EFFECTS OF DIELECTRICS ON THE SPARKING VOLTAGE.

BY E. R. WOLCOTT.

THE voltage required to produce sparking between two electrodes is materially reduced by the presence of a dielectric near one of the electrodes, under certain conditions, which are outlined in the following pages.

The phenomenon is of considerable importance in the electrical precipitation of dust and fumes from gases, because the potential difference that can be maintained between the electrodes is thereby reduced, which, in turn, decreases the efficiency of operation.

As is well known, the electrical precipitation of dust and fumes from gases is accomplished by passing such gases through an electrical field formed between two electrodes, one being of small area, such as a wire, which is called the discharge electrode, the other being of relatively large area, such as a pipe concentric with the wire, or a plate parallel to the wire, which is called the collecting electrode.

The discharge electrode is maintained at a high potential and the collecting electrode is grounded, the field between the two being unidirectional.

The dust or fumes are repelled by the discharge electrode and precipitated upon the collecting electrode.

That these deposits lower the efficiency of operation was not recognized in the early stages of electrical precipitation and consequently some of the results then obtained seemed quite anomalous. For instance, a small plant was installed to precipitate a non-conducting fume. It operated with complete success for a few hours, that is, until the collecting electrodes became covered with the deposited fume and then the efficiency of precipitation fell off rapidly. It was also noticed that, in certain cases, particles of fume appeared to be repelled by the discharge electrode towards the collecting electrode, but were not actually deposited thereon. Instead, they moved out with the gases parallel to, and but at a short distance from, the collecting electrode. Under such conditions, a faint glow was sometimes visible at night upon the collecting electrode. Many instances in actual practice have shown the advantages of the use of moisture, and it became highly desirable to determine the reason therefor.

These observations led to an investigation of the effects of various substances upon the voltage that could be maintained between the discharge electrode and the grounded collecting electrode. The effects of these deposits upon the collecting electrode, with a wire as the discharge

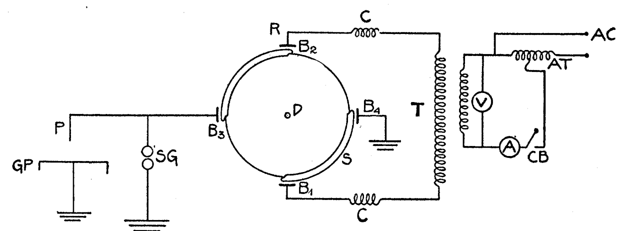

Fig. 1.

electrode, were found to be analogous to those between a point and a grounded plate, and so only results with a point and plate are included in the following tables.

The arrangement of apparatus for testing these effects is illustrated in Fig. 1.

GP is a grounded plate.

P is a metallic point connected as shown.

SG is a sphere-gap meter for measuring the peak voltage.

R is a rectifier which consists of an insulating disc *D*, 76 cm. in diameter, rotating synchronously with the alternating current.

SS are metal segments fastened on the periphery of the disc as shown.

B_1, B_2, B_3, B_4 are stationary metallic shoes, 15 cm. long.

B_1 and B_2 are connected through choke coils *CC* to the high tension terminal of the transformer *T*.

B_3 is connected to the point *P*.

B_4 is connected to the ground.

T is a 5 K. W., 110- to 100,000-volt transformer, the primary voltage of which is controlled by the auto-transformer *AT*, which is connected to the source of operating current *AC*. The primary instruments are an ammeter *A* and a voltmeter *V*. *CB* is the circuit-breaker.

The method of operation was to raise the voltage gradually by adjustment of the controlling switch of the auto-transformer until a disruptive discharge occurred between the point and the plate. The peak voltage at which this discharge took place was measured by the sphere-gap meter. The spheres were 12.5 centimeters in diameter.

The plate was large enough to prevent arcing to its edge. The distance between the point and plate was adapted to the prevailing conditions, being six centimeters in most cases.

A comparison of the peak voltages that produced disruptive discharges between a high tension point and a grounded plate, six centimeters apart, is given in the following table:

TABLE I.

Arcing Voltage between a Point and Plate.

Polarity of Point.	Kilo Volts Peak.	Kind of Discharge.	Remarks.
Negative............	136	Arc	First discharge
"	120	"	Minimum value
Positive.............	45	"	" "
"	42	Spark	" "

As first noticed by Faraday[1] the voltage required to start a spark is greater than that which it is later necessary to apply. In the present instance, this difference is shown in the first two readings of the above table.

