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XLVI. The disruptive discharge of electricity

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XLVI. *The Disruptive Discharge of Electricity.*
By A. MACFARLANE, M.A., D.Sc., F.R.S.E.*

[Plate XI.]

AT intervals during the last five years I have carried on a research on the disruptive discharge of electricity; and the results obtained have been printed in the Transactions of the Royal Society of Edinburgh*. I propose in this paper to give a summary of the results. The experiments were made principally in the Physical Laboratory of the University of Edinburgh, where I had the ever-ready advice of Professor Tait; and in making the observations I had the assistance of several gentlemen, particularly of Mr. R. J. Simpson, M.A., and Mr. P. M. Playfair, M.A.

The method adopted can be readily explained with the help of the woodcut (fig. 1), which represents the apparatus *in situ*. The electricity was furnished by means of the Holtz machine, which had one conductor (generally the negative) always earthed by means of a wire, and the other conductor connected with the rod passing through the neck of the air-pump receiver. The diameter of the receiver is 19 centimetres. The electrodes were in general circular disks; and the one was screwed on to the rod mentioned, the other to a short rod normal to the plate of the air-pump, and in conducting connexion with its metal

* Communicated by the Author.

† Vol. xxviii. p. 633, and vol. xxix. p. 561; Proceedings, x. p. 555.

Phil. Mag. S. 5. Vol. 10. No. 64. Dec. 1880.

Fig. 1.

parts and the earth. A wire covered with gutta percha connected the insulated parts with the spherical ball A, which was supported on a varnished glass stem surrounded at the base by pumice-stones soaked in sulphuric acid. The equal and similarly insulated ball B was connected with the insulated half-ring of the Thomson's reflecting electrometer. The long-range absolute electrometer represented at the corner of the table was obtained on loan from Sir William Thomson, to reduce the results to absolute measure.

Thus an essential feature of the method, due to Professor Tait, is the introduction of the two insulated balls A and B, by the separation of which to a greater or less distance the effect of a charge upon the electrometer could be reduced to any convenient amount. By this means we have been able to measure very high potentials. When the potential of A is raised by working the machine, the potential of B is raised simultaneously; and this goes on until a discharge takes place between the electrodes inside the receiver. We found that it was possible, by breaking the contact between the conductors of the Holtz machine before beginning to turn the wheel, and by turning slowly and uniformly, to cause the wire-image to move along the scale continuously, and to be at rest at the instant of the discharge. After the passage of the discharge the image fell back to a position very near to the one it started from; and the coincidence was improved by discharging the couple of Leyden jars, which were generally attached to the conductors of the Holtz machine, for the purpose of making the charging more gradual. We noted the latter position of the index, and took the difference as proportional to the difference of potentials of the electrodes at the instant of discharge; for we found, by putting a charge on the ball A, dividing the charge by means of an equal ball, and so on, that the differences referred to were proportional to the amount of charge on A. Any escape of electricity from the charged conductor was at once made evident by the behaviour of the wire-image; it was this escape which put a limit to our measurements of potential, and not the range of the electrometer arrangement. In general we took three readings for each entry, so that we might be able, by taking their mean, to eliminate any error due to small variations in the mode of passing of the spark. A notion of the amount of this error may be obtained by inspecting the readings given below (p. 398). The method admits of so much rapidity, that we have taken a series of observations involving forty discharges in the course of an hour.

Measurement of the Difference of Potential required to pass a Spark through Air at the Atmospheric Pressure between Parallel Metal Plates at different Distances.

This problem, as is well known, was investigated by Sir William Thomson* for distances between .0025 and .15 centimetre. I have been able to extend the investigation to a distance of 1 centim. The plates used as electrodes were two equal circular brass disks of 10 centims. diameter. Both were rounded at the edge; and the lower one had its face slightly convex. The distance between the plates was measured by applying a glass millimetre-scale to a mark on the upper part of the rod. The shortest distance for which readings were taken was .025 centim., and the greatest about 1 centim.; within that range the sparks were central and straight, while beyond it they passed in a curved line between the edges of the disks.

