



XLVI. On dielectrics

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salt in different solvents. Some numbers have already been given in the July number of 'Science Progress,' but for the sake of convenience they are reproduced here. The values of the specific inductive capacities of water and ethyl alcohol have been determined by several observers; but apparently the only number for methyl alcohol is one given by Teneschin, so his values for all three liquids are taken, viz. water 83·7, methyl alcohol 32·65, ethyl alcohol 25·8. Correcting these numbers for the viscosities (100; 63; 120) we get the following values, which should, if our assumptions are correct, be proportional to the molecular conductivities of a salt in the three solvents :—

Water = 100; Methyl Alcohol 63; Ethyl Alcohol 26.

Since these are measured for the pure solvent, they should give the relative molecular conductivity of an infinitely dilute solution. An investigation on the conductivities of very dilute solutions of calcium chloride in ethyl and methyl alcohols is now being made by Mr. Fitzpatrick and the present writer. There are not for these cases such definite limiting values as for water solutions, but the following relative numbers (that of the infinitely dilute aqueous solution being taken as 100) correspond to the greatest dilutions reached :—

Water 100; Methyl Alcohol 70; Ethyl Alcohol 23.

The approximation of these numbers to those given above suggest that the specific inductive capacity and the viscosity are at all events the chief factors in determining the "relative ionization power" of a solvent.

Trinity College, Cambridge,
August 15, 1894.

XLVI. *On Dielectrics*. By ROLLO APPELEYARD *.

MOST dielectrics, when submitted to the ordinary "insulation" test, show an apparent increase of resistance under the action of the testing-current. That is to say : from the moment the current has been applied, the galvanometer-spot, having reached its maximum position, falls gradually towards zero with time. The rate of this diminution, at any instant, is a measure of the so-called "electrification" of the dielectric at that instant. For commercial purposes the "electrification" is usually computed between the first and second minutes from the moment of charge ; the value thus determined is an excellent confirmatory guide

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to quality, if the general history of the material and the peculiarities of manufacture are understood. But, apart from its merely commercial bearing, "electrification" presents a wide field for scientific research. The use of the term "electrification" for this rate of change of the apparent resistance of a dielectric with the time of application of the charging current, may be called into question by those who prefer the words "polarization," or "absorption;" but, in the present stage of our knowledge of the action which determines this change, it has been thought better to adopt a term which is never mistaken in practice than to use an ambiguous expression, founded upon an equally uncertain hypothesis. "Electrification" seems to be the net result of many simultaneous actions, some of which are very obscure; the physical mechanism implied in the process is subtle and mysterious, the experimental observations are difficult to reconcile among themselves, and there is no theory to adequately account for the phenomena. It is not proposed, here, to make any attempt at solving the difficulties, but rather to present them in the form of experimental results.

Celluloid.

The first substance to be dealt with, in this regard, is "celluloid." As far as can be judged by inspection it appears to be a compound of guncotton and camphor, with a trace of lime—possibly in the form of sulphate. When seen through the microscope, small white spots become visible in a translucent yellowish substance. In texture "celluloid" resembles "cordite," but it is of lighter colour, inflammable but not explosive. The insulation of this substance was, at first, measured in the following way:—A thin circular sheet of celluloid was placed between two plane surfaces of brass 11 inches in diameter. A margin of celluloid was allowed, to prevent leakage over the edges; and a heavy weight was put upon the top plate. When this sheet was submitted to the action of a current, there was no such apparent increase of resistance as is usually to be observed with dielectrics. The galvanometer, in fact, indicated the reverse effect—the deflexion gradually increasing with time. No actual fault could be detected in any of the samples, and yet the "electrification" was negative. This curious effect was the more to be noticed as the voltage of the testing-battery was increased. The actual insulation resistance, calculated for the same sample, with this apparatus, under various currents, showed that the resistance changed enormously with the testing voltage.

In this case, and in all experiments here mentioned, the

insulation has been computed from the deflexions obtained after the corresponding voltage had been applied for one minute. The upper readings correspond with increasing voltages; the lower curve completes the cycle with diminishing voltages, and shows the falling-off of insulation with current, in a manner curiously like the hysteresis curve of iron. The observed values are given in Table I.