The difference between the arcing voltage of the negative and positive points is shown in readings two and three.[2]

The difference in voltage required to produce arcing and sparking is indicated in the last two readings. Sparking was not as noticeable with the point negative as with the point positive. These sparks were white and snappy as distinguished from the yellow, heavy arcs. The latter opened the circuit-breaker in the primary circuit of the transformer

[1] Faraday, Exp. Res., Par. 1417.

[2] It has long been recognized that the minimum potential necessary to produce a spark between a point and a plate depends upon the polarity of the point. (J. J. Thomson, Conduction of Electricity Through Gases, 2nd edition, p. 498.) In all the instances cited in the above reference this minimum potential was found to be greater for the point positive than for the point negative, but the distance between the point and plate in these experiments did not exceed a few millimeters. To compare the sparking voltage at short distances with that of several centimeters between the point and plate, the Girvin generator was so adjusted that short sparks as well as long sparks could be obtained. It was then found (since the above paper was prepared) that at sparking distances less than about 2.3 millimeters, the sparking voltage was less for the point negative than for the point positive, but that for distances greater than 2.3 millimeters, the sparking voltage was greater for the point negative than for the point positive. In other words, a curve showing the relation between sparking voltage and distance between the point and plate when the point is positive crosses a similar curve for the point negative at a position indicating about 2.3 millimeters distance between the point and plate. These curves have not been as yet accurately determined. When this is done, it is planned to publish the data thereon in a future paper.

F. G. Cottrell (U. S. Patent 1067974, July 22, 1913) recognized that higher voltage could be maintained with a negtaive discharge electrode than with a positive discharge electrode.

when set at full load current; the former scarcely affected the reading of the ammeter.

The considerable difference in arcing voltage of a discharge between a point and plate, when the point is negative and when it is positive, was utilized in the production of a high tension alternating current rectifier.[1]

With the point negative, various substances were placed upon the grounded plate, and the arcing voltage observed. A few of such substances are listed in the following table, the high tension point being 6 cm. from the grounded plate:

Table II.

Effects of Dielectrics on the Arcing Voltage between a Negative Point and a Grounded Plate.

None	120
Mica	50
Sulphur	50
Glass wool	50
Varnished cambric	70
Filter paper	90
Asbestos	100
Edge of glass plate	65
Writing paper	118
Writing paper crumpled	90

These values are merely indicative, as it will be noticed that the value of the arcing voltage depends not only upon the kind of substance, but also upon its condition. Thus, a sheet of glass resting upon, and completely covering, the plate, of course, raises the voltage necessary to produce an arc. However, as the glass is drawn across the plate so that its edge comes underneath the point, arcing occurs at a much lower voltage than when no glass is present. Likewise, when a sheet of smooth paper is laid over the plate, the arcing voltage is not altered much; but when the paper is crumpled, or there is a hole in it, the arcing voltage is materially reduced.[2]

By very careful adjustment, it is possible to maintain a voltage that will not produce a disruptive discharge, but only a silent glow. With a piece of fibrous paper having a hole about one centimeter in diameter, which, however, was not directly underneath the point, the photograph reproduced in Fig. 2 was taken. In this case the point was five inches (12.7 cm.) from the grounded plate, 60 K. V. were applied and arcing

[1] E. R. Wolcott and C. J. Erickson, Phys. Rev., N. S., Vol. IX., p. 480, June, 1917.

[2] W. J. Humphreys (Phys. Rev., Vol. 11, p. 79, 1900) noticed that certain dielectrics produced a spark between the terminals of an electrostatic machine when brought near the positive terminal, but not when brought near the negative terminal.

resulted at 71 K. V. It will be noticed that the glow is cylindrical and proceeds from the edge of the hole in the paper. If the paper is moist, or if a grounded metallic screen is laid over it, no such glow appears, and the arcing voltage is not lowered.

TABLE III.

Results when Dielectric is Discharged.

Substance.	Peak K. V.	Remarks.
100 mesh screen	116	Laid directly on plate
Mica (dry)	50	" " " "
Grounded screen over mica	116	" " " "
Sulphur (flowers)	50	Dry.
" "	112	In moist atmosphere.
Mica	112	" " "

It thus appears that the substance must be able to accumulate a charge in order to show the effect.