Five series of observations were taken, and were found to agree well with one another. One of them is plotted on diagram 1, Plate XI. The curve drawn through the points of observation closely resembles a hyperbola. I drew the asymptote which appeared to be indicated, found the equation of the corresponding hyperbola, and corrected that equation by a second application of the graphic method. Thus in one case the corrected equation is

$$V = (66.69 - 3.7142s) \sqrt{(s^2 + .2s)},$$

which gives

$$V^2 = 889.52s + 4348.5s^2 - 494.68s^3 + 3.7142s^4,$$

where V denotes the difference of potential, and s the length of the spark. For s less than 1 the third and fourth terms are small; they are probably due to the finite nature of the plates. By neglecting them we obtain a hyperbolic function for V which agrees with the curve of observation at the beginning, and is only slightly greater at the end. By this treatment of the five series of observations I obtain the following results:—

Series.	Function for V .	a .	b .
I.	$66.69\sqrt{s^2 + .2039s}$	.1020 centim.	6.800 C.G.S. units.
II.	$66.51\sqrt{s^2 + .2030s}$	.1015 "	6.752 "
III.	$67.34\sqrt{s^2 + .2035s}$	.1018 "	6.852 "
IV.	$65.95\sqrt{s^2 + .2046s}$	.1023 "	6.745 "
V.	$68.18\sqrt{s^2 + .2102s}$	.1051 "	7.163 "
Mean	$66.94\sqrt{s^2 + .205s}$	.1025 "	6.862 "

* Papers on Electrostatics and Magnetism, p. 247.

The curve given by the mean equation is drawn on Plate XI. diagram 1.

Here a and b are the semiaxes of the hyperbola represented by the equation. The value of a is independent of the absolute value of the entries; and as its different values agree well with one another, we have here doubtless an important physical constant. I have also found its manner of dependence on certain conditions.

When hydrogen was substituted for air, and sparks taken through it at the atmospheric pressure, I obtained a series of readings which yield a result similar to that for air, namely

$$V = 43.19 \sqrt{s^2 + .1369s},$$

giving $a = .0684$ centim. and $b = 2.954$ C.G.S. units. Thus a for hydrogen is less than a for air, the ratio being .66, which is very nearly the ratio of the $\frac{b}{a}$ of the two curves (.65).

When sparks were taken through air at the reduced pressure of 180 millims., the curve obtained was

$$V = 18.29 \sqrt{s^2 + .5253s},$$

giving $a = .2616$ centim. and $b = 4.785$ C.G.S. units. The value of a was always found to be greater the smaller the pressure. The distance at which the spark was first observed to pass between the edges was 1.65 centim., compared with 1 centim. for the ordinary pressure.

We found that it was possible to observe not only the maximum deflection just before discharge, but also the deflection corresponding to a continued discharge produced by turning the plates rapidly. The deflection was always less than that for the corresponding single discharge; and the zero was more displaced on the negative side of the original zero. The wire-image can be made to remain very steady, with only a slight oscillation. A discharge of this kind passed through air at the atmospheric pressure gave a curve

$$V = 45.58 \sqrt{s^2 + .2046s},$$

which is similar to that for the single discharge; for the value of a is the same, the only difference being in the diminished value of $\frac{b}{a}$. Part of this diminution may be due to the variation of the potential of the charged conductor; but I attribute a considerable portion to a facility produced by the passage of previous sparks.

Having found the function for the difference of potential V , we can deduce that for the electrostatic force R , and that for

the electric tension p' , which figures so prominently in Clerk-Maxwell's theory. For air at the atmospheric pressure we found

$$V = 66.94 \sqrt{\{s^2 + .205 s\}};$$

hence

$$R = 66.94 \sqrt{\left\{1 + \frac{.205}{s}\right\}},$$

and

$$p' = \frac{(66.94)^2}{8\pi} \left\{1 + \frac{.205}{s}\right\}.$$

On diagram 2 I have drawn the above curve for the electrostatic force, and also the curve deduced from Sir William Thomson's results. The electrostatic force is not constant, as the mathematical theory of electricity in equilibrium would lead us to expect; but it tends to become constant when the length of the spark is increased. The fact that the ratio of the $\frac{b}{a}$ of the hydrogen-curve is equal to the corresponding ratio for the air-curve, points to the gas as the cause of the anomaly. By substituting a liquid for the gaseous dielectric, I have been able to show that the anomaly depends on the characteristics of a gas as compared with those of a liquid; and I shall adduce some experiments which were designed to test whether one of these differential characteristics is, as Clerk-Maxwell* suggested, a condensation of the gas on the surface of the electrodes. The following table gives the numerical values:—

