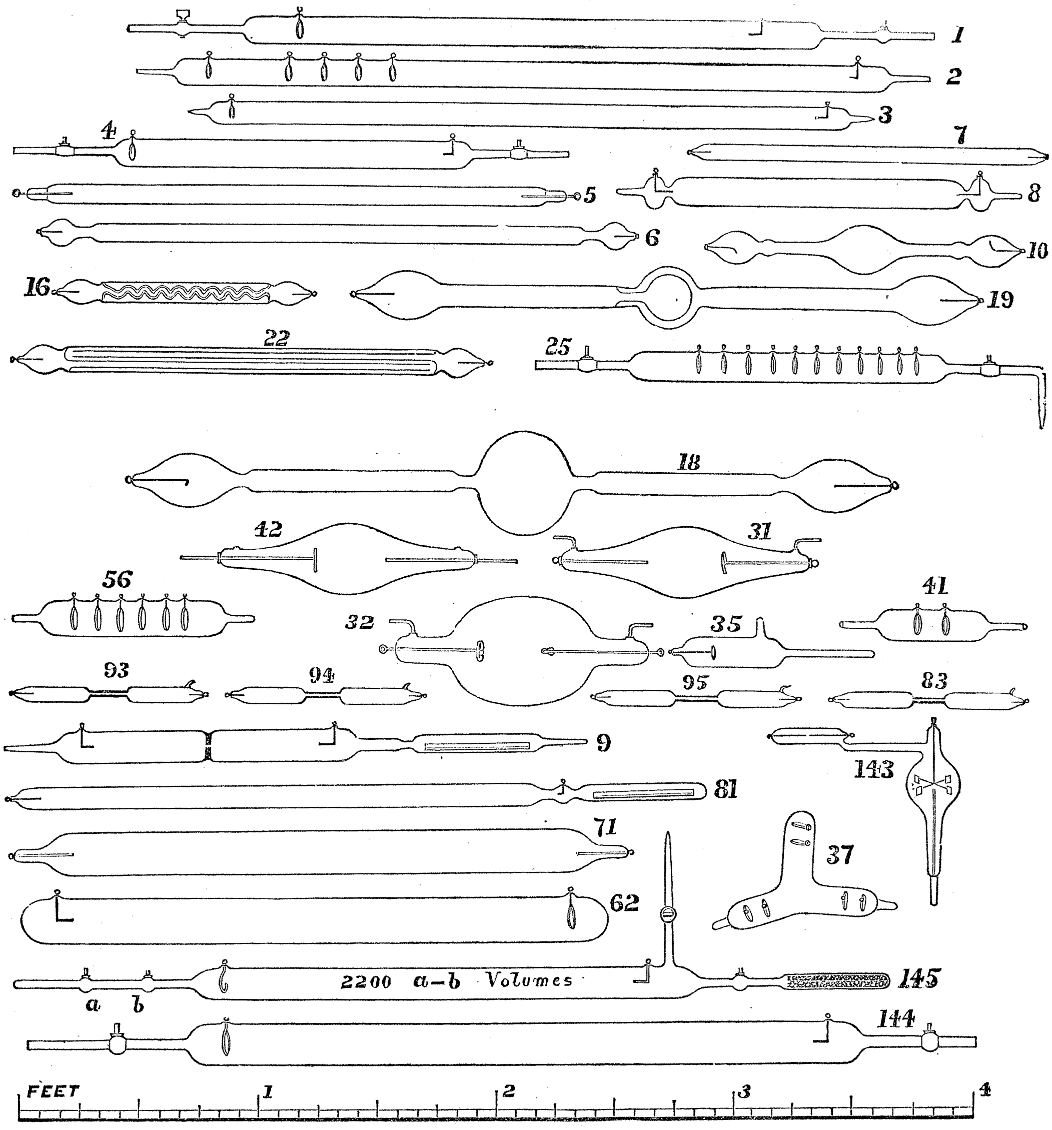
Tube 19 is one of the so-called induction tubes, the tube enclosing one of the wires ending in a closed chamber (a globe) surrounded by that portion of the tube enclosing the other terminal, so that there is not any continuous gas space from one terminal to the other.

Tube 81 has a carbonic acid vacuum, with an absorption chamber containing hydrate of potash, which produces so good a vacuum that the current from 11,000 cells will not pass continuously, but there is a flash of light on making contact in one direction but not in the other.

Tube 143 is a tube so thoroughly exhausted that a spark from an induction coil will not pass between two terminals only 0·1 of an inch apart, although of sufficient tension to jump across the wires outside the tube several inches distant; this communicates with a radiometer.

* GASSIOT (Phil. Trans., 148–150) describes several "*non-conducting vacua*" produced by absorbing substances (caustic potash, and chloride of calcium).

Fig. 37.



The diagram, fig. 38, shows the arrangement by which, in our earlier experiments, we measured the resistance of a tube. The tell-tale tube* had to be substituted for the galvanometer in the ordinary WHEATSTONE bridge, as the difference of potential between C and D fluctuated greatly in the course of the experiment, causing violent swings of the needle.†

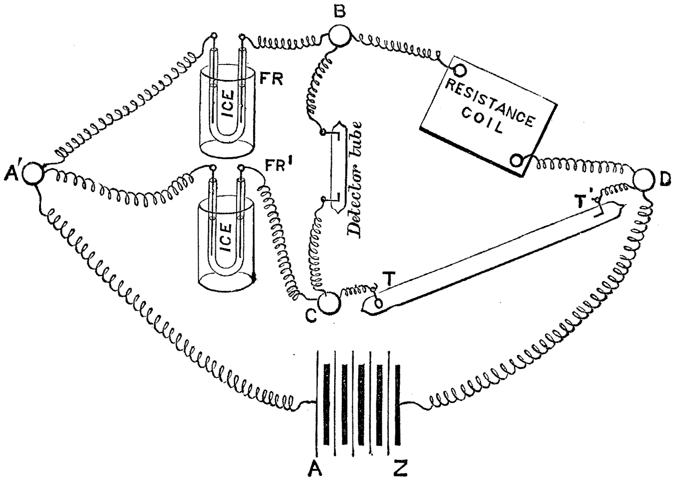
A Z is the battery, the A terminal of which is connected at A′, in the bridge arrangement, with two equal fluid resistance tubes, FR and FR′, of 420,000 ohms, placed in vessels containing ice, to keep them at a constant temperature; an adjustable coil resistance is inserted between B and D; the tube T T′, to be tested, is placed

* A tube selected for the readiness with which it permits the passage of a current of 440 cells.

† Proc. Roy. Soc., vol. xxiv. p. 167, 1876.

between D and C, the Z terminal of the battery being connected to D. When the resistance is greater or less than that of the tube to be tested there is an illumination in the detector tube between B and C; but when a current passes in T T′, balanced by a proper adjustment of the coil resistance, then the glow in the detector ceases. It was ultimately found that the detector tube might be suppressed because, as

Fig. 38.



soon as the resistance in B D is a little in excess of that of the tube, the latter gives evidence by its illumination of the current passing. After the current in a tube has commenced it is generally found that it will continue to glow, even when some of the balancing resistance, B D, is plugged out in the coil box, showing that when once started the *working* resistance becomes less. If, on the other hand, the current has been stopped entirely, it requires generally a greater balancing resistance in the coil box between B D to start it again than it did in the first instance. After standing for a short or long time it regains its normal condition, but the interval required may amount to several days. The following numbers were obtained :—

Tube	Started with	Ran up to	Nature of the Gas.
1	200,000	250,000	
2	350,000	500,000	
3	400,000	(decreased)	
4	90,000	110,000	
5	170,000	290,000	
6	270,000	500,000	N
7	170,000	370,000	
8	50,000	60,000	
9	70,000	..	CO_2
10	150,000	..	
16	450,000	500,000	
18	62,000	..	
22	500,000	..	
25	50,000	80,000	
31	35,000	40,000	
32	37,000	..	
35	15,000	17,000	
37	54,000	..	
41	32,000	..	
42	15,000	70,000	N
56	40,000	45,000	
62	102,000	140,000	N
71	80,000	130,000	Cy
81	150,000	infinity.	CO_2
83	190,000	..	H
93	over 1,000,000	..	CO_2
94	700,000	..	I
95	700,000	1,000,000	$Si\ Fl_6$

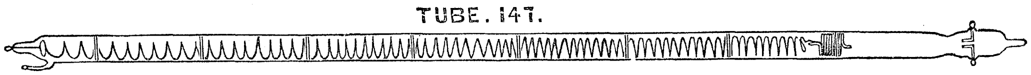
Subsequently we found it to be more convenient not to make special determinations of the resistances of the tubes beforehand in the way just described, but to obtain them by reproducing the deflection of a galvanometer, or by measurements taken with an electrometer in the manner described in pp. 165–167, while observing the phenomena of stratification. We not only save time in this way, but obtain the resistance at the actual moment of the occurrence of any particular phase.

From measurements thus made with a tube having several wires about 1 inch apart (No. 25, fig. 37), or a SPOTTISWOODE tube* with a shifting terminal (No. 147, figs. 39 and 40), we found that the resistance of a vacuum tube, unlike that of a wire, does not increase in the ratio of the distance between the terminals for the same gas at the same pressure.†

* Recently, by permission of Mr. SPOTTISWOODE, we have had made tube No. 147, with the ingenious arrangement, suggested by his assistant Mr. P. WARD, of a movable terminal, attached to a spiral of fine copper wire, which permits of its being brought into actual contact with the opposite terminal, or placed at any required distance from it; this tube is marked out into eight equal spaces by slips of paper pasted outside.

† HITTORF (Pogg. Ann. cxxxvi., 1869, pp. 1–31 and 197–234) devised several experiments to show that

Fig. 39.



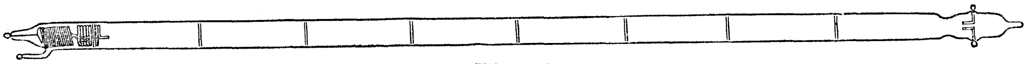


Fig. 40.

Tube 25 (CO_2) with 12 rings (not 11 as in fig. 37) 1 inch apart and 1200 cells.

	Between terminals.						
Numbers	1 to 3	1 to 4	1 to 6	1 to 7	1 to 8	1 to 9	1 to 10
Relative distances	1	1·533	2·667	3·267	3·867	4·533	5·198
Relative resistances	1	1·035	1·109	1·109	1·274	1·368	1·417

SPOTTISWOODE tube (No. 147, CO_2) and 3240 cells.

	Between the terminals at various distances from 7 to 49 inches.							
Relative distances	1	1·86	2·71	3·57	4·43	5·29	6·14	7·00
Relative resistances	1	1·24	1·24	1·49	1·35	1·63	1·78	2·10

Thus, for five times the distance the resistance, the mean of 1–9 and 1–10, is in tube 25 only 1·43, and in tube 147, 1·54 ; for seven times the distance the resistance is in tube 147, 2·1. The degree of exhaustion of these two tubes is not known, but the internal pressure is, probably, less than 1 millimetre.

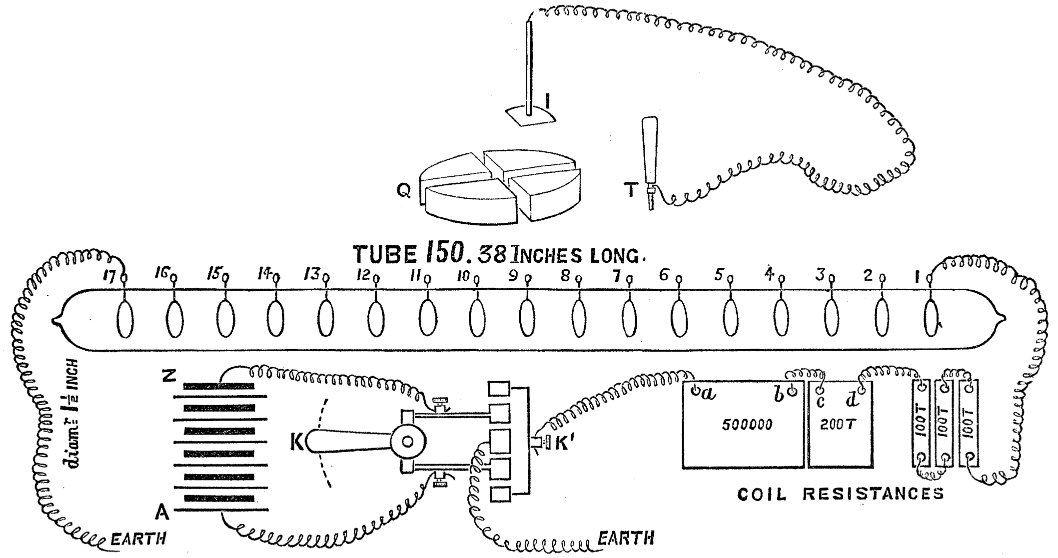
In making these experiments it was noticed that the resistance for equal distances appeared to be greater in proximity with the negative pole than in other parts of the tube, and fresh experiments were in consequence undertaken to ascertain the potential at the several rings by means of a delicate THOMSON-BECKER quadrant electrometer furnished with an induction plate, I, fig. 41, which may be adjusted to any required distance from the quadrant beneath it. The tubes employed among others were No. 25, described above, and two other longer tubes, namely, No. 149 (CO_2) with 12 rings 2 inches apart, and No. 150 (CO_2) with 17 rings also 2 inches distant. The current was led through a metallic resistance to the first ring, the last ring and the other pole of the battery being to earth. It was found that the greatest difference of potential occurs between the last ring and the last but one on the negative side, the next greatest difference being between the last and the last but

the influence of distance between the terminals varied according to the degree of rarefaction. For instance, he joined, side by side, two similar tubes, in which the distances between the terminals were relatively 12 : 1, and exhausted them together. The two terminals of the one tube were connected respectively to the two terminals of the other, and a galvanometer could be thrown into the circuit of either tube. He found that at notable pressures the discharge was exclusively across the smaller space : but at 0·5 m.m. his galvanometer did not show any difference in the currents which traversed the two tubes. SCHULTZ (Pogg. Ann. cxxxv., 1868, pp. 249–260) states that about that pressure which requires least difference of potential to produce discharge, the influence of distance between the electrodes is such that this difference of potential varies nearly in direct proportion to this distance; but when rarefaction is carried beyond that point, and the difference of potential necessary to produce discharge rapidly increases, the influence of distance between electrodes rapidly becomes inappreciable.

one on the positive side, but the difference in the former case is far greater than in the latter; in some cases there is little or no difference in the last but one and the last but two on the negative side; in these cases the last but one on the negative side was dark,* while all the others had a luminosity about them. The difference of potential between the rest of the rings is sensibly uniform.

The following observations, made December 21st, 1877, with tube 150, may be taken as an illustration of the method of measurement adopted. Batteries 6 and 7 (2400 rod cells) were employed, and adjustable resistances were inserted in circuit for the double purpose of affording the means of readily varying the strength of current without interruption, and of enabling a measurement of that current to be made with the electrometer. The connexions are shown in the diagram, fig. 41.

Fig. 41.



The circuit was first broken by removing the earth wire from ring 17, and the plug T, in connexion with the induction plate I, being touched at any point between K′ and ring 1 gave the reading for "Full Potential, open circuit;" next, the earth wire was replaced at ring 17, and the value for "Full Potential, closed circuit," was obtained by causing T to touch at K′. As these batteries had but small internal resistance, the difference between these two readings was scarcely perceptible. By touching T at rings 1, 2, &c., in succession, their potentials were

* An example of the dark space at conductors near the negative is shown at fig. 6, Plate 17. The dark spaces in a vacuum tube are regarded by De la Rive ('Comptes Rendus,' lvi., 1863, pp. 672–673) as offering less obstruction to the discharge than the bright layers. He inserted in the tube discs of metal connected to wires passing through its walls; these wires were connected to a galvanometer while the discharge was taking place: the derived current was found to be much less in the dark than in the bright portions of the discharge.

observed. The current was then reversed and similar observations were made. Next, for the purpose of making a better examination of the tube in detail, the induction plate I was lowered to that distance which gave as large a deflection for the difference of potential between the two ends of the tube as was convenient. After the potentials of the several rings had been measured in succession with both currents, the induction plate was restored to its original position, and one or two of the first observations were repeated for confirmation. The current was then varied by altering the resistance in circuit,* and fresh measurements made in the same order. Thus the following values were obtained :—

I. Circuit :—2400 rod-cells, 1 megohm resistance, tube 150. Induction plate at 2 inches distance from the quadrant.

	Current +	Differences.	Current −	Differences.
Zero	6 right= 0		6 right= 0	
Full potential (open circuit)	154 left=160	1	200 „ =194	2
(closed „)	153 or 4 „ =159	47	198 „ =192	65
Potential at ring 1	106 „ =112		133 „ =127	
„ „ 2	96 „ =102		108 „ =102	
„ „ 3	not observed		100 „ = 94	
„ „ 4	„		95 „ = 89	
„ „ 5	„	112	89 „ = 83	127
„ „ 14	26 left=32		not observed	
„ „ 15	20 „ =26		25 right= 19	
„ „ 16	16 „ =22		20 „ = 14	
„ „ 17	6 right= 0		6 „ = 0	

II. Circuit varied by substituting 800,000 ohms for the 1,000,000 ohms of wire, and inserting liquid resistance No. 3 (Part I., page 64) between the wire resistance and ring 1.

	Current + 1st Observation.	2nd Observation.	Mean Differences.
Zero	5 right= 0	5 right= 0	
Full potential (open circuit)	159 left=164	159 left=164	1
„ (closed „)	159 or 8 „ =163	158 „ =163	19·5
Potential after 800,000 ohms	139 „ =144	138 „ =143	27
„ at ring 1	112 right=117	111 „ =116	
„ „ 2	not observed	103 „ =108	
„ „ 3	„	97 „ =102	
„ „ 4	„	90 „ = 95	116·5
„ „ 15	„	25 „ = 30	
„ „ 16	„	18 „ = 23	
„ „ 17	5 right= 0	5 right= 0	

* This method of varying the current is arranged to save time. The circuit must not be interrupted in the course of a set of observations.

Current—

	1st Observation.	2nd Observation.	Mean Differences.
Zero	5 right= 0	5 right= 0	
Full potential (open circuit)	194 „ =189	192 „ =187	1
„ (closed „)	193 „ =188	191 „ =186	25·5
Potential after 800,000 ohms	166 „ =161	167 „ =162	
„ at ring 1	138 „ =133	136 „ =131	132
„ „ 17	5 „ = 0	5 „ = 0	

III. THE induction plate was lowered from 2 inches to $1\frac{1}{2}$ inches. Current—. (The current+ was not observed for want of time.)

Ring	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Readings	276	217	200	187	174	159	144	130	116	104	90	76	62	48	35	22	0
Differences	59	17	13	13	15	15	14	14	12	14	14	14	14	13	13	22	

The observation III. illustrates that which has already been said concerning the fall of potential within the tube.

It will be noticed in case I. that there was a greater difference between the scale readings with positive and with negative currents than that which would result from the mere fact of the different poles being to earth. This was caused by torsion in the suspension arising from an imperfection in the arrangement of the instrument not at that time discovered. This does not, however, sensibly affect the following deductions :—

In case I. we have for the currents in Webers—

$$C+=\frac{\frac{47}{160}\times 2400\times 1{\cdot}03}{1{,}000{,}000}=0{\cdot}0007261, \text{ and } C-=\frac{\frac{65}{194}\times 2400\times 1{\cdot}03}{1{,}000{,}000}=0{\cdot}0008281,$$

and for the difference of potential in volts (V) between the two ends of the tube—

$$(C+)\ V=\tfrac{112}{160}\times 2400\times 1{\cdot}03=1730, \text{ and } (C-)\ V=\tfrac{127}{194}\times 2400\times 1{\cdot}03=1618.$$

These differences of potential would be reproduced if for the tube were substituted metallic resistances in ohms (R)—

$$(C+)\ R=\tfrac{112}{47}\times 1{,}000{,}000=2{,}383{,}000, \text{ and } (C-)\ R=\tfrac{127}{65}\times 1{,}000{,}000=1{,}954{,}000.$$

In case II.—

$$C+=\frac{\frac{19\cdot5}{164}\times 2400\times 1{\cdot}03}{800{,}000}=0{\cdot}0003674, \text{ and } C-=\frac{\frac{25\cdot5}{188}\times 2400\times 1{\cdot}03}{800{,}000}=0{\cdot}0004190.$$

$$(C+)V=\tfrac{116\cdot5}{164}\times 2400\times 1{\cdot}03=1756, \text{ and } (C-)V=\tfrac{132}{188}\times 2400\times 1{\cdot}03=1736.$$

$$(C+)R=\tfrac{116\cdot5}{19\cdot5}\times 800{,}000=4{,}780{,}000, \text{ and } (C-)R=\tfrac{132}{25\cdot5}\times 800{,}000=4{,}142{,}000.$$

Selecting the observations with the current positive in each case and placing these in juxtaposition thus—

	C	V	R
Case I.	0·0007261	1730	2,383,000
„ II.	0·0003674	1756	4,780,000

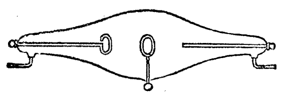
we see that when C is varied in the ratio of 2 : 1, V remains sensibly constant, R varying as 1 : 2; that is to say, though the current is halved the difference of potential between the ends of the tube remains constant—a condition which could only be brought about when metallic resistance is substituted for the tube, by doubling this resistance.

This points to the important conclusion that *other things being kept constant* and the current alone varied, we should find the value of V *strictly* constant for all values of C; but it may readily be imagined that in experiments with 'vacuum tubes' it is not easy to ensure perfect constancy of the accompanying circumstances.

To test this conclusion we extended the range of our observations by varying the value of C as much as from 1 to 135. We give below the original measurements themselves, not the mean results, in order that the discrepancies in the readings obtained for V when C was kept as constant as our powers of control permitted, may be compared with the variations, such as they are, in the values of V when the circuit was purposely varied so as to produce currents of different strengths. These observations show clearly that discharge through rarefied gases cannot be at all analogous to conduction through metals; for a wire having a given difference of potential between its ends can permit one—and only one—current to pass; whereas, we see from the following measurements that with a given difference of potential between the terminals of a given vacuum tube, currents of strengths varying from 1 to 135 can flow. We are therefore led to the conclusion that the discharge in a vacuum tube does not differ essentially from that in air and other gases at ordinary atmospheric pressures—that it is, in fact, a disruptive discharge.*

Fig. 42.

Tube 31



* See Appendix, note B.

RESULTS of observations with tube 31 (fig. 42), CO_2, January 17–18, 1878.

	Circuit.							Observation.	C.	V.
I.	2400 cells, tube 31, 1,000,000 ohms (wire), a certain liquid resistance							*a*	182	
								b	156	533
								c	184	552
								d	207	511
								e		552
II.	,,			,,	less	,,	,,	*a*	349	497
								b	349	511
								c		511
III.	,,	,,	,,	,,	,,	,,	,,	*a*	539	380
								b		475
								c	454	521
								d	481	
IV.	,,	,,	,,	,,	,,	,,	,,	*a*	1,568	478
								b	1,463	429
								c	1,536	416
								d	1,536	468
								e		442
V.	,,	,,	,,	,,	No	,,	,	*a*	1,998	460
								b		381
								c	2,053	409
VI.	,,	,,	600,000	,,	. . . .			*a*	3,208	416
								b	3,089	412
								c	3,199	421
VII.	,,	,,	400,000	,,	. . . .			*a*	3,964	400
								b	4,139	445
VIII.	,,	,,	200,000	,,	. . . .			*a*	8,584	453
								b	8,584	424
IX.	,,	,,	100,000	,,	. . . .			*a*	14,900	428
								b	15,390	466
								c	15,360	450
X.	1200	,,	20,000	,,	. . . .			*a*	24,030	435
								b	23,910	449

RESULTS of observations with tube 150 (page 165, fig. 41), January 28, 1878.

Circuit.					C.	V.
3600 cells	50,000	ohms	and tube 150		2,300	413
,,	150,000	,,	,,		1,260	386
,,	300,000	,,	,,		787	367
,,	400,000	,,	,,		625	370
,,	500,000	,,	,,		518	360
,,	600,000	,,	,,		435	367
,,	700,000	,,	,,		374	367
,,	800,000	,,	,,		331	366
,,	900,000	,,	,,		291	373
,,	1,000,000	,,	,,		267	365
,,	,,	,,	,,		269	373
,,	,,	,,	,,		266	369
,,	,,	,,	,,	and liquid resistance	203	352
,,	,,	,,	,,	more ,,	40	505
,,	,,	,,	,,	,, ,,	43	497
,,	,,	,,	,,	,, ,,	50	439
,,	,,	,,	,,	,, ,,	31	482
,,	,,	,,	,,	,, ,,	35	465
,,	,,	,,	,,	,, ,,	17	357

The results for tube 31 are given in microwebers (millionths of a weber) and volts: those for tube 150 are left in terms of the electrometer.

By fixing small rings of tinfoil to the glass near the places where the metal terminals are fused into the tube and connecting these rings to earth, we were able to cut off the leakage over the surface (which, in spite of precautions, is considerable,) and prevent it from interfering with our measurements of the potential of the gas *inside* the tube. The condition of the *outside* of the tube appears to have been the subject of much investigation by other observers: our experience points to the absolute necessity of cutting off leakage in order to obtain correct information concerning induced charges on the outside of the tube.

In a paper published in 1870 (Proc. Roy. Soc. vol. xix. p. 237), Mr. C. F. VARLEY stated: "The following laws were found to govern the passage of the current:—1st, each "tube requires a certain potential to leap across; 2nd, a passage for the current having "been once established a lower potential is sufficient to continue the current; 3rd, "if the minimum potential, which will maintain a current through the tube, be P, and "the power be varied to P+1, P+2, &c. to P+n, the current will vary in strength, "as 1, 2, &c. n. . . . It thus appears that a certain amount of power is necessary to "spring across the vacuum; after that it behaves as an ordinary conductor, excluding "that portion of the battery whose potential is P, and which is used to balance "the opposition of the tube."

Laws 1 and 2 are confirmed by our daily experience, but the experiments which then led Mr. VARLEY to the conclusion that, with a certain reservation, a "vacuum tube" behaves as an ordinary conductor, lend themselves as additional proof of the constancy of the difference of the potentials of the terminals of the tube. The essential part of Mr. VARLEY's arrangement being a battery, of internal resistance r, joined by a resistance R to one terminal of a tube, the other terminal of which is connected to the other pole of the battery, then if $P+n$ be the difference of potential produced by the battery, and P the constant difference of potential between the terminals of the tube, the current must vary as $\frac{(P+n)-P}{R+r}$ or, if R be kept constant and large enough to render variations in r negligible, C varies as n.

From these results recently obtained, it follows that what, in the following account of experiments of earlier date, is termed the "resistance of a tube," must not be considered as analogous to metallic resistance : it indicates merely that the difference of potential between the terminals of the tube was the same as that between the ends of a wire of the given resistance when substituted for the tube in the particular circuit.

THE HISTORY OF SOME TUBES.

No. 129, *Hydrogen.*

We now give an account of the very great variety of phenomena presented by the same tube charged with hydrogen, No. 129, under different conditions of exhaustion when used in connexion with batteries of various potentials, and traversed by currents of different strengths.

This tube is 32 inches long and 1·6 inch in diameter, the terminals are a bent wire and a ring, about 1 inch in diameter, both of aluminium ; it is furnished with a glass stop-cock at each end as represented in fig. 37, No. 144. The glass stop-cocks are connected with the mercurial pumps (ALVERGNIAT and SPRENGEL) and with the gas generator respectively, as shown in fig. 35.

During the course of the experiments about to be described several casualties occurred to the tube ; for example, the partial fusion and distortion, first of the ring, then of the bent wire terminal ; and by an accident the glass cocks were broken off and reattached. Notwithstanding these accidents, the same phenomena were again and again obtained under like conditions.