TABLE I.—Celluloid Sheet.

		volts 150	volts 300	volts 600	volts 750	volts 600	volts 300	volts 150
Galvanometer Readings.	1 ^m ...	19.8	85.8	533	1310	605	152	45
	2 ^m ...	20	89.3	554	1338	663	158	45
Corresponding Resistance in megohms. } =		4040	1840	597	303	526	1039	1778

This table includes the actual galvanometer-deflexions from which the insulation-resistance at each voltage was calculated. First and second minute readings are recorded, and exhibit very strikingly the apparently *negative* "electrification,"—the first-minute readings being less than the second-minute readings.

A series of tests was made upon celluloid sheets pressed, in the above manner, between two plane surfaces of metal, and the same general features were observed in each case. As no definite fault could be discovered in any sample, I was led to suppose that the abnormal change in resistance, and the corresponding negative "electrification," were to be accounted for by some complex molecular rearrangement within the substance of the celluloid itself. Leakage over the edges might obviously be urged in explanation, but the conditions did not seem to allow of any serious loss in this manner. While employing unyielding metallic surfaces against the comparatively hard surface of the celluloid, the chances of uneven pressure upon the sheet were very great: which would imply uneven electrical contact between the dielectric and the plates.

The next experiments were made with a view to test the celluloid in perfect contact with the opposed plates; to remove all chances of leakage-error; and to provide, at the same time, a more evenly distributed pressure over the surface. The hard metallic plates were therefore replaced by mercury surfaces

which conformed precisely, and without undue pressure, to the sheet of dielectric; and, at the same time, made perfect contact with it, leaving no air-spaces or spark-gaps where ozone or other gases might collect.

Circular sheets of celluloid, $11\frac{1}{2}$ inches in diameter, were employed for these tests. To prevent leakage, a 3-inch margin was allowed all round, so that the working-surface in contact with mercury was $5\frac{1}{2}$ inches in diameter. The method of fixing the dielectric sheet was as follows:—Two flat ebonite rings, $5\frac{1}{2}$ inches internal diameter, and $6\frac{1}{2}$ inches outside, were faced on each side with india-rubber, forming insulating washers. These rings were placed exactly opposite each other, flatwise, one on each side of the sheet to be tested. Circular plates of iron were now laid against the outer faces of the rings, and combined to make two mercury-tight hollow boxes, one on each side of the dielectric. The whole was then gripped vertically in an ebonite vice; after which mercury was poured in to fill the boxes. This apparatus, with the exception of the insulating rings, is the same as that designed, I believe, by Mr. Evers. The great advantage of the method is that the mercury conforms to the surface of the dielectric, leaving no air-spaces and necessitating no artificial pressure. The surface-leakage can be made as small as desired, by the simple device of leaving enough margin. Experiments made upon dielectrics fixed in this apparatus give results entirely different from those obtained with rigid metallic plates.

A sheet of celluloid $\cdot 071$ inch in thickness was the first that came under trial. Its behaviour during a cycle of voltage from 150 to 1200 volts is represented in Table II.

TABLE II.

Volts <i>increasing</i> .		Volts <i>diminishing</i> .	
Volts.	Resistance in megohms.	Volts.	Resistance in megohms.
150	82·7	1050	80·7
300	82·3	900	81·0
450	82·0	750	81·3
600	81·5	600	81·5
750	81·2	450	82·0
900	80·8	300	82·3
1050	80·6	150	82·7
1200	80·6		

The curves practically overlap. The insulation falls somewhat with the increase of voltage, but recovers its original value as the cycle is completed. There was no observable "electrification"; the first and second minute readings were in each case identical.

The next sheet of celluloid tested was 6 mils in thickness. Here again there was no sign of "electrification," though there was a distinct diminution of insulation with voltage. This sheet broke down at 1200 volts; there is nothing in the curve to indicate that such a rupture was about to take place. These results are given in Table III.

TABLE III.

Volts <i>increasing</i> .	Resistance in megohms.
150	30.0
300	29.6
450	29.2
600	28.4
750	27.7
900	26.8
1050	26.0
1200	Broke down.

A third sheet, cut from the same specimen as the last, was then tested through a cycle from 150 to 1050 volts; it showed practically no hysteresis and no "electrification," the return values being simply reproductions of the rising ones. There is the same drop in insulation with voltage as in the previous tests, as shown by Table IV.

TABLE IV.

Volts <i>increasing</i> .		Volts <i>diminishing</i> .	
Volts.	Resistance in megohms.	Volts.	Resistance in megohms.
150	26.34	900	22.72
300	25.56	750	23.48
450	24.93	600	24.15
600	24.15	450	24.93
750	23.51	300	25.68
900	22.72	150	26.52
1050	21.89		

The same sheet was then tested between hard metallic plates, the results are indicated in Table IV. A.