Length of spark, in centimetres, s .	Difference of potential in C.G.S. units.	Electrostatic force, $R = \frac{V}{s}$.	Electric tension, $p' = \frac{KR^2}{8\pi}$.
.025	5.08	203.1	1322
.05	7.56	151.2	910
.075	9.70	129.4	666
.1	11.69	116.9	544
.2	19.05	95.3	361
.3	26.06	86.9	300
.4	32.93	82.3	270
.5	39.75	79.5	251
.6	46.52	77.5	239
.7	53.28	76.1	230
.8	60.02	75.0	224
.9	66.76	74.2	219
1.0	73.48	73.5	215

* 'Electricity and Magnetism,' vol. i. p. 56.

Measurement of the Difference of Potential required to produce the same length of Spark at different pressures of a Gaseous Dielectric.

We took four series of readings for a .5-centimetre spark through air between the parallel disks above mentioned, varying the pressure from 20 millims. of mercury to the atmospheric. On diagram 3 I have plotted two of these: the upper curve was first obtained with the capacity of the conductor increased by the couple of Leyden jars; and the lower was obtained immediately afterwards with the jars off. Each of the series gave an experimental curve which coincided with a hyperbola, and more closely than in the case of the former set of curves with variable distance. The results are as follows (where p denotes the pressure, in millimetres of mercury):—

Series.	Function for V.	a .	b .
I.	$\cdot04798\sqrt{\{p^2 + 205\cdot6p\}}$	102·8 mm.	4·668 C.G.S. units.
II.	$\cdot04455\sqrt{\{p^2 + 200p\}}$	100·0 "	4·455 "
III.	$\cdot04634\sqrt{\{p^2 + 199p\}}$	99·5 "	4·611 "
IV.	$\cdot04685\sqrt{\{p^2 + 207p\}}$	103·5 "	4·851 "
Mean	$\cdot04579\sqrt{\{p^2 + 202\cdot9p\}}$	101·5 "	4·646 "

Here a is the semi- transverse and b the semi- conjugate axis of the hyperbola. The four values of a agree well with one another. To find out how it depended on certain conditions, I took several series of readings with change of a constant. With the length of spark increased to 1 centim. the equation is

$$V = \cdot08062\sqrt{\{p^2 + 219\cdot8p\}},$$

giving $a=109\cdot9$ millims. and $b=8\cdot86$ C.G.S. units. The increase in the value of a , though small, is so decided that we may infer that the greater the length of the spark the greater is the value of a .

With hydrogen substituted for air, the curve obtained was

$$V = \cdot024\sqrt{\{p^2 + 600p\}},$$

which gives $a=300$ millims. and $b=7\cdot2$ C.G.S. units. Thus, the length of the spark being .5 centim., the value of a for hydrogen is thrice that for air.

When taking the fourth of the above sets of observations, at the lower pressures we observed not only the reading for

the single discharge, but also that for the continued discharge. As in the case of variable distance, so here, the equation of the curve is similar to that for the single discharge, and is

$$V = \cdot 03503 \sqrt{\{p^2 + 205 \cdot 6p\}},$$

giving $a = 102 \cdot 8$ millims. and $b = 3 \cdot 602$ C.G.S. units. Here the ratio of the value of the $\frac{b}{a}$ for the continued discharge to that for the single discharge is $\cdot 75$; in the former comparison it is $\cdot 69$.

For a $\cdot 5$ -centim. spark through air we have

$$V = \cdot 04579 \sqrt{\{p^2 + 203p\}};$$

hence

$$R = \cdot 02289 \sqrt{\{p^2 + 203p\}},$$

and

$$p' = \cdot 00002085 \{p^2 + 203p\}.$$

The above equation evidently does not hold for pressures lower than that for the minimum electric strength; it is certainly true for the range between that point and the atmospheric pressure; for Messrs. De La Rue and Müller* have obtained the same result; and I find that Prof. Röntgen's† numbers give the difference of potential equal to a hyperbolic function plus a constant. The existence of this constant may be due to the fact that the discharge was taken between a point and a plate, and was convective in nature. The hyperbolic law is probably true up to a limit much greater than the atmospheric pressure.

