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

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[Plates 6–8.]

Part I.—THE DISCHARGE AT ORDINARY ATMOSPHERIC PRESSURES.

In the 'Journal of the Chemical Society,' November, 1868,* we first published an account of the chloride of silver battery, which we had devised as one of great constancy and well suited for studying the discharge in exhausted tubes; we shortly afterwards carried the number of cells to 200, and presented a battery of 100, part of the 200, to our friend the late Mr. Gassiot, who at that time was in search of a constant battery suitable to his investigations. Mr. Gassiot did not, however, adopt the chloride of silver battery, and it remained unemployed until 1874, when, in pursuance of a suggestion of our friend Mr. Spottiswoode, we put together for his use 1080 cells, but soon found that in order to effectually study the phenomena of the discharge it would be necessary to carry the number of cells much higher, this we have gradually done, and now possess 8040 cells in actual work, and 2680 more completed but not charged with fluid†. Amongst the 8040 cells in actual use are the first 1080 constructed in 1874, so that the constancy of the battery is thereby fully established. In the course of the increase of numbers, experience has led to many modifications of the details of the battery, but we reserve for the latter part of this communication a description of them. On the 24th February, 1875‡, we gave an account, in conjunction with our friend Mr. Spottiswoode, of some experiments made with 1080 cells, and on the 28th April, 1875, we made a verbal communication to the Society of Telegraph Engineers, when the battery of 1080 cells was exhibited.§ Subsequent to that meeting, our friend Mr. Latimer Clark, called our attention to and lent us a small work entitled 'The Electric Telegraph in British India,' by W. B. O'Shaughnessy, M.D., F.R.S., London, 1853, where, at page 14, the author describes an experimental cell of fused chloride of silver, and in justice to him we

* Journ. Chem. Soc., new series, vol. vi.; entire series, vol. xxi. p. 488.

† January 1, 1878.—The extra number now made up and charged is 2960 cells, which brings the total up to 11,000 cells. See Supplement, p. 116.

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

§ Journ. Tel. Engineers, vol. iv., No. XI., p. 202. 1876.

mention this circumstance; at the same time, we must say that the use of chloride of silver for a battery was an independent thought on our part. Dr. O'SHAUGHNESSY does not appear to have developed the idea into a workable battery, although he stated in his book that it would be of value for local circuits in signalling.

In October, 1875,* we made a communication to the Académie des Sciences of Paris, including some photographs of the stratified discharge obtained the 3rd of the previous month of August;† also a further communication to the Royal Society in 1876,‡ on the length of the spark with 600, 1200, 1800, 2400 rod cells, and subsequently, in May, 1877, a short statement of the relative length of the spark in different gases at the ordinary atmospheric pressure.§

Although we do not pretend to have solved the problem of the cause of stratification in tubes exhausted to a great extent of the gases they originally contained, we venture to think that an account of our experiments will to some extent limit the field of future inquiry, and that they may have present interest for the electrician.

We propose in the first place to deal with the discharge at ordinary atmospheric pressures, and in order that the requisite data for comparison with the results of other experimenters may be at hand, we here give the electro-motive force of our battery.

The following value was obtained by balancing a battery of 10 chloride of silver rod cells against 1 LATIMER CLARK standard mercurial cell|| (1·457 volt.). The chloride of silver battery was kept continuously working through a high resistance, and the standard cell only opposed it when the comparison had to be made.

The zinc of a battery of 10 rod chloride of silver cells, and the zinc of a LATIMER CLARK cell were connected together and to one end of a resistance of 9270 ohms. The silver of the battery of 10 cells was connected to the other end of the resistance coils. The mercury of the CLARK cell was connected to one terminal of a THOMSON galvanometer, the other terminal of which was connected to a shifting contact plug. It was found that there was no deflection of the galvanometer when this plug was inserted at 1275. Consequently

$$\frac{\text{EMF of 1 Ag Cl cell}}{\text{EMF of 1 Lat. Clark cell}} = \frac{9270}{1275 \times 10} = 0{\cdot}7271,$$

$$\text{Or, EMF of 1 Ag Cl cell} = 0{\cdot}7271 \times 1{\cdot}457 = 1{\cdot}059 \text{ volt.}$$

* Comptes Rendus, No. 16, p. 686, and No. 17, p. 746. 1875.

† A fac-simile of one of these will be given in Part II.

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

§ Proc. Roy. Soc., vol. xxvi. p. 227.

|| Phil. Trans., vol. 164, p.

Another comparison with 20 cells gave a value of 1·002 volt, II.; a comparison made by Dr. MUIRHEAD in 1875, gave 1·031 volt, III.

Electro-motive force of the chloride of silver cell is consequently:

	volt.
I.	1·059
II.	1·002
III.	1·031
Mean	1·03

In all succeeding calculations we have taken the electro-motive force as—

$$1·03 \text{ volt} = \frac{1·03 \times 10^8}{3 \times 10^{10}} = ·00343 \text{ electro-static unit.}$$

The internal resistance of the battery depends partly on the distance between the zinc rod and the chloride of silver, but mainly upon the circumstance of the chloride of silver being used in the form of powder or fused into rods; we have 3240 powder-cells and 4800 rod-cells in work; gradually and after many months the internal resistance increases in consequence of a hard skin of oxychloride of zinc forming on the zinc rods. We have taken 5 ohms for the internal resistance of the rod, and 15 ohms as that of the powder-cells in the succeeding calculations.

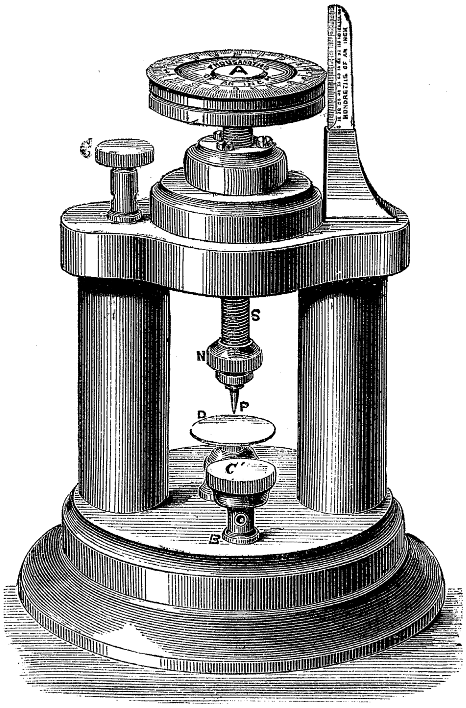
We have determined the electro-motive force of the two other haloïd compounds of silver, and find it to be as under for the three haloïds—

	volt.
Chloride of silver . . .	1·03
Bromide ,, . . .	0·908
Iodide ,, . . .	0·758

To measure the striking distance at ordinary atmospheric pressures, we have used the discharger figured below, which was made from our drawings by our assistant, Mr. JAMES FRAM, who has aided us materially during this investigation by his intelligent interpretation of our wishes, and his mechanical skill in carrying them out.

The frame work is of ebonite, and its construction sufficiently obvious; the screw S having a $\frac{1}{50}$th of-an-inch thread, has a cylindrical recess at the lower end into which is inserted one of the terminals to be used in the experiments (in this case a point P); the end of the screw has four slits cut through it, in order that it may be contracted and made to pinch tightly any terminal inserted in it by means of the binding-nut N, working on the end of the screw, which is slightly conical but still has a full thread cut upon it. The nut fixed in the cross head at the top of the frame through which the screw works is in metallic communication with the clamp C, and is divided horizontally into two parts which are pressed asunder by three spiral springs in order to prevent shake or play of the micrometer screw. At the base of the instrument is a fixed holder with a screw and binding-nut like that for the upper terminal, this is in metallic communication with the clamp C′, and holds in the above figure a terminal in the form of a disc D. To the top of the screw is fixed the ebonite wheel A, to which is fastened a metallic ring divided into 20 parts, each representing $\frac{1}{1000}$th of an inch; as the divisions are 0·35 inch apart at the outer periphery of the disc, it will be obvious that the $\frac{1}{10000}$ may be approximately estimated without difficulty. On the top of the right-hand pillar is a vertical scale by which the number of whole revolutions of the screw is read off. Before com-

Fig. 1.



mencing an experiment the discharger is connected with a battery of 10 cells through a detector-galvanometer, and the terminals approached cautiously until the motion of the galvanometer indicates contact; the length of the spark of 10 cells is so small that the reading of the micrometer is taken as zero. The screw is run up for a greater distance than the anticipated length of the spark to be measured, and when the micrometer has been connected with the battery it is gradually approached by steps.

The connexion between the micrometer-discharger and the battery is effected by means of the discharging key, shown in the figures 2 and 3, which we have designed specially for our battery, as the ordinary form of doubly reversing key, even when made much larger than usual, was found not to answer for the high potentials we employ, in consequence of the voltaic arc continuing the current after metallic contact had been broken.

The battery is connected to the discharging key at the insulated standards in which the horizontal ebonite axis A Z works, to this is fixed the ebonite handle H; there are metallic collars A and Z, carrying the pivots, fitted on the ebonite axis. These pivots are in metallic communication, by means of leading wires inserted in the ebonite axis, respectively with the spring pieces S and S′, in which are inserted renewable platinum wires held in their places by binding-nuts. The four bracket standards B B, B′ B′, are connected with the apparatus through which the discharge

Fig. 2.

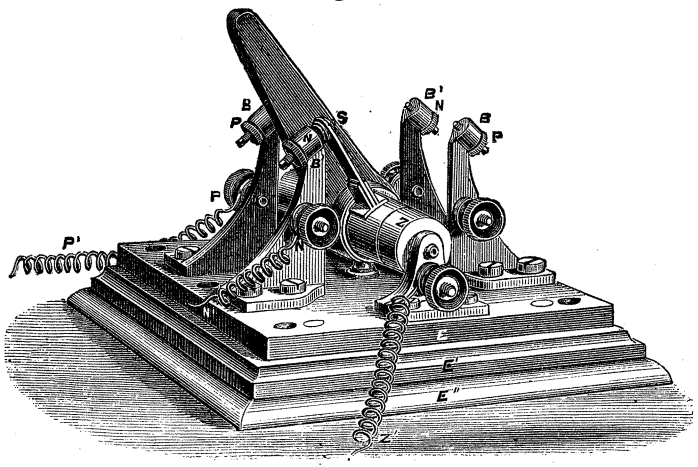
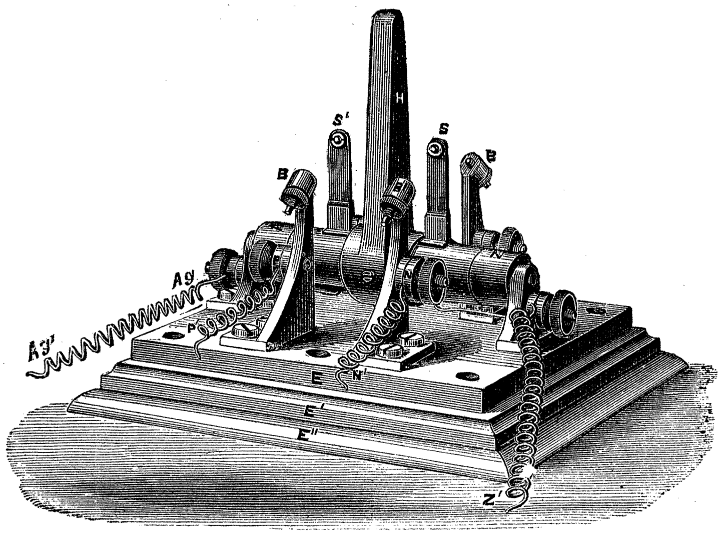


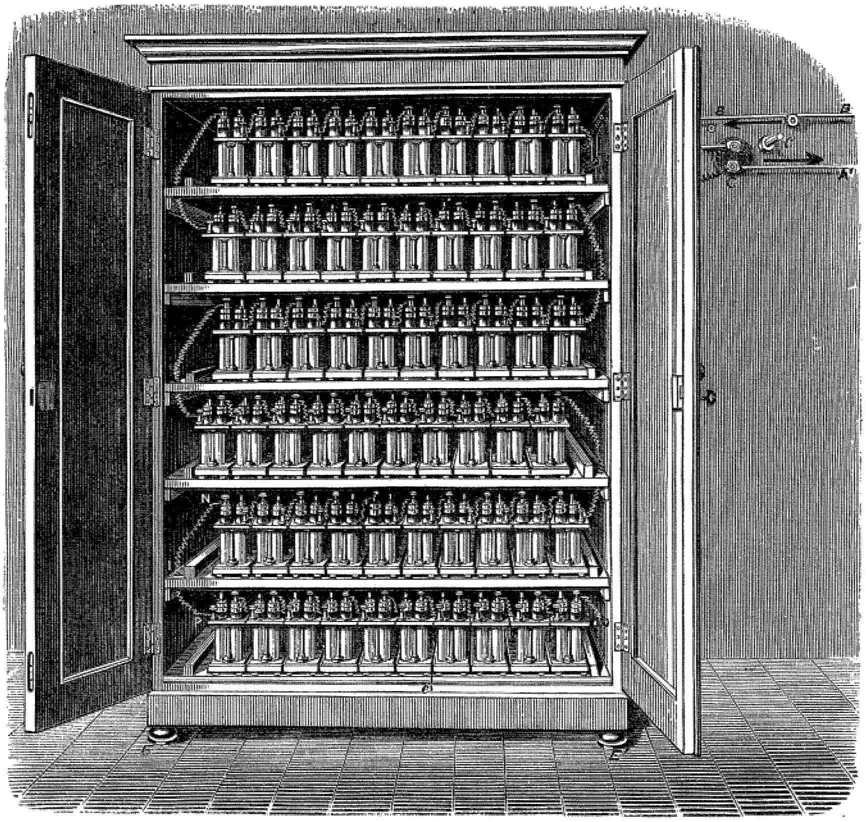
Fig. 3.



is to be made by means of the wires N′ and P′. The bracket standards, B B, and B′ B′, are connected together respectively by means of diagonal wires below the top ebonite plate E, the middle ebonite plate E′, half an inch thick, intervening between them. These bracket pieces have adjustable platinum contact wires screwed through their heads and held in position by binding-nuts. The horizontal axis carrying the spring contact pieces S S′, is held in its place by a strong spring ending in a V piece, underneath and parallel with it, which falls into one of three notches to hold it out of contact when the handle H is upright, as in fig. 3, or in contact to the right, or to the left as shown in fig 2.

After the adjustment of the distance between the terminals of the discharger, fig. 1, the current was usually sent alternately so as to make the upper terminal positive or negative by means of the discharging key just described, so that the striking distance was obtained for the current in both directions; on breaking contact with this key there is no fear of the voltaic arc continuing the current, as was found to be the case with the ordinary form of the doubly reversing keys as soon as the battery reached

Fig. 4.



4000 cells, because the double distance of B′ to S′ and S to B amounts to $2\frac{1}{2}$ inches; and it has been found that the arc will not extend after separation of the terminals to more than $1\frac{1}{2}$ inch even when the battery consists of 8040 cells.

All the wires leading from the batteries are 0·0625 ($\frac{1}{16}$th) inch diameter, and are covered with a coating of gutta percha 0·125 ($\frac{1}{8}$th) inch thick; the wires as they run round the laboratory are supported on ebonite supports in order, as far as possible, to prevent leakage. The batteries are arranged in cabinets standing on ebonite feet (E, fig. 4), and each tray of 20 also stands on ebonite feet.

Fig. 4 shows a cabinet 4 feet 7½ inches (140·9 centims.) high, 3 feet 6 inches (106·7 centims.) wide, and 17 inches (43·17 centims.) deep, inside measurement, containing a battery of 1200 rod-cells, each tray holding 20 cells; all the wires represented are covered with gutta percha, and when they connect shelf to shelf they pass through ebonite cylinders fixed in the shelves. Inside the case on the right is fixed a switch, as represented in figs. 5 and 6.

Fig. 5.

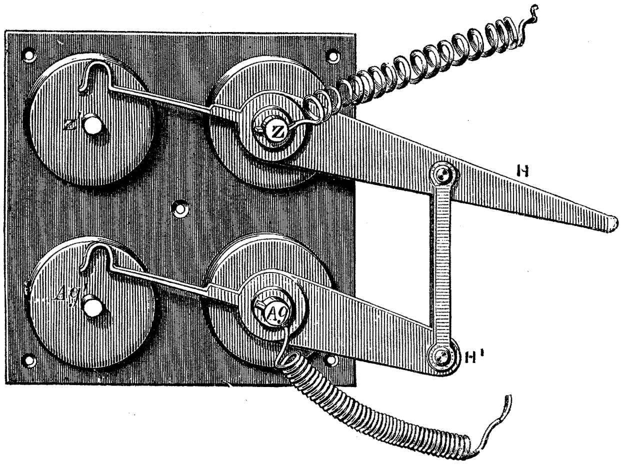
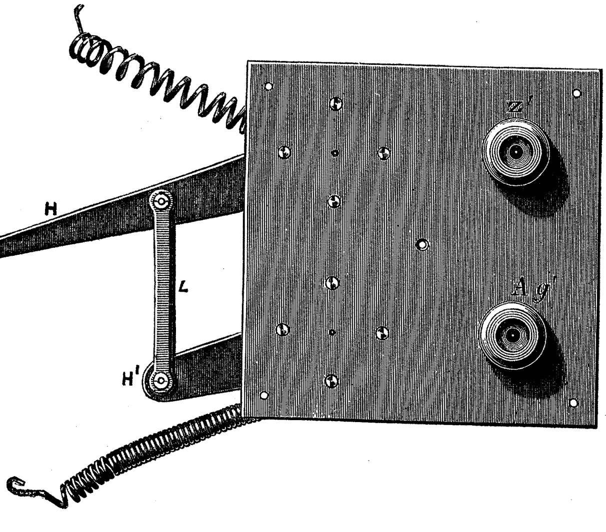


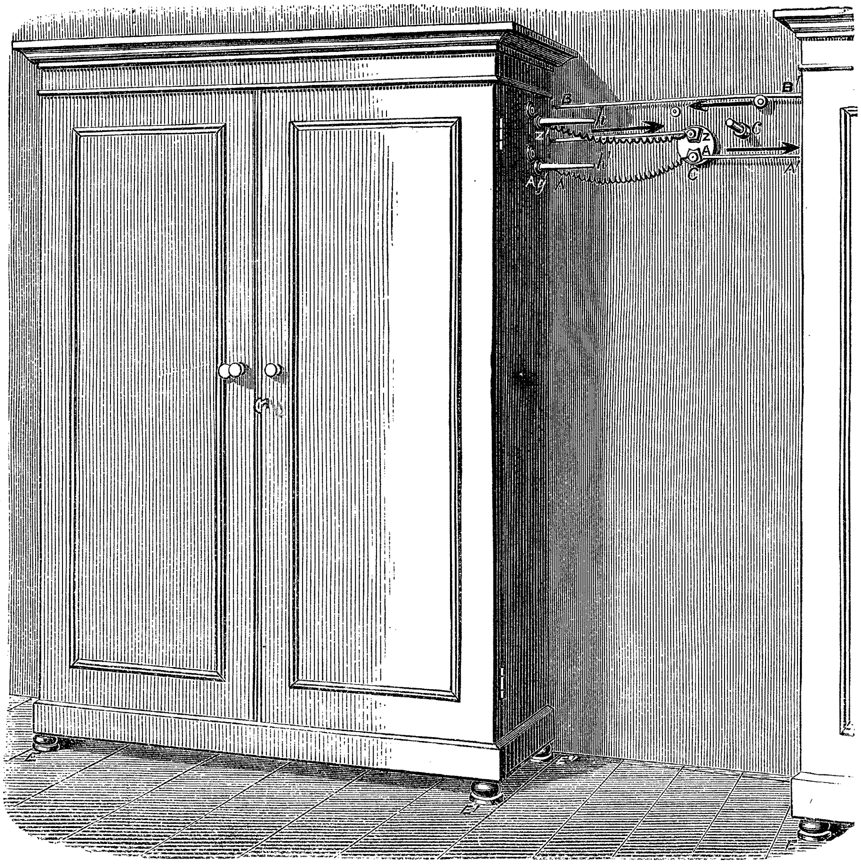
Fig. 6.



The frame work and the levers H and H′ are of ebonite; the terminal wires from the battery are connected to the axes of the lever handles A*g* and Z respectively; when the battery is not required the levers rest in the position shown in the figures, when it is to be brought into circuit the handle H is elevated so as to bring the brass spring pieces in contact with the brass rods Z′ and A*g*′ which pass to the outside of the cabinet, the outer ends of the rods are hollow in order to admit of the insertion of contact plugs (h and h', fig. 7). Fig. 6 shows that face of the switch which is screwed against the inside of the case.

Fig. 7 shows the means of connecting up the several batteries. The battery on the left being represented in circuit by the insertion of brass plugs with ebonite handles h, h', into the cylindrical hollow ends of the switch rods; when this battery is not in use the plugs are withdrawn and inserted into the supports shown in the figure attached to the end of the case, it being understood that the handle of the switch

Fig. 7.



has been depressed to throw the contact springs out of gear. The conducting wire has moreover to be rendered continuous by inserting the plug C between the jaws Z and A of the insulated plug-connector, which has a space of ·625 ($\frac{5}{8}$th) inch between the nearest points of the jaws, a distance absolutely necessary with batteries of such high tension as those we have in action.

For special experiments we have found it necessary to design and have constructed a commutator capable of reversing the current many times in a second, that shown in fig. 8 represents the form we have found most convenient to employ; it is capable of reversing the current 352 times in a second when the handle is turned 240 times in a minute, which it is not difficult to do. It will be seen that each revolution of A, B, C, D reverses twice. This piece of apparatus follows the discharging key, figs. 2 and 3, in order from the poles of the battery, the wire A*g* being in connexion with the bracket B, and the wire Z with B′ of the contact key, fig. 2.

