

CONDUCTIVITY OF INSULATING MATERIALS NEAR THE
BREAKDOWN VOLTAGE.¹

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SYNOPSIS

Conductivity of Insulating Materials up to Breakdown Voltages.—(a) In the *method of measurement* used, the recording instruments were protected from injury in case of puncture, by placing an insulated hot cathode rectifier in series with the sample being tested. This enabled the current through the sample to be limited and also controlled by controlling the temperature of the cathode of the rectifier. When with a given applied voltage the current did not reach a constant maximum value upon raising the temperature of the cathode, the voltage had reached the breakdown point. (b) *These classes of insulating materials* were found whose conductivity, respectively, (1) obeys Ohm's law throughout; (2) obeys Ohm's law up to near breakdown and then increases at an accelerated rate; and (3) increases over the whole range of voltage at an accelerated rate to breakdown. In general, material in class 3 have the greatest dielectric strength; these in class 1, the least. Results are given only for these materials, untreated cement paper, paraffined fish paper, and black treated cloth, which were selected as representative, respectively, of the three classes.

MOST of the data on the conductivity of insulating materials have been obtained from observations of tests made at comparatively low potential stresses. It is quite well known that the behavior of all insulating materials under varying voltages is not the same. Some obey Ohm's Law while others increase in conductivity with voltage at a greater rate than in accordance with Ohm's Law.

Any data to be of service should be taken under the voltage conditions to which the materials are subjected. If material is to be used not merely for its resistance to the passage of a current but to stand high electrostatic stress and prevent breakdown then this material should be studied under stresses up to and in the neighborhood of actual breakdown.

To test insulating materials over a range of voltage up to the breakdown without danger to the current measuring instruments the following scheme shown by the diagram, Fig. 1, was devised. The D.C. voltage of 12,000 volts is obtained from the rectification of the A.C. voltage from the secondaries of two transformers *AB* and *BC*, by the hot cathode rectifier *E*. The primaries of the transformers are connected in parallel to an auto transformer by which the voltage is varied. The secondaries

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are connected in series and the terminals *A* and *C* are connected to the anodes of the two-anode rectifier *E*. The middle point *B* is connected through a second rectifier *F*, and the sample *H* to the cathode of the rectifier. The cathode of this rectifier is heated by the stepdown transformer *I* connected to a 110-A.C. source. A capacity *G* consisting of ten One-M.F. condensers connected in series is connected across the

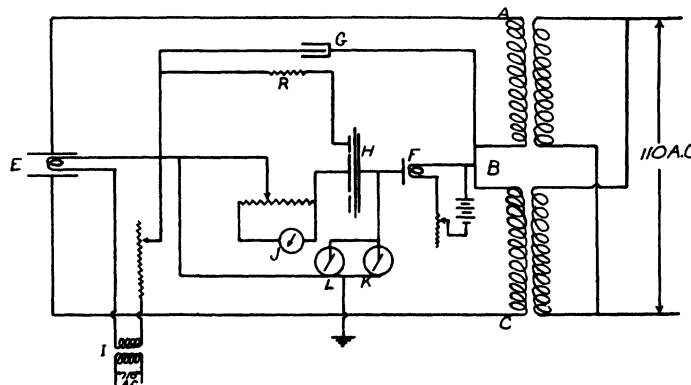


Fig. 1.

sample to maintain a constant voltage. The current through the sample is read by the galvanometer *J* which is provided with an Ayrton Shunt. The voltage across the sample is read by two electrostatic voltmeters *K* and *L*, one reading to 3,500 and the other to 15,000 volts.

The new feature in this arrangement is the insertion of the hot cathode rectifier *F* between the high tension electrode of the sample and the middle point *B* of the transformers. This rectifier with its battery and regulating resistance is well insulated. This rectifier or valve tube as it is used in this case serves as a protective device for the galvanometer. With the transformers excited no current can pass through the sample until the cathode of the rectifier *F* is heated. The value of the current which can pass through the tube is dependent upon the temperature of the filament, which is controlled by the variable resistance. Then for any given testing voltage the temperature of the cathode is gradually increased, observing at the same time the current indicated by the galvanometer. When there is no further increase of the current upon further increasing the temperature of the cathode of the rectifier it is known that the current is limited by the insulation and not by the valve. By this method one has complete control at all times of the value of the current which may flow through the instruments. If the current does not reach a steady value upon opening the valve it is a good indi-

cation that the sample is near the point of breakdown. Even in the case of actual breakdown, with the valve in the circuit, the current is limited to such a value that damage to the instruments is prevented.