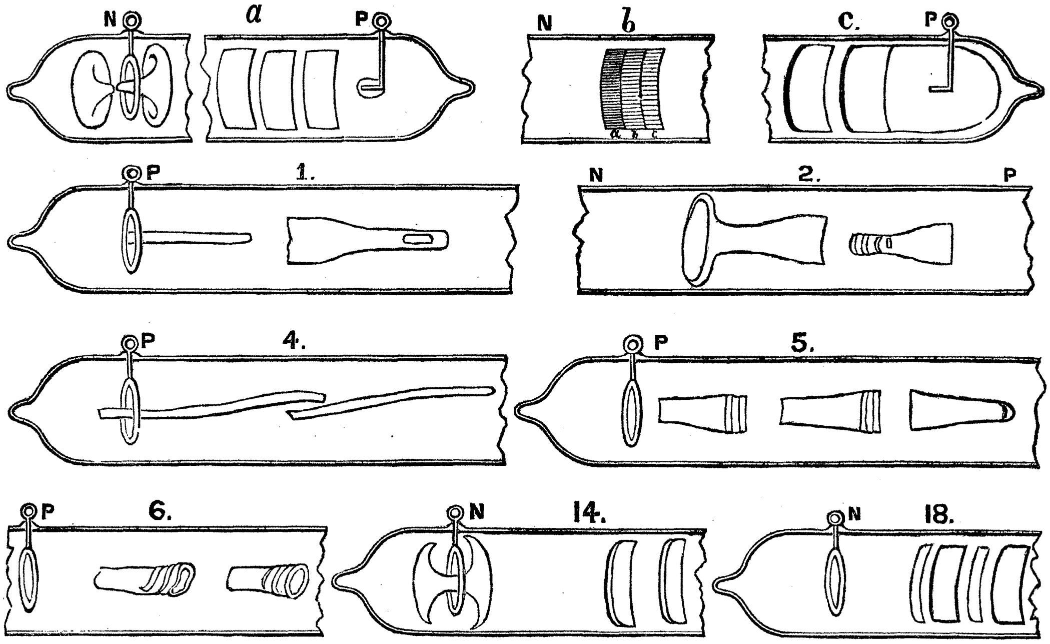
The experiments with 129 were commenced on July 1, 1876 ; great precautions were taken to thoroughly rinse out the air by completely exhausting the tube and filling it with dry hydrogen several times. The hydrogen was obtained by the solution of very pure rod zinc, like that used for the batteries, in diluted pure sulphuric acid in the proportion of 1 part of acid to 10 of water. It was dried by pumice moistened with sulphuric acid, and then with rods of hydrate of potash.

Tube 129, 1*st Charge of Hydrogen.*

Experiment 1.—Pressure 2 m.m. (millimetres), 2632 M (millionths of an atmosphere), 2400 rod cells, (C.*) 0·014210 W. Discharge agitated, the strata about 0·5 inch apart.

2.—Pressure 1·2 m.m., 1579 M, 2400 rod cells, (C.) 0·014210 W. Strata in forms like the right-hand portion of 59, fig. 46, every now and then assuming the tongue-like formation 57, fig 46.

Fig. 43.



3.—Pressure 0·2 m.m., 263 M. The current of 1080 powder cells would not pass, but that of 1200 rod cells did so, producing strata, and the peculiar discharge entering the negative ring, as shown at *a*, fig. 43, (C.) 0·007631 W, with

200,000	ohms	external resistance,	(C.) 0·003414 W;	there were 25 strata
300,000	,,	,,	(C.) 0·002675 W,	,, 24 ,,
400,000	,,	,,	(C.) 0·002200 W,	,, 23 ,,
500,000	,,	,,	(C.) 0·001866 W,	,, 22 ,,
600,000	,,	,,	(C.) 0·001622 W,	,, 21 ,,
700,000	,,	,,	the current would not pass,	

with 3,600 cells and,

6,500,000 ohms	,,	(C.) 0·000567 W,	there were still 21 strata.

4.—The exhaustion was carried still further, but as we did not at that time possess the McLeod gauge, which has been more recently attached to the

* C, when within brackets indicates that the value of the current, given in Webers, was obtained *approximately* by calculation; when not within brackets it indicates that the current was directly observed.

pumps, we cannot give the precise pressure; with 1200 rod cells, and an external resistance of 500,000 ohms (C.) 0·02414 **W**, there were 21 strata, as *b*, fig. 43, composed each of three differently coloured layers, the convex one, *a*, being blue bordered by a line of green, the middle, *b*, white, and the concave layer, *c*, reddish.* To the eye these strata were quite steady, but when examined with the rotating mirror, the blue convex layer was steady, while the reddish layer was shown to be flowing towards the negative. This phenomenon was better seen with 2400 rod cells, and an external resistance of 6,700,000 ohms, (C.) 0·000368 **W**.

5.—2400 cells and no external resistance, (C.) 0·014210 **W**. The illumination completely filled the tube, but with 500,000 ohms external resistance, (C.) 0·004718 **W**, there was a dark space of 7 inches between the last stratum and the negative pole.

6.—The exhaustion carried further. The current of 1200 cells passed intermittently, but with 2400 cells broad strata seven in 6 inches, were produced as in *c*, fig. 43, which, without resistance, at first extended to within 2 inches of, and then reached the negative pole.† With 5,670,000 ohms resistance the stratification became confused towards the positive pole.

7.—On carrying the exhaustion still further, the strata were fainter, bluer, and wider.

8.—After three more cistern-fulls of mercury had run through the SPRENGEL, the current of 2400 cells would not pass, and 3600 only gave a faint blue glow which pervaded the whole tube with indications of strata 2 inches broad, which the rotating mirror showed to be flowing towards the negative.

Air having through inadvertence been allowed to enter the tube, it was refilled with hydrogen and again exhausted.

Tube 129, *2nd Charge of Hydrogen.*

9.—Pressure 16 m.m., 21,053 **M**. 4800 cells at first passed, but it almost immediately afterwards required 8040 cells. The ring being positive, curiously formed luminous entities shot at intervals from it, remained stationary for a time, and then disappeared, to be replaced by others: the flow, as seen in the mirror, was towards the negative. The phenomena are depicted in 1, fig. 43.

The ring positive was illuminated with a red glow, the luminosities being bluish grey.

10.—Pressure 15 m.m., 19,737 **M**, 8040 cells. The luminosities produced are

* The tube having been subsequently re-attached to the pump when the McLEOD gauge was in connexion with it, the phase was reproduced at a pressure of 0·157 m.m., 207 **M**, 2400 cells, C. 0·01047 **W**.

† The phase was subsequently reproduced at a pressure of 0·046 m.m., 61 **M**, C. 0·00681 **W**.

shown in 2, fig. 43. The tube became very hot* in the immediate neighbourhood of the luminosities, which were very steady, but was much cooler at the negative and positive terminals, especially at the latter.

11.—Pressure 13 m.m., 17,105 M, 8040 cells. Luminosities were produced as the right hand diagram in 2, fig. 43 ; these were very blue, accompanied with great heat in their neighbourhood. In the rotating mirror the flow was seen to be towards the negative.

12.—The following day, the pressure being still 13 m.m., 8040 cells gave intermittent worm-like luminosities, 4, fig. 43, with the point negative : these did not occur when the point was positive.

13.—Pressure 12·2 m.m., 16,053 M, 8040 cells. The luminosities as in 5, fig. 43, when the point was negative. The flow of the luminosities was shown by the rotating mirror to be towards the negative. There was much heat developed in the neighbourhood of the luminosities, but little heat at the positive terminal, while the negative remained quite cool.

14.—Pressure 10·8 m.m., 14,211 M. Luminosities as in 6, fig. 43, which reminded one of a fish's mouth, especially as they opened and closed continually : they extended along 9 inches of the tube.

15.—Pressure 7·5 m.m., 9868 M, 8040 cells. 10 luminosities like the right-hand of diagram 2, fig. 43, but more pointed, the apex being agitated like the preceding fish-mouths.

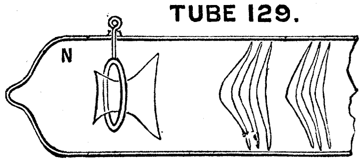
16.—Pressure 6 m.m., 7895 M, 5640 cells. The luminosities still more pointed; there was heat in the vicinity of the luminosities : 3240 just passed but the luminosities were confused.

17.—At a pressure of 1 m.m., 1316 M, the most beautiful phase of all was produced as shown in fig. 44, in some of its chief features; the current used was that of 2160 powder cells, (C.) 0·011520 W. The strata grouped themselves in threes and reached to within 6 inches of the negative ring; when 200,000 ohms resistance was introduced, (C.) 0·005658 W, the dark space extended to 9 inches. Only a portion of the luminosity about the negative ring is shown in the diagram ; besides this, the ring was surrounded with a

* DE LA RIVE (Archives Sci. Phys. Nat., xxvi., pp. 202–207) investigated the temperature of rarefied gases during the electric discharge. He employed a tube 160 m.m. long and 40 m.m. in diameter, with copper balls 10 m.m. in diameter for terminals. A pair of thermometers, whose mercury reservoirs were cylinders 30 m.m. long and 2·5 m.m. in diameter, were inserted each at a distance of 10 m.m. from its terminal. The conclusions drawn by him from his experiments are (i) that a sensible elevation of temperature accompanies the discharge in rarefied gases; (ii) that this elevation is sensibly less in the neighbourhood of the negative than near the positive electrode, provided that the gases are sufficiently rarefied, that the discharge passes easily, and that the light is stratified ; (iii) that the absolute elevations near the two terminals and the differences of elevation vary with the density and nature of the gas. DE LA RIVE remarks that these investigations are not to be confounded with those which have been made by GASSIOT concerning the temperature of the terminals themselves.

cylindrical nebulosity of about a $\frac{1}{4}$ inch in diameter, and a glow filled up the end of the tube.

Fig. 44.



18.—Pressure 0·4 m.m., 526 M, 1200 cells. Strata produced resembling the four on the right of 58, fig. 46; the convex part being blue and the concave part pink; the last stratum, nearest to the negative, had two points; the negative ring was enveloped in a cylindrical nebulosity, pink close to the terminal, the strata reached within 5 inches of the negative terminal. There was seen in the rotating mirror a rapid flow *towards the positive.*

19.—Pressure 0·2 m.m., 263 M, 1200 cells, 100,000 ohms resistance. 16 perfectly steady grey strata like 14, fig. 43, a blue line on the convex face and pink on the concave, the negative discharge like that in the same figure. With 900,000 ohms resistance the number of the strata changed to 14.

20.—Pressure 0·2 m.m., 263 M, 1200 rod cells. 39 strata were produced as in 14, fig. 43, when 400,000 ohms resistance was in circuit, the convex side being blue and the broader concave side reddish, they extended to within 5 inches of the negative. With 50,000 ohms resistance, (C.) 0·005830 W, there were 34 strata. The luminosity at the negative is correctly shown in the diagram; no flow of strata could be detected by the rotating mirror, the image remaining steady.

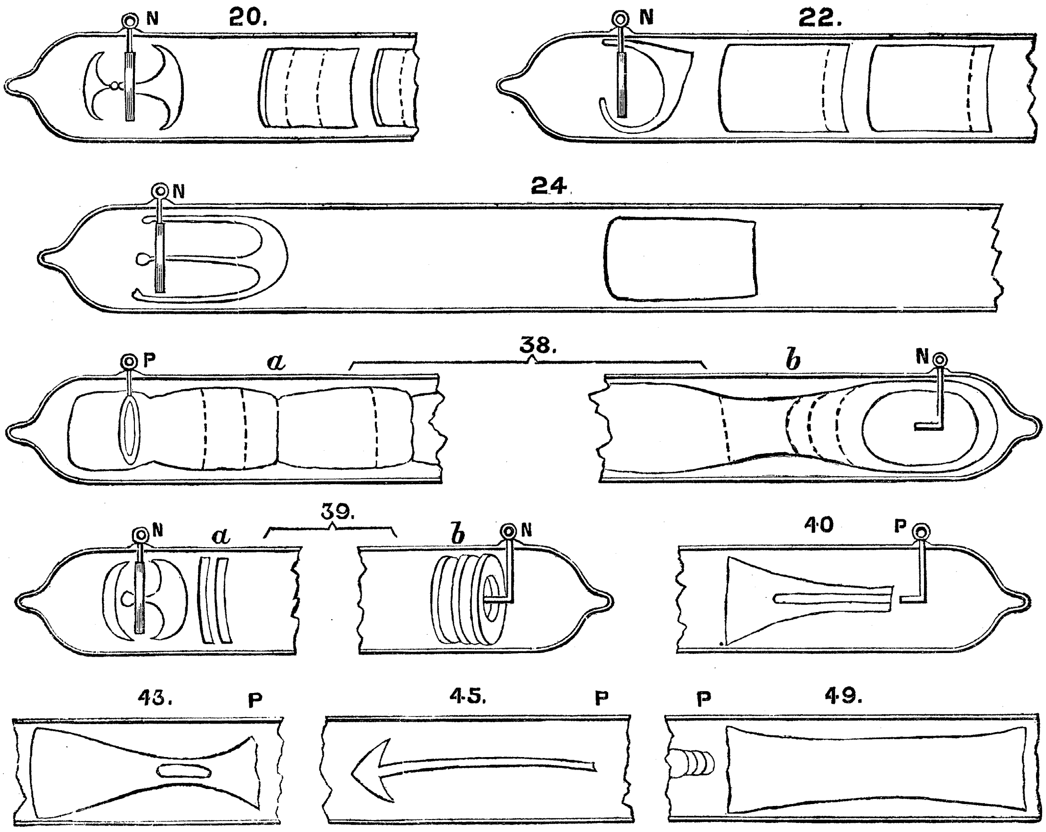
21.—Pressure about 0·1 m.m., 132 M, 1200 cells, 500,000 ohms resistance. 21 strata as 14, fig. 43, very blue on the convex face, pink on the concave, the glow on the terminals pink. Observed with the rotating mirror the strata were steady, but from time to time secondary strata formed as 18, fig. 43, which were seen to flow towards negative.

22.—The vacuum carried further by running $\frac{1}{3}$rd of a cistern-full of mercury through the pump; 1200 cells. 21 very blue strata, like *a*, fig. 43; with 100,000 ohms, still 21 strata; with 500,000 ohms, 22 strata; with 900,000 ohms the strata became like spheroids, being bounded on both sides by a convex face.

23.—The exhaustion was carried further, but the pressure was not measurable with our then means, the gauge appearing to stand higher than the barometer. The current of 1200 rod cells, (C.) 0·00763 W, did not pass very readily, and the strata were unsteady; the introduction of 50,000 ohms resistance, (C.) 0·005830 W, rendered them steady; they were 19 in number, and from time to time narrower strata introduced themselves between those first formed, as shown in 18, fig. 43. The introduction of 900,000 ohms caused the strata to widen out and to fill the space occupied by the secondary strata.

24.—After 10 cistern-fulls had run through it required a potential of 2400 cells to pass, the strata were $1\frac{1}{2}$ inch wide, and a sort of hour-glass luminosity appeared at the negative, as shown in 20, fig. 45. At times the luminosity left the centre of the negative ring and jumped towards the wall of the tube, as shown in 22, fig. 45.

Fig. 45.



25.—At the 12th cistern-full the strata became $1\frac{1}{2}$ inch wide, but at times divided into two; one peculiarity observed was that the pink was on the convex side towards the negative and not as before noticed on the concave side.* The luminosity at the negative hugged the wall of the tube whether the point or the ring was positive. The phenomena are shown in 22, fig. 45. After a while 2400 rod cells only faintly illuminated the tube, and it required 3600 to continue the phase.

26.—At the 13th cistern-full 3600 cells would scarcely pass, only causing a faint glow in the tube, and it required 5880 to produce any strata; without

* The phase was subsequently reproduced at a pressure of 0·390 m.m., 513 M, C. 0·01451 W.

external resistance there were 10 very broad strata which extended from the positive to within 5 inches of the negative; the discharge at the negative was tri-furcated. The phenomena are shown in 24, fig. 45.

27.—At the 14th cistern-full the current of 6960 cells would not pass at first, but, after the charge of 8040 had been sent through, 5880 were sufficient. With 500,000 resistance 8 strata were produced as in 24, fig. 45. With 8040 cells the broad strata were crossed by bright lines not more than 0·1 inch apart. On the end of the central point of the negative discharge there was produced a pink half hour-glass addition, the point of which joined on to it at the centre of the ring. The two points of the negative discharge close to the tube were very sensitive to the approach of the finger.*

28.—At the 16th cistern-full it required 6960 cells to pass at first, but afterwards the tube became hot,† and the current of 2400 passed, the discharge taking place most readily when the point was negative. The phenomena were as in 20, fig. 45. The flow was from positive to negative.

29.—At the 17th cistern-full 5880 cells passed, but 6960 gave the best effect: 9 strata like 24, fig. 45, slightly pink, near the negative. The F line was seen with the spectroscope. A slow flow from the positive was seen with the rotating mirror. The next day the current of 2400 cells passed, producing a confused stratification; 3600 produced a more steady one. The negative discharge left the centre of the ring and hugged the side of the

* In his 'Notice sur l'appareil d'induction de Ruhmkorff, et les experiences qu'on peut faire avec cet instrument, 3me édition, Paris, 1857,' Du Moncel claims to have been the first to announce the attraction of the luminous discharge to the wall of the vacuum chamber when this is touched by the finger. Quet et Sequin ('Comptes Rendus,' xlvii., 1858, pp. 964–967) describe the effect of approaching the hand or a ring of tinfoil to a vacuum tube: the bright strata widen out on that side of the hand or tinfoil which is towards the positive terminal, and at the edge of the tinfoil, on the same side, a large dark space occurs—the phenomenon being best seen when the hand or tinfoil is near the positive terminal; on sliding the hand *towards* the positive the strata re-enter each other, but on sliding the hand *from* the positive they issue out again. Gassiot (Brit. Assoc., Aberdeen, vol. xxix. (sect.), p. 155), in speaking of strata being very sensitive to the finger in a cylinder 4½ inches in diameter and with the terminals 20 inches apart, says: "On the four fingers being placed in succession on the stratification they disappear in succession, and may be separated to a considerable distance by placing both hands on two separate portions of the cylinder."

† Frequently during the course of experiments with the tube 129 and others, when *highly* exhausted, it has required many cells to pass in the first instance, but when the tube had become heated a much smaller number sufficed.

Gassiot has also found that warming the tube promotes the passage of a current, and with regard to very low temperatures makes the following statement (Phil. Trans., 1859, p. 146):—"In a Torricellian vacuum which gave good cloud-like strata no change occurred when cooled to +32° Fah., but at −102° Fah. all traces of strata disappeared as well as the red glow around the negative; a glow throughout the tube remained. On heating the tube to the boiling point of mercury +600° Fah. the strata were likewise destroyed. When the mercury was frozen the stratifications disappeared, but a magnet made them reappear."

tube. On approaching the finger it was repelled to the opposite side of the tube, and sometimes split into two portions, one on each side of the finger.*

30.—At the 19½ cistern-full 3600 would not pass, 4800 sufficed when the point was negative; 7 broad strata crossed with lines of narrower strata not more than 0·02 inch wide and distant. A zone of intensely blue light, 0·25 inch broad, lined the inside of the tube around the point when negative. With 8040 cells the discharge was rustling when the point was positive, and if the primary of APPS's induction coil 819 was connected in circuit, a tell-tale tube being connected to the secondary, the tell-tale became illuminated, indicating an intermittent current.

31.—At the 22nd cistern-full, 4800 cells, no material change, except that between the blue zone and the end, the tube was filled with a pink glow, and that after a time even 8040 cells would not pass except when the point was negative; but the next day 2400 cells passed in either direction even with an external resistance of 4,900,000 ohms, gas having probably been given off from the glass walls.

32.—At the 29th cistern-full 8040 cells passed only when the point was negative, a milky light filling the whole tube; heat was generated at the negative, very great in proportion to the light.

33.—After 39 charges of the cistern had been sent through the SPRENGEL pump (since the vacuum had attained 0·2 m.m.) the current of 8040 cells would only pass after the contact with the battery had been maintained for some time and both ends of the tube alternately breathed upon; in fact, the current had to be coaxed through it.† There were 9 barrel-shaped strata produced as shown in 38, *a* and *b*, fig. 45; the illumination was very feeble, and no lines could be made out with the spectroscope either in the strata or the luminous glow around the negative terminal, in this case the straight wire. Examined with the hand spectroscope the spectrum appeared indeed to be nearly continuous. In the course of our experiments we have often observed great changes in the spectrum of hydrogen as the exhaustion became greater, the C line, for example, is the first to get faint and then to disappear.‡

34.—The tube had now a small charge of hydrogen let into it, which raised the pressure to 0·5 m.m., 658 **M**. 2400 rod cells with 500,000 ohms resistance in circuit, (C.) 0·004718 **W**, produced 54 beautiful steady strata, some of which threaded themselves on the straight wire when it was made negative, exactly as in the case of GEISSLER's tube 123 before alluded to; *b*, 39,

* The phenomenon was re-observed at a pressure of 0·038 m.m., 50 **M**, C. 0·00631 **W**.

† The limit of 8040 was subsequently attained at a pressure of 0·016 m.m., 21 **M**.

‡ The variation in the spectrum of the same gas under different circumstances has engaged the attention of several physicists—notably of HITTORF and PLÜCKER (Phil. Trans. clv., 1865, pp. 1–30).

fig. 45, shows the appearance when the straight wire was negative, and *a* when it was positive. For a few seconds about 15 strata at the positive end became pink, all the others being grey; afterwards the strata in the middle of the tube were grey, those at each end being pink. The spectroscope did not show the F line distinctly. 4800 cells caused so much heat that the ring became red-hot and opened out and formed a sort of hook, as in 55, fig. 46.

Tube 129, *3rd Charge of Hydrogen.*

35.—Pressure 15·6 m.m., 20,526 M. At first the current of 4800 rod cells passed, giving a glow both at the positive and negative terminals; subsequently 5880 cells were necessary, and there shot across slowly from the positive the luminous entity 40, fig. 45. At first only 1 entity was formed, then 2, then 3, and lastly 4, the heat was great in their immediate vicinity; they flowed from positive to negative, and when the hand was approached as if to grasp them they receded from it towards the positive. After a short time a few strata were formed in the luminosities, as in 104, fig. 46. Ultimately 8040 cells were necessary, and the current only passed when the point was negative.

Tube 129, *4th Charge of Hydrogen.*

36.—Air being suspected, the tube was again filled with hydrogen and gradually exhausted; at 38 m.m., 50,000 M pressure, it was ascertained by means of the illumination of a tell-tale tube, No. 82, placed in the circuit, that a current of 8040 cells was passing when no illumination of the terminals of tube 129 could be seen, but possibly it may have passed on the outside of the tube. No. 82 has a resistance of only 16,000 ohms. Very soon afterwards, as the exhaustion was being continued by means of the water *trompe*, the terminals became illuminated.

37.—Pressure 13·5 m.m., 17,763 M, 8040 cells. One luminosity like 43, fig. 45, darted from either ring (distorted now like a hook) or straight wire, if positive, when it had reached the centre of the tube it darted back again. Ultimately 1, then 2, then 3 luminosities were produced. Great heat was evolved in the neighbourhood of these luminosities. In the spectrum the hydrogen lines C and F were very visible and air lines absent.

38.—Pressure 8·5 m.m., 11,184 M, 4800 cells. A glow about 4 inches long emanated from the positive, and then, intermittently, worm-like luminosities were formed as in experiment 12, but with this difference, that the worm-like entities were double one over the other nearly parallel to the axis of the tube.

39.—Pressure 7·8 m.m., 10,263 M. With 6960 cells, but better with 8040, (C.) 0·042430 W, 16 luminosities resembling closely fig. 6, Plate 15, when 700,000 ohms resistance was introduced in the circuit, (C.) 0·008322 W, 3 arrow-headed luminosities were produced, each 4 inches long, the first adhering to the straight wire, positive, 45, fig. 45.

40.—Pressure 6·6 m.m., 8684 M, 8040 cells. 19 luminosities something like the fifth and sixth luminosities from the positive in fig. 7, Plate 15. The F and C lines were seen with the spectroscope, especially in the glow around the negative.

41.—Pressure 5·6 m.m., 7368 M, 4800 cells. 12 luminosities like fig. 6, Plate 15.

42.—Pressure 3·9 m.m., 5132 M, 4800 cells, 200,000 ohms resistance, (C.) 0·012420 W. 10 luminosities, part of one of which is depicted on the left of 49, fig. 45. From time to time there arose in the centre of the tube a concave spindle-like formation, 49, fig. 45, which gradually extended itself to both poles, and absorbed all the luminosities. Examined with the spectroscope the C and F lines were brilliantly seen in the glow around the negative terminal, but were not visible in the spectrum of the nebulosities, notwithstanding that they were brighter than the negative glow ; there were blue, green, and red visible, but not the characteristic green and red lines of hydrogen.

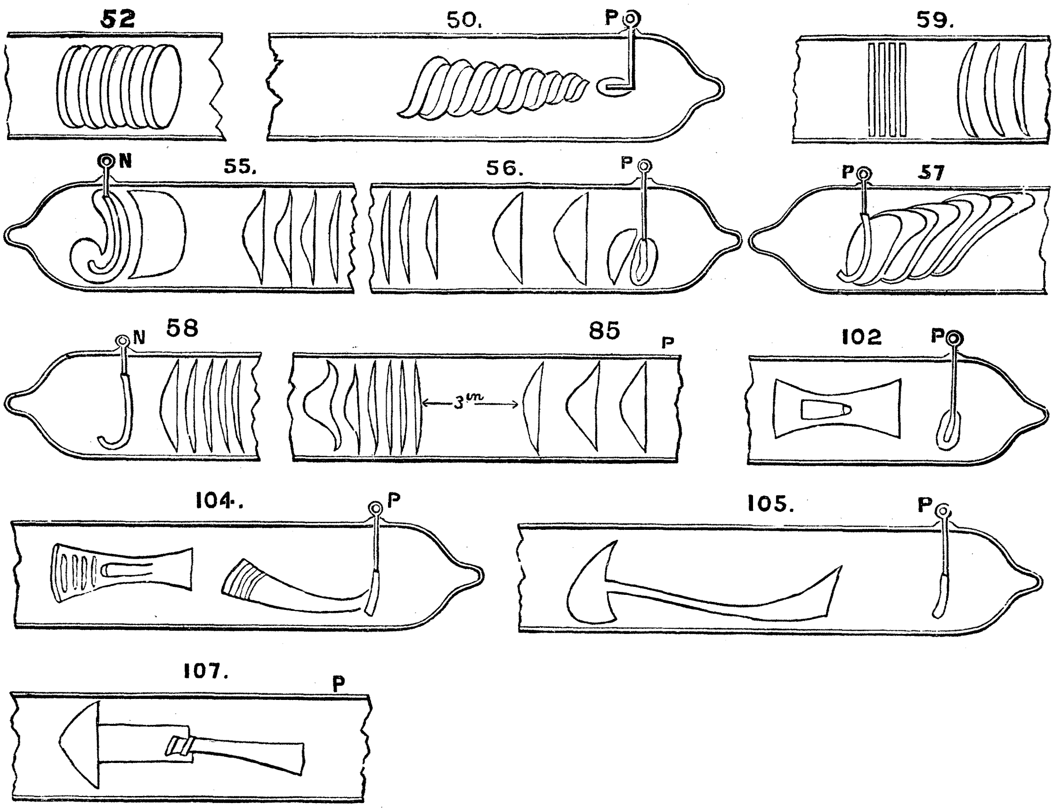
43.—Pressure 3·1 m.m., 4079 M, 4800 cells, (C.) 0·024970 W. A very curious phenomenon was presented, which has repeated itself on several occasions ; at first the plane of the strata cut the tube at right angles, the strata being perfectly steady. An agitation was afterwards visible, and the strata arranged themselves diagonally as in 52, fig. 46, and almost immediately an agitated spiral* was formed, as 50, fig. 46, at the positive, extending nearly the whole length of the tube, but there were at the negative two or three saucer-shaped steady strata convex towards it. In the rotating mirror it was seen that there was a steady flow towards the negative. The characteristic hydrogen lines were very brilliant when the spectroscope was directed to the glow around the negative terminal, but quite a different spectrum was seen on a bright stratum, with mercurial lines in the orange. Shortly after this, the current being very great, the bent wire was heated to redness and fell down as in 56, fig. 46.

44.—Pressure 1·2 m.m., 1579 M, 3600 rod cells, (C.) 0·019940 W. A beautiful formation of 72 saucer-shaped strata from the positive, one of which is seen as about to detach itself, the other strata were less convex towards the middle of the tube, and lip-shaped near the negative, all being of a fine cobalt blue colour, 55, 56, fig. 46 ; on introducing 250,000

* Gassiot (Phil. Trans., 1858, p. 4) describes a somewhat similar appearance, thus (in a Torricellian vacuum) : " As the mercury ascends in the tube the stratified discharge from the positive wire collapses, giving the appearance of a compressed spiral."

ohms resistance, (C.) 0·008504 **W**, they immediately became tongue-shaped and quite pink, 57, fig. 46; with 700,000 ohms, (C.) 0·004184 **W**, 113 perfectly steady pink strata were formed, and with 1,000,000 ohms, (C.) 0·003125 **W**, 90 strata, also pink, 58, fig. 46; with 6,900,000 ohms,

Fig. 46.