That a considerable charge was accumulated was evident from the spark that could be obtained from the mica after removing it from the plate, and also from the appearance of sparks across the mica sheet while on the plate. These were often 2 cm. long, indicating the great potential differences acquired by different portions of the sheet.

For comparative purposes, the arcing voltages between points and the effects of a dielectric, such as mica, thereon are given in the following table:

TABLE IV.

Effects of Mica on the Arcing Voltage between a High Tension Point and a Grounded Point.

Polarity.	K. V. Peak.	Discharge.	Remarks.
Alternating current	58	Arc	No mica; value at start.
" "	53	"	No mica; minimum value.
" "	46	"	Mica near high tension point.
" "	46	"	Mica near grounded point.
" "	43	Spark	Mica near grounded point.
" "	43	"	Mica near high tension point.
High tension point negative	43	Arc	The only effect of mica was to increase the sparking. No lowering of the arcing voltage was observed.
" " " "	40	Spark	
" " " "	40	Arc	
" " " "	36	Spark	

The difference between the voltage at first and the minimum voltage is again noticeable in the first two readings. The mica lowers the arcing voltage somewhat when placed anywhere in the alternating field, but the only effect was increased sparking in a unidirectional field.

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Plate I.
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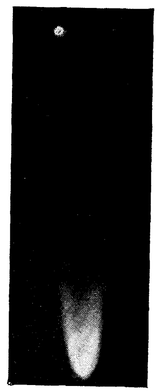

Fig. 2.

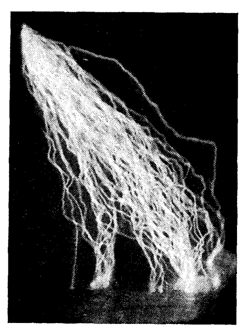

Fig. 3.

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The effect of mica at various positions in the field between a negative point and a grounded plate is given in the following table:

Table V.

Effects of Mica at Various Positions in the Field between a Negative Point and a Grounded Plate.

K. V. Peak.	Discharge.	Remarks.
120	Arc	No mica.
122	"	Mica at point.
122	"	Mica midway between point and plate
65	"	Mica near plate.
50	Spark	Mica near plate.

In the point-to-plate discharge with the point negative, the mica has little effect, except near the plate. There seems to be a certain position near the plate which gives the greatest lowering of the arcing voltage. This is not when the mica is close against the plate, but when it is about one millimeter above the latter.

The method used for examining this effect was to adjust the voltage to about that which would produce arcing when the mica was in position, and insert the mica afterwards by means of a paraffined wooden stick slotted at one end to hold the mica. As the sheet of mica was slid on to the plate sparks would jump to it as shown in Fig. 3. By pressing the mica against the plate, and then lifting it, the position for maximum lowering of the arcing vo tage could be determined.

As a basis for comparison of the actions of dielectrics and metallic points and edges, the following table is included:

Table VI.

Effects of Metallic Points Projecting up from Grounded Plate Point Negative and 6 Cms. from Plate.

Arrangement.	Kilo-Volts (Peak).
Plate only	120
Screen on plate	116
Point projecting 2 mm. from plate	78
Point projecting 3 mm. from plate	78
Point projecting 10 mm. from plate	48

The dielectrics placed on the grounded plate were not thick, being usually less than 0.1 mm. The effect is thus of a different order of magnitude than with metallic points projecting a greater distance from the plate.

The amount of dielectric necessary to produce this effect was very small, in the case of dust from a sintering machine containing 20 per cent. elemental sulphur, which was sprinkled through a 100-mesh screen upon the grounded plate, the following results were obtained:

TABLE VII.

Surface Density of Dielectric and Arcing Voltage.

Gm./Sq. Ft.	Mgr./Sq. Cm.	K. V. (Peak).
0	0	130
0.85	0.91	120
5.45	5.74	74
8.15	8.78	60
17.75	19.14	50

Plotting these results gives the curve shown in Fig. 4. A moisture content of 2.25 per cent. in the above dust was not sufficient to overcome

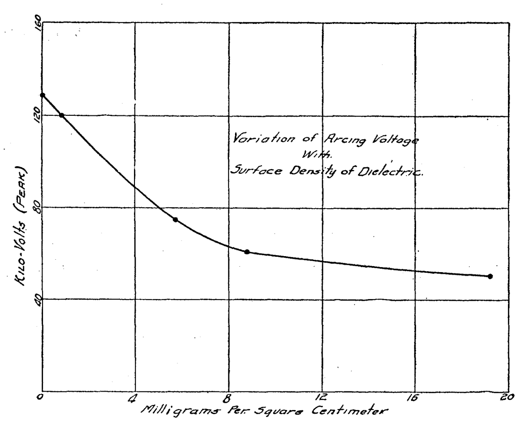

Fig. 4.

the effect, but a moisture content of 2.91 per cent. raised the arcing voltage to normal value; that is, to the value with no dust on the plate. This effect of moisture was noticed in many instances. In the case of zinc oxide, as the dielectric, 1 per cent. moisture was sufficient to eliminate the lowering of the arcing voltage.