By expanding the function for V , first in descending powers of p and secondly in ascending, we obtain

$$V = A \left\{ p + \frac{203}{2} - \frac{1}{8} \frac{(203)^2}{p} + \dots \right\}$$

and

$$V = A \sqrt{203} \left\{ p + \frac{1}{2} \frac{1}{203} p^{\frac{3}{2}} - \dots \right\}.$$

Hence when p is large compared with 203, we have

$$V = A \{p + 101\},$$

which agrees pretty well with Knochenhauer's‡ formula, namely

$$V = 1 \cdot 406 \{p + 61 \cdot 2\}.$$

When the third term is added, we obtain the formula which agrees best in form with that of Wiedemann and Rühlmann§.

* Phil. Trans. vol. clxxi. p. 78.

† Phil. Mag. Dec. 1878, p. 443.

‡ Mascart's *Electricité*, t. ii. p. 95.

§ Pogg. *Ann.* cxlv. p. 253.

When p is small compared with 203, we have

$$V = A\sqrt{203}\sqrt{p};$$

which agrees with what the conclusion of Masson* leads to when corrected by means of the law regulating the discharge between two balls (v. *infra*, p. 402).

Messrs. De La Rue and Müller† have investigated, in the case of hydrogen, the nature of the curve for pressures lower than that of minimum electric strength (.6 millim.). The difference of potential is inversely proportional to the cube root of the distance. Assuming that the discharge through their long tube (33 inches long and 2 inches diameter) and between a ring and a point electrodes is similar to that between our disks at .5 centim. apart, I obtain for the complement of the equation $V = .024\sqrt{\{p^2 + 600p\}}$ the following,

$$V = .67 \frac{1}{\sqrt[3]{p}},$$

as the equation which is true for pressures less than .6 millim. Let N denote the number of molecules in unit of volume; then when p is less than .6 millim., V is inversely proportional to $\sqrt[3]{N}$; when p is greater than .6 millim. but less than 600, V is directly proportional to $\sqrt{N}$; and when p is greater than 600 millims., V is directly proportional to N . Thus, on the one side of .6 millim. the greater the number of molecules the greater is the facility for the discharge; while on the other side the greater the number of molecules the greater is the resistance to the discharge. This appears to be a strong argument in favour of Mr. Crookes's contention for a fourth state of matter; and the pressure .6 millim. seems, in the case of hydrogen, to separate the two states. It is probable that the mode of discharge is different in the two regions.

Effect of Changing the Capacity of the Conductor.

The first two series of observations for varying pressure indicate that a change of the capacity of the charged conductor has little effect on the difference of potential required to produce the discharge between the disks. But to test this question further, I took readings for a .5-centim. spark through air at the atmospheric pressure, with the capacity of the charged conductor, 1st, increased by means of a large Leyden jar, 2nd, increased by means of the couple of small Leyden jars of the Holtz, and, 3rd, without being increased. I append

* *Ann. de Chim. et de Phys.* 3rd ser. t. xxx. p. 41.

† *Phil. Trans.* vol. clxxi. p. 65.

the record of observations in full ; both for the sake of the question considered, and also to give a sample of the observations made by the method.

	Deflection.	Zero.	Difference of potential.	Mean difference of potential.
Large jar	300	500	200	203
	295	496	201	
	290	490	200	
	293	486	193	
	296	505	209	
	297	"	208	
	296	"	209	
Couple of small jars.	298	505	207	207
	300	"	205	
	296	"	209	
	300	"	205	
	296	"	209	
Without any jar ...	315	510	195	209
	295	"	215	
	310	"	200	
	290	"	220	
	290	"	220	
	305	"	205	
	300	"	210	

If the last three readings for the large jar are, as is very probable, more correct than their predecessors, then the change of capacity has no effect upon the readings, provided the index of the electrometer is at rest at the moment of the discharge.

Effect of Heating the Electrodes upon the Passage of the Spark.

When both disks were heated before a fire before being screwed on, and sparks were taken immediately afterwards for varying distance, we obtained a series of readings which give a curve less bent at the beginning. It satisfies the parabolic equation

$$V = 87.04s - 19.56s^2.$$

The diminution of the differences of potential for the smaller sparks must have been due directly to the higher temperature of the disks, or else to an alteration of the state of their surfaces brought about by the heating. A similar result was obtained for hydrogen.