(C.) 0·000523 **W**, the tube was filled with paper-like strata 0·05 of an inch apart of a dull pink; with 12,000,000 ohms, (C.) 0·000304 **W**, they widened out to a distance of 0·2 inch, and were about 0·125 inch broad.

The tube was now removed from the pump and retained the characteristic property of showing blue strata with a large current, and changing to pink as resistances were introduced.*

Unfortunately, one of the glass cocks was accidentally broken off from 129, but the tube was repaired and again attached to the pumps on November 18, 1876. A series of experiments were made with it, the already described phenomena being reproduced, and many of them photographed.

Up to this time (August 4th, 1876) we had not made direct measurements of the currents passing in the tubes at the time of observing the

* According to Du Moncel, the change of colour on the introduction of resistance was first noticed by Ruhmkorff.

phenomena, but had merely taken observations of the deflections of the galvanometer with the batteries short-circuited, thus :—

May 25th, 1876,	3240 powder cells	. .	gave	C.	0·03251	W.
Aug. 4th, ,,	,, ,, ,,	. .	,,	,,	0·03858	,,
May 25th, ,,	2400 rod ,,	. .	,,	,,	0·12200	,,
Aug. 4th, ,,	4800 ,, ,,	. .	,,	,,	0·10410	,,
,, ,, ,,	8040 powder and rod cells		,,	,,	0·04901	,,

Tube 129, 5*th Charge of Hydrogen.*

45.—A glow at both terminals was first seen when the pressure was 17·2 m.m., 22,632 M, with 8040 cells, and great heat developed in the dark discharge near the middle of the tube. The spectroscope showed faintly the C and F lines.

46.—Pressure 16·5 m.m., 21,710 M, 8040 cells current. 1 luminosity like that on the right hand of 5, fig. 43, shot out from the positive and approached to within 6 inches of the negative, then receded back and disappeared.

47.—Pressure 15·8 m.m., 20,789 M, 8040 cells. 3 luminosities, very steady, like 5, fig. 43, which moved slowly and steadily towards the negative. The tube hottest in dark part where there was probably a non-luminous entity.

48.—Pressure 14 m.m., 18,421 M, with 6840 cells, the current was unsteady, but it was perfectly steady with 8040, and 6 arrow-headed luminosities like that on the left of 107, fig. 46, were produced and soon disappeared.

49.—Pressure 10·3 m.m., 13,552 M, with 8040 cells. 8 luminosities something like 1, fig. 43.

50.—Pressure 9·4 m.m., 12,368 M, with 8040 cells. 12 luminosities like those, fig. 7, Plate 15. The C and F lines seen in the glow around the negative.

51.—Pressure 7·7 m.m., 10,132 M, with 8040 cells. 10 luminosities like fig. 6, Plate 15, these ran together and disappeared and reappeared in a few seconds.

52.—Pressure 6·6 m.m., 8684 M, with 8040 cells. 12 luminosities very similar to those shown at fig. 5, Plate 15, the last adhering to the positive. The C line not visible in a nebulosity with the spectroscope, but that and the F line were both to be seen in the glow around the negative.

53.—Pressure 5·9 m.m., 7763 M, 8040 cells, C. 0·02056 W. 13 luminosities like those fig. 6, Plate 15. With 100,000 ohms, C. 0·01390 W, there were 10 luminosities not so wide as those when there was no resistance.

54.—Pressure 6·1 m.m., 8026 M, 8040 cells, C. 0·01910 W. At first 13 luminosities a little unsteady, then $11\frac{1}{2}$ perfectly steady, like fig. 6, Plate 15. F and C visible in the glow around negative. F was not visible in a luminosity.

55.—Pressure 4·4 m.m., 5789 **M**, 8040 cells. 12 luminosities as depicted in fig. 6, Plate 15, which is copied from a photograph* obtained in 4 seconds.

56.—Pressure 4·0 m.m., 5263 **M**, 8040 cells. 15 luminosities as shown in fig. 7, Plate 15, taken from a photograph in 4 seconds.

57.—Pressure 3·6 m.m., 4737 **M**, 8040 cells, 30,000 ohms resistance. 15 luminosities almost touching, like fig. 7, Plate 15.

58.—Pressure 3 m.m., 3947 **M**, 4800 cells, C. 0·0362 **W**, the resistance of the tube being 88,600 ohms. There were 24 steady blue strata and a space of about 6 inches confused towards the positive; with 200,000 resistance in the circuit the strata became pink, the current being 0·01469 **W**.

59.—Pressure 1 m.m., 1316 **M**, 3600 cells, C. 0·03896 **W**, the resistance of the tube being 59,170 ohms. The tube was filled to within 1 inch of the negative with strata as in 85, fig. 46; all these were blue, but they turned pink and tongue-shaped when 200,000 ohms resistance was introduced, which reduced the observed current to 0·00782 **W**. The C and F lines visible in the luminosities. When 7,590,000 ohms resistance was introduced, a very close and somewhat agitated pink stratification was produced, like the left hand of 85, fig. 46.

60.—Some gas let in, pressure 3 m.m., 3947 **M**, 3600 cells gave a current of 0·04901 **W**; the resistance of the tube was ascertained by substituting 47,000 ohms wire resistance, which produced the same deflection. The strata were blue, like those of 55 and 56, fig. 46. For about 10 inches from the negative they took up an axial backwards and forwards steady rotation of about a quarter turn. With 174,000 ohms resistance, making with the battery and tube a total of 261,000, the current measured was 0·00879 **W**. The strata turned pink and assumed the tongue-form 57, fig. 46; with 783,000 ohms in circuit very close strata like the left hand of 85, fig. 46. In the rotating mirror a flow *towards the positive* was observed until a break occurred in the stratification; the flow was then irregular and backwards and forwards.

61.—Pressure 1·7 m.m., 2237 **M**. The current of 2400 cells passed: with 3600 cells the current was 0·03858 **W**, producing perfectly steady strata of which a photograph was obtained in four seconds; a facsimile of it is given, fig. 8, Plate 15. The strata were blue, but on introducing 500,000 resistance the current was reduced to 0·00175 **W**, and the strata turned pink and assumed the form fig. 9, Plate 15, which is a facsimile of a photograph obtained in 19 seconds.

62.—Pressure 0·8 m.m., 3600 cells (C.) 0·19940 **W**. A spiral series of tongues depicted in fig. 10, Plate 15, from a photograph which, however, could

* VARLEY, C. F. (Proc. Roy. Soc., xix., 1871, pp. 238–239) succeeded in photographing by an exposure of thirty minutes an *arch discharge* in a vacuum tube, so faint that in a perfectly dark room he was "sometimes unaware whether the current was passing or not."

scarcely be exposed long enough in consequence of the screw-like motion of the tongues. This motion appeared to be from positive to negative.* On introducing 900,000 ohms resistance, (C.) 0·003414 W, the tongues grouped themselves in pairs, of which there were 40, and changed from blue to pink. Examined with the spectroscope the line C had disappeared. The tube was connected with the condenser of 42·8 microfarads and 3240 cells, a resistance of 200,000 ohms being in circuit, (C.) 0·007461 W, the apparatus was arranged as in fig. 26, Part I. At the full potential, the same spiral series of blue tongues, quite steady, was produced, and these made a complete rotation in 30 seconds. On breaking connexion between the battery and condenser, the strata gradually changed to pink as the charge of the condenser ran down through the tube. A break-contact (direct) current was observed with the galvanometer in connexion with the secondary wire of coil 819, through the primary of which the current was made to pass; this tending to show that there was a pulsation of rapid decrease and gradual increase of flow through the tube.

Tube 129, *6th Charge of Hydrogen.*

63.—The tube, at 0·9 m.m., was partially charged with hydrogen by letting in 4 small calibrated charges, which increased the pressure each time 1·4 m.m., pressure 6·5 m.m., 8684 M, the resistance of the tube was found to be 170,000 ohms, and the total resistance of the whole 8040 cells, 130,000 ohms, or an average of 16·6 per cell. With 6960 cells the current, through the tube alone, was 0·02456 W, and there were produced 9 luminous entities as shown in fig. 5, Plate 15, taken from a photograph obtained in 1½ second.

64.—The gas in the tube at the same pressure, namely 6·5 m.m., 8040 cells, C. 0·02634 W. There were 7 entities as depicted in fig. 4, Plate 15, copied from a photograph obtained in one second.

65.—Pressure 6·5 m.m., on the introduction of 300,000 ohms resistance with 8040 cells, C. 0·0138 W, making a total resistance, inclusive of the tube and the battery, of 600,000 ohms, two luminosities were produced as seen in fig. 2, Plate 15, taken from a photograph obtained in two seconds, which, however, had to be corrected from a drawing, as there was a slight movement in the luminosities.

* De la Rive (Genève Mém. Soc. Phys. xvii., 1863, p. 72) describing the appearance of a nitrogen tube, says: "ces stries semblent former une hélice animée d'un mouvement de rotation autour de son axe."
Quet ('Comptes Rendus', xxxv., pp. 949–952) remarks that the apparent undulations and rotations of the strata vanish when single discharges are examined separately; the strata are then seen to have a fixed position throughout the entire column. [These phenomena are, however, distinct from that of experiment 62. D. and M.]

66.—Pressure 3·6 m.m., 4737 **M**, 4800 cells. Strata resembling 58, fig. 46, but near the negative the strata were indistinct. In the rotating mirror the distinct strata were steady, but in the indistinct portion there was indicated a rapid flow *towards the positive.* The lines C, F, and G seen in the glow around negative terminal, but C and G were not seen in the strata.

67.—Pressure 1·2 m.m., 1579 **M**, 2400 cells, C. 0·03251 **W**. 11 narrow strata, umbrella-shaped, about $\frac{3}{4}$ of inch wide, followed by two about $1\frac{1}{4}$ inch wide, then a confused discharge, in which the rotating mirror showed a rapid flow *towards the positive.* C, F, and G lines visible in the negative glow; G and C disappeared in the strata, and F was very faint.

68.—Pressure 1·9 m.m., 2500 **M**, 3600 cells, C. 0·04256 **W**. A very beautiful phase like 85, fig. 46.

Tube 129, *7th Charge of Hydrogen.*

69.—The tube was again recharged with hydrogen. Pressure 14·3 m.m., 18,816 **M**, 8040 cells. A glow was seen on both terminals.

70.—Pressure 13·8 m.m., 18,158 **M**, 8040 cells, C. 0·00703 **W**. 2 luminosities resembling the right hand of 2, fig. 43.

71.—Pressure 7·6 m.m., 10,000 **M**, 8040 cells. 8 luminosities, like fig. 5, Plate 15.

72.—Pressure 4·5 m.m., 5921 **M**, 8040 cells, C. 0·02881. 15 luminosities like fig. 7, Plate 15. In the glow around the negative terminal G, F, and C lines were seen, the last two brilliantly, but the luminosities gave a continuous spectrum.

73.—Pressure 3·1 m.m., 4079 **M**, 8040 cells, C. 0·03657 **W**. A tendency to the spiral formation 50, fig. 46.

74.—Pressure 1·2 m.m., 1579 **M**, 8040 cells, C. 0·04686 **W**. Strata like 58, fig. 46.

75.—Pressure far below 1 m.m., 8040 cells, C. 0·01412. 8 thickened strata like 22, fig. 45.

76.—The exhaustion carried still further. 8040 only passed with a faint glow, producing no deflection of a galvanometer which could indicate a current of 0·00024 **W**. The secondary current of APPS's induction coil 821 passed, producing 6 thick strata like 22, fig. 45.

Tube 129, *8th Charge of Hydrogen.*

77.—Pressure 11·5 m.m., 15,132 **M**, 8040 cells, C. 0·00993. At first the tube was only faintly illuminated at the two terminals, with a barely visible glow throughout the tube, which became heated in the middle, then one luminosity formed at the positive 102, fig. 46. This moved several inches from it, and then returned to it again to move slowly away, the current was still 0·00993 W. The calculated resistance of the tube at this pressure is 688,900 ohms.

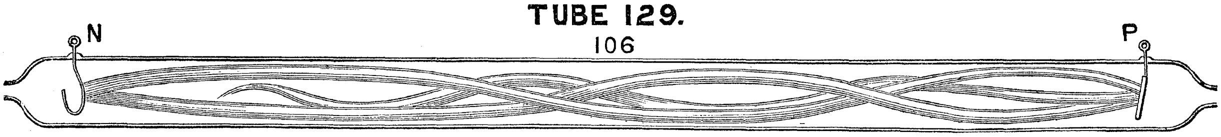
78.—Pressure 10·1 m.m., 13,289 M, 8040 cells, C. 0·00993 W. At first only a glow at both terminals, the tube became hot in the middle, a barely visible glow throughout the tube; then one luminosity as shown on the left of 104, fig. 46, which travelled slowly to within 3 inches of the negative, and was followed by a second luminosity, as seen in the same figure. The C and F lines could be seen with the spectroscope in the glow around the negative terminal, the spectrum of a nebulosity was nearly continuous.

79.—Pressure 10·2 m.m., 13,421 M, 8040 cells, C. 0·01158 W. One arrow-headed nebulosity, 105, fig. 46; the resistance of the tube was 570,000 ohms.

80.—The tube in the same state; the induced current of APPS's coil, No. 821, producing a 6-inch spark, passed like the streamer discharge of the battery in air, as shown in Part I., page 88, fig. 16. The discharge in the tube is shown in fig. 47, which brings out strongly the effect of great difference of potential on the phenomena, and also supports the hypothesis that the discharge in partially exhausted tubes is of the same nature as through air at ordinary atmospheric pressure—a disruptive one.*

Fig. 47.

TUBE 129.



81.—Pressure 8·1 m.m., 10,658 M, 8040 cells, C. 0·01331 W. 7 luminosities, part of them arrow-headed, arranged in a wavelike formation, the nebulosity nearest the positive entering one of the arrow-headed ones next to it, as shown 107, fig. 46. The resistance of the tube was 477,000 ohms.

82.—Pressure 6·8 m.m., 8947 M, 8040 cells, C. 0·0184 W. 10 nebulosities similar in character to 107, fig. 46. Resistance of the tube 304,900 ohms.

83.—Pressure 4·3 m.m., 5658 M, 5880 cells, C. 0·02371 W, resistance of the tube 175,100 ohms. 13 luminosities were obtained like fig. 7, Plate 15. The G, F, and C lines were visible in the glow around the negative terminal, but they were not visible in the nebulosities.

84.—Pressure 1 m.m., 1316 M. 2400 cells passed, with 3600 the current was 0·03251 W, the same phase as 85, fig. 46.

* GASSIOT (Phil. Trans., 1858, p. 5) describes a similar discharge as a wavy line. His tube, when cooled by a freezing mixture of ice and hydrochloric acid, gave striæ.

Tube 129, 9*th Charge of Hydrogen.*

85.—Pressure 14·1 m.m., 18,533 M, 8040 cells, C. 0·00335 W. A glow from the positive extending for $\frac{2}{3}$ the length of the tube; it began to taper down about half the length of the tube, and then great heat was developed at its extremity.

86.—Pressure 12 m.m., 15,789 M. A luminosity formed on the positive, like 102, fig. 46; it then travelled nearly to the negative and returned slowly to the positive. After a while another luminosity partly stratified, formed behind the first at the positive, but ultimately disappeared. Finally the luminosity took the form of 104, fig 46, and was partially stratified, it moved towards the negative when the markings became more pronounced, but when returning to the positive the markings disappeared.

87.—Pressure 2 m.m., 2632 M, 3600 cells, C. 0·01272 W. The phase was obtained which is shown in fig. 11, Plate 15, copied from a photograph taken in 7 seconds.

The tube was accidentally broken on January 23rd, 1877, and although it has been successfully mended it has not been re-filled, as the pumps have been occupied with other experiments.*

Tube 129, *Air.*

88.—Pressure 8·7 m.m., 11,447 M, 8040 cells. A continuous nebulous discharge, most brilliant at the positive wire, a patch of nebulous light on the negative ring.

89.—Pressure 5·5 m.m., 7237 M, 8040 cells. Three nebulous luminosities like 1, fig. 48.

90.—Pressure 2·4 m.m., 3158 M, 4800 cells. A continuous glow extending from the positive to the negative, in which the rotating mirror did not show any structure, C. 0·02320 W.

91.—Pressure 1·2 m.m., 1579 M, 3600 cells. Two or three strata formed at the extremity of the nebulous discharge near the negative.

* May 20th, 1878. This tube has since been re-attached to the pump, and several of the foregoing experiments have been repeated. The effect of running successive cisternfulls of mercury through the pump after the pressure had attained 0·18 m.m. was found to be as follows:—

1st cisternfull reduced the pressure to	0·085 m.m.,	112 M,	3,600 cells,	C. 0·01451 W,	21 strata.
2nd ,, ,, ,,	0·038 ,,	50 ,,	,, ,,	,, 0·00631 ,,	15 ,,
3rd ,, ,, ,,	0·019 ,,	25 ,,	7,760 ,,	,, 0·02131 ,,	20 ,,
5th ,, ,, ,,	0·011 ,,	14 ,,	,, ,,	,, 0·01705 ,,	17 ,,
8th ,, ,, ,,	0·008 ,,	11 ,,	8,040 ,,	,, 0·01331 ,,	indistinct.
9th ,, ,, ,,	0·003 ,,	4 ,,	11,000 ,,	,, 0·01639 ,,	faint.
10th ,, ,, ,,	0·002 ,,	3 ,,	,, ,,	,, 0·01840 ,,	,,

92.—Pressure 0·5 m.m., 658 **M**, the current of 2400 rod-cells passed. With 3600, C. 0·03071 **W**, there was a nebulous discharge from the positive almost reaching the negative, near which a few strata were formed. On disconnecting the battery the *gas* in the tube was observed to be phosphorescent and the phosphorescence continued for 6½ seconds.* The nebulous discharge was salmon coloured, not at all like the red discharge of a nitrogen vacuum.

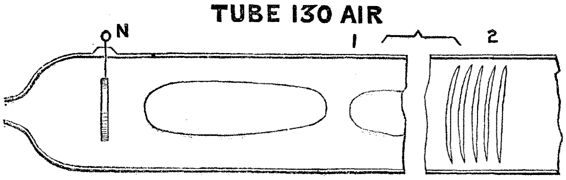
93.—Pressure had increased without leakage to 0·6 m.m., 789 **M**, 2400 cells, with 200,000 ohms resistance, C. 0·00527 **W**. There were produced, commencing at the positive wire, 21 well defined and perfectly steady strata, about 1 inch thick, like *c*, fig. 43, very bright at the convex face: the glow round the negative was cylindrical. The resistance of the tube was reproduced by the insertion of 90,000 ohms in place of the tube.

Tube 130, *Air.*

94.—Tube 130, charged with air and exhausted to a pressure of 8 m.m., 10,526 **M**, 8040 cells. One luminosity from the ring when positive, about 12 inches long.

95.—Pressure 4 m.m., 5263 **M**, 8040 cells. A continuous nebulous discharge, carmine in colour, from the point positive, reaching nearly to the negative where there was formed a separate luminosity, as represented in 1, fig. 48; with 200,000 ohms in circuit, the nebulous discharge from the positive separated into two luminosities making, with that at the negative, three in all.

Fig. 48.



96.—Pressure 3·5 m.m., 3605 **M**, 8040 cells. Strata were produced as in 2, fig. 48, but the discharge was confused in the greater part of the tube.

* GASSIOT (Dec. 1858—Phil. Trans. 1859, p. 137) says, "in some tubes (GEISSLER'S) for several seconds after the discharge had ceased the tubes remained throughout their entire length phosphorescent."

About the same time BECQUEREL, whose attention had been directed to this phenomenon by RUHMKORFF, communicated the result of his observations to the *Académie des Sciences* ('Comptes Rendus,' xlvii., 1859, pp. 404–406). The subject has since been investigated and discussed by MORREN ('Comptes Rendus,' liii., 1861, pp. 794–795); SARASIN (Archives Sci. Phys. Nat. xxxiv., 1869, pp. 243–254; Ann. de Chim. xvii., 1869, pp. 501–502; Poggend. Annal. cxl., 1870, pp. 425–434); DE LA RIVE ('Comptes Rendus,' lxviii., 1869, 1237–1238; Ann. de Chim. xix., 1870, pp. 191–192); HITTORF (Ann. de Chim. xvii., 1869, pp., 487–496), and others.

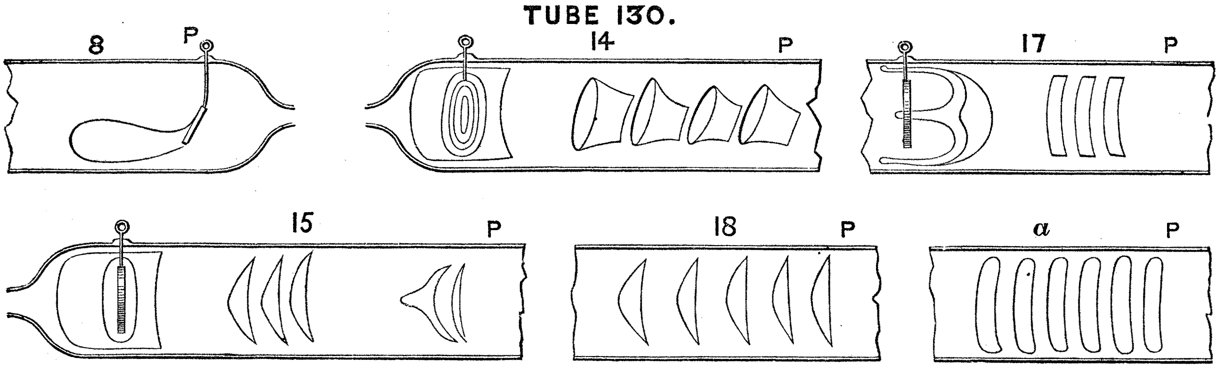
Tube 130, *Hydrogen.*

97.—The tube was exhausted and filled ten times successively with dry hydrogen. Pressure 18 m.m., 23684 M, 8040 cells. There were specks of light visible at both terminals but the discharge in the tube was non-luminous, great heat being developed about the middle of the tube.

98.—Pressure 13·7 m.m., 18,026 M, 8040 cells. There was one luminosity at the ring positive. Connected with the secondary of an induction coil instead of a battery, there was a streamer discharge like that produced under similar circumstances in tube 129, 106, fig. 47.

99.—Pressure 11·8 m.m., 15,526 M. Still one luminosity, 8, fig. 49; in the rotating mirror the reflection appeared like a fine diaper pattern, indicating a rapid motion in alternate directions.

Fig. 49.



100.—Pressure carried down by successive steps to 5·6 m.m., 7368 M, 8040 cells. The tube was filled with a nebulous discharge crossed by paper-like stratifications, the current was intermittent. The C, F, and G lines visible with the spectroscope in the nebulous illumination of the negative terminal, but the C and G lines were not visible in the strata; with 700,000 to 900,000 ohms resistance the nebulous discharge broke up into three distinct luminosities.

101.—Pressure 2·4 m.m., 3158 M, 3600 rod cells, strata like 17, fig. 49, in shape, but closer and agitated; a flow seen in the mirror *towards the positive.*

102.—Without any external leakage, the pressure had increased the following day to 3 m.m., 3947 M, 3600 rod cells; luminosities as depicted in 14, fig. 49, extended half the length of the tube towards the positive, the second half on the positive side being filled with nebulous ill-defined strata; the discharge on the ring, negative, being cylindrical.

103.—Pressure 1·2 m.m., 1579 M, 3600 rod cells. This was the first occasion of regular steady strata being observed with this tube, as shown in 15, fig. 49, resembling those seen in tube 129, 55 and 56, fig. 46, at the same pressure. It is curious that up to this pressure tube 130 had throughout only given agitated discharges, and had shown no signs of distinct well-formed luminosities. The only difference between tubes 129 and 130 is that the latter has a diameter of 1·75 inch, or 0·125 inch less than that of the former; it is 32 inches long, 28 inches between the terminals. The strata were blue, with the exception of the first and second from the negative, which, as well as the cylindrical glow on and about the negative, were pink. With 1,000,000 ohms resistance the strata turned pink. It was noticed that on first closing the circuit the strata were agitated, but after a while they became steady, the tube in the meantime becoming heated.

104.—Pressure 1·0 m.m., 1316 **M**, 3600 rod cells, 200,000 ohms resistance in circuit, steady blue strata like the three middle ones in 15, fig. 49. With 1 megohm resistance the strata became pink.

105.—Pressure 0·2, 263 **M**, 2400 cells, C. 0·04686 **W**, 34 steady blue strata were produced, which extended to within $7\frac{1}{2}$ inches from the negative, this space being dark, see 17, also *a*, fig. 49. On introducing 200,000 ohms resistance, C. 0·00879 **W**, the strata turned pink and assumed the form 18, fig. 49. With 500,000 ohms resistance the number was reduced to 21, and with a megohm to 16. The calculated resistance of the tube at the above pressure was 22,170 ohms.

106.—Photographs were taken of the tube, which had been separated from the pump and which underwent some changes; with 3600 cells the strata were blue and 61 in number, as represented in fig. 1, Plate 16, which is copied from a photograph obtained in 11 seconds.

107.—With 700,000 ohms resistance in circuit the strata were reduced to 18, and turned pink. Fig. 2, Plate 16, from a photograph taken in 90 seconds.

108.—Subsequently another change occurred in the phenomena of the tube with 3600 rod cells, the phase being most splendid, and showing 21 double strata intensely blue, but with a *carmine line* between the components.* The tube

* GASSIOT (Brit. Assoc., 1865 (sect.), p. 15): "On the change of form and colour which the stratified discharge assumes when a varied resistance is introduced in the circuit of an extended series of the voltaic battery." [4000 cells carbon and amalgamated zinc, in each cell a table-spoonfull (24 c.c.) of sulphate of mercury]. The resistance in the circuit was a tube $\frac{1}{2}$ an inch in diameter and 3 feet long, filled with water, in which two platinum wires could be inserted to different depths:—

"On depressing the wire small crescent-shaped disks of red light are observed to be rapidly produced in quick succession from the positive pole. Shortening the resistance one by one disappear at the positive until 19 remain; on still lessening resistance two disks near the negative join together, assuming the form of a double convex lens, the side near the *negative being of a slight blue tinge, that towards the positive* was detached November 17, 1876, and now, March 16, 1878, it still shows this beautiful phase. Fig. 3, Plate 16, represents the phenomena; it is copied from a photograph obtained in 40 seconds.

109.—On introducing 900,000 ohms resistance, the same number of cells being used, 26 pink strata were produced, as shown in fig. 4, Plate 16, from a photograph obtained in 90 seconds.

Tube 139, *Air.*

110.—Pressure 13·5 m.m., 17,763 M, 8040 cells. A long nebulous discharge reaching within 6 inches of the ring negative, which was illuminated with a cylindrical glow, the intervening space being non-luminous.

Tube 139, 1*st Charge of Hydrogen.*

111.—Pressure	5·9 m.m.,	7763 M,	8040 cells, C. 0·02007 W.		
,,	3·0 m.m.,	3947 M,	the current of 4800	cells passed.	
,,	2·0 m.m.,	2632 M,	3600	,,	
,,	0·9 m.m.,	1184 ,,	2400	,,	
,,	0·6 m.m.,	789 ,,	,,	,,	
,,	0·03 m.m.,	39 ,,*	,,	,,	
,,	,, ,,	,, ,,	,,	,,	with 4,000,000 ohms.
,,	0·01 m.m.,	13 ,,	3600	,,	

112.—Pressure 0·03 m.m., 39 M, 2400 cells, 4,000,000 ohms resistance, a phase was produced resembling 11, Plate 16.

Tube 139, 2*nd Charge of Hydrogen.*

113.—Pressure 16·7 m.m., 21,974 M, 8040 cells, just passed.

114.—Pressure 14·9 m.m., 19,605 M, 8040 cells, C. 0·00386 W. A glow extending from the positive half the length of the tube.

115.—Pressure 12 m.m., 15,789 M, 8040 cells. One luminosity as 3, fig. 50,

a reddish fawn, and the centre a brilliant red colour. As resistance is decreased two successively join. When resistance is removed all the 19 striæ assume the double convex form, the red central line continuing. . . . . On the sides of the tube where four or five of the disks near the negative impinge there remained a black deposit."