The figure is so distinct as scarcely to require any description; it will be seen

Fig. 8.

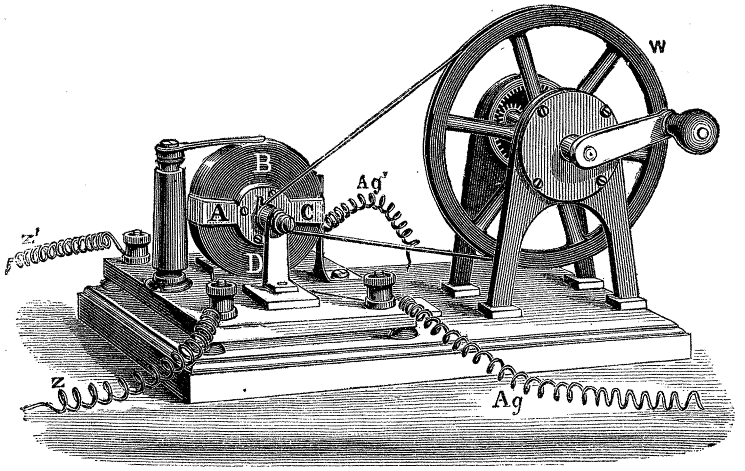
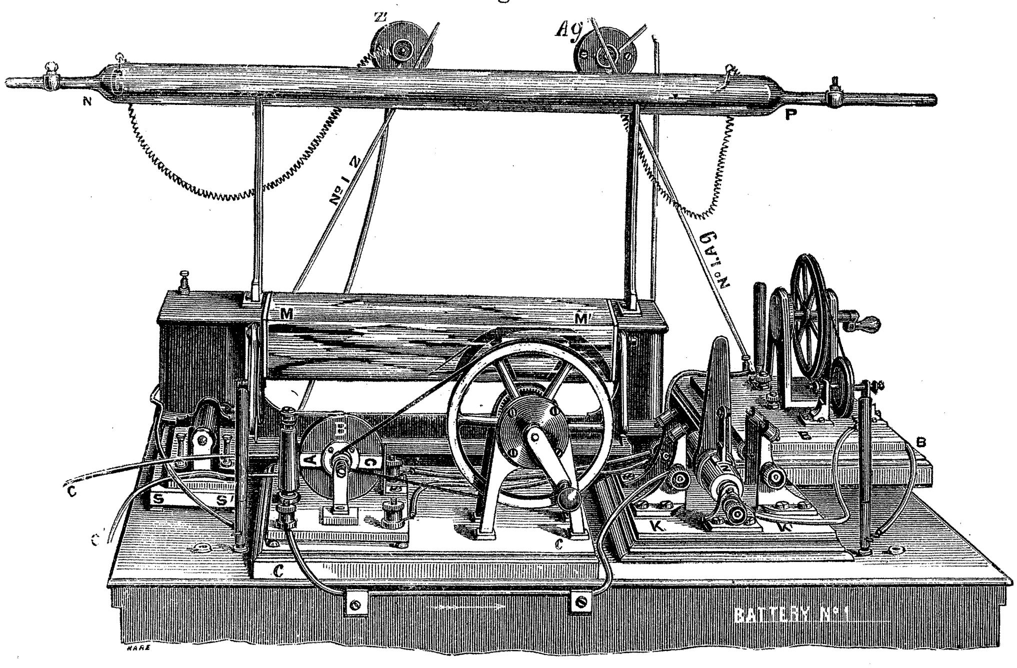


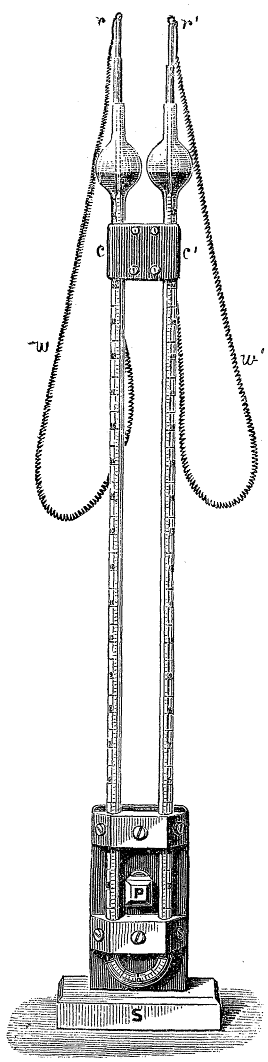
Fig. 9.



that B and D are of one piece of metal, and also A and C of another, the spring conductors making contact at 90° distance from each other; each of the uprights supporting the axis of the revolving disc is in metallic connexion with its respective insulated clamp. In the position shown in the figure the positive current passes from A*g* to the upright supporting the axis of the revolving disc and through the right hand spring to the wire Ag'; the negative current from Z to the upright on the other side of the revolving disc, only partly seen, thence through the upper spring to Z'.

Besides this we have a contact breaker very similar in appearance, and shown *in situ* in fig. 9 on the top of the dwarf cabinet of battery No. 1, containing 1080 powder-cells; this cabinet top is of ebonite and forms our ordinary working bench. The contact breaker, B B, is placed in a position preceding the discharging key in order from the poles of the battery; we have several revolving discs belonging to this piece of apparatus which make and break from 352 to 2112 times in a second. M M′ represents a revolving mirror, which has a multiplying wheel, and in which the reflection of the discharge in a vacuum tube can be seen. S S′ is a short contact key used when a condenser is employed, and it is wished to charge it up without causing the current to pass through any resistance. In the circuit we have a set of coil-resistances from 1 to 1,000,000 ohms; these are specially insulated, the wires running in grooves on insulating cylinders made of paraffined cardboard, in order that they may be kept at a distance; besides this set of resistances we have fluid resistance tubes like that represented in fig. 10; all but one have adjustable wires in order to vary the resistance; two are charged with equal parts of water and glycerine, two with distilled water; each has a plug P to throw the resistance out of circuit.

Fig. 10.



				ohms.
No. 1 has a total approximate resistance of				30,500,000
,, 2	,,	,,	,,	4,000,000
,, 3	,,	,,	,,	2,690,000
,, 4	,,	,,	,,	6,150,000
Total fluid resistances				43,340,000

These resistances gradually diminish by the absorption of ammoniacal salts from the atmosphere, and this necessitates occasionally the entire renewal of the fluid.

We have two tangent galvanometers of different degrees of sensitiveness specially insulated, which can be put in circuit by the withdrawal of two plugs, and also an induction coil, the primary of which may be brought into circuit; it is No. 819 of APPS's make, the particulars of which are as follow:—

	Length of wire. miles.	Diam. of wire. inches.	Resistance. ohms.	Turns.	Layers.
Primary .	1	·014	316	12,958	31
Secondary .	4	·0033	19,355	18,260	22

This we call a detector-coil, it being used to render evident pulsations in the current, and it will be referred to hereafter. The secondary wire of the coil is led to a delicate THOMSON galvanometer.

All these pieces of apparatus can be plugged out of circuit, when not required, in a few seconds, and each battery can be as readily brought into or thrown out of action without inconvenience or danger to the operator. Not without fear of being prolix, it has appeared to us desirable to commence by giving the preceding details, as it will facilitate the understanding of the varied experiments we have to describe hereinafter. We will commence with—

1st. *Discharge at ordinary Atmospheric Pressures.*

The discharge from a point presents many interesting features, which do not occur with other shaped terminals, which we will describe later on, page 88, and at once proceed to the discharge from spherical surfaces, first premising that we have found that the nature of the metal employed for terminals in most cases makes no difference whatever in the length of the spark (*distance explosive*) of the battery. Whatever may be the theory of the electric discharge, our experiments show that with the same terminals and the same number of cells the results have a remarkable constancy, notwithstanding the length of the interval between the experiments, and the consequently varying internal resistance of the battery from the gradual formation of the skin of oxychloride of zinc before referred to, and hereinafter to be specially discussed. *The length of the spark evidently depends essentially on the number of cells and their electro-motive force.* The spherical surfaces we have employed are of brass, 1·5 inch in diameter and having a radius of 3 inches. The discharging-micrometer (fig. 1) does not permit larger terminals to be used, but there is no reason to suppose that their diameter materially affects the results, because we found that spherical surfaces smaller in diameter gave nearly the same numbers. In evidence of the constancy of the results, we give the following numbers, some of which will be dealt with in deducing the length of spark for a given number of volts.

Striking distance between two spherical surfaces each 1·5 inch in diameter, the radius of curvature being 3 inches.

1080 cells.

	inch.
1876. Feb. 24*	0·00750
	0·00600
	0·00500
	0·00500
	0·00450
	0·00450
	0·00480
	0·00500
June 9	0·00475
	0·00450
	0·00425
June 10	0·00450
	0·00475
	0·00450
Oct. 20	0·00425
	0·00425
	0·00425
	0·00440
	0·00440
	0·00440
	0·00440
	0·00440

1200 cells.

	inch.
1876. June 9	0·00600
	0·00575
	0·00575
	0·00575
	0·00600
June 10	0·00550
	0·00575
	0·00600
	0·00625
1877. June 5	0·00650
	0·00600

2160 cells.

	inch.
1876. Feb. 24	0·0145
	0·0143
	0·0143
	0·0143
Oct. 20	0·0142
	0·0142
	0·0142
	0·0142
	0·0144
	0·0148

2400 cells.

	inch.
1876. June 9	0·0170
	0·0170
	0·0170
	0·0170
	0·0170
	0·0170
June 10	0·0175
	0·0180
1877. June 5	0·0160

3240 cells.

	inch.
1876. Feb. 2	0·02430
	0·02550
	0·02550
Oct. 20	0·02525
	0·02525
	0·02525
	0·02524
	0·02524

3600 cells.

	inch.
1876. June 9	0·030
	0·030
June 10	0·030
	0·030
1877. June 5	0·029

4320 cells.

	inch.
1876. Feb. 24	0·0360
	0·0375
Oct. 20	0·0370
	0·0372
	0·0375
	0·0375

4800 cells.

	inch.
1876. June 9	0·04400
	0·04400
June 10	0·04375
1877. June 5	0·04300

5400 cells.

	inch.
1876. Feb. 24	0·0490
Oct. 20	0·0490
	0·0495
	0·0500

* Here and elsewhere throughout this paper, except where the contrary is expressly stated, it is to be understood that the different observations recorded for the same date were obtained with different batteries.

5880 CELLS.

		inch.
1876.	June 9	0·057
	June 10	0·056
1877.	June 5	0·054

6960 CELLS.

		inch.
1876.	June 9	0·0700
	June 10	0·0705
1877.	June 5	0·0665

8040 CELLS.

		inch.
1876.	June 8	0·08500
	June 9	0·08200
		0·08300
	June 10	0·08300
	Oct. 20	0·08225
1877.	May 15	0·08200
	May 16	0·08200
		0·08400
	June 5	0·08000

The following numbers were obtained at different dates with the batteries combined in various ways :—

STRIKING distance between two spherical surfaces, 3 inches radius and 1·5 inch diameter.

Date.	No. of cells.	Striking distance. inch.	Curve.
Feb. 24, 1876	1080	0·00560	I.
	2160	0·01435	
	3240	0·02510	
	4320	0·03675	
	5400	0·04900	
June 9, 1876	1200	0·00600	II.
	2400	0·01700	
	3600	0·03000	
	4800	0·04400	
	5880	0·05700	
	6960	0·07000	
	8040	0·08300	
June 10, 1876	1200	0·00585	III.
	2400	0·01775	
	3600	0·03000	
	4800	0·04375	
	5880	0·05600	
	6960	0·07050	
	8040	0·08300	
Oct. 20, 1876	1080	0·00434	IV.
	2160	0·01433	
	3240	0·02537	
	4320	0·03730	
	5400	0·04950	
	6480	0·06288	
	7560	0·07550	
	8040	0·08225	
June 5, 1877	1200	0·00625	V.
	2400	0·01600	
	3600	0·02900	
	4800	0·04300	
	5880	0·05400	
	6960	0·06650	
	8040	0·08000	

Two spherical surfaces, 0·75 inch radius, diameters 0·4 and 0·55 inch respectively.

Date.	No. of cells.	Striking distance. inch.	Curve.
Feb. 12, 1876	600	0·00120	VI.
	1200	0·00350	
	1800	0·00930	
	2400	0·01400	
Jan. 13, 1876	1080	0·00425	VII.
	2160	0·01325	
	3240	0·02200	
	4320	0·03500	
	5400	0·04600	

These numbers were plotted down on paper ruled in millimeters, the abscissæ representing the number of cells (50 millimeters to 1000 cells) and the ordinates the striking distance (40 millimeters to ·01 inch). With the curves drawn to this scale, it was practicable to estimate to the $\frac{1}{100000}$ of an inch.

The following striking distances were obtained by reading off the ordinates at the various numbers of cells given in Table I. :—

TABLE I.

From curve	No. of cells.											
	250	500	1000	1500	2000	2500	3000	4000	5000	6000	7000	8000
I.	0·00125	0·00252	0·00525	0·00920	0·01312	0·01775	0·02275	0·03325	0·04433	—	—	—
II.	0·00125	0·00248	0·00480	0·00850	0·01325	0·01800	0·02330	0·03468	0·04625	0·05833	0·07025	0·08250
III.	0·00125	0·00250	0·00480	0·00875	0·01375	0·01900	0·02380	0·03460	0·04575	0·05750	0·07075	0·08250
IV.	0·00100	0·00200	0·00400	0·00825	0·01275	0·01775	0·02230	0·03400	0·04500	0·05678	0·06900	0·08150
V.	0·00125	0·00250	0·00512	0·00850	0·01275	0·01700	0·02250	0·03360	0·04485	0·05525	0·06700	0·07950
VII.	0·00100	0·00200	0·00385	0·00775	0·01118	0·01600	0·02000	0·03100	0·04175	—	—	—
Means	0·00117	0·00233	0·00464	0·00849	0·01280	0·01758	0·02244	0·03352	0·04465	0·05696	0·06925	0·08150
VIII.	0·00125	0·00225	0·00500	0·00846	0·01275	0·01752	0·02300	0·03350	0·04512	0·05700	0·06930	0·08180

We were led to adopt the numbers given at VIII. as more nearly representing a true mean curve, the judgment being guided by an inspection of the several curves representing the individual observations (Plate 6).

Curve VIII., it will be seen, runs very smoothly and tends to show that up to a difference of potential of 8000 cells there is not any common factor which can be used as a multiplier to furnish the striking distance for a given number of cells; for the differences between the striking distances of consecutive equal numbers of cells is an increasing quantity, the increment of increase is, however, very small after 4000 cells have been reached.

From the mean curve VIII. the following *ratios* for a given number of cells were obtained :—

TABLE II.

Difference of potential in chloride of silver cells.	Striking distance.	Ratios.	Difference.	Difference per 1000 cells.
	inch.			
250	0·00125	1,000		
			800	
500	0·00225	1,800		4,000
			2,200	
1000	0·00500	4,000		
			2,769	
1500	0·00846	6,769		6,200
			3,431	
2000	0·01275	10,200		
			3,802	
2500	0·01752	14,002		8,200
			4,398	
3000	0·02300	18,400		
			8,400	
4000	0·03350	26,800		8,400
			9,300	
5000	0·04512	36,100		9,300
			9,500	
6000	0·05700	45,600		9,500
			9,840	
7000	0·06930	55,440		9,840
			10,010	
8000	0·08180	65,450		10,010

With the mean curve VIII. it was also easy to derive numbers for volts instead of chloride of silver cells; thus the following Table III. shows difference of potential in volts requisite to obtain a spark in air at ordinary atmospheric pressures between the spherical surfaces of 3 inches radius and 1·5 in diameter.

TABLE III.

Volts.	Striking distance.	Differences.	Between volts.	Additional length of spark for 1000 additional volts.
	inch.			inch.
250	0·00100			
		125	0	
500	0·00225			
		125	and	0·00482
750	0·00350			
		132		
1000	0·00482		1000	
		338		
1500	0·00820		and	0·00751
		413		
2000	0·01233		2000	
		467		
2500	0·01700		and	0·00967
		500		
3000	0 02200		3000	
		500		
3500	0·02700		and	0·01025
		525		
4000	0·03225		4000	
		550		
4500	0·03775		and	0·01100
		550		
5000	0·04325		5000	
		575		
5500*	0·04900		and	0·01135
		560		
6000	0·05460		6000	
		610		
6500	0·06070		and	0·01190
		580		
7000	0·06650		7000	
		600		
7500	0·07250		and	0·01200
		602		
8000	0·07852		8000	

It appears that after a difference of potential 2000 volts has been reached, each additional increment of 1000 gives about the same additional length to the spark, but not exactly so, as each succeeding number is slightly in excess of its predecessor up to 8000 volts at all events; so that the striking distance for 8000 is 16·29 times that for 1000.

In December, 1859, and in the first four months of 1860, experiments were made under the direction of Sir WILLIAM THOMSON with the object of determining "the electro-motive force required to produce a spark." An account of these experiments was presented to the Royal Society by Sir WILLIAM THOMSON, and published in the Proceedings.† It appears from this account that a condenser was used which might be

* This agrees with Sir WILLIAM THOMSON'S conclusion (Proc. Roy. Soc., vol. x. p. 338), "that a DANIELL'S battery of 5510 elements can produce a spark between two slightly convex metallic surfaces at $\frac{1}{20}$th of an inch asunder in ordinary atmospheric air."

† Proc. Roy. Soc., vol. x. pp. 326–338, 1860.

charged to any potential measurable by Sir WILLIAM THOMSON'S absolute or his portable electrometer, the opposite plates of the condenser being connected to two very slightly convex surfaces, which might be adjusted to any required distance from each other. For the readiness of comparison with our own results, we have reduced into volts (Table IV.) Sir WILLIAM THOMSON'S numbers, contained in his most recent communication on the subject, and given in electro-static measurements, taking for v (the ratio of an electro-magnetic to an electro-static unit) the value of 3×10^{10}, and for a volt the value 10^8 C.G.S. unit of potential.

TABLE IV.

Inch.	Centimetres.	Electro-static force or EMF per centimetre.	Difference of potential of the opposite surfaces.	EMF in volts = electro-magnetic units divided by 10^8.	Difference of potential in volts per centimetre.
0·0034	0·0086	267·1	2·30	690	80,230
0·0050	0·0127	257·0	3·26	978	77,000
0·0060	0·0152	262·0	3·33	999	78,660
0·0075	0·0190	224·0	4·26	1278	67,260
0·0111	0·0281	200·6	5·64	1692	60,220
0·0161	0·0408	151·5	6·18	1854	45,450
0·0222	0·0563	144·1	8·11	2433	43,210
0·0230	0·0584	139·6	8·15	2445	41,870
0·0271	0·0688	140·8	9·69	2907	42,250
0·0356	0·0904	134·9	12·20	3660	40,490
0·0416	0·1056	132·1	13·95	4185	39,630
0·0522	0·1325	131·0	17·36	5208	39,310

TABLE V.—Mean results obtained with the AgCl battery, 1876. Feb. 24, June 9th and 10th, Oct. 19th and 20th.

Inch.	Centimetres.	EMF in AgCl cells.	EMF in volts.	Difference of potential in volts per centimetre.
0·00497	0·01263	1080	1113	88,060
0·00575	0·01461	1200	1236	84,590
0·01434	0·03642	2160	2225	61,090
0·01738	0·04414	2400	2472	56,010
0·02524	0·06410	3240	3336	52,050
0·03000	0·07619	3600	3708	48,660
0·03703	0·09404	4320	4449	47,320
0·04388	0·11440	4800	4943	43,210
0·04925	0·12510	5400	5562	44,460
0·05650	0·14350	5880	6056	42,210
0·06287	0·15970	6440	6674	41,780
0·07025	0·17840	6960	7168	40,180
0·07550	0·19170	7560	7785	40,160
0·08275	0·21010	8040	8281	39,420

Our results give a higher potential as requisite to produce a spark than the numbers of Sir WILLIAM THOMSON; for example, compare in Sir WILLIAM THOMSON'S results 1278 volts, 67,260, with 1236 volts, 84,590, in our table; again, 5208 volts, 39,310, Sir WILLIAM THOMSON, with our numbers, 5562 volts, 44,460. In the first case our numbers are to Sir WILLIAM THOMSON'S as 1·258 to 1, and in the second 1·131 to 1; that is, in the first case 26 and in the second 13 per cent. greater than his. But the accordance of some and the discordance of others of our results with those of Sir WILLIAM THOMSON is best illustrated by the curves on Plate 6, representing on a reduced scale (the abscissæ to $\frac{2}{5}$ths, the ordinates to $\frac{1}{2}$) the curves as originally laid down. Curves I., II., III., IV., V., VI., and VII. show the plotting down of the actual observations made by us; curve VIII. the mean curve of our results; IX. shows Sir WILLIAM THOMSON'S; the first parts of VIII. and IX. are again given in curves VIII.[a] and IX.[a], in the upper part of the plate, on the original unreduced scale. Sir WILLIAM THOMSON'S first observation was made with a difference of potential of 690 volts, and his result agrees very closely with our own. This accordance holds good up to 1690 volts, his lengths of spark rising a little more rapidly for definite increments of electro-motive force than our own; but between 1692 volts, which gave a length of spark equal to 0·011 inch, and 1854 volts, which gave a spark of 0·016 inch, there is a remarkably sudden rise in Sir WILLIAM THOMSON'S results, which is quite at variance with our experiments; from that point (1854 volts), however, the two curves are sensibly parallel up to the limit of his observations.