To investigate this effect more minutely, I constructed a modification of an arrangement suggested to me by Clerk Maxwell for the purpose, and which was similar to that adopted by Sir W. R. Grove*. Two pieces of stout platinum

* Roy. Inst. Proc. 1854.

wire pp (fig. 2) were insulated in a brass plate b by means of vulcanite plugs v , and placed so as to be in planes at right angles with one another and with the brass plate. The shortest distance between the wires was 4 millims. The figure represents the apparatus suspended by means of the upper wire from one conductor of the Holtz machine,

Fig. 2.

and the lower wire connected with the positive conductor. Only the wire which at the time was not bearing the weight could be heated without changing the distance of the wires. The wire operated on was made red-hot by bringing the terminals of a battery of four Bunsen's elements into contact with it at two points one inch apart; and the charging was made as soon as possible after the heating. Before heating, the spark required a difference of potential of 125; after heating, a mean difference of potential of 93. This was in the case of a single spark. When a continued spark was taken, a similar diminution of the deflection was observed. Here the effect could not be due to a rarefaction of the air between; it must have been due to something at the surface of the electrodes; and from the transient nature of the effect, I am inclined to ascribe it to the temperature of the surface directly.

Measurement of the Difference of Potential required to pass a Spark through Air at different Temperatures, the Pressure being constant.

To investigate this question, I constructed the apparatus in fig. 3. A glass cylinder c was fitted into two brass plates p by means of grooves. The brass disks d , which were those used in the previous experiments, were screwed on, the one to a brass rod rising from the lower plate, the other to a rod moving inside a tube fixed to the upper plate; and they were set at a distance of .9 centim. apart. The upper plate contains an orifice to allow the air to escape when the lower plate is heated, and a hole for the insertion of the thermometer. The lower plate was put to earth, and the

upper one charged by being pressed firmly against a projecting conductor of the Holtz machine. The heating was effected by means of a powerful Bunsen burner placed below the lower plate, and was carried on till the plate became red-hot. The thermometer indicated a range from 25° C. to 245° C.; and sparks were taken at each interval of 10° during both heating and cooling. The deflections are represented on Plate XI. diag. 4. The ordinates of the cooling-curve are less than the corresponding ordinates of the heating-curve—a result confirmed by two other series of observations. The falling off cannot have been entirely due to a leaking of the charge of the electrometer during the time occupied by the observations; for readings taken after the lapse of twenty-four hours showed that not more than one third of the difference could be so accounted for. The bulb of the thermometer being in the position indicated by the figure, gives the temperature of the air between the disks: hence it is probable that the effect was mainly due to the temperature or other state of the disks.

Fig. 3.

These curves also throw some light upon the question whether the difference of potential required to effect a discharge depends upon the temperature of the gas only if the change of temperature cause change of density. I have calculated the density of the air between the disks at the different temperatures, and plotted the difference of potential as ordinate to the density as abscissa. The curve obtained should coincide approximately with a portion of a hyperbola if the above question is to be answered in the affirmative. I find that it is convex towards the axis of abscissæ, and that it does not look like passing through the origin.

The Discharge through Liquid Dielectrics.

On proceeding to investigate the discharge through insulating liquids, we first took up oil of turpentine. The liquid was placed in a glass vessel of 7 inches diameter and 5 inches height. A screw passing through the bottom of the vessel served to fix the lower electrode, and also to connect it with the earth. The upper electrode was held immersed in the liquid by means of the rod of the receiver. We observed four

modes of discharge—by means of threads of solid particles, by motion of the liquid, by a disruptive discharge, and by motion of gas-bubbles. When a chain of particles was formed, the index of the electrometer indicated the passage of a current, which, when sufficiently great, broke the thread and turned into a spark-discharge. The liquid was more easily set in motion when its surface was not much above the upper plate. The bubbles of gas were formed by the passage of the spark. A disk, when used as the upper electrode, prevented them from escaping; and we observed that they were more strongly repelled when the disk was electrified positively than when negatively. At a diminished pressure they were observed to effect the discharge by carrying the electricity with them to the negative electrode. The bubble, when freely suspended, was not spherical, but had its axis in the direction of the line of force elongated. Similar phenomena were observed in paraffin oil, a liquid paraffin, and olive oil.

Measurement of the Difference of Potential required to pass a Spark through a Liquid Dielectric at the Atmospheric Pressure between Parallel Metal Plates at different Distances.