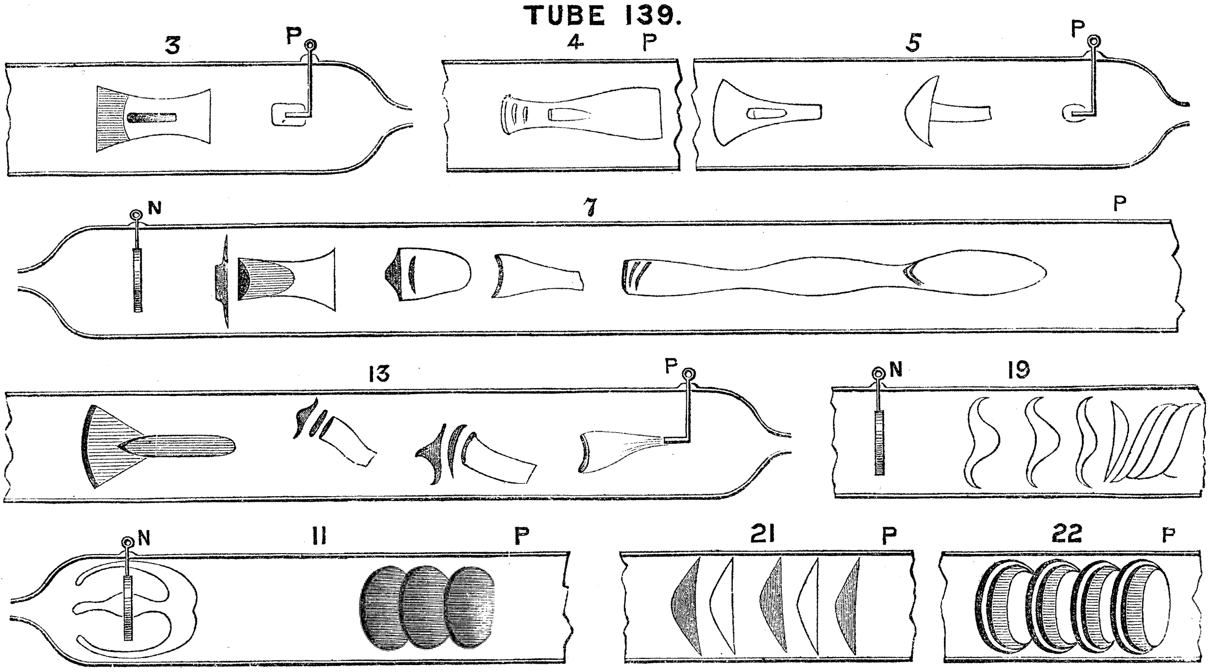
* Jan. 11, 1877. We had at that date the McLeod gauge connected with the pumps.

reminding one of 102, fig. 46, which shows a phase of tube No. 129 at 11·5 m.m., 15,132 M.

116.—Pressure 10 m.m., 13,158 M, 8040 cells. The luminosity assumed the form 4, fig. 50, closely resembling tube 129 at 10·1 m.m., 13,289 M, the left of 104, fig. 46.

117.—Pressure 9·04 m.m., 11,895 M, 8040 cells, C. 0·01412 W. Two luminosities as 5, fig. 50, recalling tube 129, at a pressure of 9·1 m.m., 11,974 M, 107, fig. 46, but in the latter the arrow-headed precedes the other luminosity.

Fig. 50.



118.—Pressure 6·319 m.m., 8314 M, 8040 cells. Three arrow-headed luminosities as depicted in fig. 3, Plate 15, copied from a photograph and a drawing made at the time. The photograph was obtained in 2 seconds.

119.—Pressure 4·1 m.m., 5395 M, 6960 cells, C. 0·0232 W. The luminosities as depicted in 7, fig. 50; the first near the negative having a peculiar flat-hat-like form, behind which are some strata convex towards the positive.

120.—The exhaustion was continued, but no regular strata could be obtained until the pressure had fallen to 0·823 m.m., 1082 M, when with 2400 cells strata, twelve in number, like the first on the left in 21, fig. 50, were produced, the rest of the discharge towards the positive being confused.

121.—Pressure 0·518 m.m., 682 M, 2400 cells. Nineteen saucer-shaped strata were formed, and from time to time fainter strata flashed in between them, the phenomena resembling fig. 5, Plate 16.

122.—Pressure 0·12 m.m., 158 **M**, 2400 cells, C. 0·01772 **W**. Only a nebulous discharge, but on introducing 500,000 ohms thick strata were produced, as 11, fig. 50; the discharge at the negative ring was trifurcated, the central arm passing through the centre of the ring.

123.—Pressure 0·03 m.m., 39 **M**. The current of 3600 cells passed.

Tube 139, 3*rd Charge of Hydrogen.*

124.—Pressure 9·331 m.m., 12,276 **M**, 6960 cells, C. 0·00703 **W**. One luminosity like tube 129, 40, fig. 45.

125.—Pressure 8·548 m.m., 11,249 **M**, 6960 cells, C. 0·01234 **W**. Four luminosities arranged in serpent-like form, as shown in 13, fig. 50.

126.—The pressure had risen without any leakage to 9·502 m.m., 12,526 **M**, 6960 cells. One luminosity like that on the left hand in 13, fig. 50. A photograph was obtained in 10 seconds but has not been copied. Another photograph obtained in 1 minute is shown in fig. 1, Plate 15; it will be observed that it has a spear-head continuation towards the negative.

127.—Pressure 6·562 m.m., 9344 **M**, 6960 cells. 10 luminosities like those in fig. 5, Plate 15. These ran together to form only two, and separated again into ten, the mouth-like ends towards the negative being in continual vibration.

128.—Pressure 4·615 m.m., 6073 **M**, 5880 cells, C. 0·02693 **W**. A series of luminosities, the first near the negative ring being the flat-hat-shape like 7, fig. 50, the remainder like fig. 7, Plate 15.

129.—Pressure 3·291 m.m., 4330 **M**, 5880 cells, C. 0·00939 **W**. Strata curiously curved, some with a concavity towards the negative, the remainder having a tendency to arrange themselves in a spiral, 19, fig. 50. The current of 4800 cells passed, but that of 3600 would only do so when the point was negative.

130.—Pressure 1·304 m.m., 1717 **M**, 2400 rod cells, C. 0·02136 **W**. Umbrella-shaped strata well defined towards the negative, but confused towards the positive.

131.—Pressure 1·244 m.m., 1637 **M**, 2400 cells, C. 0·01561 **W**.

132.—Pressure 0·401 m.m., 528 **M**, 2400 cells. Umbrella-shaped, slightly unsteady strata were obtained, between which other fainter ones introduced themselves from time to time: this phase is shown at 21, fig. 50, and also in the copy of a photograph, obtained in 10 seconds, fig. 5, Plate 16: these strata were blue. The same phase was obtained in experiment 121 at a pressure of 0·518 m.m. By the introduction of 700,000 resistance, C. 0·00088 **W**, 23 strata were obtained of a pink colour perfectly steady, as represented in fig. 6, Plate 16, copied from a photograph obtained in 20 seconds. The strata altered in form, afterwards becoming like 22, fig. 50, the convex face being green, the middle blue, and the concave face reddish. The C and F lines were seen with the spectroscope directed on the glow around the negative.

133.—Pressure 0·3425 m.m., 451 M, 2400 rod cells, C. 0·01272 W. Strata like those in tube 129, *a*, fig. 43, obtained with a pressure estimated at 0·2 m.m., 263 M, but which we had not then the means of measuring. With 200,000 ohms resistance current was reduced to 0·00580 W.

134.—Pressure 0·2608 m.m., 343 M, 2400 cells, C. 0·01102 W. A phase produced as shown in fig. 8, Plate 16, copied from a photograph obtained in 40 seconds.

135.—Pressure 0·1204 m.m., 158 M, 3600 cells, C. 0·01771 W. A phase as shown in fig. 10, Plate 16, copied from a photograph obtained in 27 seconds.

136.—Pressure 0·1103 m.m., 145 M, 3600 cells, C. 0·01575 W. A phase of 23 strata as shown in fig. 9, Plate 16, copied from a photograph obtained in 15 seconds.

137.—Pressure 0·051 m.m., 67 M, the current of 3600 cells passed intermittently; 4800 cells, C. 0·00191 W, produced a continuous illumination from the positive to within 3 inches of the negative, the discharge at the negative licking the inside of the tube as in fig. 11, Plate 16.

138.—Pressure 0·01 m.m., 13 M, the current of 4800 rod cells just passed: with 6960 cells the current produced no appreciable deflection of our galvanometer which would indicate 0·00024 W. The strata, it will be perceived, have thickened and become much wider as shown in fig. 11, Plate 16, copied from a photograph obtained in 7 seconds. The discharge at the negative licked the side of the tube and was very sensitive to the approach of the finger.

139.—By standing 16 hours the pressure had somewhat increased without leakage having occurred, and was 0·037 m.m., 49 M, 6960 cells, current less than 0·00024 W; the discharge was milky white and quite different from anything before seen with a hydrogen residual charge. The strata had become still broader, as seen in fig. 12, Plate 16, copied from a photograph, the negative discharge hugging the tube and being very sensitive to the finger. The C and F lines could not be seen with the spectroscope, but there was a double green line near *b*.

140.—A charge of hydrogen was let in, being the contents of the india-rubber tube between the glass cock on tube 139, and the cock on the four-way junction-piece, F, fig. 35; the charge was 0·001725 of the capacity of the tube and pump, and increased the pressure to 1·311 m.m., 1725 M. 3600 rod cells produced a stratification composed of umbrella-shaped strata, united in the middle of the tube by a luminosity one-third the length of the tube. The double green line near *b* had disappeared and the C, F, and G lines were visible in the spectroscope.

141.—Another calibrated charge of hydrogen was let in and raised the pressure to 2·622 m.m., 3550 **M**; the current of 3600 cells just passed: with 4800 cells a phase was produced resembling tube 129, fig. 7, Plate 15.

142.—Another calibrated charge of hydrogen increased the pressure to 3·933 m.m., 5175 **M**; 4800 rod cells just passed, but it required 5880 cells to produce a steady phase; there were luminosities produced arranged in an irregular spiral, resembling 13, fig. 50.

143.—The pump was worked and the pressure reduced to 2·548 m.m., 3343 **M**, 3600 rod cells, C. 0·02209 **W**. Strata were produced as in 19, fig. 50, with a distinct spiral formation after the first five strata near the negative. These five strata at last assumed a direction in a curved line, and took up a rapid spiral rotation at first from the bottom towards the top of the tube, and afterwards in the opposite direction.

144.—Pressure 0·7836 m.m., 1031 **M**; 1200 cells would not pass; 2400 did; but the best effects were obtained with 4800 rod cells, which gave a current of 0·03251 **W**, producing 17 beautiful and very blue strata, shown in fig. 6, Plate 16, copied from a photograph. In the spectroscope the double line near *b* was seen as well as C and F.

145.—Pressure 0·7626 m.m., 964 **M**, 3600 cells, C. 0·02544 **W**. A phase of tongue-shaped strata, as shown in fig. 7, Plate 16, which is copied from a photograph obtained in 8 seconds.

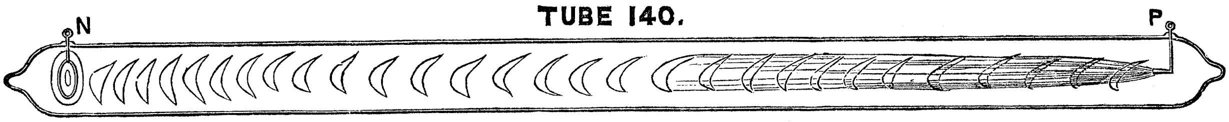
146.—Two calibrated charges let into the tube raised the pressure to 1·033 m.m., 1359 **M**; 3600 cells, C. 0·02825 **W**. 22 strata, in shape like those of 21, fig. 50.

147.—More charges of hydrogen were let in and the pump worked to bring the tube to a good phase, it was then detached from the pump, January 29, 1877, and on March 11, 1878, it had not altered, giving with 3600 cells, C. 0·03368 **W**, 24 beautifully blue strata, and with 300,000 ohms resistance inserted, C. 0·00782 **W**, 18 pink strata.

Tube 140, 29 *inches between the terminals, Hydrogen.*

148.—Pressure 2·402 m.m., 3160 **M**, 5880 cells. A phase like fig. 51, but the strata more agitated towards the positive.

Fig. 51.



149.—Pressure 1·721 m.m., 2264 **M**, 3600 cells, C. 0·10050 **W**. A phase as in fig. 51. The G, F, and C lines seen in the spectroscope.

In consequence of a crystalline deposit having formed in the tube it was detached from the pump in order to ascertain its nature: it was insoluble in bisulphide of carbon, water, alcohol, nitric, hydrochloric, or strong sulphuric acids, but by heating the tube with a spirit lamp, a little strong sulphuric acid having been previously inserted, the substance came off in yellow flakes and proved to be sulphur which was now soluble in bi-sulphide of carbon. It had existed in the first instance in one of its allotropic conditions. It was ascertained that the source of the sulphur was the vulcanized india-rubber junction tube from which it was gradually taken up by the current of hydrogen. This tube was replaced by another, 0·4 inch in diameter with 0·1 inch bore, made of ordinary india-rubber, but it was found necessary, notwithstanding its thickness, to support it by the insertion of a helix of platinum wire 0·0125 inch in diameter.

Tube 132, *Air.*

26 *inches between the terminals,* 1·75 *inch diameter.*

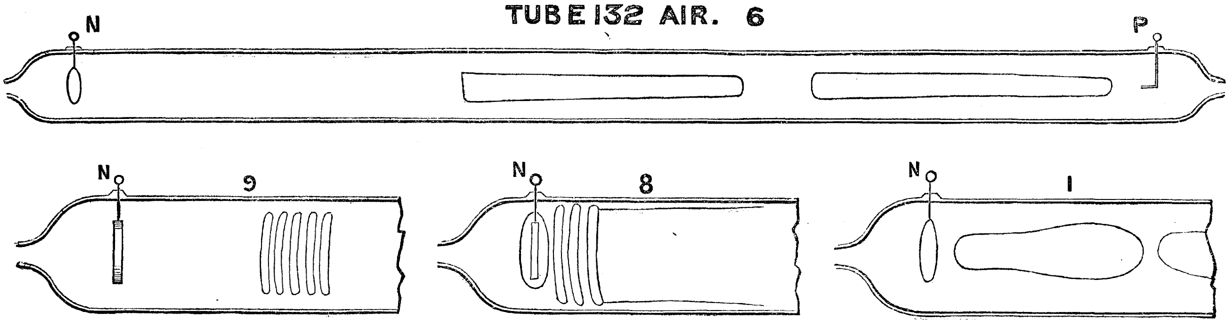
150.—Pressure 13 m.m., 17,105 M, 8040 cells would not pass; pressure 11·6 m.m., 15,263 M, the current just passed.

151.—Pressure 9·3 m.m., 12,237 M, 8040 cells. A faint glow about 6 inches long when the ring was positive.

152.—Pressure 6·3 m.m., 8289 M. 8040 cells passed at first and several luminosities emanated from the positive, but after a while they disappeared and could not be reproduced. The illumination was feeble but the amount of heat generated was great in proportion to the light.

153.—Pressure 6 m.m., 7895 M, 8040 cells. Six luminosities were produced when the ring was positive, as shown in 1, fig. 52.

Fig. 52.



154.—Pressure 4·9 m.m., 6447 M, 6840 cells. Four similar luminosities, 1, fig. 52, which were reduced to two on introducing 500,000 ohms into the circuit. These luminosities issued at the rate of about one per second from the positive, and when there were three, the middle one approached that emanating from the positive and absorbed it, leaving two. The current of 5640 cells would not pass. Similar phenomena were observed when the pressure had been lowered to 3·8 m.m., 5000 **M**.

155.—Nothing worth noting occurred until the pressure had been lowered to 2·1 m.m., 2763 **M**; the current of 3600 cells passed, producing an agitated discharge: the introduction of 50,000 ohms made the discharge steady, and two luminosities, 6, fig. 52, were produced; these pulsated and coalesced to form one, then separated into two; this phenomenon was repeated rythmically at regular intervals.

156.—Pressure 1·1 m.m., 1447 **M**. 2400 rod cells would not pass, but with 3600 there was a continuous luminosity nearly filling the bore of the tube to within a short distance of the negative ring, where there were three strata, 8, fig. 52.

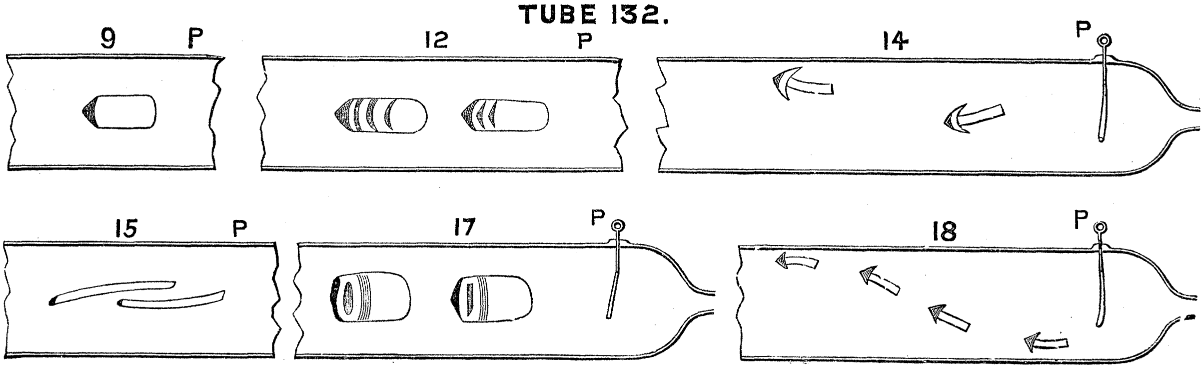
157.—A slight increase of pressure without leakage; pressure 1·2 m.m., 1579 **M**, 3240 powder cells. A rapidly flowing stratification from the negative *towards the positive*, 9, fig. 52.

Tube 132, 1st Charge of Hydrogen.

158.—The tube was filled with hydrogen and exhausted at first with the water *trompe*, which reduced the pressure to within 12 m.m., 15,789 **M** of the barometer. The tube was washed out several times with hydrogen and exhausted between each filling.

159.—Pressure 16·2 m.m., 21,316 **M**. The current of 8040 cells passed illuminating the terminals.

Fig. 53.



160.—Pressure 6·9 m.m., 9079 **M**. 5640 cells produced five luminosities, as 9, fig. 53, which after a time fell off to three, and were slightly trembling. Compare this phase with 1, fig. 52, when at nearly the same pressure the tube was charged with air. The discharges were all agitated, even when the pressure had been reduced to 1 m.m. The cause of this was found to be a broken cell in one of the batteries.

Tube 132, *2nd Charge of Hydrogen.*

161.—After repeated exhaustions, fillings, and re-exhaustions the pressure was reduced to 19 m.m., 25,000 **M**. With 8040 cells there was an intermittent flash of light through the tube, whether the point or ring were positive.

162.—Pressure 11·8 m.m., 15,526 **M**. Three worm-like luminosities with 8040 cells.

163.—Pressure 7·8 m.m., 10,263 **M**, 8040 cells. Eight luminosities as depicted in 12, fig. 53.

164.—Pressure 6·2 m.m., 8158 **M**, 8040 cells. 12 very similar luminosities, but on introducing 500,000 ohms into the circuit they changed to arrow-headed entities, as 14, fig. 53; the introduction of 1,000,000 ohms changed them into parallel worm-like entities, 15, fig. 53. With 4,500,000 ohms resistance all the luminosities disappeared, a nebulous light reaching from the positive half-way towards the negative, the interval between it and the negative being quite free from light. This nebulous light shrank in a few seconds up to the positive and disappeared, leaving a faint glow on the positive terminal. The above description will render evident how great a variety of phenomena may be produced by varying the current through a tube at a constant pressure.

165.—Pressure 4·5 m.m., 5921 **M**. The current of 5640 passed: both with this number, and with 8040 cells the same phenomena were produced without external resistance, namely thirteen beautiful blue luminosities as 17, fig. 53, agitated near the positive, but perfectly steady in other parts of the tube. With 8040 cells and 800,000 ohms resistance, a series of small arrow-headed luminosities arranged themselves in a spiral, as 18, fig. 53. Unfortunately this beautiful tube was spoiled by the accidental breaking off of one of the glass stop cocks, and, though since mended, it has not been refilled, the pumps being required for other work.

Tube 148, *Hydrogen.*

Length 32·5 *inches, distance between the terminals* 28·5 *inches, diameter* 1·75 *inch.*

166.—Pressure 18 m.m., 23,684 **M**, 8040 cells. A tell-tale tube, No. 82, placed in circuit, so as to indicate a current by its illumination, before a visible glow occurred in the large tube. 8040 cells, a current too small to measure, and evident only in the tell-tale tube.

167.—Pressure 10·5 m.m., 13,816 **M**, 8040 cells, C. 0·00580 **W**. Three luminosities with arrow heads arranged in a spiral, like 14, fig. 53, which in a few minutes settled down to one entity, with the characteristic form shown in 3, fig. 50, in the case of tube 139, at a pressure of 12 m.m. There was much heat developed in its immediate vicinity, the remainder of the tube being cool.

168.—Gas was let in, and the pressure raised to 15 m.m., 19,737 **M**, 11,000 cells. No luminosity at the positive, but a faint one at the negative, not unlike 3, fig. 50, in general shape, but twice as long, without any markings of brighter light.

169.—Pressure 13 m.m., 17,105 **M**, 11,000 cells. A serpentine line of light, extending from the positive wire right through the negative ring. In the rotating mirror a flow was observed towards the negative at very different velocities in different parts of the tube, being much more rapid in the half of the tube nearest the positive.

170.—Pressure 7·023 m.m., 9240 **M**, 7760 cells. Current, when point was positive, 0·02289 **W**, when point was negative, 0·02051 **W**. A photograph on a dry plate, obtained in one minute, showing 17 luminosities, like those in tube 129, at 4 m.m., 5263 **M**, fig. 7, Plate 15, Feb. 1, 1878. On March 14th the luminosities were fifteen in number, whether the point or ring was positive. This tube was detached from the pump, in order to retain this particular phase. It bears a record of the position of the luminosities by a metallic deposit in the cooler spaces between them.

Gassiot Tube 342, *Hydrogen.*

171.—This most interesting tube was a favourite of our friend the late Mr. GASSIOT, and was presented by him, with many others, to Mr. SPOTTISWOODE. It retains, in a remarkable degree, the record of old stratification by bands of dark deposit with clear spaces between them. It was a matter of interest to ascertain whether the lines of deposit coincided with the position of the spaces or with that of the strata. This tube is composed of a cylinder 13 inches long and $1\frac{3}{16}$ inch in diameter, having at one end a bulb 2 inches in diameter, from which project at right angles to the main tube two short lengths of tube $1\frac{1}{8}$ inch in diameter, the whole resembling in form the letter T. At the end of the tube opposite the bulb is a straight brass wire $\frac{1}{16}$ inch in diameter screwed on to a wire of platinum, and in the head of the T a brass wire, $4\frac{3}{4}$ inches long, reaching axially right across. The bulb and short tubes attached to it are completely coated with a dense black metallic deposit, and for a space of 5 inches from the bulb the main tube is stained with eight dark bands. 2400 cells gave a current 0·02289 **W**, the straight wire being positive and the cross wire in the bulb negative; there were produced beautiful double strata intensely blue, like those in fig. 3, Plate 16, completely filling the tube. Strips of paper were fastened over these strata in the region of the stains; these were found to occupy the *unstained spaces;* the stains therefore marked the *intervals,* or cooler parts, between former strata.* The insertion of 500,000 ohms changed the colour of the strata to pink and the form to that shown in fig. 6, Plate 16, but their position remained unaltered. This corroborates our experience with tube 148.

Tube 133, 27 *inches between the terminals, diameter* 1·875 *inch. Nitrogen.*

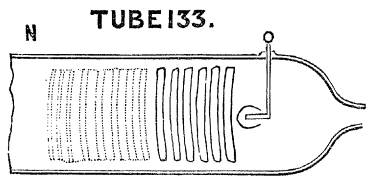
172.—Pressure 10 m.m., 13,158 **M**, 8040 cells. A nebulous light from the positive, extending half the length of the tube to the ring negative.

173.—Pressure 6 m.m., 7895 **M**, 8040 cells. Five steady luminosities, quite uniform, without indications of strata, like 6, fig. 52, but, of course, shorter; with 90,000 ohms gradually introduced the phase continued the same.

174.—Pressure 3·5 m.m., 4605 **M**. 4800 cells would not pass; with 5880 cells, four luminosities.

175.—Pressure 1·5 m.m., 1974 **M**, 3600 cells. Strata near the positive, as fig. 54. These were rather fuzzy, but were better defined with 300,000 ohms introduced.

Fig. 54.



176.—Pressure 1 m.m., 1316 **M**, 3240 cells. Similar strata: with 2,570,000 ohms, six luminosities. The discharge was red throughout the tube, except on the negative terminal, which was violet.

* GASSIOT (Brit. Assoc., 1869 (sect.), p. 46): "In one of GEISSLER'S tubes with which I have for some time experimented I obtained, by using my extended series of the voltaic battery, not only a very dense opaque deposit on the glass round the negative electrode, but five or six bands of dark deposit along the tube; in carefully examining their position I find they exactly coincided with the dark band between the striæ, that they did not increase in density by continuing the discharge like the deposit round the negative, but remained without further change.

"I have not any record from GEISSLER of the nature of the gas, &c., and have not been able to obtain similar results with other tubes obtained from GEISSLER.

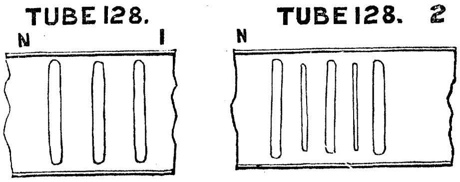
"In one of CETTI'S originally charged with arseniuretted hydrogen there was such a deposit.

"This result appeared to me to explain that the deposit in GEISSLER'S tube did not arise from particles of the negative electrode but from the gas with which it was originally charged; their being deposited exactly in the dark portions between the luminous disks may lead to a correct explanation of a phenomenon that has hitherto baffled the ingenuity of the experimentalist."

Tube 128, 25 *inches between the terminals, diameter* 2 *inches.*
*A mixture of Sulphuretted-hydrogen and Hydrogen, the Pressure of the Gas being unknown.**

177.—3240 cells connected with the VARLEY condenser of 42·8 m.f., as in fig. 26, Part I. At the full tension of the battery tongue-shaped strata, as in tube 108, 1, fig. 58; with 200,000 ohms resistance disc-shaped strata were obtained, as 1, fig. 55. When the battery was disconnected from the condenser, and its charge allowed to run down the strata became more distinct, and ultimately a thinner one introduced itself between those already existing, as 2, fig 55. It was also noticed that as the tension fell the strata at first moved *towards the positive*, then became stationary, and afterwards flowed back towards the negative.

Fig. 55.



178.—3600 cells, C. 0·01272 W, produced the phase shown in fig. 1, Plate 18, there being a tendency to form tongue-shaped strata. The figure is copied from a photograph obtained in forty seconds. On the insertion of 500,000 ohms resistance, C. 0·00432 W, the phase changed to that represented in fig. 2, Plate 18.

179.—With 3240 cells connected with the condenser, as in fig. 26, Part I., the potential of the condenser was measured with the electrometer; when fully charged, tongue-shaped strata were produced; when the potential had fallen to that of 2760 cells the phase shown in fig. 3, Plate 18, was obtained; this is copied from a photograph obtained in 75 seconds.