TABLE IV. A.

	volts 150	volts 300	volts 450	volts 600	volts 750	volts 900	volts 1050	volts 900	volts 750	volts 600	volts 450	volts 300	volts 150
1 ^m	6	23.5	61.5	161	278	156	158	186	127	117.0	95.0	39.5	11.5
2 ^m	.....	23.7	64.0	171	296	162	162	189	129	118.5	96.5	39.5	.....
	megohms 20,550	10440	6047	3076	870	283	135	199	549	1641	3915	6212	10720

“Dielectric Hysteresis.”

“Dielectric hysteresis” is here alluded to in a sense which needs a little explanation. The similarity in shape and character between some of these curves and the well-known forms of the hysteresis curves of magnetism is all that I wish to imply,—it is *not* the phenomenon of “dielectric hysteresis” proper. In an article in the *Electrotechnische Zeitschrift*, 29th April, 1892, p. 227, Steinmetz traces the analogy between a dielectric medium in an electrostatic field and magnetic bodies in a magnetic field, with a view to determining whether the loss of energy in dielectrics, under the influence of an alternating electrostatic field, would follow a law similar to that which defines the magnetic losses due to magnetic hysteresis. The experiments of Steinmetz, and of Arno, have gone to show that the energy expended in a dielectric medium, in an electrostatic field of alternating potential, is sensibly proportional to the square-root of the intensity of the electrostatic field. These losses are due to “dielectric hysteresis” proper, and are quite distinct from the mere change of resistance with voltage here described. The experimental results of Steinmetz should, however, be corrected for this other phenomenon of change, which, for the time being, we may call “dielectric mutability,” or any other term which denotes the variation of resistance with voltage; for it is clear that the energy expended during a cycle of potential cannot rightly be calculated upon the basis of constant resistance assumed by Steinmetz. With this correction, if it could be determined and applied to his results, the observed values, notwithstanding their present close agreement with those calculated, may possibly be brought even nearer to conformity.

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"Residual Charge."

The residual charge becomes a very small quantity a few minutes after breaking circuit; consecutive voltages can therefore be applied without having to wait very long for the practical disappearance of the last charge. In the above tests it was made a rule never to send a current into a sheet until the previous charge had vanished to within $\frac{1}{2}$ per cent. Although, under these conditions, the charge is quickly got rid of, yet during the first few seconds the amount left in may be very considerable. Conversely, the celluloid takes up its charge comparatively tardily. If, for instance, an attempt is made to determine the capacity of the sheet, when in the mercury apparatus, by the simple discharge method, an eye which is accustomed to watching the "throw" of the galvanometer will at once observe that the needle is under the action of an extended discharge and not of a sudden impulse. When first this phenomenon was observed I carried out the following experiment:—The celluloid was charged from 20 cells for 15 seconds. It was then discharged, not through the galvanometer, but through the short-circuit key. After two seconds the short-circuit key was opened, and there was a discharge of a few degrees to the right—that is, in the "discharge" direction; this fell in a few seconds across the zero to 5 divs. on the left, where it remained perfectly steady. This curious reversal of sign was at first rather puzzling; if the spot had merely fallen to zero, it would have been easy to refer it to complete loss of charge; if it had fallen a little to the right of zero, it could have been attributed to incomplete loss of charge; but falling, as it did, on the negative side of zero, a novel case was presented.

After several repetitions, charging with various potentials up to as high as 900 volts, this reversal still manifested itself, although the time required to attain it was of course greater as the testing-voltage increased. Days and nights of short-circuiting would not wipe it out; whatever was tried, it remained always the same negative deflexion. It is, in fact, an initial permanent E.M.F. of about '0006 of a volt with which nothing seems to interfere. It is apparently due to the contact of the mercury with the celluloid; it did not appear when metallic plates were used. This point having been so far settled, the experiments on slow discharge were repeated with 100, 200, 400, and 600 cells; the corresponding discharge-readings—after short-circuiting the sheet for two seconds in each case before discharge—were respectively 18, 36, 57, and 80 divs., falling to zero, or very nearly to zero in a few minutes, and ultimately crossing the zero to -5. The discharge from a standard microfarad charged to 30 volts is

11,103 scale-divs. The instantaneous discharge from the celluloid sheet ($5\frac{1}{2}$ in. diam., .00615 inch thick) with the same voltage, was 115 divs., which is the mean of the two readings obtained by reversing the battery. The test can scarcely be regarded as a capacity test under the above conditions. It is recorded here simply to show the phenomenon of slow discharge, and the existence of the permanent initial E.M.F.