We have investigated this experimental problem in the cases of paraffin oil, oil of turpentine, and olive oil, for a length of spark ranging from .1 to .4 centim. and, in the case of the last, .5 centim. Two precautions were requisite in making the observations:—one, to filter the liquid before beginning, so as to get rid of all solid particles; and the other, to eliminate the gas-bubbles produced by one spark before observing for its successor. It was impossible to carry the series of readings further than the above limits, because at the next greater distance the electricity escaped from the conductor and caused the image to be driven off the scale before the discharge through the liquid took place. In each case the readings gave a straight line, passing not exactly through the origin, but having a small negative intercept on the axis of ordinates.

Liquid.	Function for V.
Paraffin oil	$306.4 s - 6.1$
Oil of turpentine	$332.4 s - 7.2$
Olive oil.....	$298 s - 10$

The observations for paraffin oil are plotted on diag. 5. Thus a liquid dielectric has the electrostatic force and the electric tension both sensibly constant.

Measurement of the Difference of Potential required to pass a Discharge through Air at the Atmospheric Pressure between two Balls, between a Ball and a Plate, and between a Point and a Plate.

In the first case the electrodes were two spherical balls, each 1.5 centim. in diameter; and they were attached in the same manner as the disks. The curve obtained (diag. 6) coincides at the beginning with a parabola, but is afterwards bent in towards the axis of abscissæ. It is quite similar to that obtained by Mascart under the same conditions*. When the distance was 8 centims., violet sparks began to precede the white spark, and the electrometer simultaneously began to indicate the occurrence of a small discharge before the complete discharge. This caused the reading to be somewhat more ambiguous. At 10 centims. the electricity began to escape from the insulated wire.

On the following day a series of readings for the second pair of electrodes was obtained, and without any change in the arrangement other than the substitution for the lower ball of a circular plate 16.2 centims. in diameter. The plate was uninsulated, and the upper ball charged positively. The curve is drawn on the same diagram with that for the two balls; it also coincides with a parabola at the beginning, but at the greater distances is still more bent towards the axis of abscissæ. Violet sparks (giving an incomplete discharge) began much sooner, at 3.5 centims. compared with 8 centims.

A series of readings for the third pair of electrodes was obtained on the third day. A conical brass point was substituted for the upper ball. With the increased capacity due to the couple of Leyden jars the readings were regular; without it they were irregular. Up to 5 millims. the discharge was effected by a spark; but for greater distances there was only a faint brush or glow at the point, accompanied by a partial discharge.

Comparison of the Positive and Negative Electric Discharge.

To complete the preceding investigation, it is necessary in the second and third cases to take readings for several distances, with the ball or the point charged first with the one and then with the other kind of electricity. This I have been able to do; but as it was in the United College, St. Andrews, the apparatus was somewhat different. Instead of the receiver arrangement, I had a Henley's discharger, using respectively for charged electrode the conical point of one of the rods and

* Mascart's *Electricité*, t. ii. § 479.

a spherical ball 0·5 inch in diameter fixed on the point. A circular plate, 7 inches in diameter and fixed on the other rod, formed the uninsulated electrode. The sign of the electricity was changed by merely charging the one or the other paper conductor of the machine. The electrometer had either half-ring capable of being insulated; and I was thereby enabled to take readings in both directions for each kind of spark, and so eliminate any difference due to a bias in the instrument.

With the point for charged electrode the following results were obtained :—

Distance between point and plate.	Difference of potential for positive discharge. (1)	Difference of potential for negative discharge. (2)	Difference of (1) from (2).
$\frac{1}{2}$ inch.	76·6	67·1	9·5
1 "	86·3	76·2	10·1
2 "	102·3	95·2	7·1

The behaviour of the index showed that the discharge was not single, but a rapid succession of small discharges; for it first attained a temporary maximum deflection, and then a steady deflection slightly less than the maximum. The latter, on account of its being capable of being observed with greater precision, was the one recorded. This agrees with Prof. Röntgen's* experience. It would have been better if a comparison had also been made at a distance where the discharge could take the form of a spark; but as it is, the observations show that in the region of the brush or convective discharge the curve for the point negative is similar to that for the point positive, and slightly lower. Is this difference due to the electrical state of the air in the neighbourhood of the point?