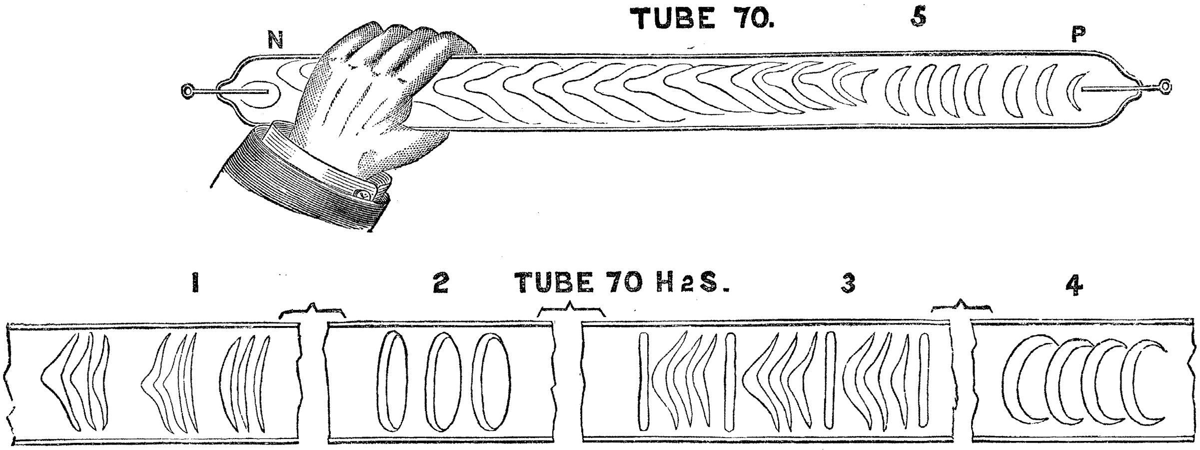
180.—Subsequently a change took place in the tube after standing for six months, when with 2400 rod cells beautiful double strata were produced, the current being 0·01639 W. The strata were of a beautiful blue colour with a carmine line between them. A photograph was obtained, but has not been engraved, as it resembles closely fig. 3, Plate 16, except that the double strata only occupied one-half of the tube, the other half towards the negative being a dark discharge.

* In those cases where the pressure is not stated, the tubes were filled and exhausted by the maker; no information being furnished as to the pressure of the residual gas.

Tube 70, 25 *inches between two straight terminals, diameter* 1·875 *inch. Sulphuretted-hydrogen, Pressure not known, the Working Resistance was from* 100,000 *to* 120,000 *ohms.*

181.—With 2160 cells, strata grouped in threes, as 1, fig. 56; on introducing 2,690,000 ohms the disc-shaped strata were produced, shown in 2, fig. 56; with 1,600,000 ohms the strata closed up to half the distance apart and became unsteady.

Fig. 56.



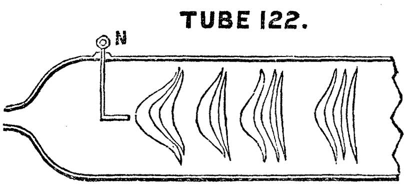
182.—The battery of 2160 cells was connected to the VARLEY condenser of 42·8 m.f., a water resistance of 300,000 ohms being in the circuit. As the charge ran down after the condenser had been disconnected from the battery, a most beautiful series of phases was obtained during the two minutes and a half which elapsed before the potential had fallen so low that the current ceased to pass. The first phase is shown in 3, fig. 56, consisting of groups of three bow-shaped strata with a disc between each group. The next is represented in 4, fig. 56; this was followed by a series of discs, as 1, fig. 55, these gradually became wider apart until there were only eight in the whole length of the tube. The discharge afterwards became a rustling luminosity and suddenly went out. Any phase could be maintained by replenishing the condenser through an adjusted resistance, FR″., fig. 26, Part I.

183.—By frequently working the tube there was gradually deposited a layer of crystalline sulphur on the inside; at last the tongue-shaped strata could no longer be obtained, but it was found that grasping the tube near the negative terminal caused their production, 5, fig. 56. Ultimately the tube became dead and the current of 8040 cells would not pass.

Tube 122, *Sulphuretted Hydrogen and Hydrogen.*

184.—3240 cells connected with the condenser. At full tension a beautiful steady stratification in groups of three strata, fig. 57, as the tension fell the strata became tongue-shaped and agitated, hugging the tube. As the tension still further fell discs were formed, which gradually became wider apart.

Fig. 57.



Tube 108, 27 *inches long,* 24 *inches between the straight terminals, diameter* 2·375 *inches.*

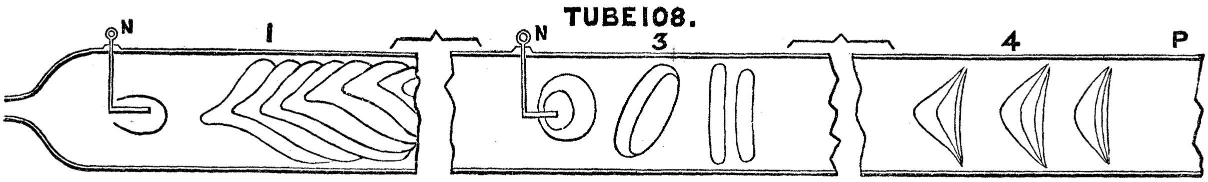
Nitrogen and Bromine.

185.—The battery was connected with the 42·8 m.f. condenser to charge it up fully, and was then disconnected; as the tension ran down, it was measured by means of the electrometer, a charge being taken from the mushroom, fig. 28, Part I., by means of the test plane T.

1080 cells gave a deflection of	24·33 divisions,	=22·5	per	1000 cells.
2160 ,, ,, ,,	51·25 ,,	=23·8	,,	,,
3240 ,, ,, ,,	80·75 ,,	=24·9	,,	,,
Mean		23·7	,,	,,

When the condenser gave a deflection of 50 divisions, = 2109 cells, there were produced, with a resistance in circuit of 1,200,000 ohms, 76 tongue-like strata, as 1, fig. 58.

Fig. 58.



186.—When the potential had fallen to 45 divisions, 1898 cells, with the same external resistance as before, strata, like 3, fig. 58, were produced; the second stratum from the negative was perfectly steady, but the others took up a dancing movement, each splitting into two.

187.—When the potential had fallen to 32 divisions, 1350 cells, still with 1,200,000 ohms resistance, there were fifteen steady strata, as 3, fig. 58; as the tension fell a little lower the stratum nearest the negative turned over, as represented, and disappeared on the negative. On falling the least degree lower the potential was too small to maintain a current and the tube went out. Although a potential of 1350 cells *kept up* the current it could not be *started* again until the condenser had acquired a much higher one.

188.—On connecting the condenser again with the battery it produced at 70 divisions, 2954 cells, with the same resistance, beautiful double strata, as 4, fig. 58.

189.—The same phenomena as described in 185 were again obtained when the potential had fallen to 42 divisions, 1720 cells. This tube was characterized by the number of the *strata decreasing as the potential fell.*

Tube 105, 27 *inches long,* 24 *inches between the two straight terminals, diameter* 2·25 *inches.*

Cyanogen.

190.—With a potential of 78 divisions, produced by 3240 cells, there were twelve and a half strata.

With a potential of		45 divisions,		1898 cells,		$13\frac{1}{2}$ strata.
,,	,,	32	,,	1350	,,	a rapid flow.
,,	,,	28	,,	1181	,,	the current ceased.

Tube 106, *about the same dimensions as* 105.

Carbonic Acid and Bromine.

191.—When the potential of the condenser was 70 divisions, 2953 cells, beautiful tongue-shaped strata were produced, which receded from a sheet of tin foil held in the hand and laid on the tube. At a potential of 58 divisions, 2447 cells, a transition took place from tongues to discs; at a potential of 42 divisions, 1772 cells, the current ceased.

Tube 104, 23·5 *inches between two straight terminals, diameter* 2·5 *inches.*

Bromine and Nitrogen.

192.—The same arrangement of condenser of 42·8 m.f., and 3240 cells, 680,000 ohms being introduced in the circuit; at a potential of 65 divisions, 2742 cells, beautiful tongue-shaped strata were produced; at 48 divisions, 1603 cells, the strata became confused; at 35 divisions, 2109 cells the current ceased.

193.—On another occasion, with a battery of 2160 cells, and the same condenser, a resistance of 400,000 ohms being inserted in the circuit, when the electrometer indicated 135 divisions (not of the same value as the preceding), tongue-shaped strata were produced; when the tension had fallen to 110 divisions, 1760 cells, the strata changed to discs, about an inch apart; when it reached 95 divisions, 1520 cells, the current ceased.

Tube 62, 25 *inches between the terminals, diameter* 2 *inches.*
Nitrogen.

194.—2160 cells connected with the 42·8 m.f. condenser, and 400,000 ohms resistance inserted in the circuit, sixteen steady strata which greatly increased in number as the tension fell.

Tube 21, 25·25 *inches between the terminals, diameter* 1·125 *inch.*
Carbonic Acid.

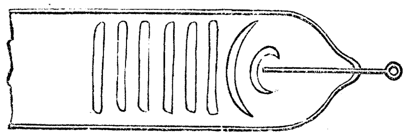
195.—The same arrangement, 3,290,000 ohms; at first with the full potential, only a confused stratification, but as the tension fell it became quite steady, and the phase could be maintained by feeding the condenser through an adjusted resistance FR″, fig. 26, Part I.

Tube 72, 24 *inches between the terminals, diameter* 1·75 *inch.*
Nitrogen.

196.—2160 cells, with the 42·8 m.f. condenser, 1,670,000 ohms resistance in circuit, the resistance of the tube was found to be from 90 to 110 thousand ohms, varying after the current had passed. A most splendid stratification *flowing* majestically *to the positive,* where one stratum vanished after another, but a corresponding one originated near the negative. This phase could be maintained for a very long time by feeding the condenser through an adjusted fluid resistance FR″, fig. 26, Part I. The shape of the strata is shown in fig. 59.

Fig. 59.

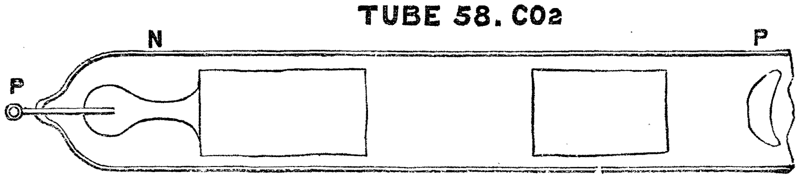
TUBE 72.



Tube 58, 20 *inches between the terminals, diameter* 1·75 *inch.*
Carbonic Acid.

197.—The same arrangement as in 194 as regards the number of cells and condenser, but with 2,690,000 ohms in the circuit. The resistance of the tube varied from 130,000 to 160,000 ohms. This tube at first gave a beautiful stratification, but after several experiments, it merely showed a tendency to stratification towards the period of cessation of the current. At nearly the full potential one luminosity formed at the positive, a considerable dark interval existing between it and another luminosity which formed in the centre of the tube, and there was a great interval between this and the glow at the negative. As the tension fell, the negative glow became globular, then elongated, and lastly reached the central luminosity; suddenly the central luminosity disappeared, and left a dark interval in its place. This last phase is shown in fig. 60.*

Fig. 60.



Tube 66, *length between the terminals* 28 *inches, diameter* 2 *inches. Hydrogen.*

198.—The arrangement the same as for 197. With the full potential a splendid phenomenon of 18 steady strata was produced; as the potential fell more strata gradually crowded in from the positive until they reached 43 in number, after which they became confused. With 6,150,000 ohms resistance in circuit there was a rapid flow in which alternating greenish and reddish cross markings were seen; the rotating mirror resolved these into strata alternately pink and greenish. The resistance of the tube was found to be

* GASSIOT (Proc. Roy. Soc., vol. xii., 1862-3, p. 336) describes a similar phase: "Depressing the wire very gradually (lessening the resistance) the positive became sharply defined, the negative retaining much of its irregular termination, but each separated by a dark interval of about one inch in length."

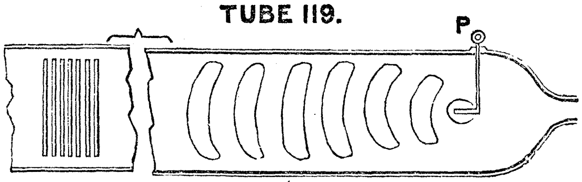
Mr. SPOTTISWOODE informs us that at an early stage of his experiments he noticed the formation of large cylindrical blocks of light or luminosities, terminated by flat ends, and separated by dark intervals often as long as themselves. These were most frequently found in tubes from 2 to 3 inches in diameter, containing coal-gas residua, at 0·5 to 0·75 m.m. pressure; they were from 2 to 3 or even 4 inches in length, and sometimes shot out from the positive terminal, then travelled along the tube, and finally disappeared in the dark space towards the negative terminal. They could be produced either by the HOLTZ machine with a very small air-spark, or with a coil furnished with one of the rapid contact breakers described in a paper (Roy. Soc. Proc. xxiii., 1875, pp. 455-462) referred to above. When observed with a revolving mirror these blocks usually showed striæ in a state of flow. He is of opinion that, at all events when produced under the circumstances here described, these blocks are essentially stratified, and that they are sections of flow, even when the velocity is too great to allow the separate striæ to be detected in the mirror.

190,000 ohms. This tube was destroyed by the sudden discharge of the condenser before the adoption of the STOKES' safety wire, figs. 69 and 70, and 26, Part I.

Tube 119, *Air.*

199.—This tube had a calibrated chamber connected to it between two stop-cocks, the calibrated portion having a capacity of $\frac{1}{1260}$ part of the tube. With 2160 cells—less would not pass—it produced at a pressure of about 1·5 m.m. 1974 M, a very close stratification, the strata being 0·05 inch apart, as at the left-hand of fig. 61. On letting in $\frac{1}{1260}$ part, by opening the stop-cock connected with the calibrated chamber, the pressure was increased to 2 m.m., 2632 M, and the strata became much wider. The exhaustion was then carried gradually further, until it required 3240 cells to pass, and ultimately 4800 ; the pressure was so low that we could not then determine it. There were only ten strata produced, as in the right hand of fig. 61, a large dark space intervening between the last stratum and the negative terminal. This tube, unfortunately, cracked near the negative terminal before the contemplated experiments could be completed. This occurred some days after an experiment during which the negative terminal had become overheated.

Fig. 61.



When the tube is composed of portions having different bores, the strata vary in *width* and *distance* in the different parts, being narrower and closer in the portions of smaller diameter. This is illustrated by tubes Nos. 18, 26, 51, and 161.

Tube 18, *Nitrogen.*

200.—This tube is represented in fig. 12, Plate 16, copied from a photograph obtained in one minute, August 3rd, 1875, and communicated to the *Académie des Sciences* of Paris.* The dimensions of the tube are as follows : length between the terminals, 32 inches ; the horizontal diameter of the left hand ellipsoidal bulb, 4 inches ; the tube connecting it with the central bulb, 12 inches ; the horizontal diameter of the central bulb, 4·25 inches ; the vertical, 5·25 inches ; the tube on the right hand of the central bulb, 11 inches ; and the horizontal diameter of the bulb on the right, 4·25

* 'Comptes Rendus,' xvi., 686, and xvii., 746, 1875.

inches. The current of 2400 cells was 0·01047 W. The resistance of the tube was found, by substituting wire resistance for it, to amount to 210,000 ohms at the time of the experiment, but several months before it had only a resistance of 18,000. In the small tubes were produced closely-packed strata, in the large central bulb were three umbrella-shaped strata much fainter; these moved towards the negative on introducing 50,000 ohms, a fresh stratum pointed at the apex entering the bulb from the right-hand tube (positive side), C. 0·00672 W. On introducing 20, 20, and 10 more thousand ohms, they retreated from the large bulb *towards the positive.*

Tube 26, *Hydrogen.*

201.—This tube is in form like 10, fig. 37; the length between the terminals 23 inches. The first bulb has a major axis, 3·25 inches, a minor, 1·875 inch, the tube joining this with the central bulb, 6 inches long, its internal diameter 0·44 inch; the central bulb has a horizontal major axis, 4·5 inches, the minor being 2·25 inches; the tube joining it to the third bulb is 5·5 long, its internal diameter 0·56 inch; the major axis of the third bulb, 3·5 inches, the minor, 2·125 inches. With 3240 cells, when the small tube was positive, C. 0·0073; when negative, 0·00481 W. When the small tube was either positive or negative it had 34 strata, while the large tube had had 25. The bulb on the positive side had three cup-shaped strata near the terminal, convex towards the negative. The central bulb had also three or four fainter pink strata, convex towards the negative; the third bulb was filled with a pink negative glow. The strata in the two tubes were blue. A photograph was obtained in 25 seconds in August, 1875, but has not been engraved, and is another of those communicated to the *Académie des Sciences* of Paris.

Tube 51, *Hydrogen.*

201*a*.—This tube was constructed to show that the extent of the glow along the negative terminal was dependent on the strength of the current. The length of the tube is 6 inches, the diameter 2 inches. The negative terminal is a platinum wire 19 inches long, and about 0·025 inch in diameter, coiled into a horizontal spiral of four complete turns, concentric with the tube; it is supported in its position by three fine glass rods running parallel to the axis of the tube. The positive terminal is straight, and extends vertically to the common axis of the tube and spiral. The distance between the last ring of the spiral and the positive terminal is $\frac{3}{8}$ inch. As the strength of the current is increased, the glow which, with a current of 0·00238 W, illuminates only the 2 inches of the negative nearest to the positive, spreads backwards until, with a current of 0·01575 W, it covers the whole terminal. The following are the observations of the lengths of wire illuminated which correspond to the various strengths of currents with 1200 cells :—

Currents .	0·00238	0·00263	0·00277	0·00347	0·00555	0·01023	0·01158	0·01575	Weber.
Lengths .	2	2·5	4·5	7	9	13·5	15·75	19	Inches.

Tube 161, *Hydrogen.*

202.—The difference of the strata in tubes of different diameter* at the same pressure and with the same current is very clearly brought out in tube 161, composed of two portions, one being 18 inches long and 1·65 inch internal diameter, the other 17·5 inches long and 0·975 inch diameter, the ratio of the sectional areas being 2·864 to 1. The terminal in the small tube is a point, in the large one a ring. With 4800 cells, the point (small tube) positive C. 0·02825 W, there were produced in the small tube 62 disc-shaped strata, and in the large tube twelve saucer-shaped strata occupying half of the length of the large tube ; beyond these the discharge was dark. With the point negative, C. 0·02451, there were produced in the small tube 54 discs, and in the large tube thirteen saucer-shaped, completely filling it. The number of strata does not therefore appear to be in the inverse ratio of the areas. The strata in the small tube were blue, but at times, with a large current, carmine, as in the capillary part of a spectrum-analysis tube, the strata in the large tube being much fainter and pink. The appearance when the point was positive

Fig. 62.

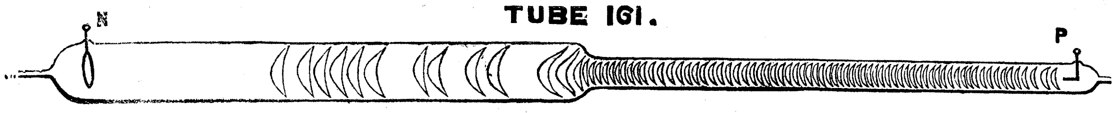
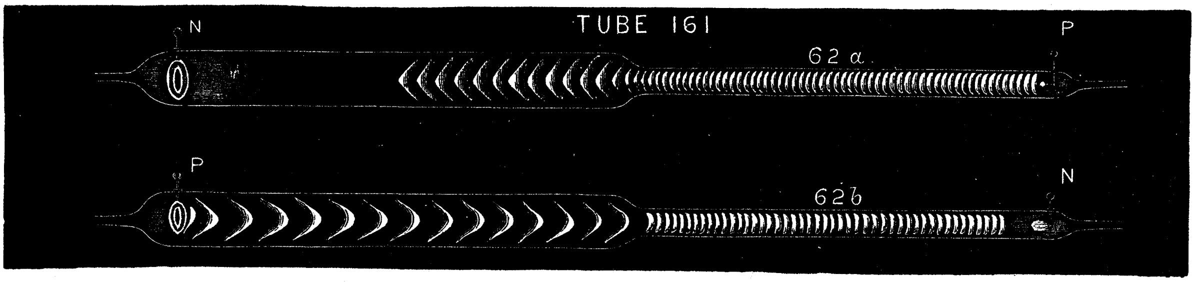


Fig. 62a.



* SPOTTISWOODE (Proc. Roy. Soc., xxv., 1876–77, p. 79) describes an experiment "on a hydrogen tube of conical form the diameter of which varied from capillary size to ½ inch, the capillary end being at the bottom, the positive terminal at the top. The principal interest of this tube consists in showing the influence of diameter upon the velocity of proper motion. The wider the tube the freer, it seems, the striæ are to move."

is shown in the diagram, fig. 62. Fig. 62a and 62b, copied from photographs obtained, the former in 15 seconds, the latter in 10 seconds, show respectively the appearances at another phase, when the small tube was positive or negative respectively.

SPOTTISWOODE *Tube* 147, *with a Shifting Terminal. Carbonic Acid.*

203.—It will be seen on reading the foregoing histories, especially those of tubes 129, 139, 130, that the strata all take their origin at the positive terminal, and that first one, then two, three, and so on, make their appearance as the pressure of the gas is diminished. A glance at Plate 15 will render this evident, all the strata having their origin at the positive terminal. But Mr. SPOTTISWOODE's elegant contrivance of a moveable terminal shows this to be the case in the most conclusive manner; * we give in Plate 17, figs. *a, b, c, d, e, f, g, h,* a representation of the strata obtained, in eight different positions of the terminal, in a tube we had made after his model by his permission; it is 56 inches long and 1·375 inch diameter, and is shown in figs. 39 and 40, page 164. Plate 17 does not give the first phase—a single stratum—formed on the positive terminal a certain distance from the negative, *which distance remains constant,* as is shown in the plate. 3240 powder cells were used with a resistance of 200,000 ohms to produce a steady discharge.

* GASSIOT (Phil. Trans., 1858, p. 12) used a tube attached to a mercurial cistern which was connected with an air-pump; as the pressure was reduced in this cistern, mercury, which originally filled the tube supported in a vertical direction, descended, producing a Torricellian vacuum of less or greater length. The surface of the mercury acted as the negative terminal. He says:—

"It is curious to observe the stratifications retreating from the negative as the mercury ascends the tube, or following it as they descend when the vessel is being exhausted, the dark line of discharge being compressed or expanded in proportion as the length of the stratification is increased or decreased."

Also in speaking of the stratified discharge as affected by a moveable glass ball (Brit. Ass. Aberdeen, vol. xxix., 1859, sect. p. 11), he says:—

"I have already stated that the stratifications near the positive wire are indistinct; but if the glass bead is placed near the positive wire and then allowed slowly to descend towards the negative, the stratifications at the positive are at first clearly defined near that terminal as at the negative, and as the bead rolls gently down, they have the appearance of following the bead and issuing one after the other from the positive wire until the bead reaches to within a few inches of the negative, when this action gradually ceases. If the tube is now inclined so as to allow the glass bead to return in the contrary direction the stratifications appear to recede, becoming more and more clearly defined, until the bead passes the positive terminal wire, when the entire discharge returns to its normal state."

Photograph.	Distances between terminals. inches.	Ratio of distance.	Current W.	Ratio of current.
a	7	1·00	0·00912	1·29
b	13	1·86	0·00858	1·22
c	19	2·71	0·00858	1·22
d	25	3·57	0·00807	1·14
e	31	4·43	0·00834	1·18
f	37	5·29	0·00782	1·11
g	43	6·14	0·00756	1·07
h	49	7·00	0·00706	1·00

The representations given in Plate 17 show the number of strata in each case; they are copied from photographs obtained in succession. The resistances of the tube for the several distances between the terminals are given in page 164. When the primary of coil 819 was in circuit, as fig. 69, page 227, the advent or retreat of a stratum produced a deflection of the galvanometer in connexion with the secondary of the coil, thus indicating a pulsation in the current.

We have already stated * that the discharge is frequently flowing and unsteady, but that *perfectly steady strata may be produced by properly regulating the current* by the gradual introduction of resistance in the circuit.† In Plate 17 we give three cases by way of example, thus :—

Tube 73, 22·5 *inches between the two straight terminals, diameter* 1·5 *inch*, C_2H_6.

204.—4800 cells, C. 0·00731 W, produced an agitated discharge throughout almost the whole length of the tube, there being only four strata, as shown in fig. 2, *a*, Plate 17. By the introduction of 200,000 ohms the current was reduced to 0·000408 W, and then perfectly steady strata were produced, as in *b* of the same figure. These are copied from photographs obtained in 20 and 30 seconds respectively.

* 'Comptes Rendus,' xvi., 686, and xvii., 746, 1875.

QUET ('Comptes Rendus', xxxv., 949–952) tried by shifting the positive terminal to drive it into the dark space near the negative. He found he could extinguish the positive light in air at atmospheric pressure, but not in rarefied gas.

† GASSIOT (Proc. Roy. Soc. 1872–3, p. 338): "No. 248. The discharge under certain conditions is continuous and under others it becomes intermittent. These conditions are, that without resistance introduced in the circuit, except that inherent in the battery, the discharge cannot be resolved by the rotating mirror, and so far must be considered continuous, but when a certain given and described resistance is introduced in the circuit the discharge becomes intermittent."

And at p. 339: "The form in figuration of the striæ and the positions they occupy in the vacuum tube appear to depend on two separate and distinct conditions, 1st, the power and energy of the battery; 2nd, the state of tension of the highly attenuated matter through which the discharge is visible."

"The striæ can be controlled, their number increased or reduced, and their places or positions in the tubes altered by the introduction of measurable amounts of resistance in circuit."

Tube 106, 23·5 *inches between the two straight terminals composed of wire about* 0·25 *inch thick, diameter* 2 *inches.*

Carbonic Acid and Bromine.

205.—4800 cells, C. 0·01840 W. A confused discharge throughout, as fig. 4, *a*, Plate 17. With 1,770,000 ohms the current reduced to 0·00238 W, when strata were produced, filling about half of tube as *b* in the same figure. These are copied from photographs obtained in 90 seconds and 4 minutes respectively.

In illustration of the *change in the number of strata produced by a variation in the current* we give a few more examples besides those already mentioned.

Tube 111, 23 *inches between the straight terminals, diameter* 2·25 *inches.*

Cyanogen.

206.—4800 cells, C. 0·01272 W. Seven strata as shown in fig. 3, *a*, Plate 17, which is copied from a photograph obtained in 15 seconds. The introduction of 1,000,000 ohms reduced the current to 0·00383 W, and then ten strata were obtained, as shown in *b* of the same figure, from a photograph obtained in 60 seconds.

Tube 105, 25 *inches between the straight terminals, diameter* 2 *inches.*

Cyanogen.

207.—3600 cells, C. 0·00834 W. Ten strata were produced, as shown in fig. 7, *a*, Plate 17, copied from a photograph obtained in 20 seconds. The introduction of 700,000 ohms reduced the current to 0·00191 W, and then there were thirteen strata, as shown in *b* of the same figure, from a photograph obtained in one minute.

In both the foregoing cases, tubes 111 and 105, *the strata increased in number with the decrease of current.*

Tube 124, 26 *inches between the straight terminals, diameter* 2 *inches.*

Sulphurous Acid.

208.—3240 cells in connexion with the condenser, as shown in fig. 26, Part I. At the full potential 29 strata were produced, as shown in fig. 4, Plate 18, copied from a photograph obtained in 12 seconds in the presence of their Excellencies Kuo Sung tao, Minister of China, and Lien Hsi-hung, Assistant-Minister, April 27th, 1877. On introducing 1,000,000 ohms, the number was reduced to 27, and just before the current ceased to pass after the battery had been disconnected from the condenser the number fell to 21.

In the case of tube 124 *the strata decreased in number with the decrease of current.*

The introduction of any substance in the tube, such as rings or flags of metal, produces an interruption of strata very much as if they acted as distinct terminals.

Tube 120, *Carbonic Acid.*

209.—This tube is 28 inches long between the end straight terminals, and 1·75 inch diameter, with two lightly suspended aluminium flags. Nine strata produced from the positive, then a dark space between them and the first flag, which is brightly illuminated. This seemed to act as a fresh terminal, from which started ten strata, beyond which there was again a dark space between them and the second flag, which in its turn appeared to act as a new terminal, being illuminated by a glow.* Five other strata were formed on the other side of this, and beyond them there was a dark space, and the negative terminal was brilliantly illuminated. Fig. 5, Plate 17, copied from a photograph shows the phenomena; no motion of the flags could be detected during the passage of the current, 0·01158 **W**.

Tube 101, *Carbonic Acid.*

210.—This tube is 25 inches long between two straight terminals, and 1·5 inch in diameter; beginning at the positive terminal on the right, at 1·25 inch is a fixed flag 0·5 inch square, beyond this at 1·5 inch another, at the middle of the tube a ring 1 inch in diameter; on either side of this ring at 1·375 inch distance are two balls about 0·375 inch in diameter, then two other square fixed flags at the same distances from the left hand (negative) terminal and from each other. It will be seen by referring to fig. 6, Plate 17, that a close stratified discharge is shown with an illumination of each of the impediments except the last two flags near the negative, as in tubes referred to at page 165. This figure is copied from a photograph taken when the tube was connected with 2400 cells and 150,000 ohms resistance, C. 0·00504 **W**.

