

THE
PHYSICAL REVIEW.

ON THE ELECTRIC STRENGTH OF SOLID, LIQUID,
AND GASEOUS DIELECTRICS.

BY ALEXANDER MACFARLANE AND G. W. PIERCE.

IN the course of a research on "The Disruptive Discharge of Electricity,"¹ Dr. Macfarlane obtained the result that the electrostatic gradient necessary to force a spark through a thin stratum of dielectric diminishes as the thickness increases, when air or other gas is the dielectric; but remains constant when turpentine or other insulating liquid is the dielectric. Mr. Steinmetz has recently obtained the same result,² and in addition has shown that a solid dielectric, such as paraffined paper, behaves in the same manner as a liquid dielectric. In order to obtain further independent data, Mr. Pierce has made a series of measurements for paraffined paper, beeswaxed paper, and kerosene oil. We had not the means of making absolute measurements, but this was immaterial, as our object was to compare these solid and liquid dielectrics with air in the most direct manner possible. To effect the comparison two discharging tables were used. On each table a pair of brass discs, about four inches in diameter, were supported parallel to one another, and the connecting-rods were attached to the poles of a

¹ Trans. Roy. Soc. Edinb., Vol. XXVIII., p. 633, and Vol. XXIX., p. 561. Proc. R. S. E., Vol. X., p. 555; Phil. Mag., Dec., 1880; Trans. Amer. Inst. El. Eng., March, 1893.

² Trans. Amer. Inst. El. Eng., Feb., 1893.

Toepler-Holtz machine, so as to form two alternative paths for the discharge. One of the tables was provided with a micrometer-millimeter scale, by which the distance between the plates could be read off accurately. It was used for the air gap. The sheet, or sheets, of paraffined or beeswaxed paper was placed between the other pairs of discs, and the discs pressed together. The air interval was at the beginning made too small, so that the spark should pass through it; for the passage of a number of sparks does not alter the air stratum, while a single spark through the solid damages it permanently. The air stratum was gradually increased in thickness until the spark preferred to pass through

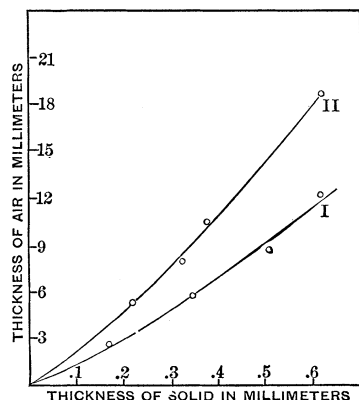


Diagram 1.

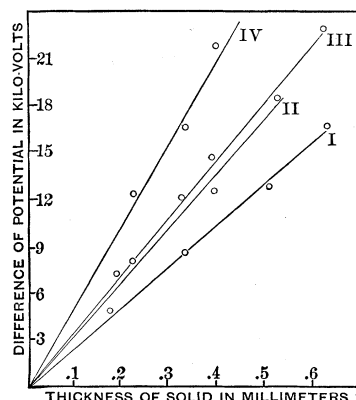


Diagram 2.

the solid. The thickness of the air interval was obtained by reading the micrometer; the equivalent thickness of the solid was ascertained by cutting out a small piece round the hole pierced by the discharge, and measuring the thickness by means of the spherometer. The sheets of paper used were prepared by taking sheets of linen typewriter paper, dipping them into the melted paraffin or beeswax, and drawing them out so as to make the saturation as uniform as possible. In the case of the kerosene oil, the plates were fixed horizontally in a glass vessel, the lower one supported on a conducting rod passing through the bottom of the vessel, the upper one suspended from a graduated rod which moved tight in the cover of the vessel. The oil was filtered before

use, and the bubbles of gas formed by a discharge removed before proceeding to another comparison.

Table I. appended gives the results for paraffined paper. The value given in the second column for the thickness of the paper, and that in the third column for the equivalent thickness of air, are the averages of all the determinations for the specified number of sheets. The fourth and fifth columns give the difference of potential in kilovolts required to pass a spark through the corresponding stratum of air, that of the fourth column being obtained from the papers of Dr. Macfarlane, while that in the fifth column is from the paper of Mr. Steinmetz.

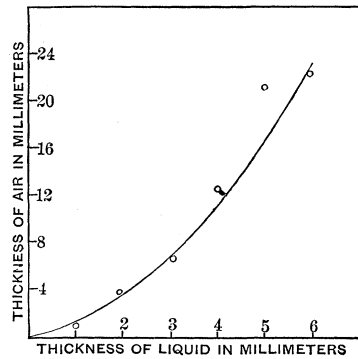


Diagram 3.