Whenever a lowering of the arcing voltage was obtained a portion of the grounded plate was covered by a non-conducting substance. When this substance was made conducting, as by wetting it, no such lowering of the arcing voltage resulted.

As mica does not wet easily, some difficulty was experienced in completely discharging it and, unless it was completely grounded, a lowering of the arcing voltage resulted.

Likewise, when the dielectric accumulating the charge was removed, as when the sulphur was burned out of the above dust, no lowering of the arcing voltage resulted.

Similar results were obtained with a 50,000 volt, direct current, 5 K.W. Girvin generator, as shown in the following table. The point was 3.17 cm. from the grounded plate:

Table.

Arcing Voltage with 50 K. V. Direct Current Generator.

Condition.	K.V. r.m.s.[1]
Positive point	25.7
Negative point	55.6
Sheet of mica over plate, point negative	27.6
Varnished cambric, point negative	47.5
Felt paper, point negative	40

The machine was protected by means of a relay, operating on the high tension current, which automatically inserted resistance in the exciting circuit of the generator when full load current was exceeded.

With this direct current generator, no sparking between the point and plate was noticeable; the discharge was always a heavy arc.

From these data it appears that a dielectric placed upon the grounded plate of a point-to-plate unidirectional discharge, the point being negative, accumulates a charge, the potential of which may be sufficient to ionize the surrounding gas, producing a glow typical of the positive discharge. This glow, being a much better conductor of electricity than other portions of the gas, decreases the total resistance between the two electrodes, and lowers the voltage necessary to produce a disruptive discharge.

However, to produce this effect, the condition of the substance is just as important as its composition. It must not only be a substance capable of retaining a charge, but it is essential that it have a certain degree of discontinuity of surface, such as a roughened or porous surface, an edge or a hole.

The roughness of surface applies only to thin sheets, such as paper, which can be punctured by the discharge. A thick sheet of roughened glass covering the entire plate does not lower the arcing voltage (in fact, raises it) since to arc requires a complete ground connection.

The effect of moist atmosphere is also very marked. During damp weather, most of the above substances showed no lowering of the arcing voltage.

[1] An Electrostatic Voltmeter, E. R. Wolcott, Electrical World, May 13, 1916.

Some experiments were also tried using other gases than air, but these have not as yet been completed

In the following summary, it is to be understood that the conclusions apply only to the distances between the point and plate which are comparatively large; that is, over 3 centimeters. The conclusions as to the sparking voltage are equally applicable to the arcing voltage, as herein defined, except that the high voltage direct-current generator showed no sparking preliminary to the arc discharge.

Summary.

1. The sparking voltage (peak) between a point and plate when the point is positive, is about half of that when the point is negative.

2. A dielectric of discontinuous surface placed over the plate (point-to-plate unidirectional discharge) lowers the sparking voltage, when the point is negative, to a value comparable to that when the point is positive.

3. The discontinuity of surface may be an edge or hole, or the body may be fibrous or porous.

4. No lowering of the sparking voltage results when means are provided for conducting away the charge, as when the deposit is sufficiently moist or is in a humid atmosphere.

5. No lowering of the sparking voltage results when means are provided for preventing the accumulation of a heavy charge as by covering the dielectric with a grounded screen.

6. An intense brush glow appears upon the dielectric when just under sparking voltage. The decrease in resistance of the gaseous medium between the electrodes thus produced is probably the cause of the lowering of the sparking voltage.

Laboratories, Western Precipitation Company,
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Fig. 2.

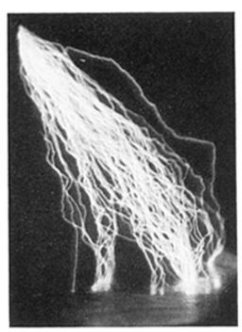

Fig. 3.