* GAUGAIN ('Comptes Rendus,' xli., 1855, pp. 152–156) compares the behaviour of gases in this respect with that of liquid electrolytes where the introduction of a metal diaphragm between the electrodes increases the resistance, and the two faces of the diaphragm act as opposite electrodes. GAUGAIN further remarks that if the metal obstruction be pierced it ceases to act as a double electrode in gases, a fact confirmed by our many experiments with tubes furnished with metal rings (fig. 41, p. 165).

In the preceding pages it has been shown that the number of strata varies with the pressure of the gas, beginning with one luminosity, then increasing in number up to a certain point as the pressure is diminished; as the gas becomes gradually attenuated the strata become thicker and fewer; lastly, the current passes with increasing difficulty, and the strata have a tendency to run together. With the mercurial pump alone we have not been able to obtain a lower pressure than 2·6 **M**, but with the employment of spongy palladium in a hydrogen vacuum we have reduced the pressure to 0·000055 m.m., 0·066 **M**.

Tube 145, *Hydrogen.*

Length 25 *inches,* 20 *inches between the terminals, one a wire, the other a ring, diameter* $1\frac{3}{8}$ *inch.*

This tube is represented at 145, fig. 37. It has an absorption chamber containing spongy palladium, obtained by heating its cyanide to redness; this chamber is $5\frac{1}{2}$ inches long, $\frac{5}{8}$ inch in diameter, and is about half-full of palladium, which is held in its place by plugs of palladium-foil. At one end of the tube is a short capillary calibrated tube contained between two glass stop-cocks, the first communicating with the tube, the second with the hydrogen generator.

The tube was repeatedly exhausted and filled with dry hydrogen, while the absorption chamber was being heated in a copper air-bath to a temperature above the range of the mercurial thermometer; a double saddle-screen of tinned iron, placed on the small tube connecting the absorption chamber with the glass cock, effectually protected the latter from excessive heat. At various pressures from 35 m.m., 46,053 **M**,* at which the current of 11,000 cells just passed where the ring was positive, most of the phenomena recorded for tube 129 were obtained, but the following are the experiments for which the tube was specially constructed.

In the first instance, in order to test the absorbing power of the palladium, it was heated for some hours, and the tube was very completely exhausted; it was then filled with hydrogen at the atmospheric pressure, and kept at this pressure while the palladium cooled. The tube was exhausted again, and it was found that at 10 m.m. the palladium gave off hydrogen sensibly at ordinary temperatures; then the air-bath was heated above the range of the mercurial thermometer, when the gas filled the

* MORREN, A. ('Comptes Rendus,' liv., 1862, p. 736) states that he obtained a current in hydrogen at a pressure of 24 m.m., which caused a deviation of 1° of his galvanometer; at a pressure of 2·8 m.m. the deviation was at a maximum 46°, and at 0·06 m.m. the current was less, the deviation being 30°. He gives the currents also in carbonic anhydride, nitrogen, and carbonic oxide. In the Ann. de Chim., iv., 1865, pp. 320–352, is an elaborate investigation on the electric conductibility of gases at very low pressures, by this author, the pressure of the gas being estimated by allowing a known volume of gas to enter a tube of known capacity in which had been produced a torricellian vacuum; he found (p. 333) the transmission of electricity to cease at a pressure of 0·0037 m.m. with nitrogen.

tube, both pumps, and the McLeod gauge to a pressure of 410 m.m., 539474 M, thus showing that it was capable of absorbing a large volume of gas.

211.—The tube was now exhausted, first with the Alvergniat pump, which was subsequently shut off at the cock C, fig. 35, afterwards with the Sprengel, the cock between the absorption chamber and the tube being left open.

When the pressure had reached 0·005 m.m., 6·58 M, the current of 11,000 cells would pass only when the straight wire was negative. When the pressure was 0·00137 m.m., 1·8 M, the current would not pass in either direction. The exhaustion and absorption were carried on until the pressure fell to 0·000055 m.m., 0·066 M, at which pressure there was, of course, no current. The Apps's induction coil 821, set to produce a 1-inch spark, would not pass at first, but did so after the current had been made to pass with a 6-inch spark. The pressure rose to 0·0024 m.m., 3·2 M.

212.—Exhaustion to 0·00016 m.m., 0·2 M, having been again obtained, the absorption chamber was shut off, and a charge of gas from the calibrated tube, the capacity of which is $\frac{1}{2200}$ that of the main tube, was let into the tube and Sprengel pump; it increased the pressure to 0·226 m.m., giving $\frac{1}{6490}$ for the ratio of the capacity of the calibrated chamber to that of the tube plus the Sprengel pump and McLeod gauge. When the gas was let in the current of 11,000 cells, 0·04201 W, immediately flashed through the tube, and produced twenty blue strata, like those in fig. 9, Plate 16, reaching to within 7 inches of the negative. 1200 cells gave a current 0·00580 W, and produced nineteen grey strata, the concave face of that nearest the negative being pink.

213.—The absorption chamber was now opened, and in about five minutes the pressure was reduced to 0·0268 m.m., 35 M. 11,000 cells, C. 0·01102 W, produced nine milky broad strata, like those in fig. 12, Plate 16. In 45 minutes the pressure had decreased to 0·00137 m.m., 1·8 M, and 11,000 cells would not pass.

214.—Two charges let in; pressure 0·435 m.m., 571 M, 1200 cells, C. 0·00993 W, twenty-two pink strata as fig. 5, Plate 16; 2400 cells, C. 0·02634 W, rendered the strata blue, and like fig. 4 of the same Plate.

215.—Third charge, pressure 0·6423 m.m., 844 M, 2400 cells, C. 0·02776 W.

216.—Fourth charge, pressure 0·8968 m.m., 1180 M, 2400 cells, C. 0·02925 W. twenty-four blue strata, like fig. 4, Plate 16.

217.—Fifth charge, pressure 1·1294 m.m., 1486 M, 2400 cells, C. 0·02925 W, twenty-two blue and very deep cup-shaped strata.

218.—Sixth charge, pressure 1·396 m.m., 1836 M, 2400 cells, C. 0·02850 W. An agitated stratification of tongues crossing each other and producing a kind of × form. The C and F lines, which had been faint in the other phases, were bright in the negative glow, but not in a stratum.

219.—Seventh charge, pressure 1·6656 m.m., 2191 **M**, 1200 cells would not pass; 2400 cells, C. 0·02728 **W**. The cup-shaped strata became longer, and curved at the end, reminding one of a Phrygian cap.

220.—Eighth charge, pressure 1·9265 m.m., 2534 **M**, 2400 cells, C. 0·02728 **W**; only a confused discharge. 3600 cells, C. 0·03620 **W**; very deep cup-shaped steady blue strata, as deep as those in fig. 7, Plate 16, but not, like them, tongue-shaped. C, F, and G lines visible with spectroscope.

221.—The absorption chamber was now connected with the tube. With 3600 cells, phenomena in the reverse order were obtained. The pressure was observed to have fallen in a few minutes to 1·003 m.m., 1318 **M**; in 10 minutes to 0·1245 m.m., 164 **M**; and in 45 minutes to 0·0217 m.m., 28 **M**, when it required 4800, and subsequently 6300 cells to pass. At first when the saucer-shaped strata had disappeared, twenty-one disc-shaped strata presented themselves; these widened out, and there were successively sixteen, fourteen, and twelve, becoming like figs. 8, 9, 11, and 12, Plate 16, respectively. When the two last phases were produced, the hydrogen lines could not be seen either in the strata or the glow on the negative ring, but, instead of them, mercury lines came out strongly.* There is reason to think that at this stage there was little gas, except mercury vapour, in the tube.

It is to be observed that, with a very high degree of exhaustion, the tongue-, and saucer-shaped strata are no longer produced in a hydrogen vacuum, and that the strata assume the disc-form usual with carbonic acid, air, and nitrogen.

Tube 81, 25·5 *inches between the terminals, diameter* 0·875 *inch.*
Carbonic Acid.

222.—This tube is connected with a smaller one containing a stick of potash, see 81, fig. 37.† The current of 11,000 cells will only just flash across in one direction after the tube has remained at rest for some months so as to allow of the complete action of the potash. On heating the potash bulb gas is given off, and then the current of 2160 is sufficient, the maximum current with this battery being 0·00238 **W**. On heating the bulb still more it required 3240 cells to pass, and ultimately this was insufficient; by allowing the potash bulb again to cool the current of 3240 cells passed, and very close strata were produced, nine in an inch; then, as it still further

* Hittorf (Pogg. Ann. cxxxvi., 1869, pp. 1–31) measured the quantity of mercury vapour from his pump absorbed by a silver surface. He found it amounted in certain circumstances to 0·25 milligramme per square centimetre per diem. Morren (Ann. de Chim. iv., 1864–5, pp. 325–352) describes the difficulties he encountered from the presence of the mercury vapour as well as of other gases which he believes are usually dissolved in mercury.

† Gassiot describes experiments with such a tube, Roy. Soc. Proc. x., 1860, p. 402.

cooled, the vacuum becoming better, seven, six, and so on to two in an inch were produced; lastly, before the current ceased to pass, the strata rapidly widened out, *flowing towards the positive.*

Tube 9, *Hydrogen.*

223.—This is a tube with a diaphragm of glass having a hole in it 0·25 inch diameter, the length between the terminals being 11 inches; it also has a potash chamber for the complete absorption of moisture, 9, fig. 37; with 2160 cells, the potash chamber having been previously heated, about three strata were produced in the compartment near the positive; as the chamber cooled and the vacuum became more perfect, six strata formed in this compartment, completely filling it, and one after the other appeared to squeeze through the small hole in the diaphragm into the negative compartment, where two strata formed, each double, like those in fig. 3, Plate 16.

Tube 116.

224.—This is one of the so-called induction tubes, like, in some respects, that shown in 19, fig. 37; it consists, however, of three chambers, the distance between the terminals being 37 inches. It is composed of a large central tube 18·5 inches long, 2·25 inches diameter, terminating at each end in a bulb 2·5 inches in diameter, and containing carbonic acid. Enclosed in these bulbs are two smaller bulbs 2·125 inches in diameter, connected each with a spheroidal bulb, the major axis of which is 3·375, and the minor 2·5 inches; these contain nitrogen. In these spheroids the terminals are placed, so that each is enclosed in a separate chamber (see Plate 18, fig. 5). On connecting this tube with 6960 cells a flash is perceived in the several compartments of the tubes; on reversing the current another flash, but no continuous illumination as with the induction coil. As in an induction coil there is a series of rapid reversals of current, it is evident that it illuminates induction tubes by an alternate charging up and discharge of the leyden jars formed by the contained bulbs, on each side of which is residual gas, which acts as the carrier of electricity. By rapidly reversing the current of the battery by means of the key, figs. 2 and 3, page 59, Part I., the tube becomes illuminated, but not so well as with an induction coil. On, however, employing the rapid commutator shown in fig. 8, Part I., which alternates the current 352 times or less in a second, a most splendid illumination of the tube takes place, producing an appearance shown in fig. 5, Plate 18, copied partly from a photograph obtained when 6960 cells were used and with about 150 reversals of current in a second. The two spheroidal chambers communicating with the enclosed globes became illuminated with pink and red streamers, and the long central tube with olive grey strata, apparently convex in both directions, but which the rotating mirror separated into two components, one convex in one direction, the other in the other. In the photograph only a continuous light is seen in the central tube, so that the detail, there shown, is from eye observation.

Sensitiveness to External Influence.

225.—In the preceding description we have alluded to the sensitiveness of tubes to the approach of the hand, or touch of the finger; the tube shown in fig. 63, containing cyanogen, is an example of an extreme case: it gave tongue-shaped strata, and these entirely disappeared on the touch of a finger, all the tongues running into a continuous wave-discharge constricted near the finger.

Fig. 63.

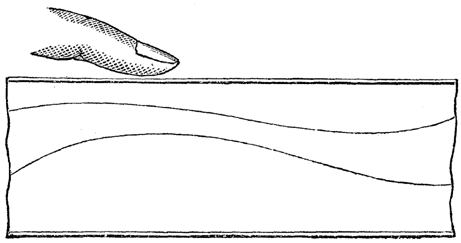
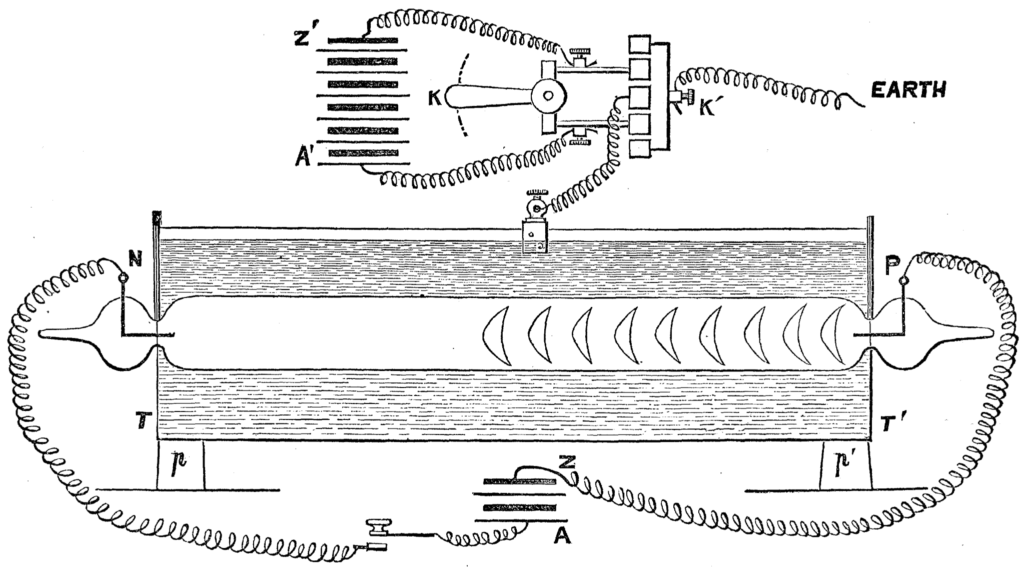


Fig. 64.



An endeavour was made on the suggestion of Professor STOKES to throw some light on the effect of external influence on the character of the strata, in the manner shown in fig. 64.

Tube No. 8, 14 *inches long, diameter* 1·5 *inch.*

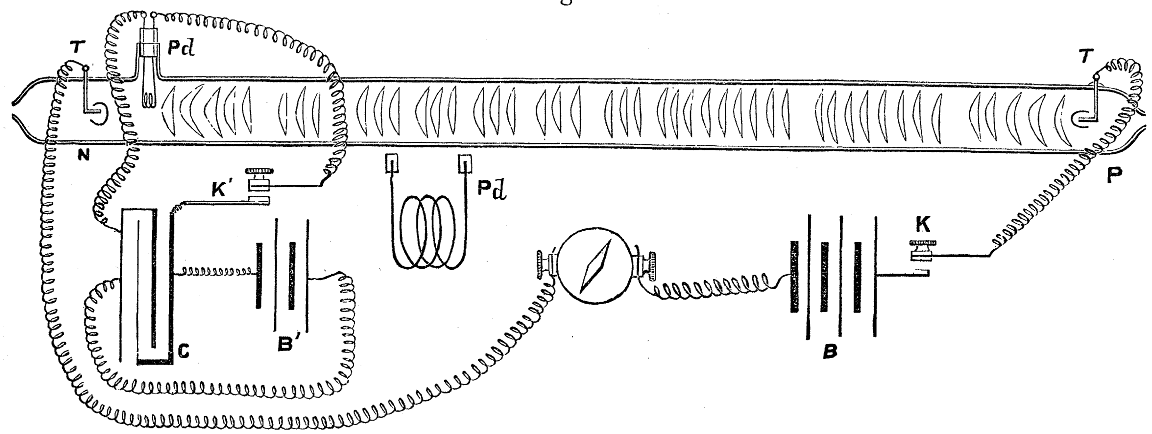
226.—This tube was placed in a metallic trough, 15 inches long, 4·5 inches deep, and the same wide; the trough was insulated on four paraffin cylinders *p p′*, and filled with water, and also with a solution of common salt. The resistance of the tube was 60,000 ohms, 1200 cells would pass, but 2400 were used with a resistance of 200,000 ohms, giving eight strata, C. 0·00259 W. On connecting one pole of the battery, and one terminal of the tube to earth, and the other pole to the other terminal of the tube, it was found that the difference of potential between the two terminals of the tube was the same, 1131 volts, whether the tube was in air, water, or a solution of common salt, and whether the trough was insulated or connected to earth.

The experiment was repeated, but with the addition of the employment of a second battery A′ Z′ of 3240 cells, which was used to charge up the trough alternately + or − whilst the current of a battery of 1460 cells passed continuously through the tube. At each reversal of the charge of the liquid in the trough, a flash of light passed through the whole length of the tube, and the strata made a slight movement towards the negative terminal and back again to their original position. It was thought that the discharge, under the influence of induction, might take a hollow cylindrical form, but this did not occur.

Tube 160, *Hydrogen.*

227.—This tube was constructed with the object of sending the analogue of a smoke ring through a tube in which a steady stratification had been procured and sustained: fig. 65 shows the arrangement.

Fig. 65.



The tube is 40 inches long and 1·875 inch in diameter, and has a stop cock at each end; near one of the ends is a small tube, 0·75 inch in diameter, fastened to the main tube at right angles, and fitted with a glass stopper, in which two stout platinum wires, 0·043 inch diameter, are melted; there is soldered, with gold, to the two platinum wires a spiral of palladium made of wire 12 inches long and 0·0125 inch diameter, P*d*, in the diagram. The palladium coil was charged to saturation with hydrogen, by immersing it in dilute sulphuric acid and making it the negative pole of a bichromate battery of six elements; after it had been washed in distilled water it was dried and inserted in the tube. The two stout wires of platinum, to which the palladium coil is attached, are connected to a condenser of 10·9 m.f., charged with 3240 cells. One of the wires leads to K′ so that no current can pass from the condenser until this key is pressed down, when this is done the charge passes and by suddenly igniting the wire drives off the hydrogen.

On first making the experiment, through inadvertence, the condenser was not connected with the palladium coil, but the current in the tube heated it and drove off the hydrogen, producing the effect to be described. Pressure 1·003 m.m., 1320 **M**, 5120 cells, 300,000 ohms resistance, saucer-shaped strata as shown in the diagram. As soon as the palladium coil became heated it suddenly drove back the strata about one-third the length of the tube from the negative, and the current subsequently became agitated. After the liberation of the gas the pressure was increased to 1·088 m.m., 1432 **M** or by 112 **M**, the pressure before and after discharge being as 1 to 1·08.

This experiment was repeated with 4800 cells without external resistance,

Pressure	0·9965 m.m.,		before the discharge of the condenser,
,,	1·0381	,,	after ,, ,, ,,
Difference	0·0416	,,	55 **M**,

double strata were produced from the positive to the palladium coil which was on the negative side. On liberating hydrogen by the discharge of the condenser these were driven back 14 inches towards the positive, and subsequently only a confused discharge was produced.

When the terminal near the coil was positive the same phenomena were not produced on the discharge of the condenser.

When, instead of liberating gas from the palladium coil, calibarted charges of hydrogen were let in during the passage of the current, the strata were narrowed radially for a few seconds, then again occupied the whole diameter of the tube, but were confused and agitated. Each fresh puff of gas was accompanied by a fresh radial collapse, and, at the same time, by a repulsion of the strata from the negative, whether the puff of gas entered from the negative or from the positive end.*

The wires of this tube had been enclosed nearly up to their extremities in capillary glass tubes; after repeated discharges these tubes fuzed and enclosed the wires nearly completely, only leaving a section of them free. When this had happened a very striking phenomenon was observed at the negative terminal on sending a current of 5120 cells through the tube, numerous sparks were thrown off from the extremity of the wire in a very thin sheet at right angles to the axis of the tube, producing the appearance of spokes of a wheel; the discharge throughout the tube was not stratified. Not the slightest projection occurred either backwards or forwards in the direction of the length of the tube, showing that there is a lateral force existing at the negative terminal. The axial direction of the positive impulse, combined with the radial direction of the negative, at right angles to it, may play an important part in the production of stratification.†

* De la Rive (Genève Mém. Soc. Phys. xvii., 1863, p. 75) made similar experiments; he introduced during the passage of a current in a vacuum a charge of the same gas that it contained, in quantities sufficient to lower the column of mercury $\frac{1}{4}$ or $\frac{1}{2}$ a millimetre. If the gas were introduced at the negative end striæ well defined were immediately formed in the dark space of the same diameter (that of the tube) as the striæ already existing, but much closer and narrower. These gradually extended the whole length of the tube, entangling the original striæ in their course. When the admission of gas had been stopped the luminous column gradually receded from the negative and the tube took up its normal appearance. If the gas were introduced at the positive end, instead of striæ occupying the whole length of the tube *a narrow jet* of brilliant light was seen to advance along the axis of the tube in the interior of the luminous column, which immediately extended through the dark space near the negative. When the admission of gas had ceased the tube returned to its normal condition. In the same paper (pp. 73–74) the author describes some experiments in which he had a gauge attached to the vacuum tube: the mercury column was observed to oscillate during the discharge through a range of, under favourable circumstances, 0·4 m.m.; De la Rive considers that these two experiments support the opinion of Reiss, of Berlin, that these phenomena are purely mechanical.

Spottiswoode showed a similar experiment at a recent meeting of the Royal Society.

† Varley (Proc. Roy. Soc., xix., 1871, p. 239) constructed a tube in which a slip of talc, 1 inch long, $\frac{1}{10}$ inch broad, and weighing $\frac{1}{10}$ of a grain, was attached in the middle to a fibre of silk stretched diametrically across the tube; the position of the vane was not between the terminals, two rings, but between one end of the tube and one of them. When the discharge, which was in the form of an arch, passed between the two terminals no effect was produced on the vane; when, however, the arch was influenced by an electro-magnet and made to play upon either the lower or upper end of the vane that part of the vane was repelled, no matter in which direction the current was passing, in some cases as much as 20°. The author states that in his opinion the arch is composed of *attenuated particles of matter projected* from the negative pole in all directions, but that the magnet controls their course.

The view that the striæ are aggregations of matter, and that their formation is a mechanical process, appears to receive some support from the fact described by Spottiswoode in a paper on the rapid-contact-breaker (Proc. Roy. Soc. xxiii., 1875, pp. 445–462). In the case of the double discharge the striæ of the one discharge fit exactly into the spaces of the other, indicating thereby that the distribution of the residual gas at the close of one discharge is such as to favour a similar distribution in an immediately succeeding discharge, and that time is necessary for a fresh distribution.

See also Appendix, note C.

The two tubes about to be described present some very remarkable phenomena, which show that the terminals in some cases are able to absorb the gases of the vacuum tubes and to give them off again under the influence of the current.

Tube 48, length 7 inches, between the terminals $2\frac{3}{4}$ inches, diameter $1\frac{1}{2}$ inch.

228.—The residual gas is hydrogen, the negative terminal a spiral, the positive a straight wire, both of palladium 0·05 inch diameter; with 1200 cells, C. 0·01331 W, with 2400 cells, C. 0·02371 W; in the latter case the deflection of the galvanometer was reproduced by 40,000 ohms inserted in the circuit in lieu of the tube.

Both wires before the experiment were bright and metallic; there were produced six strata at the positive and a glow around the negative, a copious mirror-like translucent deposit forming on the tube about the negative, which, examined by the microscope with a power of 260–570 linear, appeared to consist of cubes or four-sided prisms $\frac{1}{22000}$ inch across. If the current was continued for about a minute a central zone was cleared by the heat and the deposit carried further along the tube. Gradually there was formed a similar deposit, but not so dense, on the tube round the positive terminal. The curious part of the phenomenon is that the negative and positive terminals, having become mat and black as if covered with a deposit of spongy palladium, resume their metallic appearance on laying the tube aside for a week or two; in the mean time the deposit is entirely re-absorbed by the terminals, which become white like frosted silver, and the glass is left quite clear. This experiment has been repeated very many times with the same result. Is the deposit a definite compound of palladium and hydrogen? *

Tube 49, length 9 inches, between the terminals $3\frac{1}{2}$ inches, diameter $1\frac{3}{8}$ inch.

229.—The residual gas hydrogen, the negative terminal a spiral of palladium, the positive an aluminium wire; 2400 cells, C. 0·01982 W; the resistance reproduced by 70,000 ohms. Similar phenomena were produced, except that around the positive terminal, the aluminium wire, there was no deposit.

We have made several experiments with tubes containing other gases besides those already mentioned, for example:—hydrochloric, HCl, hydrobromic, HBr, and hydrofluosilic, $4HF,SiF_4$, acids; carbonic oxide, CO, olefiant gas, C_2H_4; phosphoretted hydrogen, PH_3; arsenetted hydrogen, AsH_3; dioxide of nitrogen, N_2O_2. But we have nothing special to mention at present with respect to them, and they all require a more extended study.

* GRAHAM, 'Chemical and Physical Researches,' collected by ANGUS SMITH, 1876, pp. 281–299. TROOST and HAUTEFEUILLE, 'Comptes Rendus,' lxxviii. pp. 686–690, describe a compound Pd_2H.

Throughout our researches we have not seen in a carbonic acid vacuum any umbrella-, saucer-, or tongue-shaped strata as shown in Plate 11, figs. 2, 6, and 7, respectively; so far as our experience goes they are always of the disc-form shown in figs. 8, 9, 10, 11, 12, Plate 16, and fig. 1*h* in Plate 17.

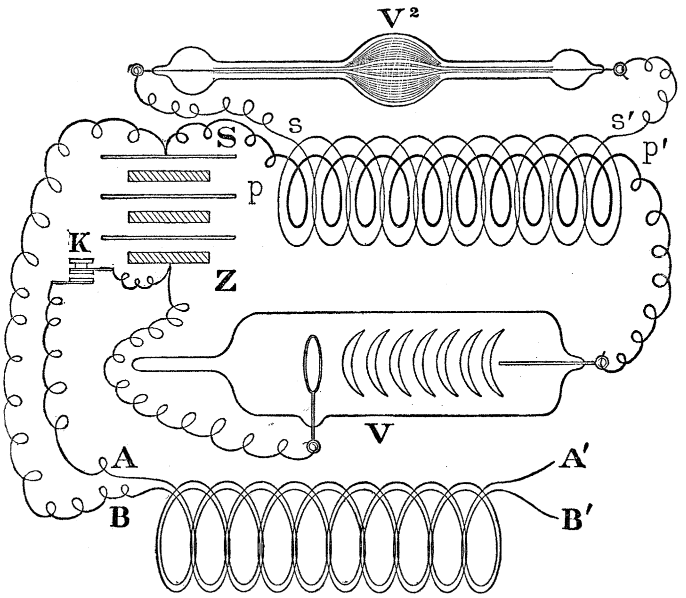
On the other hand, hydrogen, phosphoretted hydrogen, and arsenetted hydrogen will give the umbrella-, saucer-, and tongue-like strata.

Some tubes containing sulphurous acid give these forms of strata, while cyanogen gives the disc-shaped as in carbonic acid.

Tubes prepared by Dr. GEISSLER containing a mixture of gases, such as phosphoretted hydrogen and hydrogen, carbonic acid and bromine, nitrogen and bromine, as a rule give a most beautiful stratification and point to the desirability of a more extended study of the effect of mixture of gases on the electric discharge.

In 1875 we made a communication to the Royal Society, in connexion with our friend Mr. SPOTTISWOODE, on Electrical Discharges in Vacuo,* in which were described some phenomena bearing on the cause of stratification in vacuum tubes; we have recently repeated the experiments obtaining the same phenomena, and we have, this time, recorded them by photography, as shown in Plate 18, fig. 6, *a* and *b*, fig. 7, *a* and *b*, and fig. 8, *a* and *b*. The diagram, fig. 66, exhibits the arrangement of the

Fig. 66.