Gutta-Percha.

Appended are the results of some tests upon a sheet of pure gutta-percha, in the mercury apparatus, at high voltages. The thickness of this sheet was about 2 mils; the diameter of the circular mercury surface in contact with it, bounded by the insulating rings, was, as before, $5\frac{1}{2}$ inches. Curves drawn from the tabulated results exhibit the phenomenon of dielectric hysteresis, and show that the effect of the current, up to a certain point, is to increase the resistance; there is a subsequent tendency in the opposite direction, which would probably end in the breaking-down of the sample. There was no initial electromotive force to be observed with the gutta-percha.

Four separate tests were made upon the sheet, two with a cycle commencing at maximum volts, and two commencing at the minimum. In each case, whether beginning at the maximum or minimum volts, there was a decided increase of resistance as the result of a cycle. With such a thin sheet as 2 mils the test was a very severe one for the gutta-percha; hence it is not surprising that the curves are somewhat broken. Two-thousandths of an inch of material is here effectively contending against 1200 volts, and setting up a barrier of 3000 million ohms over an area of $5\frac{1}{2}$ inches.

A very interesting point about these four tests is that when the cycle commences at maximum voltage the subsequent readings are far steadier, and the curve of resistance and voltage smoother, than when minimum volts are started with; this is clearly indicated by a comparison of the four curves which may be drawn from these tables.

There is no absolute need to short-circuit the apparatus in order to remove the residual charge of the sheet; but short-circuiting probably quickens the process. This is a matter for further experiment. It was found that the sample of gutta-percha completely lost its charge after twenty-four hours, whether short-circuited or not, and during that time it regained its normal condition as regards insulation resistance. Twenty-four hours was therefore allowed between each of the four tests upon the gutta-percha sheet. As a rule, about ten minutes' rest was given between the consecutive voltages of individual tests; this was found to be time enough to practically discharge the sheet when short-circuited.

TABLE V.—Gutta-Percha sheet (G_2).
(Volts *increasing*.)

	volts 150	volts 300	volts 450	volts 600	volts 750	volts 900	volts 1050	volts 1200
1 ^m ...	26.2	49.8	68.4	82	unsteady 130	unsteady 150	unsteady 160	steadier 171
2 ^m ...	25.6	47.6	65.0	unsteady 98	117	135	160	159
	2272 [~]	2384 [~]	2614 [~]	2910 [~]	2290 [~]	2383 [~]	2602 [~]	2789 [~]
	volts 1050	volts 900	volts 750	volts 600	volts 450	volts 300	volts 150	volts 1200
1 ^m ...	steady 126	100	73	53.5	38.5	24.5	12.0	170
2 ^m ...	126	100	75	49.0	31.0	18.0	9.2	148
	3303 [~]	3572 [~]	4079 [~]	4459 [~]	4645 [~]	4845 [~]	4961 [~]	2805 [~]

Temp. = 66° F

TABLE VI.—Gutta-Percha sheet (G_2).
(Volts *diminishing*.)

	volts 1200	volts 1050	volts 900	volts 750	volts 600	volts 450	volts 300	volts 150
1 ^m ...	steady 171.2	137.6	112.5	91.8	71.8	54.2	39	20.0
2 ^m ...	166.0	135.0	111.5	89.5	68.0	49.0	34	17.7
	3220 [~]	3510 [~]	3670 [~]	3760 [~]	3840 [~]	3320 [~]	3530 [~]	3470 [~]

	volts 300	volts 450	volts 600	volts 750	volts 900	volts 1050	volts 1200
1 ^m ...	38.5	53.5	69.5	84	100	118.5	steady 145
2 ^m ...	33.8	48.0	64.5	81	98	a little unsteady 119.0	143
	3570 [~]	3870 [~]	3970 [~]	4130 [~]	4130 [~]	4070 [~]	3900 [~]

23rd April, 1894.

Temp. = 64°·5 F.

TABLE VII.—Gutta-Percha sheet (G_2).
(Volts *increasing*.)

	volts 150	volts 300	volts 450	volts 600	volts 750	volts 900	volts 1050
1 ^m ...	22.0	unsteady 74	unsteady 85	steady 84.5	steady 100.0	unsteady 118.2	unsteady 143
2 ^m ...	21.6	54	71	80.5	94.5	118.0	139
	2960~	1730~	2280~	3050~	3230~	3260~	3140~

	volts 1200	volts 1050	volts 900	volts 750	volts 600	volts 450	volts 300	volts 150
1 ^m ...	unsteady 167	154	125	96.5	70.5	52.5	34.0	16.6
2 ^m ...	193	152	123	96.0	67.0	44.2	27.5	14.6
	3070~	2920~	3080~	3350~	3660~	3690~	3760~	3920~

24th April, 1894.