For a study of the conductivity of insulating materials up to the point of breakdown three samples from the same sheet of material were prepared. As might be expected by one familiar with insulating materials, there is considerable variation in conductivity among these samples and this is shown by the curves which follow. The tests were made with a guard ring to prevent surface leakage to the measuring instruments. Close contact of the electrodes with the sample was obtained by the use of powdered graphite. The lower electrode was a round shallow tray filled with powdered graphite and smoothed off with a straight edge to a depth of about two millimeters. Upon this was placed the sample to be tested. Two concentric cylindrical glass rings were fastened with shellac upon the upper surface of the sheet material. The space between the rings occupied by the guard ring and the surface inside the inner ring were covered with the powdered graphite upon which were firmly pressed the guard ring and the central electrode respectively. The resistance of the graphite layer itself was negligible being only a few ohms. The contact, especially for an unpolished surface, was better than a contact of mercury since the powder could be rubbed into the small surface irregularities. That this was true was actually proven by trial.

For the materials tested the current came to practically a steady value in two to five minutes after the application of voltage. Hence the values used in this work were obtained after a steady reading of the galvanometer was observed.

Tests were made on a variety of commercial insulating materials, observations being made from comparatively low voltage to breakdown voltages for the particular sample. From the results obtained all these materials may be divided into three classes:

1. Materials whose conductivity varies directly with voltage according to Ohm's Law.
2. Materials whose conductivity varies according to Ohm's Law up to the neighborhood of breakdown after which the conductivity increases at an accelerated rate to breakdown.
3. Materials whose conductivity over the whole range increases at an accelerated rate to breakdown.

Of quite a number of materials tested three have been chosen which illustrate the three classes. Fig. 2, untreated cement paper, is representative of the first class. This shows a straight line relationship between conductivity and voltage up to breakdown. Fig. 3, paraffined

fish paper, illustrates the second class. Here the straight line relationship holds up to the neighborhood of breakdown where there is a marked increase in the slope of the curve after which breakdown soon occurs. Fig. 4, for black treated cloth represents the more numerous materials

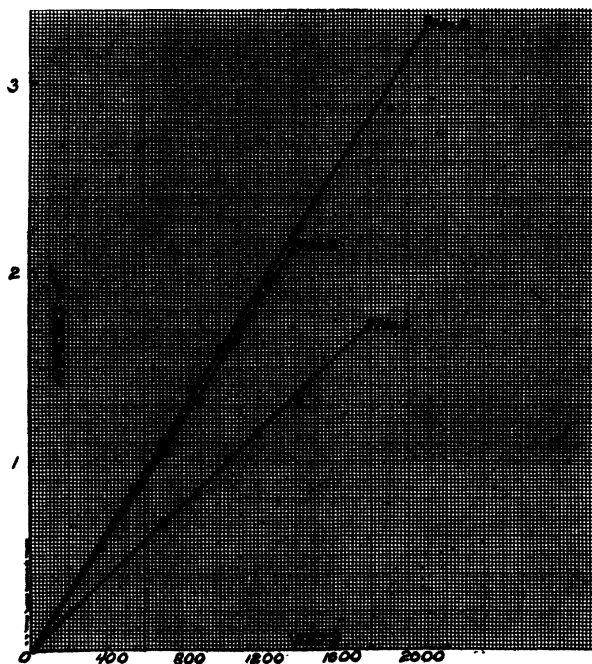


Fig. 2.

Untreated cement paper. Thickness = .015 in.

of the third class. This curve shows that there is an increasing slope to the curve from low voltages up to the point of breakdown.

From a comparison of calculated specific resistances of the various materials tested there is no apparent relation between specific resistance and breakdown voltage. It is quite apparent that the curves for Class 1, give no indication of breakdown. In Class 2, the breakdown point is clearly indicated by the upward slope just before breakdown. In Class 3, we might say that breakdown is liable to occur after the slope of the tangent to the curve exceeds an arbitrary angle determined from experience. From a comparison of the voltage gradient at breakdown, the results show that the materials in class 3 have the greater dielectric strength and those of Class 1, the poorest. Class 1, has the characteristics of a conductor in that the resistance is independent of voltage while Class 3, has no true resistance but only apparent resistance which

is a function of the applied voltage. In class 1 the current is no doubt due to the free electrons in the material under the directive force of the applied potential. In Class 3, the number of free electrons is a function