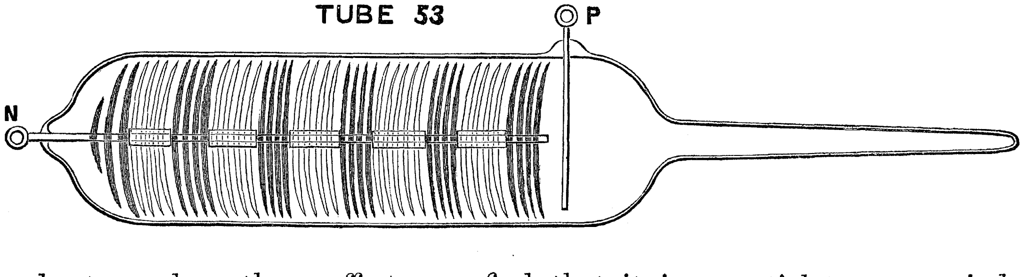
apparatus; S Z, a battery of 1080 cells connected at one terminal, S, to the primary of an induction coil P P′, thence to the straight wire of the vacuum tube V, the other, a ring in this case, being connected to the Z terminal of the battery; the positive current consequently passed from S through P P′, and through the tube V. The secondary wire S S′ of the induction coil was connected to a tell-tale tube V². Under

* Proc. Roy. Soc., vol. xxiii. p. 356, 1875.

the circumstances just described, it will be remembered that a nebulous discharge occurred in V without stratification, and that no illumination of the tell-tale tube took place. The battery was also connected at the S terminal, without any intervening resistance, to one side A A′ of a condenser, the Z terminal to a key K; when this was pressed down, then, and only then, the other side of the B B′ condenser was connected with the battery, and it became charged. With the condenser in action strata were produced in V, and the tell-tale tube V^2 was illuminated, showing that an induced current was produced in the secondary wire; this we ascribed to a periodic overflow from the condenser, in addition to the current which was passing continuously from the battery.

230.—One of the most beautiful examples of the difference of discharge, with and without the condenser, was presented in December, 1874, by tube 53, which is represented in fig. 67, half-size. The negative wire lies in the axis of the tube, and reaches to within 0·25 inch of the positive terminal which enters the tube at right angles to it. On the negative wire are several glass beads or bugles, kept in place by expanding the wire in one direction by a slight blow with a hammer; the resistance of the tube, which was charged with carbonic acid, was found to be 50,000 ohms. With 980 powder cells, without the condenser, a beautiful tuft of violet light appeared on each of the spaces of uncovered wire, without the slightest indication of stratification, but on pressing down the key K in fig. 66, so as to connect the battery with a condenser of 0·5442 m.f. capacity, the tell-tale tube lighted up, and the discharge throughout tube 53 was stratified, as shown in fig. 67, the strata on the uncovered portions of the wire being violet, and those on the glass-covered part salmon coloured, and much fainter.

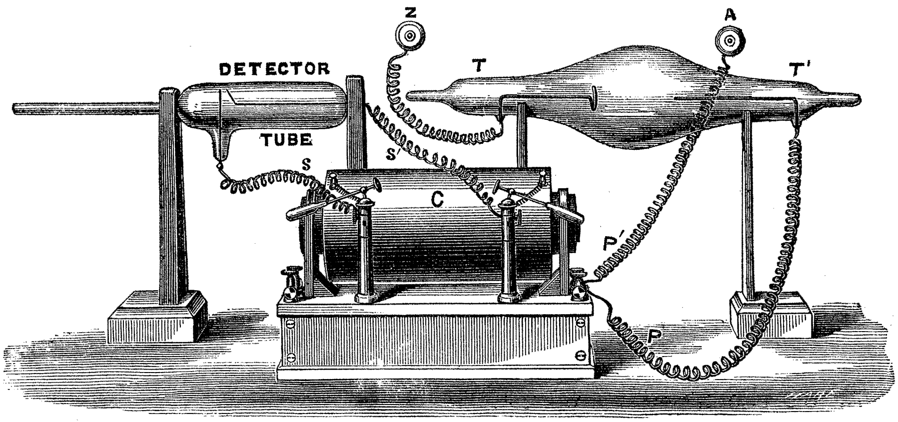
Fig. 67.



In order to produce these effects, we find that it is essential to use an induction coil, the primary of which presents very little resistance; for example, APPS's 815, the particulars of which are given in Part I., page 106, the resistance of the primary being only 0·245 ohm. They cannot be obtained by using the induction coil 819, Part I., page 64, this offering too much resistance, 316 ohms.

In order that the copies of the photographs in Plate 18, referring to the phenomena, may be understood, we insert fig. 68, which shows the disposition of the tube T T′, the coil 815, and the tell-tale tube which is placed close to T T′, so that it may be photographed at the same time as T T′. The A terminal of the battery is connected to the primary of the coil at P′, the other end of the primary being connected through the wire P to the tube; the second wire of the tube is connected to the Z terminal of the battery; the ends of the secondary wire of the coil to the terminals of the tell-tale tube. The condenser is not shown in fig. 68.

Fig. 68.



In all the figures on Plate 18 relating to these phenomena, namely, figs. 6, *a* and *b*, 7, *a* and *b*, and fig. 8, *a* and *b*, the copy of the *a* photograph represents the condition of things when the condenser *is not* connected with the battery, the copy of the *b* photograph the phenomena when it *is* connected. In the *a* series there is no stratification in the vacuum tube and no illumination of the tell-tale tube, in the *b* series there is stratification, and the tell-tale tube is illuminated in consequence of an induced current, produced by the periodic overflow of the condenser and consequent pulsation of current, which coincides with the production of strata.

Tube 42, *Coal Gas.*

231.—Tube 42 is represented in fig. 37, its extreme length is 12·5 inches, between the terminals 2·125 inches, its greatest diameter 3 inches, the resistance 85,000 ohms. 1080 cells, C. 0·00912 W, without the condenser, produced a nebulous light around the cup-shaped negative and reaching the heart-shaped positive, but without any strata being visible in the discharge; the tell-tale tube was not illuminated, thus showing that there was no detectable pulsation in the current, fig. 6, *a*, Plate 18. When, however, the condenser was connected with the battery by pressing down the key K, fig. 66, then the discharge was a stratified one, and the tell-tale tube indicated by its illumination that the current through tube 42 was a pulsating one, fig. 6, *b*, Plate 18. These two figures are copied from photographs each taken in 60 seconds.

Tube 44.

232.—Similar in shape to 42, but with two magnesium spherical terminals 0·375 inch in diameter, distance between them 2·25 inches, the largest diameter of the tube 3·125 inches, resistance 42,000 ohms. With 1080 cells, without the condenser, C. 0·01331 W, a spherical nebulous glow around the negative ball, a slight glow on the positive, and no illumination of the tell-tale tube, fig. 7, *a*, Plate 18. When the condenser was attached the discharge became stratified, and the tell-tale lighted up, fig. 7, *b*, Plate 18. These are copied from photographs obtained in 60 seconds.

Tube 32, *Coal Gas.*

233.—This is represented in fig. 37; the terminals are of aluminium, the negative being a cup 1 inch in diameter, and the positive heart-shaped; they are 2·75 inches apart. The elongated bulb is 7 inches long and 4·5 inches in diameter, resistance 57,000 ohms. With 1080 cells, C. 0·01390 W, a nebulous glow on the negative without any stratification, and a slight glow on the positive, but no illumination of the tell-tale, fig. 8, *a*, Plate 18; with the condenser a stratified discharge and the tell-tale brilliantly illuminated, fig. 8, *b*. By charging up the condenser of 44·8 m.f. and allowing it to run down through the tube, it was ascertained, by measurement with the electrometer, that the current of 415 cells would just pass.

The battery of 1080 cells gave a current of ·03754 weber in short circuit; the condenser employed in all cases was $\frac{1}{6}$th of G, Part I., page 99, having a capacity of about 0·66 microfarads; when brought into action, by pressing down the key K, fig. 41, there was no intervening resistance between it and the battery, and supposing it to be completely discharged automatically as soon as it was charged to the full potential, the current was sufficient to effect this 52·77 times in a second.* To pass through the tube, however, the battery-current had to expend a certain amount of electro-motive force to overcome the impediments offered by the residual gas in the tube, and also the small resistance of the primary of the induction coil, so that the potential in the condenser might become somewhat higher than that necessary to overcome these impediments, and therefore from time to time an extra current from the condenser could pass through the tube, producing pulsations in the current through the primary of the induction coil, which are rendered evident by the glow in the tell-tale tube connected with the secondary wire of the coil. These

* The time required to charge the condenser to the potential of 1 volt would be $\frac{1}{0·03754}\times 0·00000066=$ 0·00001758 second, or it would be charged to the potential of 1080 cells (assuming them to be equal to volts) $\frac{56990}{1080}=52·77$ times per second.

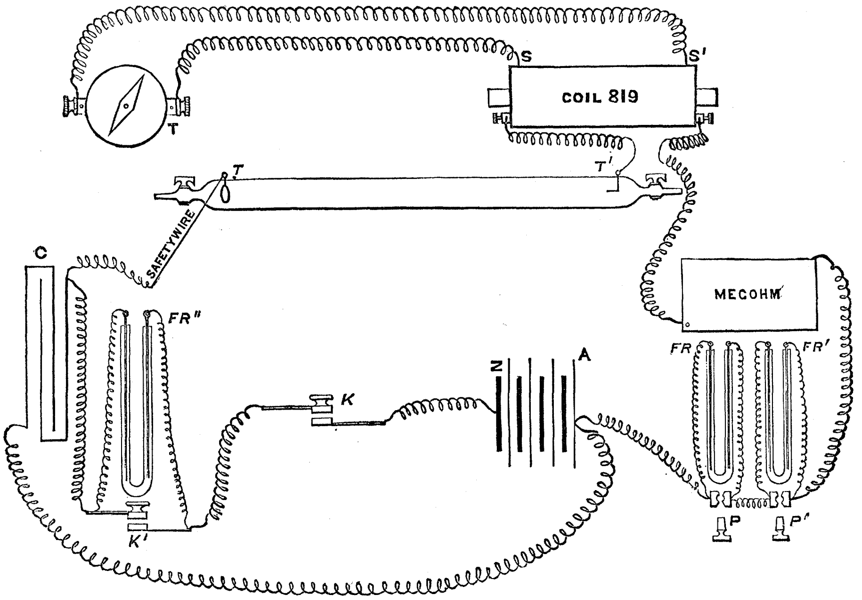
intermittent extra currents would in all probability occur when the potential of the condenser had risen only a very little above that of the terminals in the tube, and would consequently take place very many times more rapidly than 52·77 times in a second of time, as nothing approaching the full charge of the condenser passes on these occasions.

The phenomena do not occur when a very large condenser, 42·8 microfarad for example, is employed in the way shown in fig. 26, Part I., page 100, for then no current passes through the tube until the condenser has become charged to a sufficiently high potential, and this occupies a sensible time, about thirty seconds, and when it passes it does so continuously and steadily.

On the other hand with a small condenser, used as shown in fig. 66, the current commences to pass almost instantaneously through the tube, and in all probability divides itself as soon as the key K is pressed down, part continuing to pass through the tube, and part entering the condenser and discharging itself intermittently through the tube.

In order to test whether it would be possible to render evident pulsations, in the current, too feeble to cause the illumination of the tell-tale when perfectly steady strata are produced in tubes containing residual gases, we arranged the detector apparatus as shown in fig. 69.

Fig. 69.



A Z is the battery; A being connected through the fluid resistances FR FR′ (which can be plugged out of circuit by means of P and P′), the megohm, and the primary of coil No. 819, to the terminal T′ of the tube; A is also connected direct to one plate of the condenser C. Z is connected through the key K to the fluid resistance FR″ (which can be plugged out by pressing down the key K′), thence to the other plate of the condenser, and through the safety wire to the other terminal T of the tube. The secondary wire of coil 819 is connected to a delicate THOMSON galvanometer T.

The apparatus being so arranged, if K is pressed down the condenser charges up (more rapidly when K′ is also pressed down than when the current is allowed to pass through the resistance FR″), and when it has reached a certain potential the current commences to pass steadily through the tube and the primary of the induction coil 819, and will continue to do so after the connexion with the battery is interrupted by raising the key K.

The condenser discharges itself more or less rapidly through the tube according to its resistance, and the external resistance introduced into the circuit at FR, FR′, and the megohm. The fluid resistance FR″ has no effect upon the time occupied by the charge running out of the condenser, as the current does not pass through it when the key K is allowed to rise so as to disconnect the battery, as will be easily seen by referring to the diagram. The only use of FR″ is to regulate the rate of *inflow* of the charge, and it may be so adjusted as to feed the condenser exactly as fast as it loses its charge. By pressing down the keys K′ and K the condenser is maintained at the highest potential possible with a given number of elements, a given tube, and a certain external resistance.

It is quite evident that even if pulsations do take place in the current through the tube, no effect would be produced on the galvanometer in connexion with the secondary of the induction coil, provided the rise and fall of the current were equal and in equal periods. The case would, however, be different provided either the rise or the fall were more rapid relatively to the other, and one might expect under these circumstances that there would be some movement of the needle of the galvanometer, notwithstanding that its period of oscillation was not synchronous with the pulsations of the current.

A dynamometer would evidently be a much better instrument for detecting pulsations in the primary current, because the reversal of the current does not affect its deflection, which is cumulative in the same direction. We had one constructed as delicate as possible in which the moveable coil was suspended by a platinum wire only 0·001 inch in diameter, but it was found to be far too sluggish for our purpose.

Between the terminals of the THOMSON galvanometer is inserted a shunt-box, by which the current of the secondary wire may be reduced to $\frac{1}{10}$th, $\frac{1}{100}$th, or $\frac{1}{1000}$th part before passing through it; this shunt-box also has a short-circuit plug, by means of which, when so desired, the current may be entirely shut off from the galvanometer. The shunt-box is not shown in the diagram.

In order to ascertain the direction of the current in the secondary wire, the condenser was disconnected in the first instance, the short-circuit plug of the galvanometer being removed, and contact made with the battery so as to send the current through the tube, the swing of the galvanometer indicated the direction, say to the right, for the make-contact or *inverse* current; the contact was then broken and the swing, say to the left, was that for break-contact or *direct* current. It is almost needless to state that the primary current was suitably reduced by inserting resistances in the circuit, and that of the secondary by the use of suitable shunts to prevent injury to the THOMSON galvanometer.

Having thus ascertained the direction of swing for *direct* or *inverse* currents, the condenser was connected up, the short-circuit plug having been previously inserted between the terminals of the galvanometer so as to prevent any disturbance of it on making contact; as soon as the condenser had acquired a sufficiently high potential the short-circuit plug was removed. If the battery were left on there was frequently a slight *inverse* (make-contact) current indicated by the swing of the galvanometer. If the battery was now (after the insertion of the short-circuit plug) disconnected, there was a continuous *direct* current observed as the charge of the condenser ran gradually down so soon as the short-circuit plug was removed. The first of the two cases was equivalent to an infinite number of make-contacts, the second to an infinite number of break-contacts. Many observations were made with coil No. 819, which we had taken to pieces several times during the course of our trials on account of suspected leakage from the primary to the secondary wire. It was ultimately entirely remade in February, 1878, and the secondary wire coiled on a separate ebonite cylinder to ensure efficient insulation, which was accomplished.

COIL 819 when altered was thus composed.

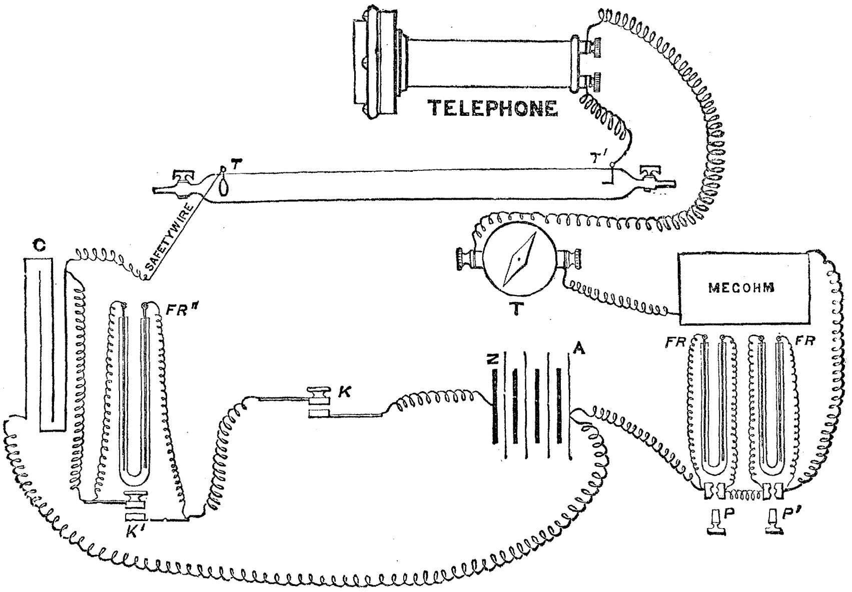
Approximate internal diameter.	External diameter.	Length of wire.	Diameter of wire.	Resistance.	Turns.
inch.	inch.		inch.	ohms.	
0·6	2·2	1700 yards	0·014	0·304	12920 primary.
3·2	4·6	14 miles	0·0033	42000	26289 secondary.

In every case where the strata are to the eye or rotating mirror perfectly steady, slight deflections of the needle are seen; these generally indicate a resultant *direct* current (break-contact), and in the fewer number of cases an *inverse* current indicating, in the first case, a *sudden* decrease and *slow* increase of current through the tube. These deflections, though very manifest, do not amount to more than about three or four divisions of the galvanometer scale, a deflection which indicates a current of only 0·00000000023 W. At the advent or retreat of a stratum at the positive pole there is frequently produced a deviation of 300 divisions, indicating a current of 0·00000001812 W; before a stratum leaves the positive terminal or dies out on it, there is usually a tremulous motion of that stratum visible to the eye and indicated by rapid pulsations of the galvanometer.

On the suggestion of Professor CLERK MAXWELL we have recently introduced the telephone into the primary current, as shown in fig. 70, and also in the secondary current of coil 819.

In all cases where the condenser C was discharging itself gradually through the tube a low rustling sound was distinctly audible to sensitive ears so long as the stratification remained *apparently* perfectly steady. When the phase of confused stratification, which immediately precedes extinction, was reached, the sound in the

Fig. 70.



telephone became very loud and rose in pitch, with some tubes becoming quite shrill. These results, therefore, confirm the conclusion already arrived at from other experiments, namely, that the discharge in vacuum tubes is intermittent; but we do not pretend that they make it manifest that stratification is *dependent* upon intermittence.*

In the course of our experiments we have arrived at the following facts :—

1. *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, but must be of the nature of a disruptive discharge, the molecules of the gas acting as carriers of electrification.*

* Mr. SPOTTISWOODE informs us (June 3, 1878) that he has also tried the telephone inserted in the circuit, both from the HOLTZ machine and from the great condenser, and found that the rushing noise was coincident with well developed striæ. The sound, however, occasionally became inaudible (to human ears, D. and M.), and afterwards recovered its strength. When the tension in the condenser fell below a certain point, or the speed of the machine was reduced below a certain rate, indicated by a sudden change in the configuration of the striæ, the rushing noise was replaced by a musical note, the pitch of which fell with the tension. The range of this note was in some cases considerably greater than an octave, and its pitch fell more often by semitones than gradually. The range both in pitch and in duration was increased by resistance introduced in the circuit. The pitch of the note was lowered by bringing the finger near to the tube, and thereby constricting the discharge.

The gases in all probability receive impulses in two directions at right angles to each other, that from the negative being the more continuous of the two. Metal is frequently carried from the terminals and is deposited on the inside of the tube, so as to leave a permanent record of the spaces between the strata.*

2. *As the exhaustion proceeds the potential necessary to cause a current to pass diminishes up to a certain point, whence it again increases, and the strata thicken and diminish in number, until a point is reached at which, notwithstanding the high electromotive force available, no discharge through the residual gas can be detected.*† Thus, when one pole of a battery of 8040 cells, was led to one of the terminals of tube 143, fig. 37, which has a radiometer attached to it, the other terminal of the tube, distant only 0·1 inch, being connected through a sensitive THOMSON galvanometer to the other pole of the battery (earth), the current observed was not greater than that which was found to be due to conduction over and through the glass. Although no current passed, the leading wires acting inductively stopped the motion of the radiometer, as has been observed by Mr. Justice GROVE.
3. *All strata have their origin at the positive pole.* Thus, in a given tube, with a certain gas, there is produced at a certain pressure, in the first instance, only one luminosity which forms on the positive terminal, then, as the exhaustion is gradually carried further it detaches itself, moving towards the negative, and being followed by other luminosities, which gradually increase in number up to a certain point.
4. *With the same potential the phenomena vary irregularly with the amount of current.* Sometimes, as the current is increased, the number of strata in certain tubes increases, and as it is diminished their number decreases ; but with other tubes the number of strata frequently increases with a diminution of current. If the source of the current is a charged condenser, the flow being from one of its plates through resistances and the tube to the other : then, as the potential of the condenser falls and the current diminishes, the number of strata alters ; if the strata diminish in number with the fall of potential, then the stratum nearest the positive wire disappears on it, the next then follows and disappears, and so on with others ; if, on the other hand, the charge of the condenser is very gradually increased, the strata pour in, one after the other, in the most steady and beautiful manner from the positive.
5. *A change of current frequently produces an entire change in the colour of the strata.* For example, in a hydrogen tube from a cobalt blue to a pink.

* DE LA RUE and MÜLLER, Phil. Trans., 1878, Vol. 169, p. 90 and p. 118.

† From observations with pressure varying from 6·4 to 145·1 millims., WIEDEMANN and RUHLMANN conclude that the accumulation requisite to produce discharge increases with the pressure at first quickly, then more slowly; towards the upper limit of their experiments it becomes nearly proportional to the pressures.

It also changes the spectrum of the strata; moreover, the spectra of the illuminated terminals and the strata differ.

6. *If the discharge is irregular and the strata indistinct, an alteration of the amount of current makes the strata distinct and steady.* Most frequently a point of steadiness is produced by the careful introduction of external resistance; subsequently the introduction of more resistance produces a new phase of unsteadiness, and still more resistance another phase of steady and distinct stratification.
7. *The greatest heat is in the vicinity of the strata.* This can be best observed when the tube contains either only one stratum, or a small number separated by a broad interval. There is reason to believe that even in the dark discharge there may be strata; for we have found a development of heat in the middle of a tube, in which there was no illumination except on the terminals.
8. *Even when the strata are to all appearance perfectly steady, a pulsation can be detected in the current; but it is not proved that the strata depend upon intermittence.*
9. *There is no current from a battery through a tube divided by a glass division into two chambers, and the tube can only be illuminated by alternating charges.*
10. *In the same tube and with the same gas, a very great variety of phenomena can be produced by varying the pressure and the current. The luminosities and strata, in their various forms, can be reproduced in the same tube, or in others having similar dimensions.*
11. *At the same pressure and with the same current, the diameter of the tube affects the character and closeness of the stratification.*

Our special thanks are due to Professor STOKES for many valuable suggestions and criticisms during the course of our investigation.

We have very great pleasure in stating that during the last twelve months we have had the benefit of the zealous assistance of Mr. W. SHARPEY SEATON, formerly in the service of Professors Sir WM. THOMSON and FLEEMING JENKIN, and that we have found his familiarity with electrical measurements, and his resources in devising methods of overcoming the many impediments we have encountered in connexion with them, of the greatest value. Mr. FRAM has continued to give us zealous, intelligent, and patient assistance, and has helped us over many difficulties. The photographs copied in Plates 15–18 were taken by Mr. H. REYNOLDS, Mr. DE LA RUE's former assistant in astronomical photography.*

Our experiments are still going on, and we may have, at a future time, some more

* Phil. Trans. 1862, pp. 333–416.

facts to contribute to the general stock of knowledge ; but the field before us is so inexhaustible, that we think it better to offer the small amount of produce we have collected, with much labour, rather than wait, and by slightly increasing the offering, make it more acceptable. We are now engaged in determining the differences of potential between the terminals corresponding to different pressures with a given gas and a given vacuum tube. We defer for the present the suggestion of any theory to account for stratification, in the hope of being able to confirm experimentally certain views which we entertain as to the cause of this phenomenon.

April 10*th*, 1878.

ERRATUM.

Part I., page 112, *for* $\frac{0 \cdot 0001713 \times 63 \cdot 4}{10} =$

read $\frac{0 \cdot 0001713 \times 63 \cdot 24}{10} =$

APPENDIX.

NOTE A, RELATING TO PAGE 155.

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NOTE B, RELATING TO PAGE 168.

GROVE (Phil. Trans., 1852, p. 87) makes the following conjecture on this subject in his paper on the Electro-Chemical Polarity of Gases: "Whether gases at all conduct electricity, properly speaking, or whether the transmission is not always by the disruptive discharge, the discharge by convection, or something clearly analogous, is perhaps a doubtful question; but I feel strongly convinced that gases do not conduct in any similar manner to metals or electrolyte."

BECQUEREL made a most elaborate series of experiments on the "conductivity" of gases at high temperatures—red heat, and beyond. These are described very fully in the Annalés de Chimie, xxxix., 1853, pp. 355–402, and in abstract in the Comptes Rendus, xxvii., 1853, pp. 20–24. The discharge was obtained between two concentric cylinders, namely, a strained wire in the axis of a tube, both being of platinum; the tube was capable of being closed at the ends so as to permit experiments at any pressure down to about 3 or 4 millims., the limit of his pump. He found that by heating the tube to incandescence he could produce a discharge with one cell even at atmospheric pressure, and that the current was still further increased if the pressure were diminished. This result applied to all gases, pressures and temperatures tried, commencing at incandescence. The order of "conductivity" at a red heat at atmospheric pressures with one cell was, hydrogen, oxygen, chlorine, $\left\{\begin{matrix}\text{air,}\\ \text{nitrogen,}\end{matrix}\right\}$ carbonic anhydride; but with very high temperatures and small pressures there seemed to be a tendency to equal "conductivity."

He introduced a "rheostat," consisting of a U tube filled with fluid into which wires could be inserted to a less or greater depth, and having adjusted the resistance so as to obtain a given deflection when the tube was in circuit, he subsequently put the tube out of circuit and again adjusted the rheostat so as to obtain the same deflection; the difference between the two readings was taken by him as the resistance of the tube in terms of the rheostat.

Although he interprets his results differently, and is inclined to consider that gases at high temperatures really *conduct* electricity, they seem to us to support our hypothesis that the discharge is a disruptive one in all cases, even at the high temperatures he experimented with. For his measurements show that when he employed a definite potential and adjusted the external resistance to produce different currents, the resistance of the gas appeared to decrease with the increase of current, this agreeing so far with our results. But we are quite at a loss how to reconcile the following experiments with ours:—

"La seconde série de déterminations experimentales met en évidence un fait assez curieux: c'est que pour la même intensité électrique (the same amount of current), la resistance de l'air chauffé au rouge est d'autant plus grande que le nombre des éléments de la pile est aussi plus grand." Being unable to render an account to ourselves of this very remarkable result, we have, May 28th, 1878, made some experiments with tube 31, employing 1200, 2400, 3600, 4800, and 6300 cells, and by the introduction of *wire* resistance maintained a constant deviation of the galvanometer of 29°, we found that the *apparent* resistance of the tube was represented in each case by about 30,000 ohms. Our experiment differed from that of BECQUEREL, in that we employed rarefied gas at ordinary temperature instead of heated gas at atmospheric pressure, and our rheostat consisted of wire and not of a liquid electrolyte.

WIEDEMANN and RÜHLMANN (Poggend. Ann., cxlv., pp. 235-259, 364-399) by very different means have apparently arrived at the same result as our own. They started from the ground that the observations of one of them (G. WIEDEMANN) on the amount of heat generated in a Geissler-tube had demonstrated that rarefied gases did not behave like metallic conductors as had been asserted by other experimentalists (MORREN, Ann. de Chim. et de Phys., 4e série, iv., p. 325; Poggend. Ann., cxxx., p. 612; DE LA RIVE, Compt. Rend., vi., p. 669: Archives de Genève, nouv. sér., xvii., p. 53; HITTORF, Pogg. Ann., cxxxvi., p. 201, &c.); for the heat generated in the tube was far from varying as the *square* of the current. WIEDEMANN and RÜHLMANN selected for their source of electrification the HOLTZ machine, which was driven by a hydromotor, so as to give a constant current, and had so great an internal resistance as to render negligible the resistance of the external part of their circuit. By ingenious contrivances they succeeded in measuring the time-interval between the rapidly-succeeding flashes of which the discharge in rarefied gases, under the circumstances of their experiments, was proved to consist. They found that, when other things were kept constant and the current alone varied, the time-interval between a pair of successive discharges was inversely proportional to the current: in other words, the quantity which flowed across the tube at each discharge was constant for all the values of current investigated by them. Hence, as fast as a certain definite accumulation of electricity (density) was attained on the terminals, these discharged themselves, became recharged to the same accumulation and discharged themselves again, and so on. So far, therefore, as their observations extend, they seem entirely accordant with our own result stated above, for it is obvious that as the interval between the discharges in their experiments did not exceed 0·002 second, the effect on any electrometer as yet devised would be practically the same as if the terminals were kept constantly charged to that potential which they have when the accumulation is sufficient to cause discharge; *à fortiori*, would this be the case when a battery of small internal resistance is substituted for the HOLTZ machine. The range of WIEDEMANN and RÜHLMANN'S observations on this point appears, however, to have been very limited; in their illustrations of the constancy of the quantity flowing across at each discharge when the current is varied, the relation between the maximum and minimum currents employed is 40 : 24·5.