It must be remarked that, notwithstanding the accordances in the distances between the terminals, when the spark jumped in our oft-repeated experiments, it seldom occurred actually at the point of nearest approach, although it usually did so in close proximity with it. The distances observed for successive increments in the number of cells are, it will be seen, considerably less with spherical surfaces (not so much as a fourth in many cases) for high tensions than with a point and a disc, and moreover the increase of increment with spherical surfaces does not conform to the ratio of the square of the number of cells, as before referred to in a communication to the Society, and published in the Proceedings, vol. xxiv. p. 167, 1876.

The difference in our results with spherical surfaces of three inches radius of curvature and those of Sir WILLIAM THOMSON with very slightly curved surfaces, induced us to make other experiments, with some so nearly flat that at their peripheries (0·687 inch from the centre) the distance was about 0·004 inch when the centres touched. The following three series of observations were made, viz. :—

TABLE VI.—Showing the length of spark between two nearly flat surfaces.

Curve.	1200 cells.	2400 cells.	3600 cells.	4800 cells.	5880 cells.	6960 cells.	8040 cells.	
	inch.	inch.	inch.	inch.	inch.	inch.	inch.	
	0·014	0·021	0·031	0·049	0·059	0·075	0·089	June 25, 1877.
	0·011	0·023	0·033	0·051	0·058	0·073	0·086	June 26, 1877.
	0·011	0·018	0·033	0·047	0·058	0·072	0·090	June 26, 1877.
X. Mean	0·012	0·021	0·032	0·049	0·058	0·073	0·088	

The mean results are laid down in curve X., Plate 7, where curves VIII. and IX. are repeated from Plate 6 for the sake of comparison. By inspection of these curves it will be seen that curve X. is sensibly parallel with curve VIII., the lengths of spark with the planes being uniformly greater than those with the spherical surfaces. The mean values for 1200 and for 4800 cells are abnormally high; but this would cease to be the case if the observations 0·014 for 1200 cells, June 25th, and 0·051 for 4800 cells, June 26th, be neglected. Above 2400 cells the curve of the planes is intermediate between Sir WILLIAM THOMSON'S (curve IX.) and our curve of the spherical surfaces (curve VIII.). Table VII. is given for comparison with Table III.

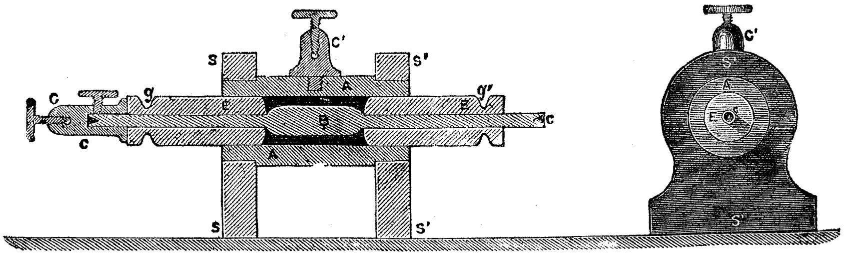
TABLE VII.—Two planes.

Volts.	Striking distance. inch.	Difference.	Between volt.	Additional length of spark for 1000 additional volts.
250	0·00233		0	
		242		
500	0·00475			
		250	and	0·00975
750	0·00725			
		250		
1000	0·00975		1000	
		420		
1500	0·01400			
		300	and	0·00725
2000	0·01700		2000	
		325		
2500	0·02025			
		500	and	0·00825
3000	0·02525		3000	
		505		
3500	0·03030			
		595	and	0·01100
4000	0·03625		4000	
		675		
4500	0·04300			
		630	and	0·01305
5000	0·04930		5000	
		470		
5500	0·05400			
		355	and	0·00825
6000	0·05755		6000	
		620		
6500	0·06375			
		625	and	0·01245
7000	0·07000		7000	
		630		
7500	0·07630			
		645	and	0·01275
8000	0·08275		8000	

The striking distance is very little more for 8000 than eight times (8·487) that given for 1000, which may be too great for the reason stated in page 85.

On the suggestion of Professor E. MASCART, of the Collége de France, Paris, who honoured us with a visit to our laboratory in April, 1877, we have determined the striking distance between two concentric cylinders; fig. 11 shows the arrangement of the apparatus. S S, S′ S′ are two ebonite stands supporting the outer cylinder A A of brass, 2·5 inches long, and bored with a perfectly true hole, 0·4895 inch diameter; B is the inner cylinder, also of brass, which was turned at first nearly of the diameter of the hole of the outer cylinder; on its axis, of one piece with the cylinder, are fitted two ebonite cylinders E E, *exactly* fitting the hole; their outer ends have a groove

Fig. 11.



turned in them, in which the string of a hand-bow works to turn the cylinder on its centres c, c when it is wished to reduce it in size; C, C′ are clamps for connecting the outer and inner cylinder respectively with the battery. When it is wished to make the inner cylinder less in size, the clamp C is removed, and the cylinder is put on dead-centres, and made to rotate with the hand-bow, and reduced by turning off a very small quantity at a time between each trial of the striking distance; the quantity removed between each trial was generally 0·001 inch or less, and by this means the striking distance was ascertained to 0·0005 inch.

In the first instance the same cylinder was reduced to determine the limit of the striking distance for the several numbers of cells employed; on a repetition of the experiment, seven inner cylinders were turned to the size at which the spark just passed and retained; this delicate work was executed with great care and skill by Mr. FRAM.

TABLE VIII.—Length of spark between two concentric cylinders.

Curve.	1200 cells. inch.	2400 cells. inch.	3600 cells. inch.	4800 cells. inch.	5880 cells. inch.	6960 cells. inch.	8040 cells. inch.	Date.
	0·0086	0·0248	0·0534	0·0655	0·0780	0·0897	0·0983	June 5, 1877.
	0·0093	0·0281	0·0451	0·0638	0·0711	0·0821	0·1015	June 29, 1877.
XI. Mean.	0·0089	0·0264	0·0492	0·0646	0·0746	0·0859	0·0998	Plate 7.

In taking the striking distances the current was reversed after a first trial, so as to make the outer cylinder positive and negative alternately ; in the majority of cases the longest spark was obtained with the outer cylinder positive. For the first 1200 cells the striking distance between two concentric cylinders is less, but after that number greater than between nearly flat surfaces, as will be seen by comparing the numbers given in Table VI. with those in Table VIII.*

From curve XI., Plate 7, the following ratios for a given number of volts were obtained.

* M. GAUGAIN, Annales de Chim. et de Physique, 4e série, T. VIII., pp. 115 to 118, has investigated the striking distance between two concentric cylinders, using, however, much higher potentials than we have employed. His experiments show that if the inner cylinder is kept constant and the number of elements and the diameter of the outer cylinder are increased or diminished, the density required to produce a spark does not change at the moment of the spark jumping. If the inner cylinder is increased or diminished in diameter, then the density is lessened or increased. Our results calculated in accordance with the formula

$$\mu = \frac{N}{r \log \frac{R}{r}}$$

where μ = density,
N = number of cells,
R = radius of outer cylinder,
r = radius of inner cylinder,

give the following numbers :

No. of Cells.	Length of Spark. Inches.	Density μ.
1200	0·0089	3163
2400	0·0264	2217
3600	0·0492	1889
4800	0·0646	2002
5880	0·0746	2190
6960	0·0859	2330
8040	0·0998	2438

From these results, and from our own with spherical and plane surfaces, as well as those of Sir W. THOMSON, it is evident that the density is not constant for short lengths of spark (1200 cells) ; after that number it is pretty uniform, except in the case of 3600 cells, where it reaches a minimum.

TABLE IX.—Two concentric cylinders.

Volts.	Striking distance. inch.	Difference.	Between volts.	Additional length of spark for additional 1000 volts.
250	0·0017		0	
		16		
500	0·0033			
		17	and	0·0069
750	0·0050			
		19		
1000	0·0069		1000	
		52		
1500	0·0121		and	0·0121
		69		
2000	0·0190		2000	
		78		
2500	0·0268		and	0·0170
		92		
3000	0·0360		3000	
		90		
3500	0·0450		and	0·0168
		78		
4000	0·0528		4000	
		62		
4500	0·0590		and	0·0127
		65		
5000	0·0655		5000	
		41		
5500	0·0696		and	0·0087
		46		
6000	0·0742		6000	
		50		
6500	0·0792		and	0·0098
		48		
7000	0·0840		7000	
		60		
7500	0·0900		and	0·0122
		62		
8000	0·0962		8000	

The striking distance for 8000 is 13·94 times that for 1000.

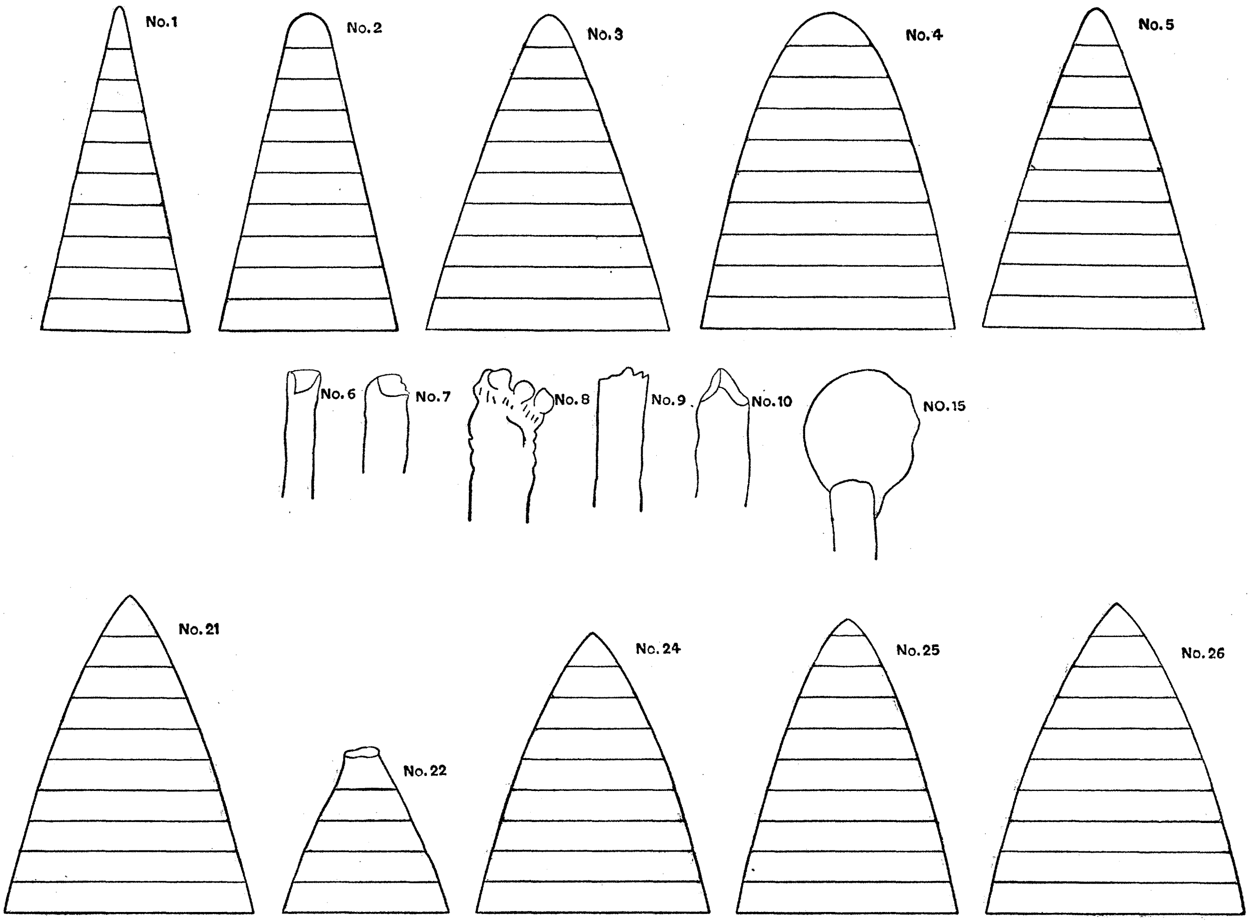
We now give some numbers to show that the striking distance between a point and a disc is remarkably constant for the same number of cells, provided that attention is paid to the shape of the point, for we have found by numerous experiments that much depends on its actual outline; for example, a conical point of 20° angle gives a spark of considerably less length than one of the same base and altitude, but paraboloidal in form; thus, when the point is positive, with 5640 cells, the ratio of the striking distance when the conical point is employed to that of a paraboloidal point is as 0·7764, and with 8040 cells as 0·7784 to 1.

With high tensions, 5000 to 8000 cells, the spark is longest when the point is positive, but with low tensions up to 3000 cells it is generally longest when the point is negative, as will be seen from the following numbers :—

Number of cells. (col. 1).	Length of spark. Point + (col. 2). inch.	Point − (col. 3). inch.	Ratio of col. 2 to col. 3.	Remarks.
8040	0·3430	0·1900	1·8	Mean of three observations made on different days.
5640	0·2230	0·1280	1·7	March 4, 1876.
,,	0·2420	0·1320	1·8	Feb. 15, 1876. A different point used.
3240	0·0600	0·0600	1·0	Feb. 12, 1876. A point of 20° used.
2160	0·0285	0·0400	0·71	Jan. 21, 1876. ,,
1080	0·0034	0·0050	0·67	Jan. 12, 1876. Battery No. 1 (powder) used.
,,	0·0037	0·0055	0·67	,, No. 2 ,, ,,
,,	0·0030	0·0057	0·67	,, No. 3 ,, ,,
,,	0·0070	0·0107	0·67	,, No. 5 (rod) ,,

In order to arrive at the best form of the point we took a wire of copper, brass, silver, platinum, zinc, magnesium, or steel, and turned it in a lathe to various outlines, making slight alterations as to sharpness, bluntness, or curvature between successive trials of the length of spark, and when a distinct result was obtained the

Fig. 12.



point was placed under a microscope, and drawn by means of the camera lucida, a scale of $\frac{1}{100}$ths of an inch being subsequently drawn by means of the camera with the same magnifying power, and used for laying down co-ordinates for studying the shape of the point.

Fig. 12 represents some of these drawings reduced to half size, the spaces between the parallel co-ordinates being $\frac{1}{100}$ths of an inch; those figures without co-ordinates are drawn to the same scale.

The lengths of spark obtained with these terminals *positive* and a disc are as follow :—

Date.	No. of point.	No. of cells.	Length of spark. inch.		Diam. inch.	
1876. March 18	1	5640	0·173			
„ 17	2	„	0·200			
„ 17	3	„	0·243			
„ 18	4	„	0·125			
„ 21	5	„	0·230			
„ 22	6	„	0·162	Platinum wire	0·009	
„ 22	7	„	0·215	„	0·0125	
„ 22	8	„	0·198	Aluminium wire	0·015	fused by current previous to taking length of spark.
„ 22	9	„	0·182	Platinum wire	0·0125	
„ 22	10	„	0·2105	Copper wire	0·0155	
„ 23	15	„	0·1615	Platinum wire	0·0125	fused by current previous to taking length of spark.
April 11	21	„	0·229			
„ 16	22	„	0·216	Point accidentally flattened on ascertaining zero point.		
„ 20	24	„	0·244			
Oct. 19	25	8040	0·345			
1877. Feb. 13	26	„	0·342			

Experiments with a point, positive, and negative hollow terminals of different forms gave no very marked result, except that a hollow paraboloid gave the longest spark.

Date.	Negative terminal.	Positive terminal.	Number of cells.	Length of spark. inch.
1876. April 10	Disc 1·1 diam.	Point like 21	5640	0·239
„ 11	Hollow sphere 1·375 inch diam.	„	„	0·220
„ 11	Hemisphere 1·375 diam.	„	„	0·245
„ 11	Hemisphere 0·95 inch diam. .	„	„	0·230
„ 11	Hollow paraboloid	„	„	0·255

With the data obtained by means of the microscope, it was ascertained that the longest spark was procured when the point assumed a form resembling a paraboloid (points 3, 5, 21, 24, 25, and 26); the curved outline, which corresponded to that found experimentally, was one in which each succeeding ordinate was in the ratio of the square root of the odd numbers 1, 3, 5, &c., the sectional areas being consequently in the ratio of the odd numbers. The first ordinate was taken as 1·33 to the first abscissa 1. A diagram was laid down with 120 such ordinates to a scale of four feet for the length of the point, and then reduced by successive steps with a pantagraph to the size shown in fig. 13, X, this, with a certain modification,* served as a guide for a cutting-pantagraph to shape a cutting tool to be used in a lathe for forming the point of the size Y, fig. 13, to be actually used as

Fig. 13.

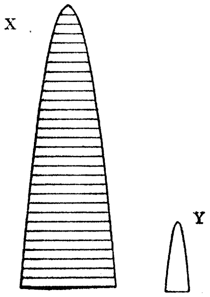
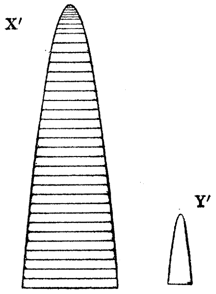


Fig. 14.



a terminal. Experiment proved that all the points made with this tool gave the mean length of spark obtained previously, namely, with 8040 cells, 0·340–0·350 inch.

The greater part of the curve of the point so laid down corresponds to a paraboloid or more correctly to intersecting parabolas.

We were induced to construct a second tool to make a truly paraboloidal point such as is shown in fig. 14 at X′ and Y′; this new point gave precisely the same length of spark, although it will be seen that the extremity of it (X′) does not terminate in an actual point like in fig. X. Subjoined are the lengths of spark between a point *positive* and a disc *negative*, which we quote to show the constancy of the results under the same conditions.

* As the guiding arm of the pantagraph carries a point which works in a groove, whilst the cutter to form the tool is a cylinder, a guide line parallel to the curve of X, but distant four times the radius of the cutter, has to be laid down to guide the tracing point, the reduction being to one-fourth.

FORM of terminals, a paraboloidal point + and a plate of 1·1 in. diameter —.

1080 CELLS.

	inch.
1875. April 8	0·0038
1876. Jan. 12	0·0034
	0·0038
	0·0030
Feb. 24	0·0033
	0·0033
	0·0033
	0·0038
	0·0038
Mar. 23	0·0040
	0·0035
	0·0040
	0·0030
	0·0035
April 1	0·0035
	0·0040
	0·0040
	0·0033
May 10	0·0030
	0·0030
May 26	0·0030
	0·0030
June 7	0·0035
	0·0035
Oct. 19	0·0037
Mean	0·0035

1200 CELLS.

	inch.
1875. Dec. 20	0·00625
	0·00700
1876. May 28	0·00625
	0·00600
	0·00500
	0·00600
Mean	0·00608

2160 CELLS.

	inch.
1875. June 29	0·02476
July 3	0·02400
Dec. 20	0·02000
1876. Jan. 21	0·02850
Feb. 24	0·02100
Oct. 19	0·02000
	0·02000
	0·02000
	0·02000
	0·02175
	0·02250
Mean	0·02204

2400 CELLS.

		inch.
1875.	Dec. 18	0·0220
		0·0260
		0·0265
	Dec. 20	0·0265
	Dec. 30	0·0250
	Dec. 31	0·0270
1876.	May 28	0·0210
		0·0260
		0·0270
		0·0260
		0·0260
		0·0260
		0·0260
		0·0260
	Mean	0·0255

3240 CELLS.

		inch.
1875.	July 21	0·064
		0·058
	Aug. 19	0·070
	Nov. 5	0·054
		0·049
	Nov. 8	0·055
	Dec. 20	0·043
1876.	Jan. 12	0·075
		0·106
		0·095
	Feb. 24	0·075
		0·068
		0·068
	April 1	0·062
	May 26	0·042
	Oct. 19	0·073
		0·073
		0·073
		0·074
		0·074
	Oct. 23	0·063
		0·061
		0·061
		0·061
		0·061
	Mean	0·067

3600 CELLS.

		inch.
1876.	May 28	0·0845
		0·0855
		0·0855
		0·0855
	Mean	0·0850

4320 CELLS.

		inch.
1876.	Jan. 20	0·1290
		0·1320
	Jan. 23	0·1525
	Feb. 24	0·1240
		0·1280
	April 1	0·1370
	Oct. 19	0·1125
		0·1125
		0·1125
		0·1135
	Mean	0·1253

5400 CELLS.

		inch.
1876.	Feb. 24	0·2020
		0·2130
	April 1	0·2225
	Oct. 19	0·2040
		0·2040
		0·2050
	Mean	0·2084

5640 CELLS.

Date.	Distance between terminals. inch.	Date.	Distance between terminals. inch.
1876. Feb. 15	0·2315	1876. April 17	0·2430
,, 15	0·2420	,, 20	0·2443
Mar. 4	0·2230	May 9	0·2400
,, 4	0·2400	,, 10	0·2340
,, 11	0·2420	,, 25	0·2320
,, 15	0·2410	,, 26	0·2380
,, 17	0·2430	,, 28	0·2280
,, 21	0·2400	,, 29	0·2350
,, 31	0·2430	,, 29	0·2200
April 1	0·2400		
		Mean =	0·2370

5640 CELLS.

Date.	Form of terminals.	Distance between terminals. inch.
1876. Jan. 10	A conical point of 20° + and plate of 1·1 in. diam. −	0·180
,, 11	,, ,, ,,	0·174
Feb. 12	,, ,, ,,	0·194
,, 12	,, ,, ,,	0·212
,, 14	,, ,, ,,	0·188
Mar. 15	,, ,, ,,	0·175
	Mean =	0·184

Ratio of the striking distance with a conical and with a paraboloidal point =

$$\frac{184}{237} = 0·7764.$$

8040 CELLS.

Form of terminals.
A paraboloidal point + and a plate from 1·1 in. to 1·5 in. diam. −

Date.	Distance between terminals. inch.	Date.	Distance between terminals. inch.	Date.	Distance between terminals. inch.
1876. May 28	0·341	1876. Aug. 12	0·348	1876 Dec. 5	0·355
,, 28	0·340	,, 15	0·352	,, 9	0·340
,, 29	0·340	,, 18	0·348	1877. Jan. 5	0·340
June 7	0·343	,, 19	0·343	Feb. 13	0·342
,, 8	0·340	Oct. 14	0·353	April 24	0·320
,, 10	0·335	,, 17	0·345	,, 24	0·340
,, 27	0·335	,, 19	0·345	May 7	0·340
July 10	0·340	,, 19	0·341	,, 15	0·344
,, 15	0·340	,, 21	0·341	,, 15	0·330
,, 19	0·344	,, 24	0·340	,, 18	0·348
,, 22	0·342	,, 25	0·340	,, 22	0·330
,, 25	0·340	Nov. 7	0·340	,, 23	0·340
,, 31	0·343	,, 27	0·355	,, 24	0·340
Aug. 4	0·340	,, 28	0·355	,, 28	0·350
,, 5	0·340	Dec. 1	0·355	,, 28	0·358
				Mean =	0·343

8040 CELLS.

Date.	Form of terminals.	Distance between terminals.
1877. May 24.	Conical point of 20° + and a plate 1·5 in. diam. —	·267

Ratio of the striking distance with a conical and with a paraboloidal point =

$$\frac{267}{343} = 0·7784.$$

On Plate 8 we have laid down in curves the observations made on different occasions with a paraboloidal point and a disc from 1·1 inch to 1·5 inch in diameter, the point being uppermost, and made positive or negative; each particular case is distinguished in Table X. by the letters P and N, which always refer to the point, and denote that the spark was longest when so charged. Special experiments have shown that it makes no difference in the length of spark whether the point or disc is uppermost.