With the ball as charged electrode the following results were obtained :—

Length of spark.	Difference of potential for positive spark. (1)	Difference of potential for negative spark. (2)	Difference of (1) from (2).
$\frac{1}{4}$ inch.	118·8	129·7	— 10·9
$\frac{1}{2}$ "	179·6	201·7	— 22·1
$\frac{3}{4}$ "	219·2	227·3	— 8·1
1 "	234·6	234·3	·3

In the case of the first two distances the discharge took place in the form of a single loud white spark, the index gave only

* Phil. Mag. Dec. 1878, p. 141.

one reading, and fell back after the passage of the spark almost to its ultimate position. At the third distance, when the charge was negative, hissing sparks, giving only very small discharges (as indicated by the behaviour of the index), preceded the loud spark, which gave complete discharge; but when the charge was changed to positive, no hissing discharges were observed preceding the loud discharge. At the fourth distance hissing discharges preceded the loud discharge in both cases; but they were much more numerous in the case of the negative than of the positive charge.

The readings for the positive discharge and for the negative discharge, when plotted, indicate each a curve similar to that of diag. 6, but with these two differences—first, that in the region of the single spark the negative curve is higher than the positive, and, secondly, that it passes into the brushy state at a less distance and then becomes lower. The readings appear to indicate that the brushy sparks begin at the same difference of potential for the two. Thus the preeminence of the positive spark is due to the fact that it requires a less difference of potential.

This result agrees in one respect with, but differs in another from, that obtained by Wiedemann and Rühlmann* under somewhat similar circumstances. They used a ball 2·65 millims. in diameter, and instead of the plates a larger ball of 13·8 millims. in diameter, which was not insulated like the plate, but connected with the other conductor of the Holtz machine. The pressure was also different, the greatest at which the observations were taken being 55 millims. Their result agrees in this, that the curve for the small ball negative lies above that for the small ball positive for distances between 3 and 12 millims.; and differs in this, that their curve for the small ball positive is convex towards the axis of distances.

Measurement of the Dielectric Strengths of different Substances.

Prof. Chrystal† has pointed out the two modes in which the dielectric strength of a medium may be measured:—1st, by the value of the electrostatic force when the electricity is on the point of passing from one molecule to the next; and 2ndly, by the maximum value of that electric tension which, according to the theory of Faraday and Clerk Maxwell, exists in the dielectric when under induction. He uses the phrase dielectric strength to denote the latter; as it is convenient to have a name for the other physical quantity, it may be called specific resistance. In the following table I have embodied

* Pogg. Ann. cxlv. p. 372.

† Encyc. Brit. "Electricity," p. 60.

Dielectric.	Relative specific resistance, Comparison at 5 centim.	Square of specific resistance.	Dielectric strength, $p' = \frac{KV^2}{8\pi \times (.5)^2}$	Values given by other experimenters.				
				Faraday.	Wiedemann and Rühlmann.	De La Rue Müller.	Röntgen.	Masson.
Air.....	1.000	1.000	251.4	1.00	1.00	1.000		
Carbonic acid	.951	.905	227.4	.92	.80	1.065	3287	
Oxygen	.930	.865	217.5	.73	.77	1.000	2402	
Hydrogen	.634	.402	101.1	.53	.65	.547	1296	
Coal-gas	.985	.874	219.8	.71				
Nitrogen .....	.....	.....	.....	.88	1.09	7.46		
Olefant gas .....	.....	.....	.....	1.08				
Muriatic-acid gas.....	.....	.....	.....	1.59				
Carbonic oxide.....	.....	.....	.....	.....	.....	.....	2634	
Marsh-gas.....	.....	.....	.....	.....	.....	.....	2777	
Nitrous oxide .....	.....	.....	.....	.....	.....	.....	3188	
Paraffin oil	3.7	13.7	3442 × K	.....	.....	.....	.....	16.0
Oil of turpentine	4.0	16.0	8851	.....	.....	.....	.....	
Paraffin (liquid)	2.4	5.76	2896	.....	.....	.....	.....	
" (solid).....	5.0	25.0	12575	.....	.....	.....	.....	
Olive oil	3.5	12.3	3080 × K	.....	.....	.....	.....	
Ether.....	.....	.....	.....	.....	.....	.....	.....	7.8
Spirit of wine of commerce .....	.....	.....	.....	.....	.....	.....	.....	8.0
Water .....	.....	.....	.....	.....	.....	.....	.....	11.6
Absolute alcohol .....	.....	.....	.....	.....	.....	.....	.....	12.0

the results of my own measurement, and have also entered values given or deduced from data given by other experimenters.