NOTE C, RELATING TO PAGE 221.

In support of the observation as to possible dependence of stratification upon the concurrence of axial and radial impulses from the positive and negative terminals respectively, we quote the following experiments :—

GASSIOT (Phil. Trans., pp. 1–16) used tubes supported in a vertical position, in which were produced Torricellian vacua, with an arrangement for causing the mercurial column to rise and cover one terminal or fall, and leave it exposed. "When the upper wire is negative and the lower positive, if the mercury in the globe is allowed to ascend the tube, the stratifications collapse, but the dark band between them and the negative glow remains; as the mercury rises the stratification merges into a series of rings on the surface of the mercury, which when the circuit of the primary is broken is not found to be tarnished, but as bright as when the experiment commenced. On reversing the direction of the current, when the mercury is permitted to ascend immediately it covers the negative wire the stratifications disappear and the interior of the globe is filled with bluish light; a bright spot of light is visible on the end of the positive wire, but the mercury no longer exhibits the red glow, its entire surface, until it ascends to within an inch of the positive wire, being covered with a brilliant white phosphorescent film about one-eighth of an inch in thickness."

He also (Phil. Trans., 1859, pp. 137–160) had constructed a tube in which a moveable terminal might be made to drop into a brass tubular case surrounded by a glass protecting tube of small bore which projected beyond the brass case, so that the point could at will be made to project beyond this glass sheath or to fall within it. "When both wires were exposed the stratified discharges show the clear cloud-like appearances so often described, whether A (the moveable terminal) is positive or negative; but if A is made negative and the tube inclined so as to let the wire drop into the brass tubing, almost all trace of stratifications immediately disappear."

He found that if he enclosed the terminals in a glass tube of very small bore projecting about an eighth of an inch beyond the end of the wire, the emanation from the negative might be constrained to take a forward direction. "The negative discharge issuing through the orifice as from a jet. . . . . If the wire (negative) is inclined a little the discharge will impinge against the side of the vacuum tube, brilliantly illuminating the spot on which it impinges. . . . . If the discharge is continued for a few seconds that portion of the tube on which the discharge impinges will be sensibly heated."

GASSIOT also states (Phil. Trans., 1858, p. 10) that: "The emanation of particles only proceeds from the negative, not in a direct line from the positive, but laterally." Again, p. 11: "Such particles being always deposited in a lateral direction from the wire, and not beyond the line on the glass tube even with the end of the wire." p. 13: "The force from the positive is not accompanied by the transfer of particles from the metallic terminal."

HITTORF (Pogg. Ann. cxxxvi., 1869, pp. 1–31 and 137–194) describes various experiments bearing on this point. Thus, in a tube having two parallel electrodes at 4 m.m. distance, the negative glow radiated in all directions through the tube, but the positive discharge appeared only on the side of its terminal which was remote from the negative electrode. In another tube it was observed that when one of the terminals was bent back upon itself, if this is made positive, the discharge curls round so as to present itself towards the negative; but when the bent terminal is made negative the glow remains directed away from the positive. He also describes an interesting experiment which exhibits in a striking manner the influence of the size of the space surrounding the electrodes, but it is complicated by the influence of the distance between the terminals, which latter influence has a value varying with the degree of rarefaction as shown by other experiments of the same physicist (*see* footnote, p. 163). A vessel consisting of two spherical glass bulbs joined by a short glass tube of 1 m.m. in diameter had two straight wires, for terminals, running horizontally one through each bulb and extending into the junction-tube so as to leave a space of only 1 m.m. between their extremities. The bulbs were also connected at the upper ends of their vertical axis by another long glass tube of the same bore as the short junction-tube. As the gas within the double vessel was rarefied, the discharge which, at higher pressures, had passed exclusively through the short tube began to divide itself and passed through the long circuitous route in proportion increasing with the decrease of pressure until a degree of rarefaction was attained, at which it passed *exclusively* through the long junction tube.

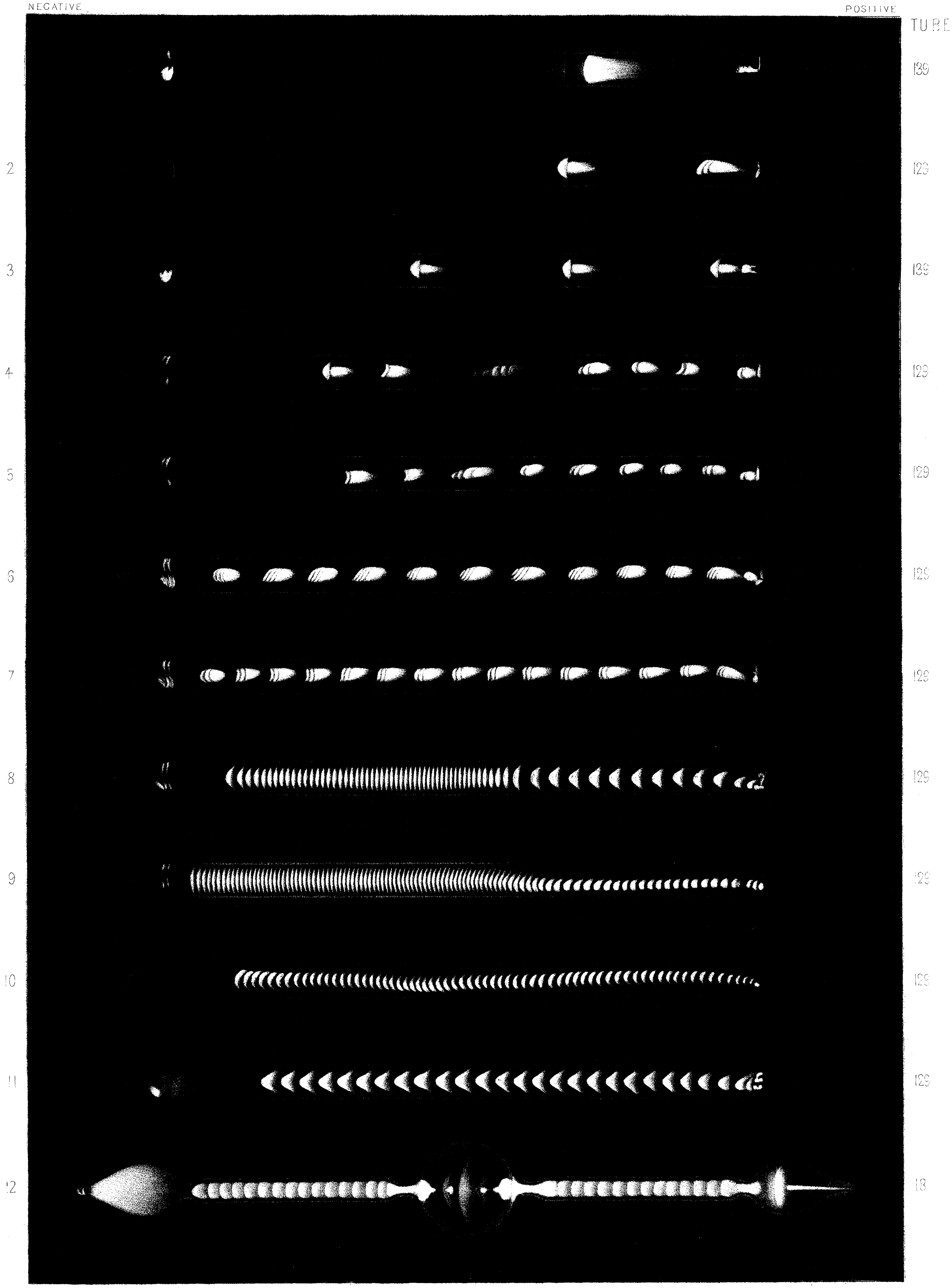
It has been noticed by ourselves and others that the size of the negative terminal has considerable influence upon the general character of the discharge, and that with a very small negative it is difficult to produce striæ at all.

With a view of testing this further, SPOTTISWOODE constructed a tube in which the length of one terminal could be altered, while the total distance between the extremities of the two terminals remained unchanged. With this contrivance it was found that when the negative terminal was lengthened the dark space was shortened by a prolongation of the positive column. Thus the tube being about 12 inches in length, an increase in the length of the negative terminal from 3 to 6 inches caused a diminution in that of the dark space from 3 to 1·5 inches.

The importance of size of the negative terminal was also illustrated by SPOTTISWOODE in a striking manner with a tube 18 inches in length and 1·75 in diameter, containing from 30 to 50 cubic centimetres of mercury. When the tube was laid on its side so as to leave the negative terminal, which was small, free from mercury, the tube was filled with an unbroken glow of light; but as soon as the mercury touched the terminal, a fine column of striæ was developed. When the mercury spread along any considerable part of the tube, the column still stretched out towards the negative terminal; but it was repelled to the side of the tube opposite to that occupied by the mercury, and the individual striæ assumed an oblique position, as if under the influence of two forces, one along the other at right angles to the axis of the tube.

INDEX TO PART II.

[*The Figures printed in Italics refer to the Experiments.*]



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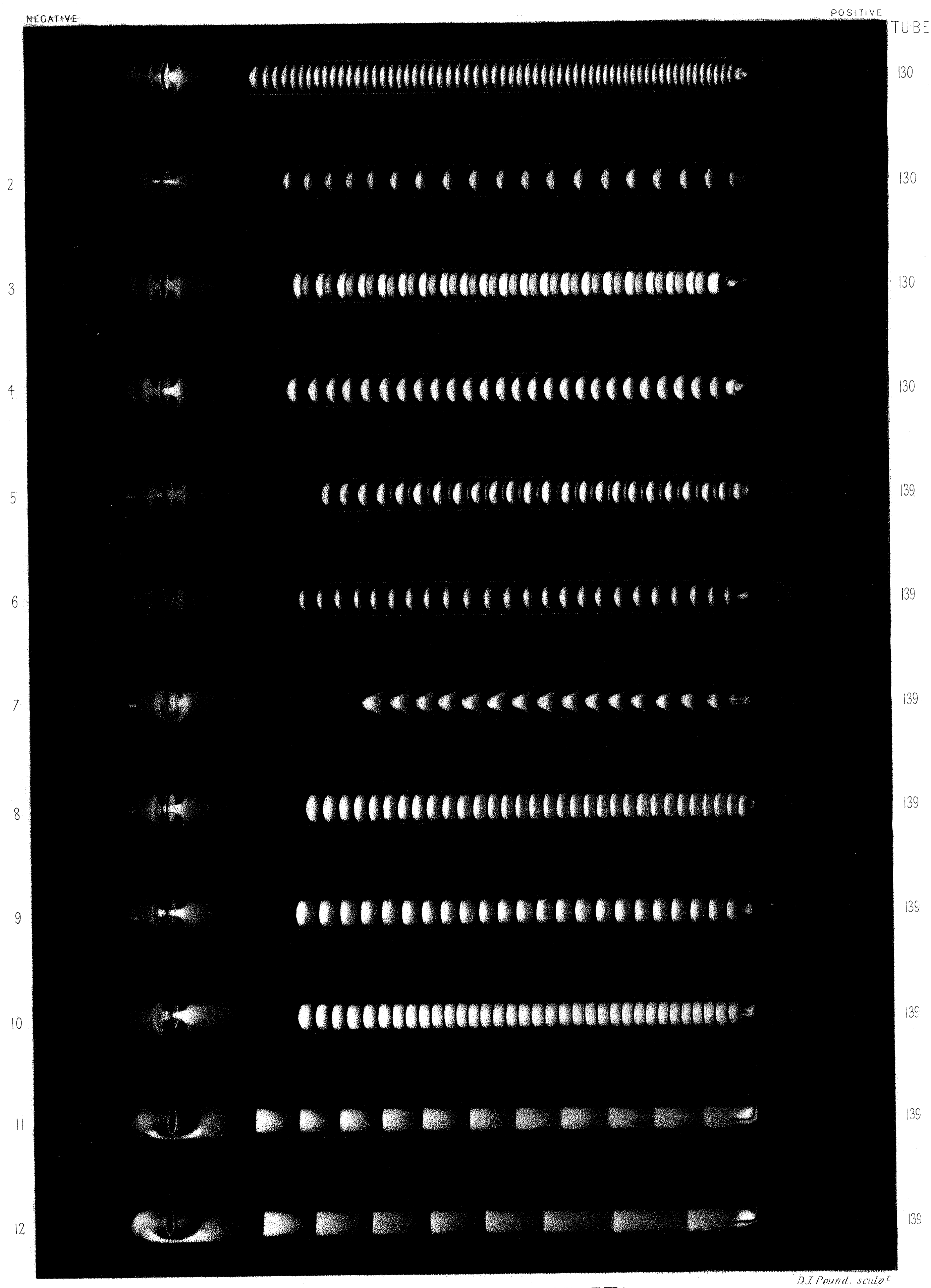

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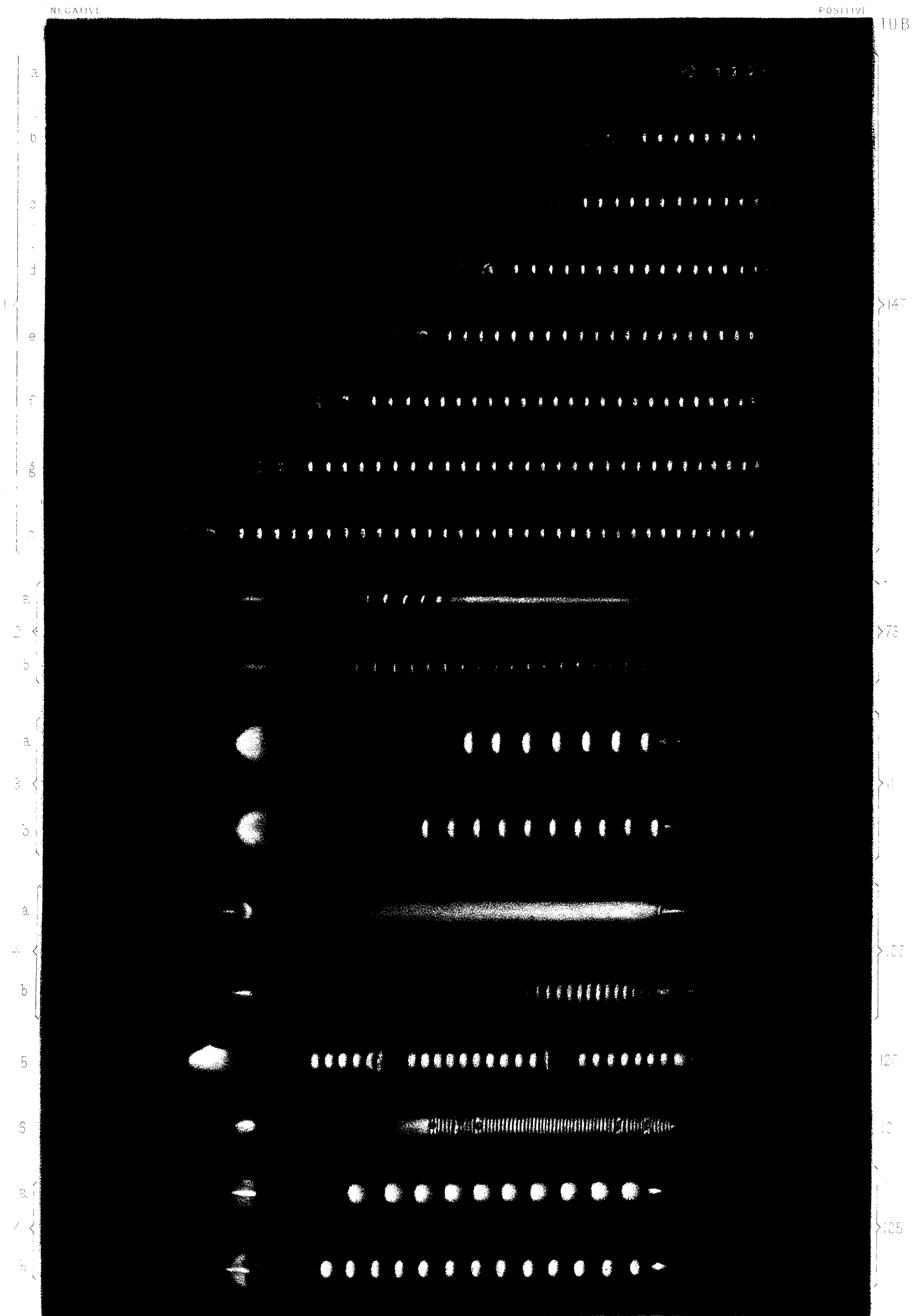

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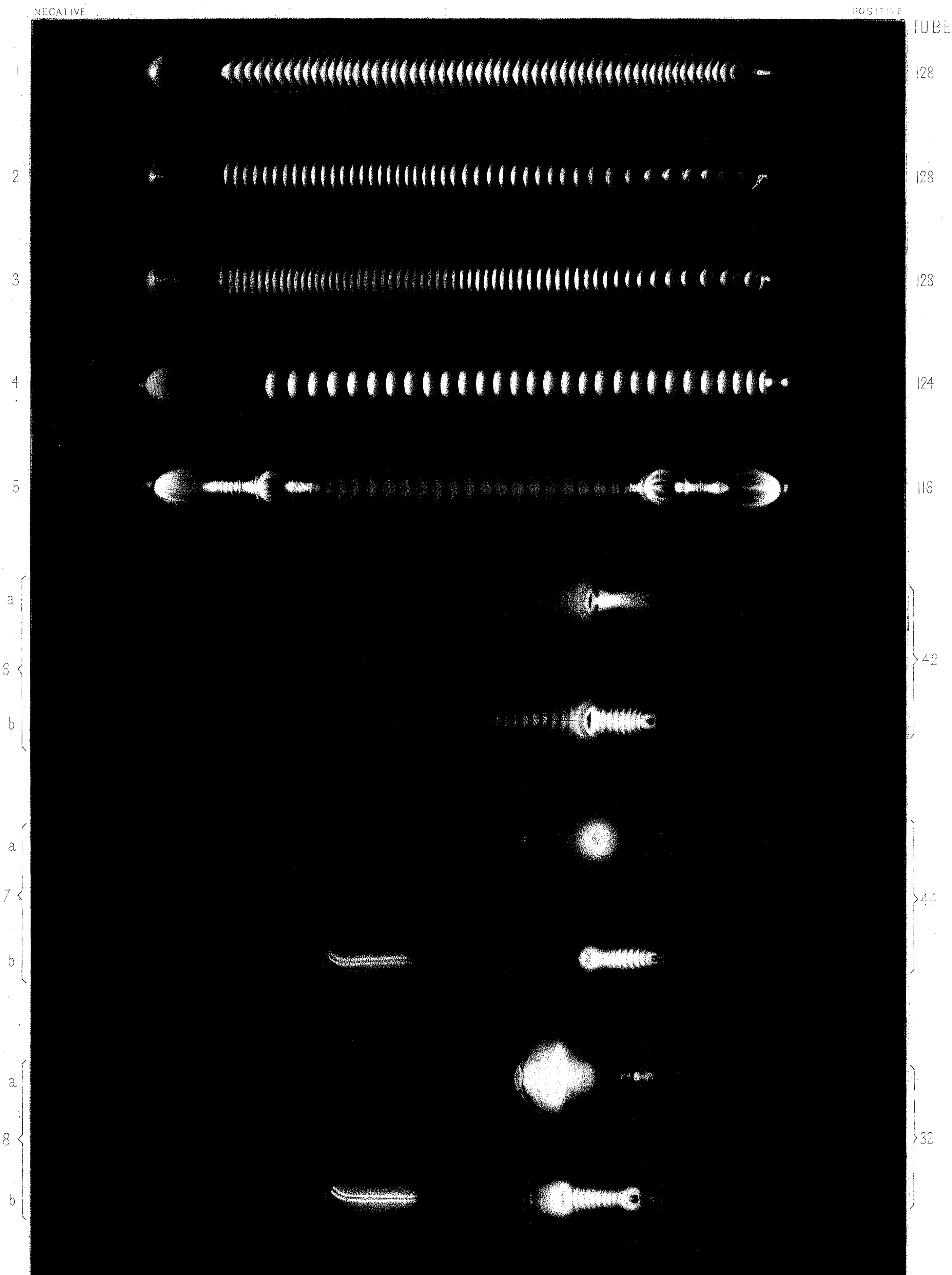

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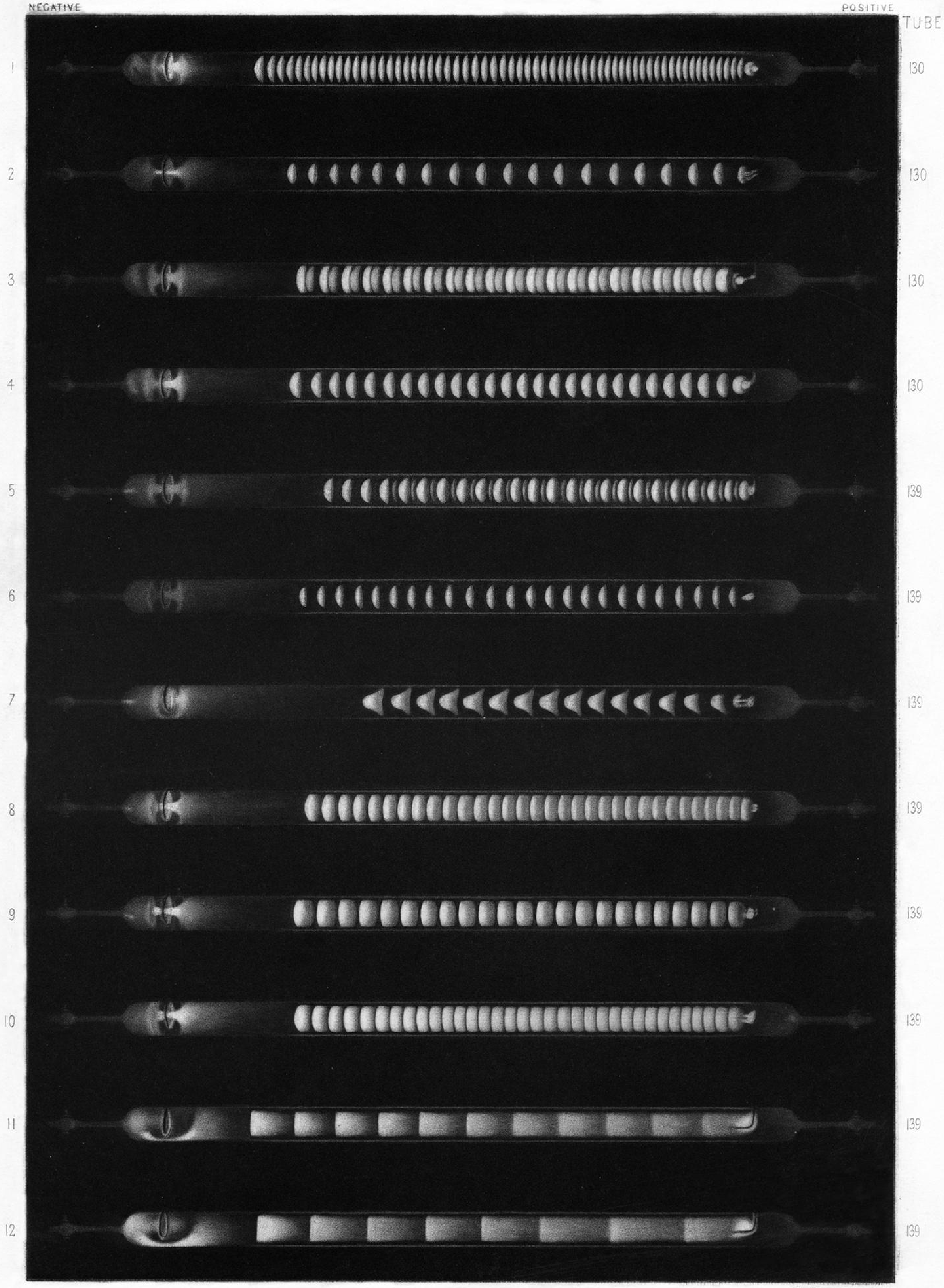

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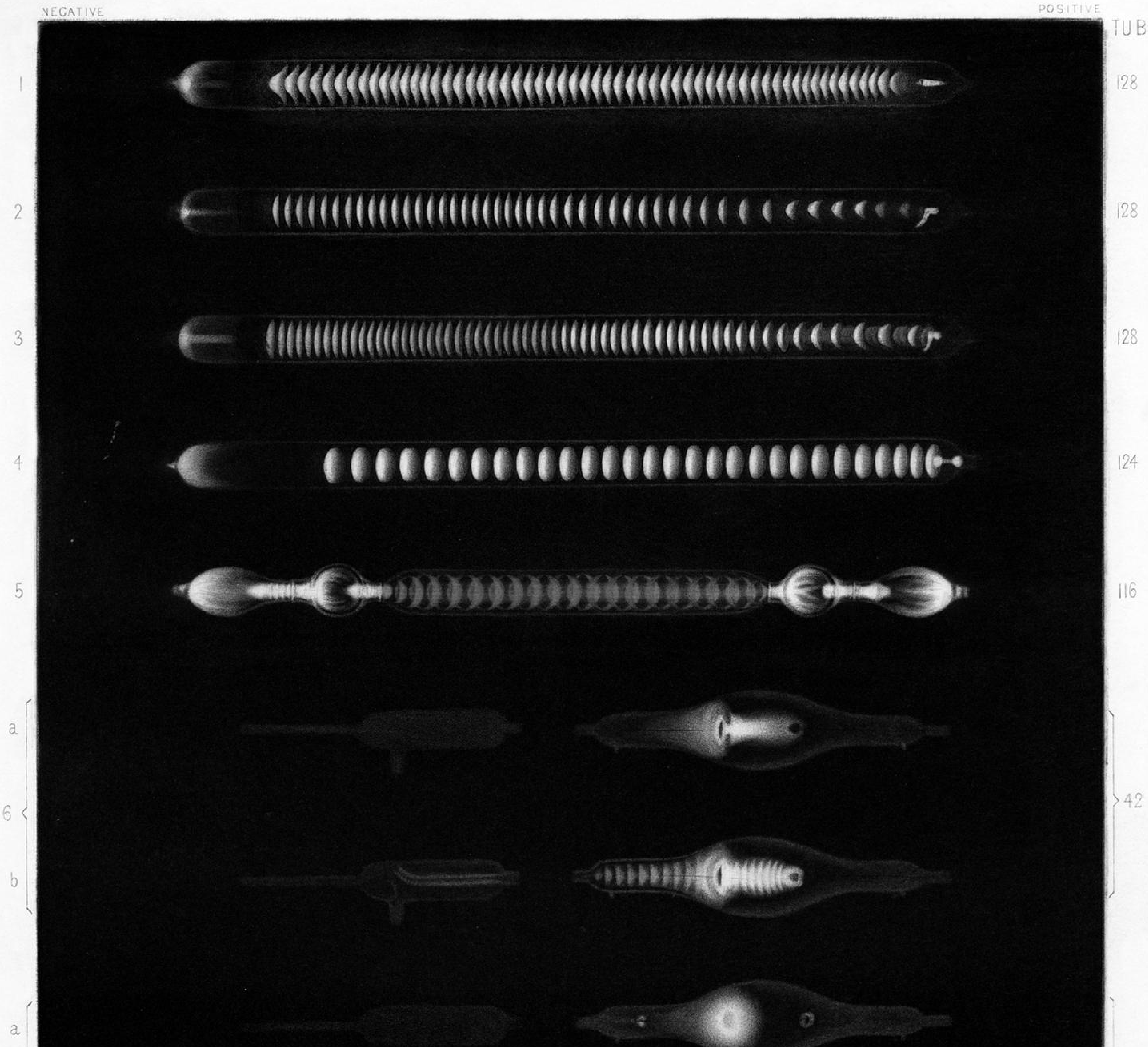

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