TABLE X., showing the lengths of spark in the curves of Plate 8.

Curve.	1080 cells. inch.	2160 cells. inch.	3240 cells. inch.	4320 cells. inch.	5400 cells. inch.	6480 cells. inch.	7560 cells. inch.	8040 cells. inch.	
XIII.	0·0055 N	0·0207 N	0·0734 N	0·1127 P	0·2043 P	0·2510 P	0·3150 P	0·3410 P	Oct. 19, 1876.
XVII.	0·0026 N	0·0165 N	0·0703 N	0·1260 P	0·2075 P	0·2280 P	..	..	Feb. 24, 1876.
XIX.	0·0102 N	0·0460 N	0·0750 N	0·1035 N	0·1650 N	..	..	..	Jan. 12, 1876.
XX.	0·0063 N	0·0400 N	0·0950 P	0·1525 P	0·1620 P	..	..	..	Jan. 23, 1876.
XXI.	0·0033 P	0·0285 P	0·1063 P	0·1305 P	..	..	..	..	Jan. 21, 1876.

MEAN of observations, pages 80 to 82.

Curve.	1080 cells. inch.	1200 cells. inch.	2160 cells. inch.	2400 cells. inch.	3240 cells. inch.	3600 cells. inch.	4320 cells. inch.	5400 cells. inch.	5640 cells. inch.	8040 cells inch.
XVI.	0·0035	0·00608	0·02204	0·0255	0·0670	0·085	0·1253	0·2084	0·237	0·343

SPECIAL observations.

Curve.	1200 cells. inch.	2400 cells. inch.	3600 cells. inch.	4800 cells. inch.	5640 cells. inch.	6840 cells. inch.	8040 cells. inch.	
XIV.	0·0058 N	0·0255 N	0·08525 P	0·1675 P	0·235 P	0·296 P	0·346 P	May 28, 1876.

Curve.	1200 cells. inch.	2400 cells. inch.	3600 cells. inch.	4800 cells. inch.	5880 cells. inch.	6960 cells. inch.	8040 cells. inch.	
XVIII.	0 00475 N	0·0200 N	0·0620 N	0·1520 P	0·2000 P	0·248 P	0·3400 P	June 26, 1877.

Curve.	600 rod cells. inch.	1200 rod cells. inch.	1800 rod cells. inch.	2400 rod cells. inch.	
XXIII.	0·00330 N	0·01300 N	0·0345 N	0·0535 N	Jan. 6, 1876.
XXIV.	0·00191 N	0·01075 N	0·0380 N	0·0565 N	Feb. 12, 1876.
XXV.	0·00205 N	0·01635 N	0·0415 N	0·0600 P	Feb. 12, 1876.
XXVI. Mean.	0·00242	0·01337	0·0380	0·0567	
XXVII. Theoretical.	0·003544	0·014176	0·03196	0·0567	

It is remarkable that the striking distances of 1080 and 2160 cells in curve XIX., and especially those of XXIII., XXIV., and XXV., obtained soon after two batteries each of 1200 rod cells were first charged up, in a single day, are much greater than those observed with the same number of similar cells on subsequent occasions. Compare, for example—

	1200 cells.	2400 cells.
XIV.	0·0058	0·0255
XVIII.	0·00475	0·0200
with the mean of XXIII., XXIV., XXV.	0·01337	0·0567

By standing, as has been before stated, an oxychloride of zinc is formed on the surface of the zinc rods, and we have further noticed that the fluid in the cells becomes slightly alkaline; it is possible, but not certain, that the EMF may be diminished in consequence of the alkalinity, and the striking distance influenced by the change.* But, on the other hand, when a second series of 2400 cells was charged up, on May 27 and 28, 1876, no such unusual length of spark was obtained; hence we conclude that some special cause influenced the long discharge XXIII., XXIV., XXV., to be discovered by future experiment. A comparison of the numbers obtained when spherical or flat surfaces were used as terminals with those when a point and a disc or two points were used, will show that for low tensions the striking distance is fully as great, and in some cases greater, with spherical or flat terminals, than when one terminal was a point or when both were points.

From the curves laid down on Plate 8, which represents the original plotting reduced to $\frac{2}{5}$ths in each direction, we have deduced the numbers given in Table XI.

But, in the first instance, a mean curve was drawn for each of the irregular curves representing the actual observations; these mean curves are not given in Plate 8, in order to avoid confusion.

TABLE XI.—Showing the length of spark from the mean curves derived from those shown in Plate 8.

Curve.	1000 cells. inch.	2000 cells. inch.	3000 cells. inch.	4000 cells. inch.	5000 cells. inch.	6000 cells. inch.	7000 cells. inch.	8000 cells. inch.
XIII.	0·0057	0·0220	0·0540	0·100	0·160	0·220	0·283	0·347
XIV.	0·0050	0·0195	0·0550	0·110	0·173	0·236	0·298	0·358
XVI.	0·0030	0·0200	0·0567	0·108	0·169	0·233	0·299	0·366
XXVII.	0·0040	0·0160	0·0405	0·082	0·137	0·198	0·264	0·337
XXII. Mean of XIX., XX., XXI.	0·0080	0·0330	0·0710	0·114	0·158	..	..	..
XII. Mean	0·0051	0·0221	0·0554	0·103	0·159	0·222	0·286	0·352
XII*a*. Theoretical . . .	0·0055	0·0220	0·0495	0·088	0·1375	0·198	0·2695	0·352

* The batteries were on November 29th restored to their normal current-force by the addition of hydrochloric acid as described in the footnote to page 112, the cells then had an electro-motive force of 1·052 volt; before the addition of acid the fluid was slightly alkaline, and a cell was found to have an electro-motive force of 1·024 volt, which is not much less than that of the restored cell. Consequently the additional length of spark XXIII., XXIV., and XXV. cannot be accounted for by a greater electro-motive force at the time the experiment was made.—December 13, 1877.

TABLE XII.—Showing the results in volts.

Curve.	1000 volts. inch.	2000 volts. inch.	3000 volts. inch.	4000 volts. inch.	5000 volts. inch.	6000 volts. inch.	7000 volts. inch.	8000 volts. inch.
XII. Mean . .	0·0049	0·021	0·053	0·097	0·150	0·210	0 273	0·335
XII*a*. Theoretical	0·0052	0·021	0·047	0·083	0·130	0·187	0·255	0·330

It will be seen from the above that curve XII., Plate 8, laid down from the means of all the observations, accords very closely with curve XII*a*, Plate 8, drawn on the hypothesis that the striking distance between a point and a plate is in the ratio of the square of the number of cells, as we stated to be the case in a previous communication.* It would, however, appear that there is a tendency in the curve to converge towards the theoretical curve as the battery is increased beyond a certain number of cells; and, therefore, it is possible that the law of the squares may not hold for very high numbers; at about 4000 to 5000 cells the curve diverges from the theoretical curve, but it approaches it again in the majority of cases beyond that number up to 8040 cells.

With two points the length of spark is greater for high potentials, 5400 to 8040 cells, than between a point and disc, but not for low potentials, as will be seen from the following numbers laid down in curve XV., plate 8:—

TABLE XIII.—Length of spark between two paraboloidal points.

Curve.	1080 cells. inch.	2160 cells. inch.	4320 cells. inch.	4320 cells. inch.	5400 cells. inch.	6480 cells. inch.	7560 cells. inch.	8040 cells. inch.
XV.	0·005	0·024	0·0614	0·1307	0·2287	0·2895	0·3620	0·401

By laying down a smooth curve, XVA, fig. 15, through the observed distances in curve XV., we have obtained the numbers given in Table XIIIA for multiples of 1000 cells; the second line shows the lengths of spark on the hypothesis of their being in the ratio of the squares of the number cells.

TABLE XIIIA.—Length of spark between two paraboloidal points.

Curve.	1000 cells. inch.	2000 cells. inch.	3000 cells. inch.	4000 cells. inch.	5000 cells. inch.	6000 cells. inch.	7000 cells. inch.	8000 cells. inch.
XVA.	0·005	0·021	0·053	0·110	0·178	0·249	0·324	0·401
Theoretical	0·0062	0·0251	0·0564	0·1002	0·1566	0·2255	0·307	0·401

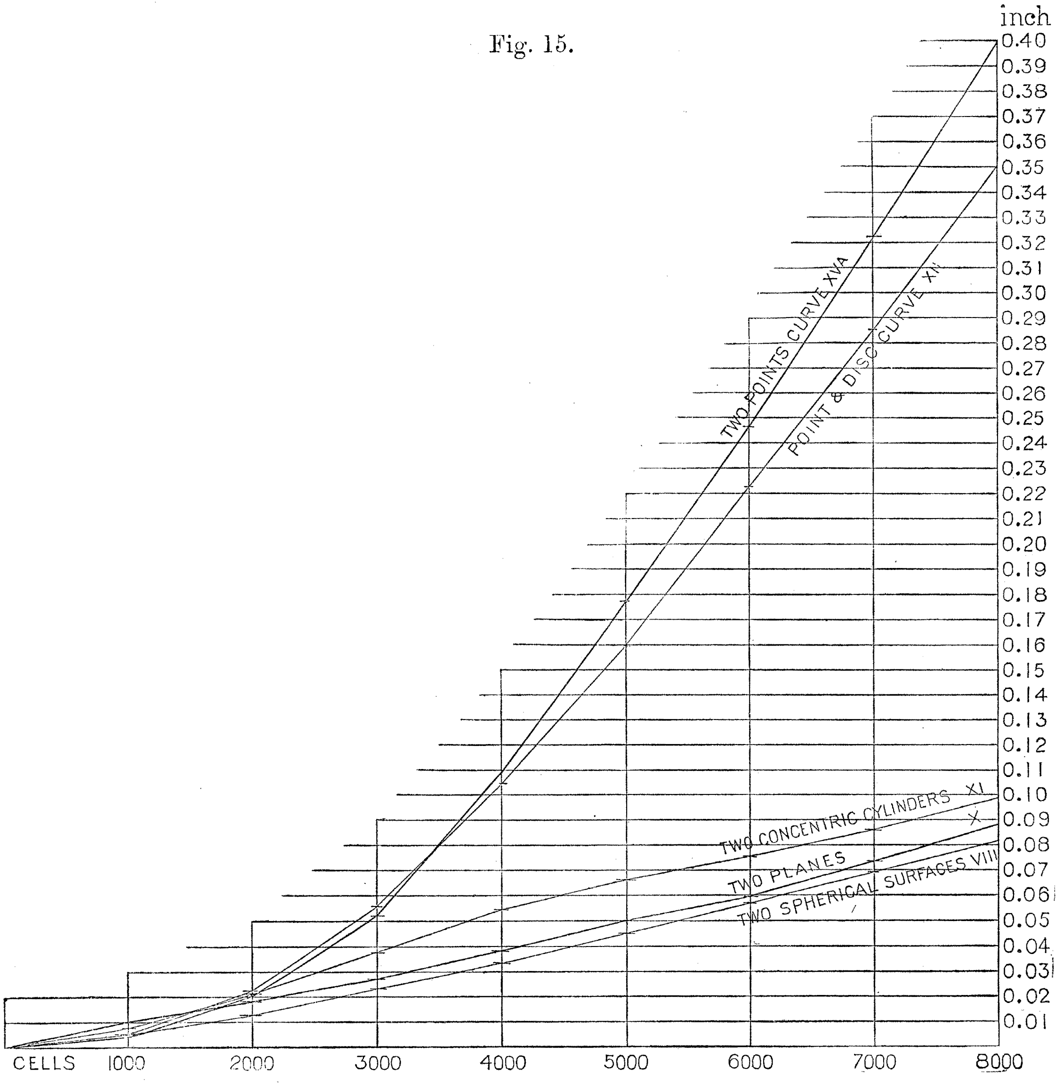
In order to show at a glance the relative striking distances between two spherical and two plane surfaces, two concentric cylinders, a point and a disc, and two points, we laid down on the same scale curves VIII., X., XI., XII., and XVA; the diagram, fig. 15, is a pantagraphic reduction of them to one third of the originals.

We may, however, state that we place greater reliance on the measurements of the length of spark up to that for 2000 cells between spherical surfaces than between

* Proc. Roy. Soc., vol. xxiv. p. 168.

planes; for not only is it difficult to keep the latter absolutely parallel, but also there is a tendency to discharge near the peripheries of the discs, notwithstanding that they are 0·125 inch thick, and are bounded by carefully rounded edges.

Fig. 15.



By connecting the battery with a condenser a much more dense spark passes, giving rise to a greater or less explosion as the capacity of the condenser is greater or less. The length of the spark is not affected in the case of spherical terminals being used, but is considerably shortened in that of a point and plate: thus with 8040 cells—

	Without condenser. Length of spark. inch.	With condenser. Length of spark. inch.
Two spherical surfaces 1·5 inch diameter and 3 inches radius	0·082	0·082
Point positive and disc negative	0·340	0·268

The condenser E, page 99, used in the above experiment, has a capacity of 0·148 microfarad.

With a Muirhead condenser of 13 microfarads' capacity, the 8040 cells gave a spark of 0·265 inch between a blunt point, positive (it is impossible to retain a good point with such heavy discharges, as metal is carried off at each explosion), and a flat surface 0·125 inch diameter, negative.

The actual jump of the spark when a point and disc or two points are employed as terminals is preceded by a luminous discharge (streamers), presenting phenomena of an interesting character, an extremely minute quantity of electricity passing as compared to that when the spark jumps and forms the arc, but still it is sufficient when caused to pass through a vacuum tube to illuminate it strongly.*

In illustration of this we quote the following numbers based on the statement before made, namely, that the electro-motive force of the battery per cell is taken at 1·03 volt, and the internal resistance at $4800 \times 5 + 3240 \times 15 = 72{,}600$ ohms.

	Weber.
8040 cells in short circuit would give a current of	0·1140
8040 cells, after the jump at 0·34 inch and the formation of the arc, the external resistance having been found to be 58,000 ohms	0·0634
8040 cells, at 0·36 inch between the terminals, the measured resistance being 327 megohms, with the point positive	0·0000247
8040 cells, at 0·36 inch between the terminals, the resistance being 274 megohms, with the point negative	0·0000302
8040 cells, at 0·30 inch between the terminals, the resistance 181 megohms, with the point negative	0·0000458
8040 cells, distance 1·16 inch, resistance 5890 megohms, the point positive or negative	0·0000014

Taking for unit the current which passes with no external resistance, that when the spark has jumped and the arc is formed is 51 per cent.; at 0·36 inch distance, 0·0217 per cent. $= \frac{1}{4600}$th; at 1·16 inch, 0·00123 per cent. $= \frac{1}{81300}$th. Taking for unit the current which passes when the arc is formed, the streamers at 0·36 inch give a current of 0·039 per cent., or $\frac{1}{2564}$th part of it.

Many determinations were made of the current passing between a paraboloidal point and a disc at various other distances beyond the striking distance. In order to make these measurements, the point was connected with one terminal of the battery, the other terminal being to earth; the opposed disc was connected to one terminal of a THOMSON galvanometer, whose constant had been accurately determined; the other terminal of the galvanometer was to earth. Every care was taken to prevent leakage, and the shunts were adjusted to suit the current. A danger to be guarded against was the jump of the spark, as the current which would then pass would injure the galvanometer.

From the above figures it will be seen that the streamer-discharge from a paraboloidal

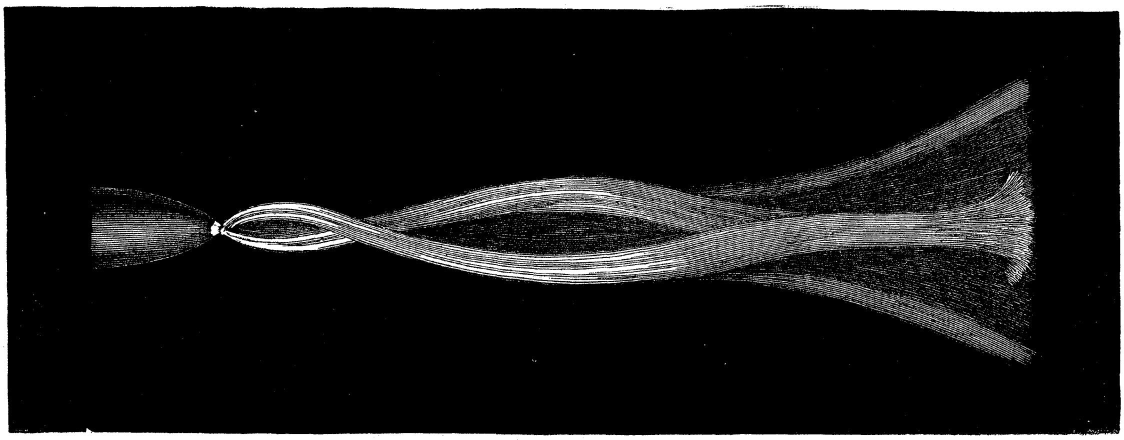
* Proc. Roy. Soc., vol. xxiv. p. 169, 1876.

point at 0·36 inch distance from a plate diminishes the potential of the battery of 8040 cells by only $\frac{1}{4600}$th part, or less than two cells.

This discharge from the point when positive has mainly to the naked eye a stream-like appearance, consisting of a waving line of light surrounded by a very faint sugar-loaf luminosity and producing a rattling or strong hissing sound; from the point when negative it consists of a glow of light paraboloidal in form and extending from the point to the disc, but much more brilliant at the point, the noise of the discharge being much less than when the point is positive. The disc, especially when positive, soon becomes covered with a peach-like bloom, and the deposit assumes the appearance of NEWTON'S rings.

Small as this current is, it is, nevertheless, very manifest from its brightness and the rattling or loud hissing noise it produces; it frequently continues for some minutes before the spark actually jumps between terminals placed at the striking distance asunder; the streamer-discharge becomes brighter just before the jump and formation of the arc, and this suggested the possibility of particles being carried off in increasing quantity from the point to the disc, and thus contributing to the production of the spark. In order to test this hypothesis, the terminals were placed at the striking distance and a continuous blast from a blowpipe bellows sent between them;

Fig. 16.



this did not, however, have any effect on the length of the spark, but it deflected the arc when once it had formed.

Under the microscope the discharge, from the point when positive, is seen to consist of several streams of light, which twist round each other like loosely-bound strands, as shown in fig. 16, representing the discharge between the terminals in a horizontal discharger. Part of the discharge from the point negative is shown in fig. 17.

In order to study these discharges, we had constructed for us a microscope (fig. 18) with a revolving mirror placed at an angle formed by the two tubes composing the body of the microscope, which is bent for the convenience of observation. That part beyond the upright is formed of ebonite, in order to protect the eye from accidental shocks. The discharger used when this microscope is employed is

Fig. 17.