Temp. = 63° F.

TABLE VIII.—Gutta-Percha sheet (G_2).
(Volts *diminishing*.)

	volts 1200	volts 1050	volts 900	volts 750	volts 600	volts 450	volts 300	volts 150
1 ^m ...	231	143	99	68	50.0	37.6	25.8	13.0
2 ^m ...	187	131	94	65	48.7	35.6	24.0	12.3
	1620~	2290~	2330~	3430~	3720~	3700~	3570~	3550~

	volts 300	volts 450	volts 600	volts 750	volts 900	volts 1050	volts 1200
1 ^m ...	25.6	37.4	47.0	58	73	91	109
2 ^m ...	23.8	34.6	44.5	58	75	92	117
	3600~	3720~	3970~	4020~	3780~	3600~	3430~

25th April, 1894.

Temp. = 62° F.

The small opaque white spots, observed within the celluloid under the microscope, led to some further experiments to investigate the effect of isolated foreign particles within the substance and upon the surface of dielectrics. Coarse brass filings were scattered as thickly as possible over one face of a warmed strip of gutta-percha, 16 inches long, 2 inches wide, and $\frac{1}{4}$ inch thick. The insulation of such a strip is not exactly what might be expected; when tested even with 750 volts its resistance was practically infinite, and was certainly greater than 600,000 megohms. A charged gold-leaf electroscope could not be discharged with such a strip in this condition. If, however, a wet cloth was passed once over the non-metallic face of the strip, or if it was simply breathed upon, the insulation fell to 5000 megohms, and the strip now easily discharged the electroscope. A round rod of gutta-percha can be warmed and rolled in a heap of brass filings so as to appear almost like a brass rod, and such a rod does not discharge the electroscope. This would be an instructive experiment for schools and instrument-makers.

"Sensitive" Dielectrics.

The next experiments were made with rods formed of a mixture of gutta-percha and brass filings melted together in various proportions. The length of these rods was about 20 inches, and their diameter $\frac{3}{4}$ of an inch. Contact was made with the ends for about $1\frac{1}{2}$ inches by tin-foil which was bound round with wire. It is found that, for small proportions of brass filings, the resistance between the ends of these rods is exceedingly high, and this high resistance is maintained until about 2 parts, by weight, of brass are mixed with one part, by weight, of gutta-percha. Here a "critical" point of proportionality between the two substances occurs, *under* which the rods have a very low resistance, of something like one ohm; and *above* which the resistance is exceedingly high, and can only be measured in megohms. Several rods were made at or near this "critical" point, and in no case could a medium resistance of, say, a few hundred ohms be attained. All the rods were either of very high or very low resistance.

The method of making them is to warm a sheet of gutta-percha upon a hot plate, using French chalk to prevent sticking. The filings are sprinkled in as soon as the sheet becomes soft. The whole is then made up into a pudding, which is again flattened out into a sheet; this is repeated until a good mixture is arrived at. The compound is then rolled into rods.

TABLE IX.

No. of Rod.	Proportion by weight $\frac{\text{G.P.}}{\text{Brass}}$	Approximate Resistance.
1	$\frac{1}{2}$	·2 ohm.
2	?	·07 „
3	$\frac{1}{3}$	·11 „
4	$\frac{1}{4}$	∞ .
5	$\frac{2}{1}$	∞ .
6	$\frac{2}{3}$	283,000 megohms.
7	$\frac{4}{7}$	173,000 „
8	$\frac{1}{2}$	∞ .
9	$\frac{1}{2}$	770 megohms.
10	$\frac{1}{3}$	·37 ohm.
11	$\frac{2}{5}$	1·68 „
12	$\frac{1}{2}$	19 ohms.
13	$\frac{4}{9}$	3·9 „
14	$\frac{4}{11}$	·48 ohm.
15 .....	....	1·5 megohm.