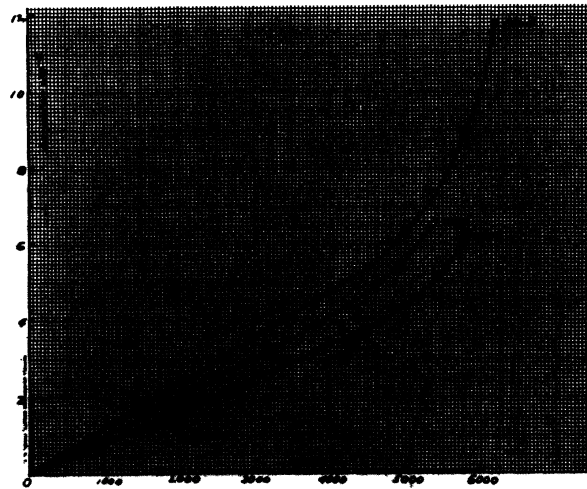


Fig. 3,

Paraffined fish paper. Thickness = .015 in.

of the applied potential. At the point of breakdown, then the number of free electrons is enormously increased, in Class 1 breakdown takes place very suddenly, while in Class 3, the change is more gradual.



Fig. 4.

Treated cloth (black) No. 1010. Thickness = .011 in.

While no claims are made that the work here reported is complete, considerable useful information has been obtained as to how insulating material behaves at potentials near the breakdown. The method devised may be useful also for further work in investigating the nature of breakdown of insulating materials.

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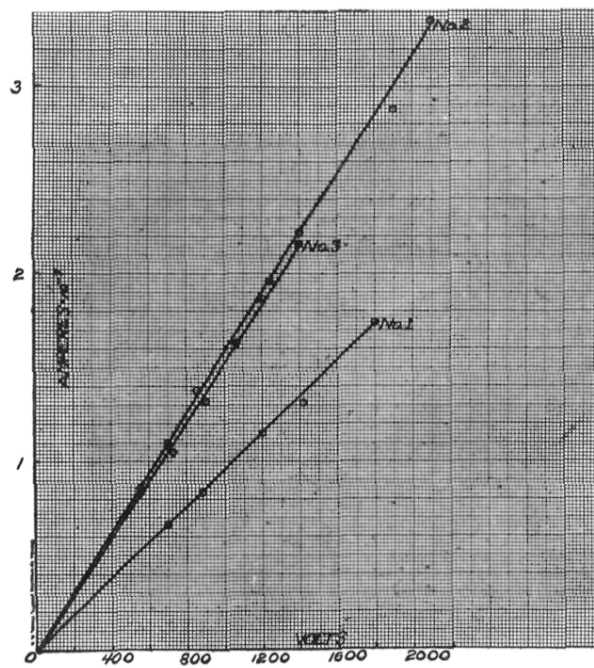


Fig. 2.
 Untreated cement paper. Thickness $\approx .015$ in.

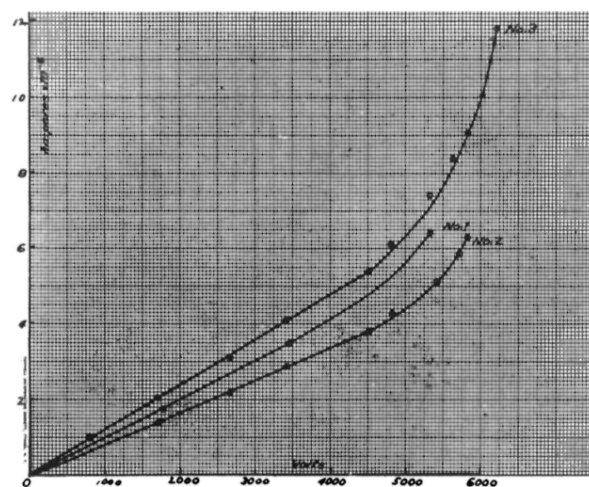


Fig. 3.

Paraffined fish paper. Thickness = .015 in.

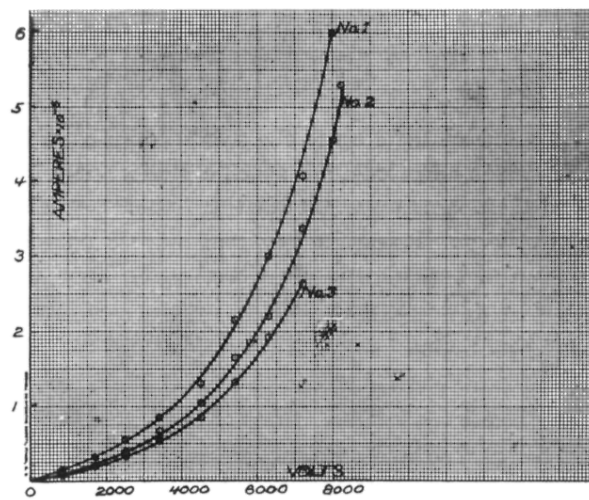


Fig. 4.

Treated cloth (black) No. 1010. Thickness = .011 in.