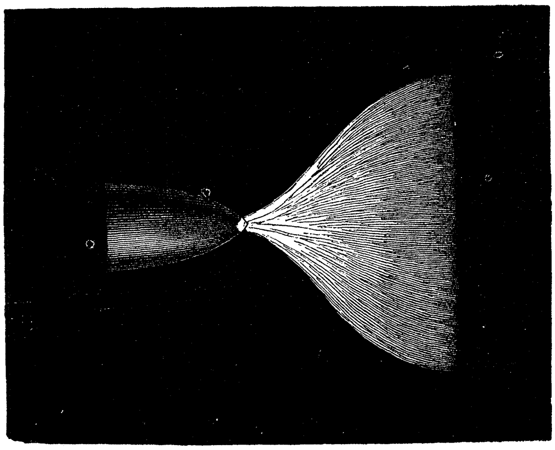
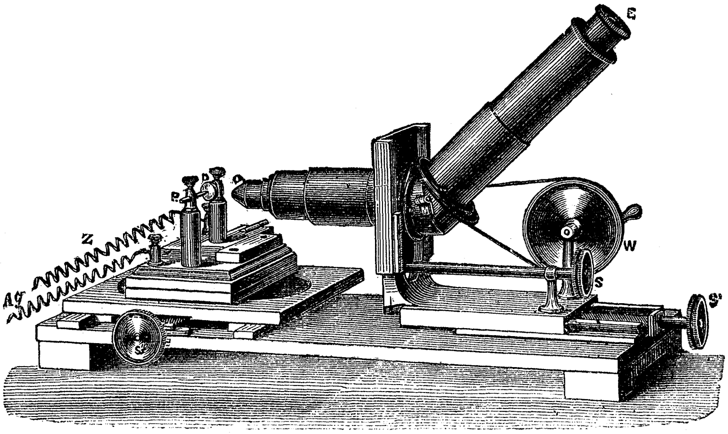


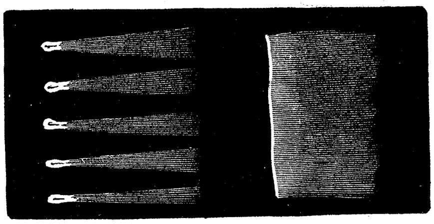
Fig. 18.



horizontal, as seen in the figure, in order to permit of the employment of the mirror which is mounted on a horizontal axis; the point P is placed in the fixed upright, and the disc D in that upright which is attached to the adjustable slide. The screw S′ is used to approach or recede the microscope in order to adjust to focus; S″ to bring the point horizontally, and S to elevate or depress the microscope by means of a pinion and rack to adjust the point vertically in the field. O is the object-glass and E the eye-piece; W, a multiplying-wheel giving five revolutions of the mirror for one turn of the handle, which may be rotated with ease 200 times in a minute, so that the mirror can be caused to make 1000 revolutions in a minute, or about 17 revolutions in a second. The whole framework of the stand is of ebonite to ensure insulation.

When the revolving mirror is set in motion it is seen that the streamer-discharge is in reality to a great extent intermittent. At times a moderate rotation-velocity of the mirror serves to show this by the production of a number of distinct images, as seen in the left-hand drawing in fig. 19; at others it requires the full speed of the mirror. The discharge appears much more continuous with the point negative, so much so that the image is generally seen in the microscope as a sheet of light brightest near the point, and nearly uniform in a direction at right angles to the axis of the mirror; the right hand drawing shows the appearance when the point is negative. The difference in the sound emitted when the point is positive and negative respectively appears to afford an additional proof of less continuity in the case of the positive, see also page 118.

Fig. 19.



When a high resistance, 4 megohms for example, is inserted in the circuit, the character of the discharge is completely changed, instead of jumping across and forming an arc, a series of brilliant snapping sparks pass between the terminals at more or less rapid intervals, exactly like the sparks from a small Leyden jar; these pierce a piece of writing paper interposed between the terminals producing minute holes. The spark does not jump at the full distance when the 4 megohms' resistance is inserted; and, to produce an almost continuous succession of intermittent sparks, it is usually necessary to approach the point to 0·30 inch, when, without resistance, the spark with 8040 cells would jump and form the arc at 0·34 inch.

When a point and a disc are used as terminals, and a piece of glazed writing paper, say 0·00425 inch (0·01079 centims.) thick, is laid on the disc, a very strong adhesion of the paper to the disc takes place, and it requires a strong pull to draw it along; this phenomenon was first noticed by our assistant, Mr. FRAM. In order to measure this force of adhesion we used a spring dynamometer, with a clip to hold the strip of paper, $1\frac{1}{2}$ inch wide (the width of the disc). Under ordinary states of moisture of the atmosphere, with 8040 cells it required a pull—

When the point was positive.	When it was negative.
grains.	grains.
of 1300	of 2900
1300	2800
1100	3200
Mean 1233	Mean 2933

to draw the paper along the disc, presenting a surface of 1·767 square inch (11·401 square centims.) a flat plate laid on the paper required to be loaded, in order to indicate the respective pulls, to 5,200 grains when the point was positive, and 8,900 grains when negative. This strong adhesion arose evidently from the charging up of the upper surface of the paper with the opposite electricity to that of the disc, and hence it appeared probable that by making the paper thoroughly dry the upper surface ought to take a higher charge and cause a stronger adhesion, and this was found to be the case.

In order to measure the force of adhesion when the paper was well dried, we had successively made two new dynamometers, as the first only ranged to 4000 grains; the pull so much exceeded our anticipations, that the second—from 3000 to 10,000 grains—was found to be insufficient. Ultimately, one ranging from 10,000 to 50,000 grains was employed. The strain required to pull away the paper was—

With the point negative, 30,000 grains.
,, positive, 18,000 ,,

These strains were reproduced when the paper was under the pressure of 129,690 grains (8403·8 grms.) and 53,530 grains (3468·6 grms.) respectively. On the hypothesis of two parallel plates (the upper surface of the paper and the disc-terminal) each of area (A) = 11·401 square centims., at a distance (D) = 0·01079 centim., the thickness of the paper, between which there is a force of attraction (F) = (gW) = 8403·8 grms. × 981 and 3468·6 grms. × 981 in the several cases, we have the following values for the difference of potential (V) between the two planes :—

$$F = g\,W = A\frac{V^2}{8\,\pi\,D^2}$$

$$\text{whence, } V = D\sqrt{\frac{8\,\pi\,g\,W}{A}}$$

or, when the point was negative—

$$V = 0{\cdot}01079\sqrt{\frac{8 \times 3{\cdot}14159 \times 981 \times 8403{\cdot}8}{11{\cdot}401}} = 46{\cdot}0205 \text{ electro-static units.}$$

$$= 46{\cdot}0205 \times \frac{3 \times 10^{10}}{10^8} = 13{,}806{\cdot}15 \text{ volts.}$$

and, when the point was positive—

$$V = 0{\cdot}01079\sqrt{\frac{8 \times 3{\cdot}14159 \times 981 \times 3468{\cdot}6}{11{\cdot}401}} = 29{\cdot}5563 \text{ electro-static units.}$$

$$= 29{\cdot}5663 \times \frac{3 \times 10^{10}}{10^8} = 8869{\cdot}89 \text{ volts.}$$

The value obtained for the point positive does not differ very greatly from the number of volts (8281) actually employed; but that for the point negative is in the ratio of 1·67 to 1.

In calculating the force of attraction, it has been assumed that it was the upper surface of the paper which was charged to the highest negative or positive potential, according as the point was negative or positive, but it is possible that a zone of almost full potential was at some nearer distance from the metallic disc. It has been suggested that the whole mass of the paper serves as a conductor, resting on only a few points on the lower disc, and that the intervening film of air is the insulator; against the correctness of this hypothesis is the fact that the adhesion is much stronger when the paper is made to insulate better by being dried. With paraffined paper black-leaded on the upper surface the adhesion was with point N 900 and with point P 400 grains, and it was almost inappreciable when the upper surface of the slip of paper had a disc of tin-foil pasted on it.

There is no measurable adhesion when a spherical surface is substituted for the point: this was to be expected, for there is scarcely a visible glow, and consequently little transference of electricity before the jump of the spark. The only effect observed was that the slip of paper was attracted diagonally to both terminals, forming a bridge through which a minute current passed when the terminals were separated beyond the striking distance.*

When one of the terminals consists of a very fine platinum wire 0·002 inch diameter, and about 0·56 inch long, held in a holder like that used for holding needles in a mathematical instrument box, but adapted to go into our discharger, the wire takes up a straight, circular, or elliptical oscillation, the glow at the point forming a continuous line of light marking its course; with the point positive the excursion is less than when negative, being with a potential of 8040 cells, and a distance between the terminals of 0·32 inch, about 0·375 inch, while with the point negative it is much more brilliant and about 0·8 inch. By interposing a resistance of 4 megohms the statical discharge takes place from the extremity of the wire, frequently producing a beautiful and brilliant figure by the apparent crossing and interlacing of the bright lines of discharge from different points in the path of the oscillating wire; these occur at such short intervals that the discharge looks like a persistent pattern of intricate engine-turning. By approaching the wire cautiously it is generally possible to cause the end of it to fuse into a minute globule, and the discharge then becomes much more striking. With 4 megohms' resistance the static spark is longest and brightest when the wire is negative; if the wire is very straight the oscillations take place in a cycloidal curve in a vertical plane, the discharge occurring at equal distances from the middle of the path as the minute globule at the end of the wire attains the limit of the greatest discharge from either side, so that two streaks of light are seen continuously; if the wire is slightly

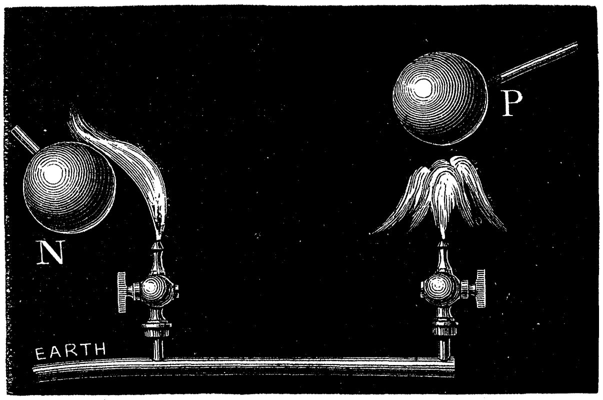
* Professor STOKES, to whom we communicated these results, has favoured us with some remarks, which we insert with his permission in Note A.

bent the oscillation is conical or elliptical, and the figure produced by the discharge is then much more continuous and beautiful, because the distance from the point to the plate remains nearly constant. The difference of the amount of excursion of the wire when positive or negative is one of the many instances of the difference of the positive and negative electric force.

In the foregoing account of the length of the spark no mention has been made of the atmospheric conditions in relation to pressure, temperature, or hygrometric state, because it was found that it was not affected thereby to any appreciable amount, the laboratory being warmed during the cold period; but it is nevertheless certain that some effect must be produced by variations in temperature, as it was found that a very high temperature, such for example as that produced by the flame of an insulated spirit lamp, caused a much greater jump between the terminals, for instance, with 8040 cells, the length of spark between a point and a ball 1 inch in diameter was 1 inch, and between two points 1·375 inch; the length of the spark is somewhat influenced by the position of the flame, and is greatest towards the point or oxidising part of it.

When the terminals are placed opposite to two gas jets emanating from the same gas pipe in metallic communication with the gas main, and consequently to Earth, the flame opposed to the negative terminal is attracted, and that opposed to the positive repelled, as was observed to be the case with static electricity by M. NEYRENEUF,* at whose request we have made the experiment. Fig. 20 shows the arrangement and effects observed.

Fig. 20.



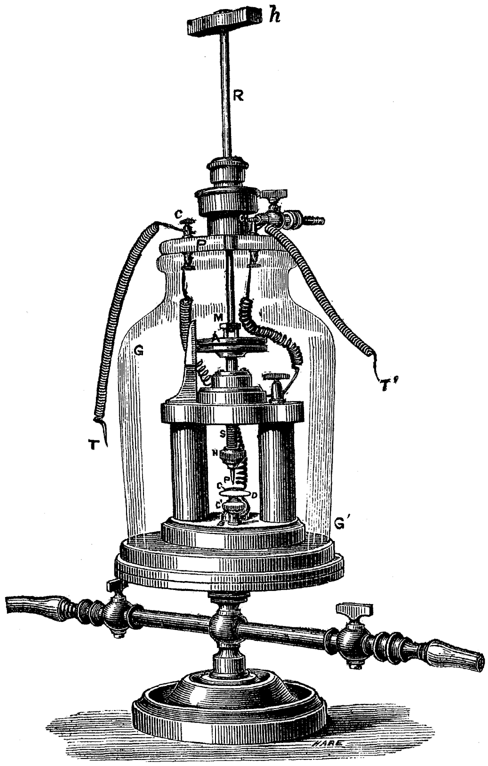
We have already stated that in most cases the nature of the metal makes no difference in the length of the spark, and this applies to brass, copper, silver, steel, plåtinum, magnesium, and zinc; but there is a striking exception, namely, aluminium, which gives a considerably longer spark when used for a terminal in the shape of a point; thus, when the point was positive, with—

* Annales de Chemie et de Physique, 5e serie, t. ii. 1874.

Date.	Cells.	Copper point + Length of spark.	Aluminium point + Length of spark.	Ratio of spark with aluminium to that with copper =
		inch.	inch.	
1876. March 21 and 22	5640	0·240	0·320	1·300
1877. July 9 . . .	8040	0·340	0·411	1·209
„ 10 . . .	„	0·340	0·414	1·217
			Mean	1·242

The length of the spark differs in various gases at ordinary atmospheric pressures, as we anticipated that it would do from our experience with vacuum tubes; but the difference in the length of the spark does not bear any precise ratio either to the specific gravity of the gas or its viscosity in reference to mechanical impulse; we therefore propose to ascribe it, at all events provisionally, to a difference of *electric viscosity*. In order to make experiments on the discharge in different gases, we placed the discharger, already described page 58, fig. 1, under a bell glass G G′ (fig. 21), open at the top and covered with a glass plate, P.

Fig. 21.



The glass plate has two screw-clamps, which are connected at its under surface with wires led from the screw-clamps *c* and *c′* (fig. 21) of the discharger. In connexion with these, on the outside surface, are two other screw-clamps c c′ with which the terminals of the battery T T′ are connected. Through a stuffing box in the glass cover a steel rod R passes; this, below the glass, carries a crutch M, with two ebonite pins, which drop into corresponding holes made to receive them in the micrometer wheel A, fig. 21; the rod has on the top, outside the jar, a cross handle *h* of ebonite for turning it. The distance of the terminals is easily regulated by means of this rod, as the micrometer can be read through the bell glass. Before admitting any gas into it, the bell glass was exhausted by the mercurial pump to a pressure of less than a millimetre, then filled with dry gas, and again exhausted and recharged. The following Tables XIV. and XV. show the results obtained both with spherical surfaces 1·5 inch in diameter and 3 inches radius, and also with paraboloidal point and a disc 1·5 inch diameter.

TABLE XIV.—Striking distance between two spherical surfaces with 8040 cells.

Gas.	Striking distance.	Ratio of striking distance. Referred to air.	Referred to hydrogen.	Ratio of electric viscosity. Referred to air.	Referred to hydrogen.
	inch.				
Air	0·082	1·000	0·547	1·0000	1·828
Hydrogen	0·150	1·829	1·000	0·5467	1·000
Oxygen	0·082	1·000	0·547	1·0000	1·828
Carbonic anhydride	0·077	0·939	0·513	1·0650	1·949

TABLE XV.—Striking distance between a point + and disc − with 8040 cells.

Gas.	Striking distance.	Mean ratio of striking distance. Referred to air.	Referred to hydrogen.	Electric viscosity. Ratio to air.	Ratio to hydrogen.
	inch.				
Air	0·344 0·300	1·000	0·5733	1·000	1·745
Hydrogen	0·600 0·562	1·808	1·0000	0·553	1·000
Nitrogen	0·402 (air 0·300)	1·340	0·7153	0·746	1·399
Oxygen	0·212 0·220	0·674	0·3718	1·484	2·689
Carbonic anhydride	0·120 0·160	0·441	0·2409	2·268	4·149

When charcoal terminals are used the jump of the spark is about the same as with other terminals having a similar shape; the charcoal points may be separated when 8040 cells are used to 1·25 inch generally, and occasionally to 1·5 inch without breaking the arc. If the current were greater, as would be the case with larger cells, the arc would no doubt be much longer. The arc presents the ordinary characters, as shown in fig. 22; but that which takes place when the terminals are vertically one over the other, as in our discharger, is different, on account of its being undisturbed by upward air currents which deflect the arc.

The appearance of the arc is different in different gases, as will be seen in fig. 23, where 1 represents the arc in air; this when examined with the microscope presents an evidently stratified appearance, especially in the barrel-shaped surrounding of the central bright spindle; the laminæ are extremely close, and seen with very great difficulty, even with the revolving mirror of the microscope, which must be caused to revolve at different velocities to render them apparent; with a moderate magnifier, a hand lens, the barrel-shaped surrounding appears as if shaded with lines across it. As one examines the arc with the mirror revolving at a great velocity, evidence of the carrying of minute particles is given by streaks of bright light, which cross the field.

The arc in hydrogen, with the point positive, is shown in 2, fig. 23; the central spindle is surrounded by a beautiful blue halo, like a glass shade illumined by

Fig. 22.

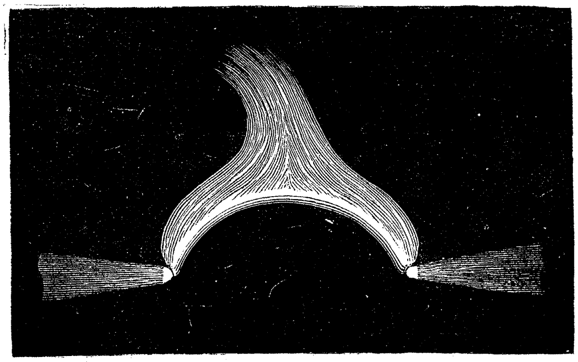
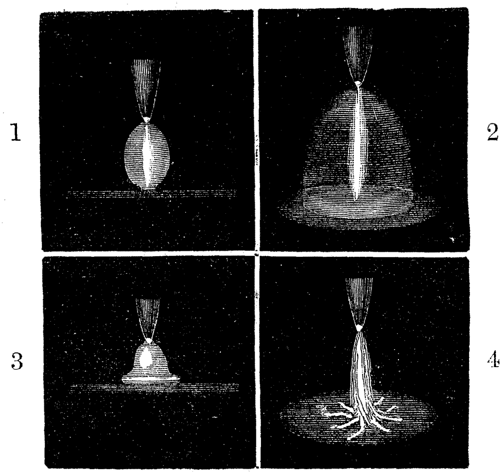


Fig. 23.



fluorescent light, and very brilliant on the disc; with 8040 cells the spark jumped on one occasion 0·562 inch when the point was positive, and only 0·462 inch when negative; the ratio of negative to positive 1 = 0·822. With 4 megohms' resistance in the circuit, the streaming discharge from the point positive, at 0·502 inch distance, was carmine in colour. This distinctive colour is a proof that the gas in which the discharge takes place is the carrier of electrification in the streamer discharge. The appearance of the arc when the point is negative is shown in 4; it moves about very rapidly, and forms a star-like appearance on the positive disc; when the point is negative, before the jump of the spark, a very pale glass-shade-like halo, of a saddened olive tint, extends from the point almost to the outer periphery of the disc.

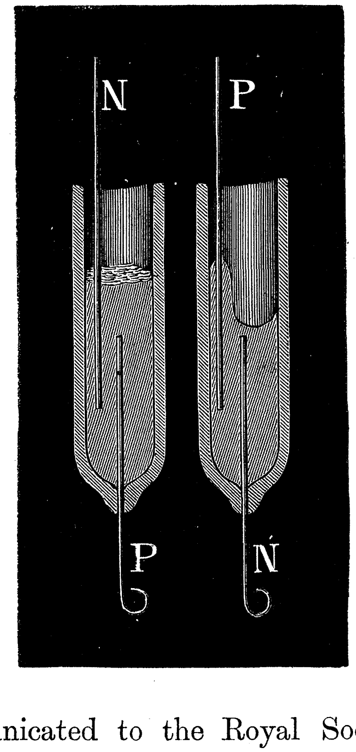
The arc in nitrogen is reddish-violet, the jump with 8040 cells being 0·402 inch when the point is positive, and 0·272 inch when negative, or in the ratio of negative to positive of 0·677.

In oxygen the arc presents a similar appearance to that in air, the mean jump with 8040 cells being 0·216 inch with the point positive, and the mean when negative 0·137 inch, the ratio of negative to positive being 0·634 to 1. The arc in carbonic anhydride is shown in 3, fig. 23.

From the foregoing observations, it would appear that hydrogen in a residual vacuum, together with the employment of aluminium for terminals, present the most favourable conditions for the passage of the voltaic current.

The spark with 8040 cells jumped 0·5 inch between two points placed vertically one over the other in a tube containing absolute alcohol, and provided with a vent to permit of the alcohol vapour escaping as soon as the arc is formed. Dr. BLEEKRODE, it

Fig. 24.



will be remembered, communicated to the Royal Society a paper 'On Electrical Conductivity and Electrolysis in Chemical Compounds,'* in which he gave an account of some experiments performed in our laboratory; as we do not propose to enter into this subject already in the skilful hands of that able chemist and physicist,

* Proc. Roy. Soc., No. 175, 1876.

we merely recall what has been stated by Dr. BLEEKRODE, that fluids such as bisulphide of carbon (CS_2), benzine ($C_6 H_6$), tin tetrachloride ($SnCl_4$), hydrochloric acid (HCl), cyanogen ($C_2 N_2$), zinc ethyl ($Zn (C_2 H_5)2$), are all strongly agitated when the current passes, but there is no electrolytic decomposition. The fluid is repelled by the negative and attracted by the positive pole, as shown in fig. 24, giving proof of a molecular motion taking place during the passage of the current, this has been found to occur even when the current passes slowly from one plate of a condenser to the other. We cannot, however, refrain from observing in reference of Dr. BLEEKRODE's experiments, that it is most remarkable that fused chloride of lithium (LiCl) is readily decomposed by four BUNSEN cells, and fluid hydrochloric acid (HCl) resists a potential of 5640 cells; the accepted notions of electrolysis evidently requiring reconsideration.

Battery in combination with an Accumulator (condenser).

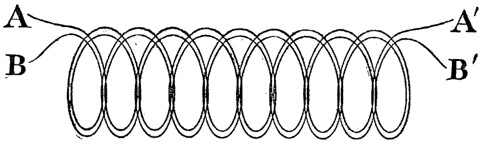
For several experiments we employ the accumulated charge of a condenser, and have condensers of different constructions and capacities, thus :—

1st. Two globes, covered with tinfoil and then with india-rubber, to prevent the dispersion of the charge ; the axis is supported on ebonite uprights attached to a wooden base. The globes are 18 inches (45·72 centim.) in diameter, and present each a superficies of 7·07 square feet (65·68 square decim.) ; the capacity of each = 0·00037 microfarad.