Table IX. gives the proportion by weight of these rods and the corresponding resistance. When rods made up in this way are submitted to the action of oscillating discharges, they behave in a similar manner to the "impulsion" cells of Prof. Minchin and the tubes of M. Branly. If, for instance, one of the low-resistance rods of, say, four parts by weight of gutta-percha to nine of brass filings is connected to one arm of a Wheatstone's bridge and balanced, an oscillatory discharge made anywhere near it will, in nearly all cases, produce a considerable diminution of resistance—in some cases amounting to more than 10 per cent., and, in one experiment, to as much as 45 per cent. This charge remains until restored to the former condition of things by a slight mechanical tap. I have repeated this experiment upon seven different rods, and have, in each case, obtained a diminution when the discharge-spark passed at the oscillator. The small-resistance

rods of Table IX. were all sensitive to these electromagnetic oscillations. The high-resistance rods do not come within the range of measurement of the usual form of Wheatstone's bridge; the ordinary insulation-test was therefore applied, using a battery of 400 Leclanché cells. In this way resistances up to 600,000 megohms could be measured. A rod composed of 4 parts, by weight, of gutta-percha, to 7 parts of brass filings had practically infinite resistance. Another, having 2 parts, by weight, of gutta-percha to 3 of brass, had 100,000 megohms. A third, made up in the ratio of 4 parts gutta-percha to 7 of brass, was of infinite resistance. Four rods were made in the proportion 1 gutta-percha to 2 of brass, which is near the critical ratio of conductor to insulator; their resistances were, respectively, ∞ , 40 megohms, and 12 ohms. The .17 ohm rod exhibited a decided, but not very great diminution of resistance under the influence of the oscillator. Apparently, the high-resistance rods are unaffected by the discharges. The 40 megohm rod was not of very constant resistance, the spot moved up and down the scale; the spark had therefore to be passed at moments when the spot halted,—the result was not very satisfactory. At one time it was thought actually to *increase* the resistance of this rod. The 12 ohm rod was especially interesting from its extreme sensitiveness; in one condition it had a resistance of 19 ohms, the sudden passage of a spark at the oscillator reduced this by 45 per cent. The rod was generally unstable. The 40 megohm rod seemed the one most nearly corresponding, in its galvanometer-readings, with a faulty cable; the readings being erratic. Its resistance has, at times, been as high as 770 megohms. This rod is probably unstable in some opposite direction to the 12 ohm rod; they were both made in the same proportions and in the same manner. In Table IX. they appear as No. 9 and No. 12 respectively.

Alternating Voltages.

Tests were now made upon specimens submitted to alternating currents, and I have to thank Mr. George Bousfield for assisting me in this part of the experiments. I took the strip sprinkled with filings, and two rods; these were first tested for insulation in the ordinary way, with the following results :—

Dielectric.	Resistance.
Strip	= ∞ .
No. 6	= 283,000 megohms.
No. 9	= 47.2 megohms.

The strip began to break down under the action of the alternating current at 900 volts ; at 3000 volts it was emitting small local arcs, some crimson, others violet. After the application for some time of this high voltage the number and brilliancy of the arcs diminished,—the insulation had apparently improved. At 5500 volts there were bright discharges similar to the first. These were not of the nature of long sparks, but of small local arcs.

Rod No. 6 gave way at 6500 volts and exhibited the same apparent improvement in insulation. The arcs shot out in miniature flames, like very small blowpipe blasts ; locally, as in the case of the strip.

With rod No. 9 sparking commenced at 1500 volts, having the appearance of small beads of crimson and violet light burning themselves out at fixed points. When these specimens had become cool their insulation was again tested.

Dielectric.	Resistance.
Strip	$= \infty$.
No. 6	$= 70,750$ megohms.
No. 9	$= 2020$ megohms.

The strip thus appears to have recovered entirely. No. 6 has fallen to a quarter of its first value, and No. 9 has greatly improved, under this trying ordeal.

Rod No. 15 was compounded of iron filings, Sr, &c., with a view to obtaining a brilliant discharge. The salts brought the insulation down rather low ; there was a great deal of heat generated, and little else. Such a rod should probably be made simply of metallic powders intermixed with the dielectric.

XLVII. *On the Resistance of a Fluid to a Plane kept moving uniformly in a direction inclined to it at a small angle.* By Lord KELVIN*.

§ 1. **L**ET q be the velocity ; i its inclination to the plane ; and u , v its components in and perpendicular to the plane. We have

$$u = q \cos i, \quad v = q \sin i.$$

§ 2. Suppose now the moving body to be not an ideal infinitely thin plane, but a disk of finite thickness very small in comparison with its least diameter, and having its edges everywhere smoothly rounded. If the fluid is inviscid and incompressible, and the boundary containing it perfectly

* Communicated by the Author.