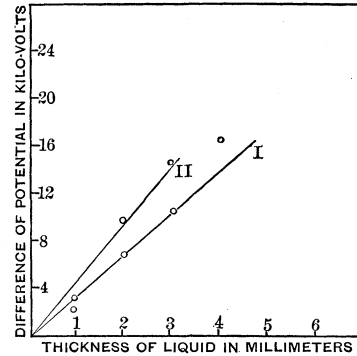


Diagram 4.

In Table II. the results for beeswaxed paper are tabulated in a similar manner.

Table III. gives the results for kerosene oil. The value entered for the equivalent stratum of air is the average of all the determinations made for the given stratum of oil.

The diagrams appended exhibit the results graphically. In Diagram 1, curve I. is for paraffined paper, and curve II. for beeswaxed paper; in Diagram 3 the curve is for kerosene oil.

The equivalent thickness of air is not proportional to the thickness of the solid or liquid, but increases more rapidly as the stratum increases. The curves are concave towards the axis of ordinates. Now the curve giving the differences of potential for different thicknesses of air is concave towards the axis of

abscissæ. Diagrams 2 and 4 are designed to test whether these opposite bendings neutralize one another. In Diagram 2, curve I. gives the difference of potential for paraffined paper, and curve III. for beeswaxed paper, using Steinmetz's values of the air equivalent; while curves II. and IV. give the same, using Macfarlane's values of the air-equivalent. In Diagram 4, curve I. is for Steinmetz's values, and curve II. for Macfarlane's values. All these curves are very approximately straight lines passing through the origin.

From these and the other results mentioned above we may conclude that thin strata of a solid or liquid dielectric are equally strong whatever the thickness, while thin strata of a gaseous dielectric grow weaker as the thickness is increased. Viewed in the light of the mathematical theory of electricity in equilibrium, it is the gaseous dielectric which is anomalous. The cause does not appear to be any surface phenomenon, but rather to be due to the greater rarity of a gas which allows discharge by convection to be more readily set up. For the greater thicknesses convection is sometimes started in a liquid dielectric, and it is observed that the discharge then takes place at a lower difference of potential.

A table of electrostatic gradients is appended, Table IV., which has been compiled from this and the other investigations mentioned. Where Steinmetz has a value for the same dielectric, it is placed in a parallel column.

TABLE I.
PARAFFINED PAPER.

Number of sheets.	Thickness of paper in millimeters.	Thickness of air in millimeters.	Diff. of Potential in kilovolts (Macfarlane).	Diff. of Potential in kilovolts (Steinmetz).
1	.174	2.63	7.2	5.
2	.339	5.42	12.6	8.9
3	.506	8.47	18.6	13.
4	.620	11.76	—	16.5

TABLE II.
BEESWAXED PAPER.

Number of sheets.	Thickness of paper in millimeters.	Thickness of air in millimeters.	Diff. in Potential in kilovolts (Macfarlane).	Diff. of Potential in kilovolts (Steinmetz).
1	.214	5.18	12.3	8.2
2	.326	8.05	16.7	12.1
3	.390	10.5	22.2	14.9
4	.606	18.3	—	22.3

TABLE III.
KEROSENE OIL.

Thickness of oil in millimeters.	Thickness of air in millimeters.	Diff. of Potential in kilovolts (Macfarlane).	Diff. of Potential in kilovolts (Steinmetz).
1	1.0	3.6	2.5
2	4.0	9.9	6.9
3	6.8	15.	10.5
4	12.5	—	17.
5	20.8	—	—

TABLE IV.
ELECTRIC STRENGTH.

Dielectric.	Electrostatic gradient in kilovolts per centimeter.		Dielectric.	Electrostatic gradients in kilovolts per centimeter.	
	Macfarlane.	Steinmetz.		Macfarlane.	Steinmetz.
Oil of turpentine	94	64	Paraffined paper	360	339
Paraffin oil . .	87	—	Beeswaxed paper .	540	—
Olive oil . . .	82	—	Air (thickness, 5 mm.)	23.8	16
Paraffin (melted)	56	81	CO ₂ “ “	22.7	—
Kerosene oil . .	50	—	O “ “	22.2	—
Paraffin (solid) .	130	—	H “ “	15.1	—
			Coal gas	22.3	—