2nd. Two cylinders, made of many folds of paper, covered with tinfoil and then with several other layers of paper ; they are supported on three ebonite feet. Each cylinder has a superficies of 16 square feet (148·64 square decim.) ; these have each a capacity of 0·00052 microfarad.

3rd. Coil condensers, composed of two insulated copper wires coiled together side by side on a reel, shown in the diagram (fig. 25) :—

Fig. 25.



Coil A consists of two wires, 174 yards (159 metres) long, and $\frac{1}{16}$ of an inch (0·16 centim.) diameter ; these wires are covered with gutta-percha in two layers, being together $\frac{1}{32}$nd of an inch (0·08 centim.) thick ; this has a capacity of 0·014 m.f.

B. A similar coil, 350 yards (320 metres) long, with a capacity of 0·031 m.f.

C. A coil of the same thickness and length of wire, 350 yards, covered with india-rubber and linen, $\frac{3}{32}$nds of an inch (0·24 centim.) thick = 0·028 m.f. This coil supports a charge of 3600 cells, A and B only 2400.

4th. Plate condensers :—

D. Four condensers, formed of sheets of tinfoil and sheets of ebonite $\frac{1}{32}$nd of an inch (0·08 centim.) thick ; these each are in four sections :—

	Square feet.	Square decim.	Microfarad.	
D 1	29	269·5	0·0924	These support a charge of 3600 cells, but are liable to break down with 4800.
D 2	145	1347	0·4518	
D 3	145	1347	0·4704	
D 4	145	1347	0·4741	

E. Composed of tinfoil, separated by two sheets of vulcanized rubber, each $\frac{1}{32}$nd of an inch thick ; it is in four sections and has a total surface of 75 square feet (698 square decim.), and a capacity of 0·1485 m.f. ; this bears a charge of 8040 cells.

F. A condenser, composed of tinfoil and paraffined paper, in eight sections ; it has a total capacity of 42·8 * m.f., and was made for us by Messrs. VARLEY ; it is capable of withstanding a charge with 3240 cells.

G. A similar condenser, made under the direction of Dr. MUIRHEAD, of 240 sheets of tinfoil, with seven sheets of paraffined paper interposed ; this presents a surface of 364·5 square feet (3386 square decims.), and has a capacity of 3·94 microfarads ; it bears a charge of 8040 cells.

H. Another, made under the direction of Dr. MUIRHEAD, with eight sheets of paraffined paper between the layers of tinfoil ; the surface of this is 2200 square feet (204·38 metres), and the capacity 20 microfarads.

5th. We sometimes employ Leyden jars of the following dimensions :—

	Square inches.	Square decim.	Microfarad.
H 1	57	3·68	0·0016
H 2	258	16·64	0·0049
H 3	442	28·51	0·0066

We give the foregoing particulars as affording useful information to other experimenters who may have occasion to employ accumulators. The coil condensers we have found useful in certain cases, as for example those already communicated to the Royal Society.† The VARLEY condenser is of very great value for experiments with vacuum tubes, for when once charged up, and then disconnected from the battery, and the charge allowed to run down through a tube, it maintains a current frequently for ten minutes without replenishing, the phenomena varying as the potential falls ; when any particular phase in the stratification occurs, it may be sustained by connecting the condenser with the battery through a suitably-adjusted resistance, which permits of the inflow being exactly equal to the outflow. The potential at each end of the tube and at different points in the circuit may be ascertained for

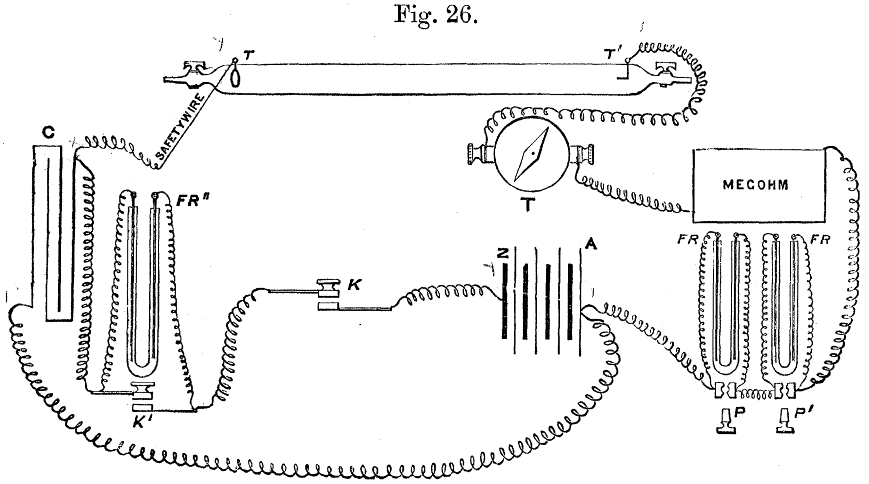
* The condenser of 47·5 m.f., described Proc. Roy. Soc., vol. xxiii. p. 358, broke down with 1080 cells.

† Proc. Roy. Soc., vol. xxiii. p. 356.

each phase by means of an electrometer; from these observations, data may be derived with respect to the current and the apparent resistance of the tube at each epoch. In using a condenser of this capacity certain precautions are necessary, for it several times has happened that there is no indication of a current until a sudden jump takes place which destroys the vacuum tube; this was remedied by placing a safety wire of platinum, 0·002 inch in diameter and 10 inches long, between the tube and one terminal of the condenser. Such a wire was found to permit of only 4 per cent. of the charge passing, and though frequently deflagrated by this amount of charge during the course of the experiments, it has effectually protected the tube by thus breaking off the connexion. We are indebted to our friend Professor STOKES for the suggestion of the introduction of resistances during the charging of the condenser and also for that of the safety wire.

Fig. 26 is a diagram of the arrangement. C, the condenser, one side of which is in

Fig. 26.



connection permanently with the battery at A, the other side is in connection with the battery at Z only when the key K (corresponding to K K′, fig. 9, page 63) is pressed down; this connection is either through the adjustable fluid resistance FR″ or direct, without intervening resistance, when the key K′ (corresponding to S S′, fig. 9) is pressed down; T T′ is the tube to be experimented with; the current from the condenser has to pass through the safety wire, the tube, and the adjustable coil resistance in the megohm, or the adjustable fluid resistances FR, FR″ [see also fig. 10, page 64], which may be plugged out by the plugs P and P′; or through both coil resistances and fluid resistance if so required. When K is raised, the charged condenser supplies the current.

We have already stated* that a charge of 47·5 microfarads, with 1080 cells, deflagrates 10·5 inches (26·67 centims.) of platinum wire, 0·005 inch (0·127 millim.) in diameter; when the condenser of 42·8 microfarads is charged up, with 3240 cells, the charge deflagrates the same length of wire, but 0·0125 inch (0·317 millim.) in diameter.

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

The condenser of 42·8 is to that of 47·5 as 0·9434 to 1; the sectional area of the larger to the smaller wire is as 6·25 to 1; so that the effect of the disruptive discharge of 42·8 microfarads, with 3240 cells, as compared with that of 47·5 microfarads, with 1080 cells, is as 6·62 to 1 for the same capacity. As the relation of the electric energy in the two cases is that of the capacity multiplied by the square of the potential, the quantity of wire deflagrated should be $0·9434 \times 3^2 = 8·5$ to 1.

When $2\frac{1}{2}$ inches of the same size wire, 0·0125 inch, of either platinum, gold, silver, copper, iron, zinc, or aluminium, is strained across and kept in close contact with a piece of plate glass, perforated with two holes to admit of screw clamps to press the ends of the wire tightly against it, and the charge sent through it, the wire is dispersed with a strong explosion, like that of a pistol, the metal being driven into and strongly adhering to the glass for some distance from the wire. The stain presents the appearance of lines of force, recalling magnetic lines, in consequence of the cloud or smoke-like stain being furrowed with lines converging towards the clamps. On examination with the microscope, it was seen that minute globules of metal existed at the termination of the furrows, which they had evidently ploughed up through the cloud-like deposit, leaving a line of unstained glass. Several of these globules, of gold, were measured under the microscope with a spider-line micrometer, and the following diameters were obtained among others:—0·00004, 0·00386, ·00463, 0·009 inch, they are all smaller than that of the wire exploded. The greater number were exceedingly minute, ending in a cloud-like stain too small to admit of measurement. All along the path of the discharge the deposit appears in cross striæ, which remain visible on the disintegrated surface of the glass when the film of metal is dissolved; the greatest dispersion is not close to the ends of the wire, but towards the middle, and was found to be—

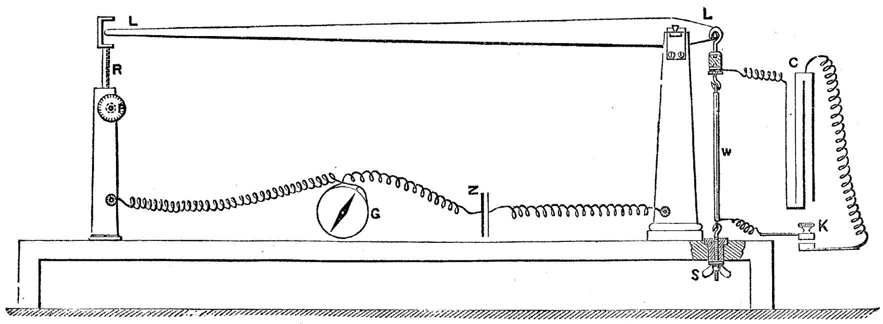
With gold, 0·5.	With silver, 0·3.	With platinum, 0·3.
0·5.		,, 0·3.
0·55.		
0·6.		

of the total length of the wire from the positive pole. The plate when gold has been deflagrated exhibits the metal in the several varieties of ruby, green, and violet.

The appearance of the stain of an exploded wire, suggested the thought of a stress at right angles to the path of the discharge; and experiments were made in order to ascertain whether a wire was either shortened in consequence of an expansion of its diameter, or lengthened by the particles being driven away from each other in the direction of its length by the discharge of 42·8 microfarads charged with 3240 cells, but the results were entirely negative. The diagram, fig. 27, shows the arrangement of the apparatus.

To the short end of a steel-yard L L′, whose relative lengths on each side of the fulcrum are 1 and 13·6, was hung a brass wire W, 8 inches long and 0·2 inch diameter, by means of an insulated hook with a clamp for connexion with one plate of the condenser C. The wire was strained down in opposition to a small weight on the long arm of the steel-yard by means of the insulated screw-hook S connected with the contact-key K; when the charge is to be sent through the wire, this key has to be pressed down. To the metallic support of the lever is attached one terminal of a

Fig. 27.



single cell A Z, the other terminal being connected through a Thomson-galvanometer G to the adjustable metallic fork R. If contact between the long arm of the steel-yard and either the top or bottom of the fork takes place, then a current passes and the movement of the galvanometer indicates that the wire has either shortened or lengthened. When the long arm of the lever was adjusted to 0·001 inch from touching the top or the bottom of the fork, as the case might be, and the charge in the condenser was sent through the wire, contact was not made, showing that no shortening or lengthening to the extent of $\frac{1}{13600}$ inch occurred at the time of the discharge. When 8 inches of platinum wire, 0·0125 inch diameter, was experimented with, no instantaneous shortening of the wire took place at the moment of its deflagration. When 8 inches of iron wire, 0·03 inch diameter, was experimented with, a downward movement of the long arm of the lever to the extent of 0·375 inch occurred, showing an elongation by the heating effect of the discharge of $\frac{0\cdot375}{13\cdot6}=$ 0·02786 inch; the contraction of the wire in cooling brought the long arm of the lever to nearly, but not quite, its normal position; the elongation indicates a temperature of about 300° C., but it is most probable that it was higher, so that it may be safely concluded that the elongation of the wire was solely due to the heat.

We have made experiments to ascertain the amount in chemical equivalents required to fully charge the 42·8 microfarads accumulator by connecting a voltameter in the circuit to one of its plates, from one terminal of the battery, the other terminal to the other plate. The connexion in every case was continued for two minutes, although the evolution of the mixed gases in the voltameter had nearly ceased in thirty seconds; a very minute quantity, indeed, of gas continues to be liberated, however long the accumulator remains in connexion with the battery; this we attribute to a leakage.

In all cases either four or five charges were made, because the quantity of gas evolved is extremely small. The voltameter was specially constructed and subdivided, with a sufficient space between each division, to 0·02 of a cub. centim.

	Charge, with No. of cells.	Mixed gases evolved. cub. centim.	Temperature. Cent.	Barometer. millims.
I.	1080	0·0075	19·8	759·19
	2160	0·0150		
	3240	0·0250		
II.	1080	0·0100	20·8	756·14
	2160	0·0150		
	3240	0·0250		
III.	3240	0·0247	19·1	725·92
IV.	3240	0·0278	22·2	755·13

CHARGE with 3240 cells reduced to 760 millims. and 0° Cent.

	Mixed gases. cub. centim.
I.	0·02276
II.	0·02256
III.	0·02156
IV.	0·02487
Mean	0·02294

Taking 1000 cub. centims. at 760 millims. and 0° Cent. of mixed gases at 0·5365 grm., the charge is represented by—

$$\frac{0·02294 \times 0·5365}{1000} = 0·000012307 \text{ grm. water decomposed,}$$

equivalent to 0·000166145 grm. silver reduced. A Weber of current flowing for one second would, according to KOHLRAUSCH (Pogg. Ann., vol. cxlix., 1873), reduce 0·0011363 grm. silver, and this being the quantity contained in a condenser of one farad when charged to a potential of 1 volt, we have—

$$\frac{0·0011363 \times 42·8 \times 3240 \times 1·03}{1,000,000} = 0·0001623 \text{ grm. silver,}$$

reduced by the charge of the 42·8 microfarads at the potential of 3240 AgCl cells. The ratio of the value observed by us (0·000166145 grm.) is to that calculated from KOHLRAUSCH'S numbers, as 102·3 to 100.

The *quantity* of electricity which flows into an accumulator to charge it fully, is in direct ratio of the number of cells ; the potential also is proportional to the number of cells in series used to charge it, so that the electric energy is in the ratio of the capacity multiplied by the square of the potential.

Cells.	I. Ratio.	II. Ratio	Mean
1080	1·00	1·0	1·00
2160	2·00	1·5	1·75
3240	3·33	2·5	2·91

Taking experiment I., which was made with rod batteries which had been just previously tested, we have the ratios 1, 2, and 3·33 as the charges of the 42·8 microfarad condenser, with respectively 1080, 2160 and 3240 cells. We might, therefore, anticipate that the effects in deflagrating a wire would be as 1, 4, and 10.

A direct experiment with platinum wire 0·0125 inch diameter gave the following results, the charge with—

Cells.		Inches.	
1080	heated	1	to the fusing point.
2160	deflagrated	4	
	heated	5	to the fusing point.
3240	deflagrated	10·5	
	melted	11	into globules.
	heated	13	to the fusing point.

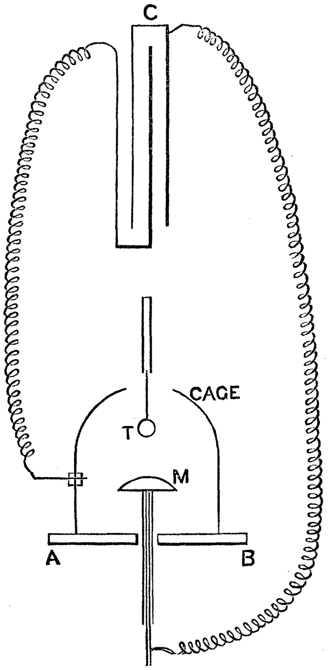
As occasionally we have accidentally been exposed to shocks, it appeared to us permissible, in self-protection, to ascertain whether life or health was in any way endangered by them; we therefore made an experiment on a rabbit, with the condenser of 42 8 microfarads charged with 2160 cells; the discharge was passed from the inside of one ear to the throat, but produced no other effect than to paralyze the fore paws for about an hour; it appeared, however, that but a very small portion of the charge had passed through the rabbit, inasmuch as afterwards, when the condenser was discharged, the report was nearly as loud as when the condenser is at full potential. Professor STOKES accidentally received the charge of this condenser, with 3240 cells, without injury (like the rabbit, he got only a small fraction of the charge), and one of us (DE LA RUE) has had a shock from the whole battery, without a condenser, of 8040 cells; the shock was severe, and its numbing effects were felt for some hours; in every case the skin is pierced by a number of minute holes and cauterised where the charge enters.

Experiments were made to test the portion of a charge that passed from a condenser when the opposite plates were connected by a certain length of platinum wire of a definite diameter. In order to measure the fall in potential of the condenser, one of its plates is placed in connexion with the cage (fig. 28), consisting of a glass shade lined with tinfoil, and having a hole in the top to permit of the insertion of a test plane, T, for taking a charge from the mushroom, M, in connexion with the other plate of the condenser, C. The shade rests on a glass disc, also coated with tinfoil, except at the centre, where a space 3 inches in diameter is left uncoated. For the suggestion of this arrangement, having for its object to insure that the test charge shall be always at the full potential, we are indebted to Professor STOKES. The cage is quite close to the quadrant electrometer, which we charge always to the potential of 2400 cells; it is rendered much less sensitive than usual by the separation of the suspension threads. The test plane we use up to 3240 cells is a brass disc 2 inches in diameter.*

* Recently we have found it to be more convenient to use a quadrant electrometer furnished with an induction plate placed above one of the quadrants and adjustable in distance from it.—Dec. 13, 1877.

42·8 microfarads were charged with 2160 cells, and gradually discharged by connecting the opposite plates many times in succession through a platinum wire of 0·002 inch diameter and 12 inches long, the wire being deflagrated by each discharge.

Fig. 28.



The potential of the condenser was measured from time to time by the quadrant electrometer, and from these measurements the quantity passing at each discharge was deduced; they were as follows:—

		Divisions.	
Deflection of electrometer when condenser was fully charged=		200	$\frac{50}{6}$=8·33
,, ,, after condenser had been discharged	6 times=	150	
,, ,, ,, ,,	11 ,,	110	$\frac{90}{11}$=8·18
,, ,, ,, ,,	15 ,,	80	$\frac{120}{15}$=8·00
,, ,, ,, ,,	18 ,,	55	$\frac{145}{18}$=8·125
		Mean	8·16

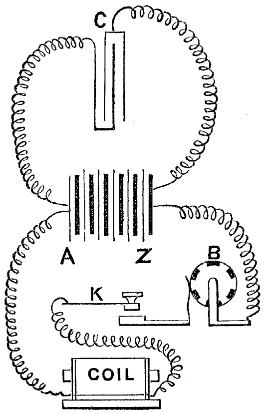
So that, on the average, each discharge took $\frac{8\cdot16}{200}$, or 4 per cent., of the whole charge; and this quantity, there is reason to believe, is quite as great as that which passed through the rabbit.

Secondary Current induced by a Primary Current of High Potential.

Our experience with the detector-coil already described, and other smaller coils, all of which gave very long sparks in relation to the current, under the conditions about to be described, led us to make experiments with one of APPS's usual coils for 6-inch sparks.

The diagram (fig. 29) shows the arrangement of the apparatus: A Z, the battery, is

Fig. 29.



connected *permanently* with the condenser C, A to one plate, Z to the other; the A terminal of the battery is also connected to one terminal of the primary of the coil, the Z terminal to a make-and-break-wheel B, to be worked by hand, thence to the key K, which is connected to the other terminal of the coil.* If the key K is pressed down, and the wheel B is made to rotate, it is evident that a current will pass, or not pass through the primary of the coil, according as a conducting or a non-conducting tooth of the break-wheel is in connexion with the contact spring; but the battery is never disconnected from the condenser by the rotation of the break-wheel; therefore, when the make-and-break-wheel permits of the current passing through the primary of the coil, it is the *accumulated* charge of the condenser which actually passes through it, and hence produces a very exalted effect in comparison to that of the battery alone. Experiments were made with APPS's 819 coil, already described; also with—

APPS's coil, 815.

	Length of wire.	Diam. of wire. inch.	Resistance. ohms.	Turns.
Primary	78 feet	0·06	0·245	270
Secondary	4408 yards	0·0055	2196·000	13,000

and APPS's coil, No. 821, for producing a 6-inch spark:—

	Length of wire.	Diam. of a wire. inch.	Resistance.	Turns.
Primary	66 yards	0·065	0·22	250
Secondary	$5\frac{1}{4}$ miles	0·0068	4900·00	24,000

* The break-wheel B B and key K K′ are shown in position, fig. 9, page 63.

On one occasion, with coil 815, in connexion with coil C of 350 yards, 0·028 microfarad, as a condenser, and 3240 powder cells, which evolved 0·3 cub. centim. mixed gases per minute in the voltameter, 3-inch sparks were obtained, with a moderate rotation of the contact breaker.

APPS's No. 821 coil, either with its own condenser or $\frac{2}{5}$ths of LADD's condenser, D 2 =0·1807 microfarad, produces a rapid succession of 6-inch sparks when worked with 6 cells in series of a zinc-carbon battery, charged with a solution of bichromate of potash and sulphuric acid, the plates being 12 inches by 5 inches, and each zinc between two carbon plates; the make-and-break being effected automatically by the usual hammer-and-anvil arrangement. This battery evolved 152 cub. centims. of mixed gases per minute, when the current passed through a voltameter having a resistance of 17 ohms, and containing a mixture of 1 part sulphuric acid and 10 of water. The chloride of silver battery evolved only 0·5 cub. centim. of mixed gases under the same circumstances, consequently only $\frac{1}{304}$th part; nevertheless, as great or even greater effects were obtained with it than those with the zinc-carbon battery.