Column 2 gives the relative difference of potential (or of electrostatic force) required, compared with that for air, to pass a .5-centim. spark between the parallel disks, the substance being at the atmospheric pressure. It is necessary to make the comparison at a standard distance and pressure; for, as has been shown, the curves for the different dielectrics, when the distance or pressure is varied, are not similar to one another. The gases were compared directly for the length of spark mentioned; and the ratio was taken from the mean of eight or so readings. As the liquids could not be compared directly for so long a spark, the comparison was made at .4 centim. and the readings reduced to .5 centim. by means of the appropriate laws. The paraffin examined is of low melting-point. We liquefied it and poured it into the vessel containing the disks, took several .3-centim. sparks through it in the liquid condition, and, after allowing it to solidify for twenty-four hours, took one spark through it to determine its specific resistance in the solid state. The latter is double the former.

The numbers in column 3 are the squares of those in column 2; they are proportional to the dielectric strengths, provided K , the specific inductive capacity, is constant. In calculating the values of the dielectric strength for oil of turpentine and paraffin, I have taken $K=2.2$ and 2 respectively, from the table in Gordon's 'Electricity' *.

I have calculated the values entered under Faraday from his equivalent mean intervals†, taking those for the positive discharge. It will be observed that the numbers are uniformly less than those of column 2, and that they agree better with those of column 3. This is because the electrodes used were two balls, in which case the difference of potential is proportional to the square root of the distance.

Those entered under Wiedemann and Rühlmann I have calculated from the formulæ‡ which they give for the discharge through different gases at different pressures when the electrodes are two equal balls, the negative one being un-insulated. The comparison is made at 80 millims. pressure. The order is the same as in column 3 and column 5. Those entered under De La Rue and Müller§ and Röntgen|| are the values given by these physicists. It will be observed that

* Vol. ii. p. 134. † 'Experimental Researches,' vol. i. § 1388.

‡ Pogg. *Ann.* cxlv. p. 364.

§ Phil. Trans. vol. clxix. p. 95.

|| Phil. Mag. Dec. 1878, p. 446.

they place carbonic acid differently. This may be due to the difference in the nature of the discharge employed, which may have decomposed the substance in the one case and not in the other.

Masson's* values were obtained by means of the method of Faraday. It is interesting to note that the value he gives for oil of turpentine is, as it ought to be, equal to the square of the specific resistance which I have given.

XLVII. *On the Thermic and Optical Behaviour of Gases under the Influence of the Electric Discharge.* By E. WIEDEMANN.

[Concluded from p. 380.]

5. *Connexion between Spectral Phenomena, Elevation of Temperature, and Quantity of Electricity.*

I HAVE attempted to solve the problem of the connexion between the quantity of electricity passing through a gas of given pressure, the quantity of energy produced, and the corresponding changes in the spectral phenomena only in one particular case, which, however, seemed to me to be of especial interest. I have determined *what amount of energy is necessary to change the band spectrum of hydrogen into the line spectrum.*

The observations were made in the following way:—A calorimeter was passed over the horizontal capillary tube of a discharge-tube, and the spectrum was observed, as near as possible to the place where it fitted on the tube, by means of a spectroscope with a horizontal slit. The band spectrum was then changed into the line spectrum by interposing air-sparks. If the spark-length is gradually increased, beginning with none, the band spectrum is at first very bright; but soon the three hydrogen-lines make their appearance beside it, then the ground becomes fainter and the hydrogen-lines brighter, until at last the band spectrum disappears almost suddenly. The change is so sudden that it may often be recognized by the eye without the spectroscope. This order of phenomena has already been observed by Wüllner and others. When the spark-length necessary had been determined, the rise in temperature of the calorimeter t and the number of discharges were determined. From this the rise of temperature for one discharge at the given pressure was calculated, and then, by dividing by the pressure, what the rise of temperature would have been if the pressure had been only 1 millim.

If a denote the rise in temperature of the calorimeter in a minute caused by a current of deflection 100, W the water-equivalent, z the number of discharges in a second with the

* *Ann. de Chim. et de Phys.* 3rd ser. t. xxx. p. 25.