With 1080 cells and the LADD condenser D 2, 0·4518 microfarad, connected permanently with the battery, a dense spark, 3·5 inches long, was obtained on making contact with the key, so as to send the accumulated charge through the primary of the coil, but only a feeble spark on breaking contact.

With 2280 cells and condenser D 2, under the same circumstances, a full 6-inch spark was obtained, and a rapid succession of such sparks when the break-wheel made 44 contacts in a second.

With 3480 cells, on making contact, the same effects, and a rapid succession of such sparks when the break-wheel made 62 makes-and-breaks in a second.

It seemed probable that the battery could charge up larger condensers with sufficient rapidity, and this was shown to be the case by the following experiments:—

With 3480 cells and condensers D 2 and D 3, 0·9222 microfarad, dense sparks not only passed between the terminals of the secondary coil, but other sparks, longer than 6 inches, jumped from every part of the coil when the break-wheel made 212 contacts in a second.

With the same number of cells and condensers D 1, 2, 3, 4, 1·4887 microfarads and 352 breaks in a second, the sparks were as long, but denser, than in the last-named case.

It appears from the foregoing experiments that a high potential is very favourable to the production of induction effects when used in connexion with accumulators of suitable capacity. The *accumulated* high-tension charge passes at each make contact, and produces effects partly dependent on the potential and partly on the quantity of current, which must be, however, considerably less in a given time than that when a battery of large plates is employed (6 zinc-carbon cells, 12 × 5 inches).

Although it was not anticipated that the production of these exalted effects in comparison with the current was due to any effect with regard to the induced magnetism in the iron core, nevertheless some direct experiments were made to test this point.

A horse-shoe electro-magnet, weighing 1854 grains (0·265 lb.), surrounded with 1102 yards of insulated copper wire of 0·014 inch diameter, in 4352 turns and 34 layers, and presenting a total resistance of 200 ohms, consequently very small in comparison with the internal resistance of the batteries, was employed in making the experiments. The armature was suspended on a delicately-poised steel-yard, accurately divided, and provided with a suspender for the weight, mounted on rollers to permit of its being moved smoothly along the long arm of the lever, so as not to give any shock which might disturb the armature.

Observations were made of the weight supported by the magnet when 1200, 2400, and 3600 cells were used, the current passing in each case being at the same time measured by a galvanometer, the value of whose deflections had been determined in absolute units of current. The following results show that the weight supported by an electro-magnet was not merely proportional to the current, but increased with the number of cells :—

Number of cells (col. 1).	Current (col. 2). Weber.	Weight supported (col. 3). lbs.	Col. 3. / Col. 2. Weight in lbs. per Weber.	Ratio to 1200 cells as unity.
1200	0·09443	26·6	281·6	1·000
2400	0·09261	32·3	340·9	1·211
3600	0·08298	31·5	379·6	1·348

Other experiments were made with an electro-magnet formed of the same core, but with the substitution of coils composed in all of 37·6 yards of insulated copper wire, 0·052 inch diameter, in 246 turns, and having a resistance of 0·6 ohm. The results obtained confirm the statement that the weight supported increases with the number of cells for the same current :—

Number of cells (col. 1).	Current (col. 2). Weber.	Weight supported (col. 3). oz.	Col. 3. / Col. 2. Weight in oz. per Weber.	Ratio to 1200 cells as unity.
1200	0·10660	66	619·0	1·000
2400	0·08898	63	707·9	1·144
3600	0·08399	62	738·2	1·192

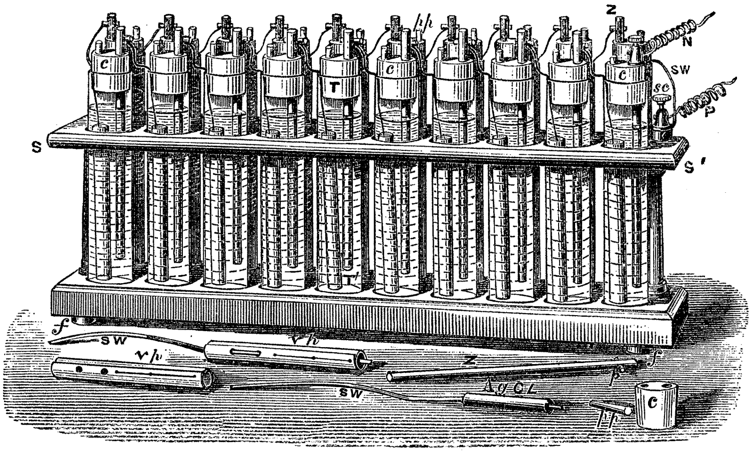
This electro-magnet, with the last-named coil composed of 37·6 yards, supported 42 pounds when the zinc-carbon battery of six cells in series, described at page 92, was connected with it, giving a current of 14·35 Webers. The weight divided by the current comes out 46·8 as the weight in ounces per Weber. The foregoing results must not be accepted as *final*, as the experiments will be repeated at a future opportunity.

Description of the Battery and its Working.

We now proceed to give some account of the battery, of the working of which we have had nearly three years' continuous experience.

As originally constructed, the chloride of silver battery had open cells, and the zinc element was amalgamated;* since then we have constructed batteries in which the cells (tubes) were closed with vulcanised rubber stoppers, perforated to admit of the insertion of the zinc rod, the silver wire connected with the chloride of silver was inserted between the stopper and the side of the tube, it being previously covered with several folds of thin sheet gutta-percha to protect it from the action of sulphur in the vulcanised stopper. The amalgamation of the zinc has the advantage of preventing, to a great extent, the strong adherence of the oxychloride of zinc to which we have referred in an early part of the paper, but presents the great disadvantage of amalgamating and ultimately rotting the thin flattened silver wire;† so that having to choose between two evils,

Fig. 30.



we have preferred not to amalgamate the zinc when it is intended to keep the batteries one or more years in action. Fig. 30 shows a nest of 20 rod cells of the most recent construction already described,‡ but of which we have not before given any drawing. The several components of the battery are shown at the base of the stand: Z, the zinc rod with the plug *p*, inserted in a hole at the right-hand end; AgCl, the chloride of silver rod, cast on the flattened silver wire SW; V*p*, a vegetable parchment cylinder, open at both ends and perforated towards the top with two holes to admit of the silver wire SW being interlaced through them, as shown in the figure immediately above it;

* Journal of the Chem. Soc., new series, vol. vi., entire series, vol. xxi. p. 488, 1868.

† Platinum, which would not amalgamate, might be substituted, but it would cost £55 extra per 1000 cells.

‡ Proc. Roy. Soc., vol. xxiii. p. 357.

the vegetable parchment is made to adhere so as to form a cylinder by means of shell-lac varnish on the edge of the last layer, of which there are three of one continuous piece; as the shell-lac varnish does not effectually secure the adherence of the vegetable parchment (for nothing does it effectually) a few stitches of thread are made at the lower end, the interlacing wire preventing the vegetable parchment from unfurling at the upper part. The use of the vegetable parchment cylinder is to prevent contact between the zinc rod and the chloride of silver; C is the paraffin stopper perforated with two holes, one for the zinc rod to pass through, the other for filling in the liquid, the second hole is ultimately stopped by a paraffin plug *pp*.*

The stand S S′, $16\frac{1}{4} \times 3\frac{1}{2}$ inches and $4\frac{1}{2}$ inches high, is made of Honduras mahogany and holds 20 cells; it is supported on four ebonite feet *f*, *f*, $\frac{1}{2}$ inch high; on the top rail at the right or left corner, for the alternate shelves of the cabinet, is fixed a screw-clamp *sc* supported on a cylinder of ebonite fitted in the stand, the silver wire SW of the last cell is inserted between the screw-clamp and this ebonite support, and held fast by screwing the clamp tightly into its support. The zinc of the terminal cell has also a screw-clamp screwed on it. The zinc terminal clamp of one tray of 20 cells is connected by a gutta-percha covered wire N, one end being inserted and screwed fast into it, and the other end into the clamp *sc* connected with the silver wire of the terminal cell of the adjoining tray. The cells are glass tubes with flat bottoms, $5\frac{1}{2}$ inches high and $1\frac{1}{8}$ inch in diameter; they pass through holes in the top rail and into recesses in the bottom of the stand. When the trays are put together a hot iron, like a soldering-bit, is run round the edge of the tube and round the zinc rod, this melts a little of the paraffin, making the joint tight and securing the zinc in its place. The flattened silver, on which the chloride of silver is cast, of one cell is connected with the zinc of the adjoining cell by passing it through the hole in the top of the rod, and securing it by pressing in the taper plug *p* with a pair of pliers; these wires are 8 inches (20·32 centims.) long, 0·05 inch (0·127 centim.) wide, and 0·009 inch (0·0229 centim.) thick, and weigh each 13·53 grains (0·88 grm.). The holes in the stopper for charging the tubes are lightly closed by the insertion of the small paraffin plug *pp*, when the liquid has been inserted. The chloride of silver rods† are 2·125 inches (5·4 centims.) long, and 0·3 inch (0·762 centim.) diameter, and weigh 200·12 grains (12·97 grms.); the vegetable parchment cylinders are 3·8 inches (9·65 centims.) long, and 0·44 inch (1·12 centims.) diameter. The zinc rods are

* The zinc rod is procured from the Belgian Vieille Montagne Zinc Company; the chloride of silver rods, cast on the silver wires from Messrs. JOHNSON and MATTHEY, Hatton Garden; the paraffin stoppers from Messrs. FIELD, Paraffin Works, Lambeth Marsh; the stands from Messrs. TISLEY and SPILLER, No. 172, Brompton Road, who are prepared to supply all the materials, and also to make the battery complete; the glass tubes from Mr. HICKS, No. 8, Hatton Garden, and Messrs. NEGRETTI and ZAMBRA, Holborn Viaduct.

† The cast chloride of silver rods and the silver wires for 1366 cells cost £140 3*s*. 10*d*. = 2*s*. per cell, including the labour of casting.

6 inches (15·24 centims.) long, and 0·22 inch (0·56 centim.) diameter, and perforated at the top with a hole 0·1 inch (0·25 centim.) in diameter, to admit the silver wire of the adjoining cell.

The fluid used for charging the batteries is chloride of ammonium, 23 grms. to 1 litre of distilled water; by making use of a glass siphon with a long arm of india-rubber tubing, provided with a pinch cock, and terminating in a glass tube drawn down to enter freely into the hole in the paraffin stopper, it was found that 2400 cells could be charged by one person in ten hours.

Generally an enormous breakage of tubes takes place, the smaller number while inserting the stopper, but far the greater number without any apparent cause, in many cases after filling in the fluid, but chiefly before the battery has been charged. This is a serious trouble, for as much as 33 per cent. of breakage occurs, and arises mainly from the tubes not having been properly annealed.

The battery behaves, on the whole, extremely well, and all the better the more frequently it is used, for idleness is its bane, as it permits of the slow formation and close adhesion of a skin of oxychloride of zinc, which interposes an enormous resistance in each cell, and reduces the current sensibly when the battery is worked in circuits of small resistance; but for experiments with vacuum tubes, the current is amply sufficient, and has, in most cases, to be reduced by external resistance in order to protect the terminals of the tubes from fusing. It is remarkably constant, and if coupled up through a resistance with a galvanometer in circuit, the deflection of the needle has been found to remain constant for several hours; this we have had frequent occasion to do when determining the value of the deflections of our galvanometers in absolute units by electrolysis. For example, a battery of 10 elements in series was connected through two galvanometers to a decomposition cell containing a solution of 1 part crystals of silver nitrate and 5 parts of water; both electrodes were of silver, and were weighed before the commencement and at the end of the experiment. The current was continued for exactly 1 hour, during which time one galvanometer showed a constant deflection of 77°·75, the other with fewer coils 60°·75, when it was found that—

The positive electrode had lost	0·617 grm., and
The negative electrode had gained	0·616 „
Mean	0·6165 „

$$\frac{0·6165}{3600}=0·0001713 \text{ grm. per second.}$$

The resistance of the battery was 55 ohms, that of the decomposition cell was 3 ohms, and that of two galvanometers together was 5·24 ohms, making a total resistance of 63·24.

$$\frac{0\cdot0001713 \times 63\cdot4}{10} = 0\cdot0010833 \text{ grm. of silver per second,}$$

reduced by 1 cell with a resistance of 1 ohm.

A similar experiment with acidulated water in a voltameter having a resistance of 20 ohms gave in 6 minutes 7·2133 cub. centims. of mixed gases at 0° Cent. and 760 millims; this corresponds to 0·001035 grm. of silver reduced per second by 1 cell through a resistance of 1 ohm, showing, on the supposition that the resistance had been accurately ascertained, that in the latter case about 5 per cent. of the current passed without an equivalent evolution of the mixed gases.

In order to eliminate small errors in the determination of the internal resistance of the battery, a single cell was built up of 10 rod cells so as to form one element of small resistance, namely, 0·297 ohm; it was coupled up to the nitrate of silver decomposition cell through various resistances, making from 1·672 to 106·175 ohms total resistance in the circuit, the deflection of the galvanometers remained constant for 30 hours. The mean of four experiments gave 0·0010945 grm. of silver deposited per second by 1 AgCl cell through 1 ohm. This amounted to 94 per cent. of KOHLRAUSCH's number multiplied by 1·03 volt, the electro-motive force of the chloride of silver cell—

$$\frac{0\cdot011363^{*} \times 1\cdot03}{10} = 0\cdot0011704,$$

KOHLRAUSCH's number being for the C. G. S. electro-magnetic unit, of which the Weber is one-tenth.

When the deposit of oxychloride has caused a greater reduction of current than is convenient, the battery may be restored to its original condition by scraping the zinc rods, which is easy of accomplishment; thus, 2400 rod cells charged up December 15th, 1875, after being short-circuited for about half-an-hour to start the battery, evolved in a voltameter 2 cub. centims. of mixed gases in a minute; on April 9th, 1877, the battery only evolved 0·45 cub. centims. per minute. Twenty cells were taken to pieces, and the zinc rods scraped to remove the crust which had formed on them, this battery of 20 then evolved 2·85 cub. centims. per minute. The whole of the batteries were subsequently taken to pieces, and the zinc rods scraped; it required, on the average, six days to take to pieces and re-make up each 1200 cells of the rod battery.† From each of the batteries, 6 and 7, each containing 1200 cells, there was

* EVERETT's C G. S. Units, p. 77.

† This operation was conscientiously performed by a pupil and workman of Messrs. TISLEY and SPILLER, Mr. HENRY HAWKINS, who has put together most of our batteries, and of whose zeal and intelligence we are able to speak in high terms.

Since this communication was sent in, it has been found that a more expeditious mode of restoring the battery to its original current force is to withdraw the small paraffin plug used to close the hole in the stopper through which the cells are charged, and to introduce into each cell, containing 50 cub. centim., 1 cub. centim. of pure hydrochloric acid, sp. gr. 1·16, containing 31·8 per cent. HCl gas, removed 514 grms. oxychloride of zinc ten months after charging; from battery 5, of 1200 cells, 894 grms.; and battery 4, 1200 cells, 809 grms., sixteen months after charging. This deposit is in hexagonal plates, and on analysis was found to have the following composition :—15 ZnO, 3 $ZnCl_2$ + 20 H_2O.

	Theory.		Found.		
18 Zn	1173·6	59·07	58·33	58·33	
15 O	240·0	12·08			
6 Cl	213·0	10·72	11·82	11·82	11·40
20 H_2O	360·0	18·13	17·40	16·20	
	1986·6	100·00			

The formation of oxychloride of zinc is not peculiar to the chloride of silver battery, but takes place in all batteries where the zinc is immersed in a solution of a neutral chlorine compound (zinc chloride, sodium chloride, ammonium chloride).

We found the vulcanised stoppers to be a source of great trouble; in the first place, their elasticity frequently causes the tube to split, not at first possibly, but after the lapse sometimes of many months. Moreover, after a year or so, many of them become in some measure conducting, and slowly run down the cell, and we have had many cases where a current of high potential has run along the top, and set fire to the stopper. We have, therefore, entirely discarded vulcanised stoppers, substituting paraffin in our recent batteries and replacing broken down cells with vulcanised stoppers by others with paraffin. The paraffin stoppers may be cast solid, as they are easily bored in a lathe with the American drill; generally about five sizes are requisite to suit the various dimensions of the tubes used for cells, for it is quite impossible to obtain them of uniform diameter.

After having been in almost daily use during ten months, it was found that, in batteries 6 and 7, 3·57 grms. of the chloride of silver rod, weighing originally 13 grms., had been reduced, and 4·57 in batteries 4 and 5, which had been in use sixteen months; so that, when once set up, the life of the battery is sufficiently long, say three years, to admit of a great variety of experiments being made with it before it becomes necessary to renew it. The loss of silver is not great, and on this point we are able, in consequence of an accidental circumstance, to give precise information; 600 powder cells which had been charged up each with 14·5 grms. chloride of silver, ran down in consequence of portions of the zinc rod falling down on to the chloride

equivalent to 0·3689 grm. acid. It is better to dilute the acid with an equal volume of distilled water before introducing it into the cells, which is conveniently done by means of a graduated pipette furnished with a stop cock. An effervescence takes place, and it is therefore necessary to allow the tubes to remain twenty-four hours without the small paraffin plug being replaced, in order to permit the hydrogen, which is generated, to escape; the acid dissolves 0·3295 grm. of zinc, or its equivalent of oxide. It required two days for each battery, 1200 cells, to perform this operation.—Nov. 29, 1877.

(this is now obviated by placing six discs of vegetable parchment on the chloride), the total weight of silver contained in the charge was—

$$\frac{600 \times 14{\cdot}5 \times 15{\cdot}4325 \times 3}{480 \times 4} = 209{\cdot}78 \text{ troy ounces of silver.}$$

The quantity recovered was 206·92
Loss 2·86 or 1·38 per cent.

Working in a large way this percentage, though small, would be still diminished, so that the chloride of silver battery is not costly in its working; and we venture to believe that it is destined yet to find a place in telegraphy, for which its great constancy, and the very little attention it requires, particularly suit it. It is without question a valuable implement for scientific research, and a source of great comfort to the operator, who finds it always ready at hand whenever he enters the laboratory.

Both the iodide and bromide batteries appear to form a much larger quantity of an oxyhaloïd compound than the chloride; the iodide solution especially seems to act on the zinc rods, causing filaments of metal to form, and bridge across towards the iodide of silver element. They may be useful in making up in combination with chloride cells a battery of an exact number of volts, thus—

	volts.
3 cells chloride = 3 × 1·03 =	3·09
1 cell bromide	0·908
	3·998
Average per cell	0·9995

The Discharge in Air at Pressures less than the Ordinary Atmospheric Pressure.

Only a few experiments have as yet been made by us on the length of spark at different pressures below that of the atmosphere, but we intend to pursue this investigation with a micrometer discharger of longer range than that shown in fig. 1, page 58. The following results were obtained with our present means with a point and a disc and 8040 cells:—

Pressure. millims.	Fraction of an atmosphere.	Length of spark. inch.	Ratio to length at 1 atmosphere.	Ratio of length of spark to dilatation.
760	$\frac{1}{1}$	0·34	1	$\frac{1}{1} = 1{\cdot}0000$
326·82	$\frac{1}{2{\cdot}326}$	0·68	2	$\frac{2}{2{\cdot}326} = 0{\cdot}8598$
229·17	$\frac{1}{3{\cdot}316}$	1·02	3	$\frac{3}{3{\cdot}316} = 0{\cdot}9046$
197·29	$\frac{1}{3{\cdot}852}$	1·19 (limit)	3·5	$\frac{3{\cdot}5}{3{\cdot}852} = 0{\cdot}9086$

so that with a point and a disc the length of spark is not precisely in the inverse ratio of the pressure.

With two spherical surfaces, each of 3 inches radius of curvature and 1·5 inch diameter, the following results were obtained with 8040 cells:—

Pressure. millims.	Fraction of an atmosphere.	Length of spark. inch.	Ratio to length at 1 atmosphere.	Ratio of length of spark to dilatation.
760	$\frac{1}{1}$	0·079	1·00	$\frac{1}{1}$ = 1·000
602	$\frac{1}{1·262}$	0·100	1·26	$\frac{1·26}{1·262}$ = 0·999
414·7	$\frac{1}{1·833}$	0·200	2·52	$\frac{2·52}{1·833}$ = 1·375
299·5	$\frac{1}{2·537}$	0·400	5·04	$\frac{5·04}{2·537}$ = 1·986
141·5	$\frac{1}{5·370}$	0·800	10·08	$\frac{10·08}{5·370}$ = 1·876

With spherical surfaces the spark is longer in the last three cases than it would be if in the inverse ratio of the pressure; nearly, indeed, twice as long when the pressure is reduced to about two-fifths.

The comparison between the striking distances with spherical surfaces, and with the point and disc, points to the probability of the distances coinciding at a certain degree of rarefaction.

Note A.

"I should attribute the difference of adhesion of the paper to the plate according as the point was positive (P) or negative (N) to the different facility with which electricity passes by discontinuous, and not too rapidly succeeding, discharges from points P and N; the facility being much greater from the former. The points I have in view are not the metallic point alone, but also those ends of the fibres of which the paper consists which happen to be at the surfaces. The dried paper is a very bad conductor. Its upper surface is electrified by the electrified air whether the metallic point is P or N, and the electricity passes down through the bad conductor so slowly that the supply of electricity from the electrified air suffices to keep up a good charge on it. When the metallic point and consequently the paper is P, the ends of the fibres and other little roughnesses on the under face of the paper, by the property of P points, part with their electricity readily to the plate, so that the under portion of the stratum of paper is pretty well free from charge. When it is N, the negative electricity of the paper has much greater difficulty in passing into the plate, and therefore there is more charge in the paper, and that too is situated (in the mean) further down, so that the paper and plate are equivalent to a condenser thinner than the paper itself, and therefore capable of receiving a greater charge than a metallic plate whose lower surface is at the height of the upper surface of the paper, and which is opposed to the actual plate, the paper being supposed removed.

"When the paper is damp, it conducts so much better that the electrification by the electrified air cannot keep pace with the loss by transfer to the plate, and there is small charge, and therefore small attraction. When the upper electrode is greatly curved there is little electrification of the air, and therefore the charge of the paper resting on the lower electrode could not be kept up."

SUPPLEMENT.

February 11, 1878.

On January 1st, 1878, we charged up with liquid the 2960 cells we had been preparing during the four previous months; 1500 of these were rod cells, and 1460* powder cells. Before combining them with the 8040 cells already in use we had the latter thoroughly examined and defective elements renewed. Advantage was taken of the preparation of the new cells in order to ascertain whether the old ones had retained their initial electro-motive force; this was done by means of the quadrant electrometer referred to in the footnote to page 104, one pole of each battery being connected to earth, the other to the induction plate of the electrometer, and the following numbers were obtained:—

Battery.	No. of cells.	Scale division.
No. 1.	1080 powder.	Deflection per cell=0·1069, made up afresh with new liquid.
2.	1080 „	„ „ =0·1040.
3.	1080 „	„ „ =0·1099, made up afresh with new liquid.
4.	1200 rod	„ „ =0·1008, cells contained 6·8 per cent. $ZnCl_2$.
5.	1200 „	„ „ =0·1046, „ „
6.	1200 „	„ „ =0·1050, „ „
7.	1200 „	„ „ =0·1063, „ „
8.	1500 „	„ „ =0·1110, new battery.
9.	1460 powder	„ „ =0·1096, „

The sum of the deflections of all the batteries equals 1173 scale divisions; the mean deflection per cell of 8 and 9 was 0·1103, therefore $\frac{1173}{0\cdot1103}=10,640$ cells of the potential of the new ones, that the whole 11,000 were equal to when the observation was made.

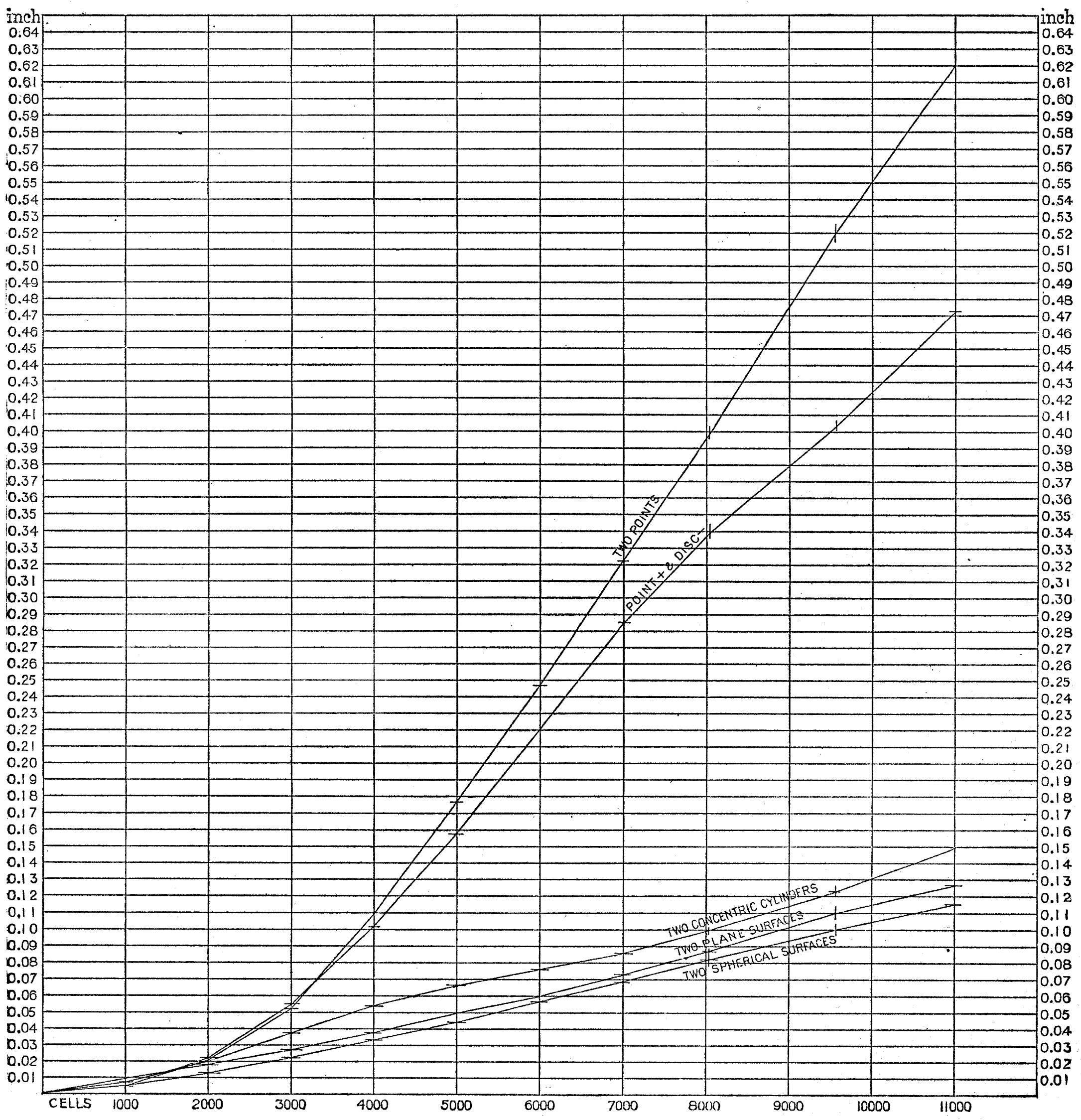
It was found by direct experiment with several of the trays of 20 cells that the formation of $ZnCl_2$ lessened the potential of the battery, and that it could be restored by removing the old liquid and charging the cells with a fresh solution of chloride of ammonium in the ratio of 23 grms. to 1 litre of distilled water.

In giving the following particulars of the measurements of the striking distances, it is necessary to state that as No. 8 battery contains 1500 cells and No. 9 battery 1460 cells, by adding No. 8 and 8 and 9 to the old series of 8040, we obtain 9540 and 11,000 cells respectively. It was not thought necessary to commence all the measurements afresh, as this would have occupied much time and uselessly wasted the life of the battery, so that we have contented ourselves with merely taking the striking distance of the 8040 cells, each time for the several forms of terminals, and then the *additional* striking distance for 9540 and 11,000 cells respectively. These additional lengths of spark we have added on to the several means obtained for 8040 cells, as

* The powder cells will be used to renew any of those in batteries 1, 2, 3 which may become exhausted, and will be replaced by rod cells.

showing more correctly the true striking distances than could be obtained by a few isolated experiments.

Fig. 31.



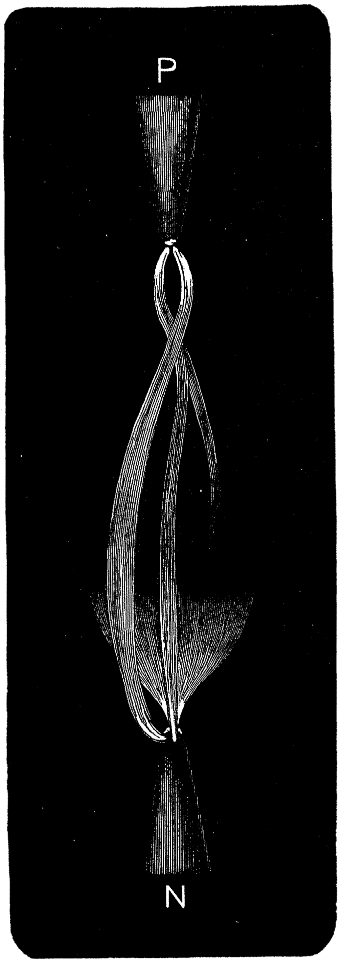
LENGTHS of Spark.

No. of cells.	Two points.	Point + and disc −	Concentric cylinders.	Plane surfaces.	Spherical surfaces.
	inch.	inch.	inch.	inch.	inch.
8,000	0·4000	0·3400	0·0990	0·0882	0·0818
9,000	0·4760	0·3805	0·1142	0·1020	0·0938
10,000	0·5515	0·4248	0·1310	0·1157	0·1050
11,000	0·6200	0·4730	0·1496	0·1280	0·1170

The foregoing numbers were obtained from curves laid down from the means of the actual observations of differences in the length of spark between 8040 and 9540, and 11,000 cells respectively; the diagram, fig. 31, shows the curves on a reduced scale. It is presumable that if the whole battery had the potential of cells newly charged the striking distances for 11,000 cells would be for—

Cells.	Two points.	Points and disc.	Concentric cylinders.	Plane surfaces.	Spherical surfaces.
	inch.	inch.	inch.	inch.	inch.
11,000	0·6412	0·4889	0·1546	0·1323	0·1210

Fig. 32.



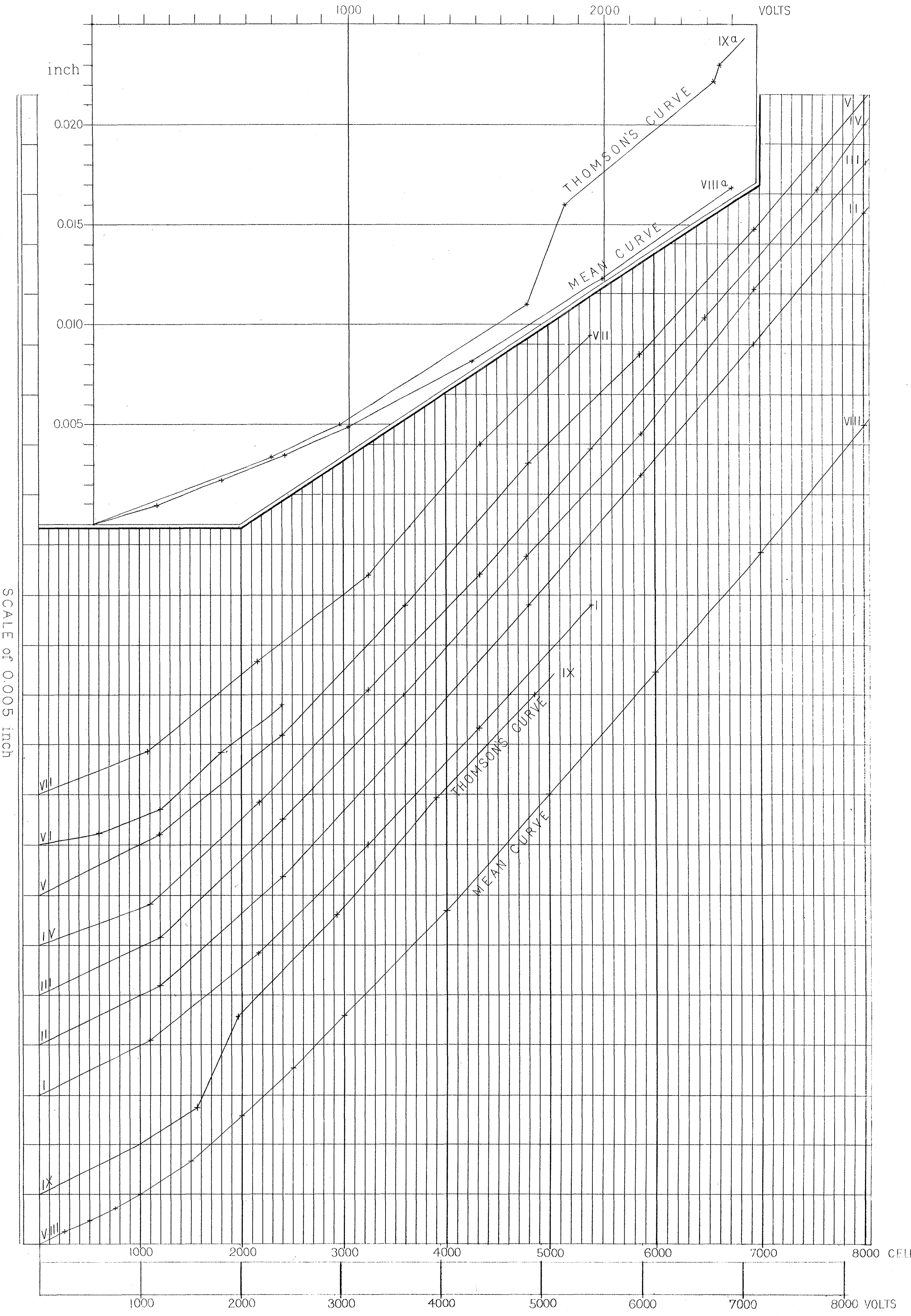
It will be seen that the curve for two points runs on pretty smoothly with that obtained up to 8040 cells, whilst that for a point and disc bends inwards and no longer conforms to a curve, laid down on the hypothesis of the length of spark being in the ratio of the square of the number of elements.

We must state that our insulation is put to a severe test when 11,000 cells are connected in series, and that there is an evident leakage when one pole is connected to earth. This may have some but not a great effect on the length of spark.

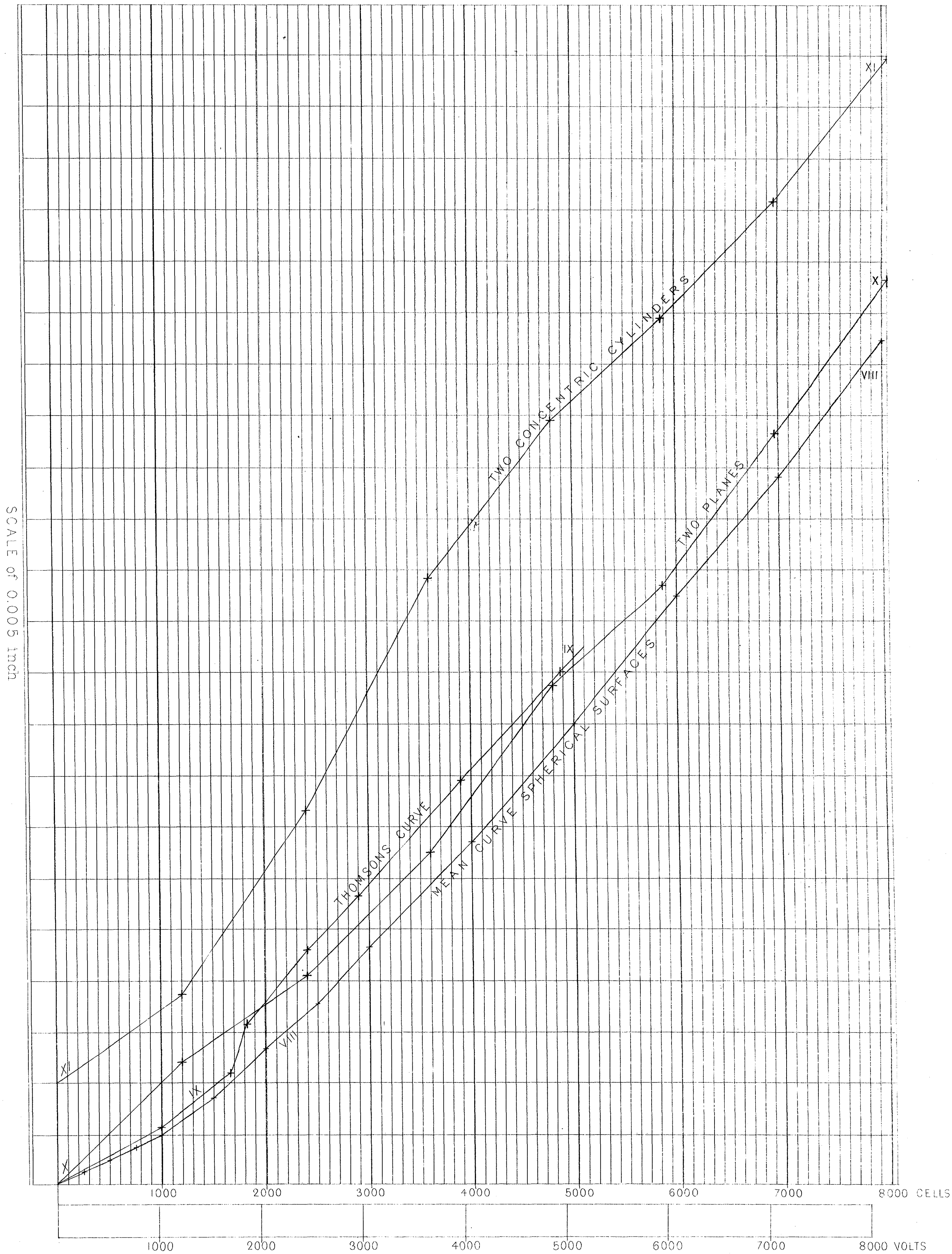
The 11,000 elements made manifest an interesting phenomenon in the streamer-discharge, which precedes the jump of the spark and formation of the arc, confirming what we have previously stated at pages 88–100, namely, that the discharge is more continuous at the negative pole than at the positive. It was seen that when two points were used as terminals in the discharger (fig. 1, page 58) with this number of elements there was a continuous brush-discharge at the negative, while from the positive an intermittent streamer-discharge took place, and that the streamers emanating from it enveloped the negative brush-discharge without in the least disturbing its form. This phenomenon is well represented on a scale of 4 to 1 in fig. 32.

INDEX TO PART I.

CURVES OF LENGTH OF SPARK BETWEEN SPHERICAL SURFACES.

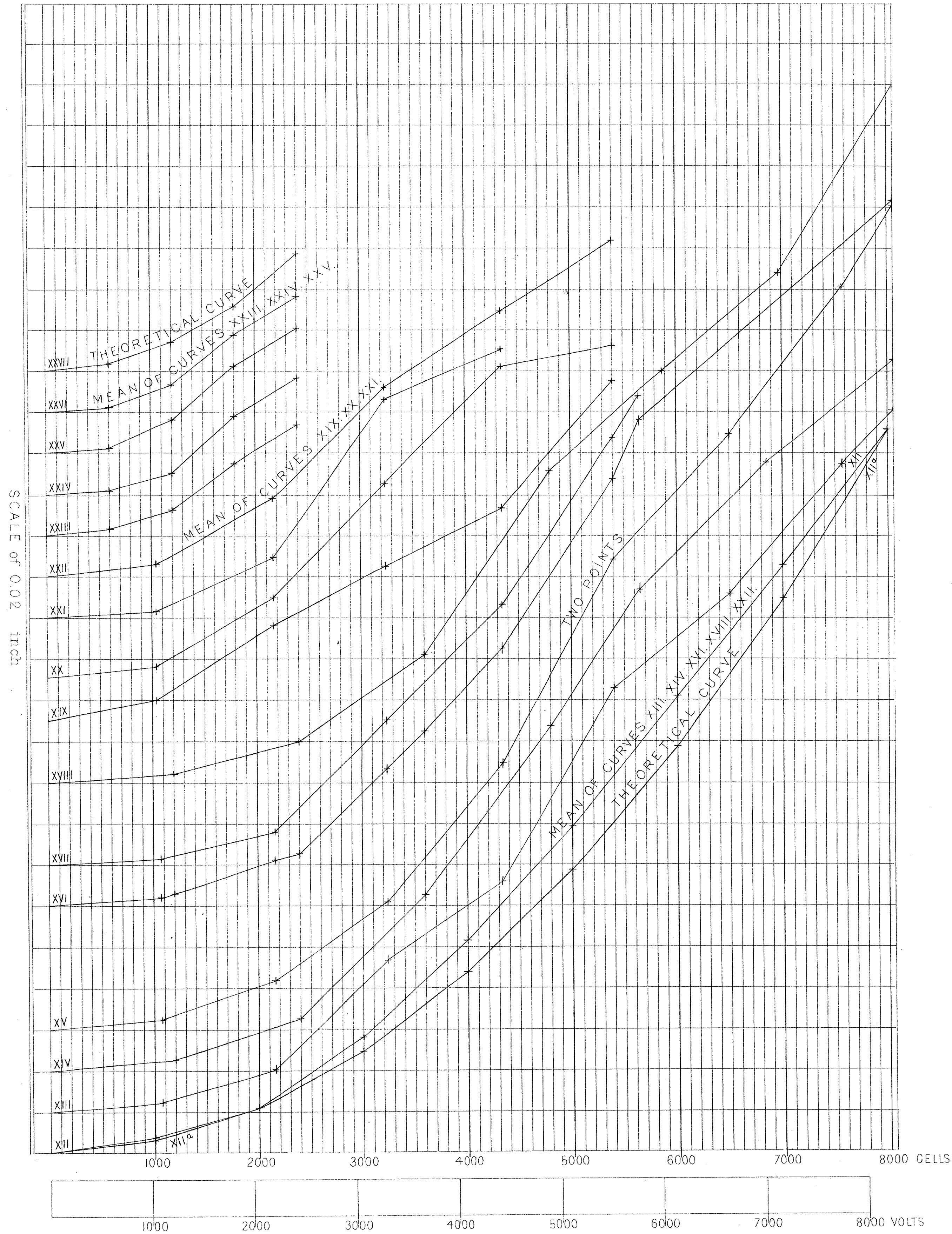


CURVES OF SPARK BETWEEN PLANE SURFACES & CONCENTRIC CYLINDERS.



Warren De La Rue. delt *D J Pound. Sculpt*

CURVES OF LENGTH OF SPARK BETWEEN A POINT AND A DISC.



Warren De La Rue, del.t *D. J. Pound. Sculp.t* 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* $\frac{0\cdot0001713\times63\cdot4}{10}=$

read $\frac{0\cdot0001713\times63\cdot24}{10}=$