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ELECTRICAL BREAKDOWN OF DIELECTRICS WITH  
A DIPOLE STRUCTURE

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Foreign Technology Division  
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20 July 1972

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FTD-HC-23-1176-72

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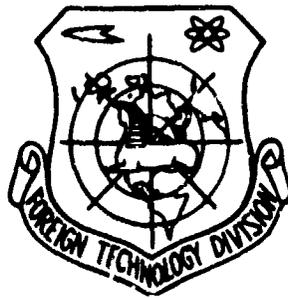
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by

N. Prikhod'ko



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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

|   |  |
|---|--|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Foreign Technology Division<br>Air Force Systems Command<br>U. S. Air Force | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED |
| 2b. GROUP   |  |

3. REPORT TITLE  
ELECTRICAL BREAKDOWN OF DIELECTRICS WITH A DIPOLE STRUCTURE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)  
Translation

5. AUTHOR(S) (First name, middle initial, last name)  
N. Prikhod'ko

|                        |                             |                      |
|------------------------|-----------------------------|----------------------|
| 6. REPORT DATE<br>1945 | 7a. TOTAL NO. OF PAGES<br>9 | 7b. NO. OF REFS<br>4 |
|------------------------|-----------------------------|----------------------|

|   |   |
|---|---|
| 8a. CONTRACT OR GRANT NO.<br><br>b. PROJECT NO.<br><br>c.<br><br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>FTD-HC-23-1176-72<br><br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) |
|---|---|

10. DISTRIBUTION STATEMENT  
Approved for public release; distribution unlimited.

|                         |   |
|-------------------------|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY<br>Foreign Technology Division<br>Wright-Patterson AFB, Ohio |
|-------------------------|---|

13. ABSTRACT

On the basis of data obtained in the breakdown of water and glycerine, as a function of the variation of the temperature, and also from data concerning breakdown voltages for ice, Seignette salt, and polar liquids, it follows that with the variation of the dielectric constant of the matter its breakdown voltage also changes. The variation of the breakdown voltage of a dielectric may be explained by the variation of the internal field. It is demonstrated that in sharply heterogeneous fields liquids having large dipole moments have a considerably decreased electric strength in comparison with nonpolar liquid. During breakdown in pulsed voltage dielectrics with a dipole structure show a temperature dependence of the breakdown voltage. In conclusion, the author expresses his gratitude to Professor Doctor A. A. Vorob'ev for suggesting the subject and supervising the work.

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Security Classification

| 14. KEY WORDS  | LINK A |    | LINK B |    | LINK C |    |
|--|--------|----|--------|----|--------|----|
|  | ROLE   | WT | ROLE   | WT | ROLE   | WT |
| Dielectric Breakdown<br>Dielectric Constant<br>Dielectric Strength<br>Water<br>Glycerine<br>Quartz |        |    |        |    |        |    |

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FTD-HC-23-1176-72

## UNEDITED ROUGH DRAFT TRANSLATION

by Joint Publications Research Services

FTD-HC-23-1176-72

ELECTRICAL BREAKDOWN OF DIELECTRICS WITH A  
DIPOLE STRUCTURE

By: N. Prikhod'ko

English pages: 9

Source: Tomsk. Universitet. Sibirskiy Fiziko-  
Tekhnicheskiv Institut. Trudy, (High-  
Voltage Laboratory), No. 2, Vol. 6,  
1945, pp. 114-119.

Requester: AFWL

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FTD-HC-23-1176-72

Date 20 July 1972

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## ELECTRICAL BREAKDOWN OF DIELECTRICS WITH A DIPOLE STRUCTURE

[ Article by N. A. Prikhod'ko; Tomsk, Trudy Sibirskogo fiziko-tehnicheskogo instituta, High-Voltage Laboratory, Russian, No 2, volume 6, 1942, signed to press 15 October 1939, pp 114-119]

### 1. Introduction

Up to this time the question remains open as to what determines the beginning of the disruption of the electric strength of solid and liquid dielectrics, the effect of either the superimposed potential difference or the achievement of a definite magnitude of the intensity of the internal field in the dielectric.

Having applied a voltage  $V$  to a capacitor filled with the liquid being tested, we subject each particle of this liquid to the effect of an electrical field. The intensity  $E$  of the electrical field, actually operating at the given point on a particle within the liquid, as a consequence of the dielectric polarization of the dielectric, will differ from the calculated magnitude  $F$ , as

$$F = \frac{V}{d},$$

where  $d$  is the distance between the electrodes.

The difference will depend upon the polarization of a unit of volume  $J$  and is expressed by the formula

$$E = F + \frac{4\pi}{3} J.$$

The magnitude of the polarization may be connected via the molecular polarization capacity with the magnitude of the dielectric constant of the matter by means of the Clausius-Mossotti formula and the well-known

expression may thus be obtained for the magnitude of the internal field

$$E = \frac{E + 2}{3} F \quad (1)$$

This expression is arrived with reference to gases and vapors. However, we may assume that this formula at least qualitatively describes the phenomena in dipole liquids also.

From formula (1) it is apparent that the internal field will be a factor of  $(\epsilon + 2)/3$  greater than the external field. Consequently, if in electrical breakdown of the dielectrics the internal field plays a part, then the magnitudes of breakdown voltages obtained in the experiment are obviously understated.

In this article certain experiments in the breakdown of dielectrics with different magnitudes of the dielectric constant are described, the results of which are explained with a consideration of the internal fields in the dielectric. The measurements were conducted on pulsed voltage, with a duration of  $10^{-6}$  seconds.

In the brief effect of the voltage, as the measurements of Dittert demonstrate, adequately pure electrical conditions are provided and thermal phenomena are reduced to a minimum.

## 2. Experiments with Water and Glycerine

To determine the dependence of the possible effect of the internal fields on the magnitude of the breakdown voltage, experiments were conducted with water and glycerine. Water and glycerine, in a variation of temperature, change their dielectric coefficients, and in this case, according to formula (1), the magnitude of the internal field will also change.

For measurement of the dielectric constants in water and glycerine in an impact voltage, at a value of the voltage close to breakdown value, a device was assembled according to a scheme which Kobeko and Kurchatov used (reference 2) in measuring the dielectric constant of Seignette salt in pulses.

The measuring capacitor, mounted in quartz, is submerged into the bath filled with the liquid being tested. The heating is performed by an electric furnace submerged into the bath, containing the liquid being tested;

the temperature was measured by a mercury thermometer. The results of the measurements are presented in Figure 1.

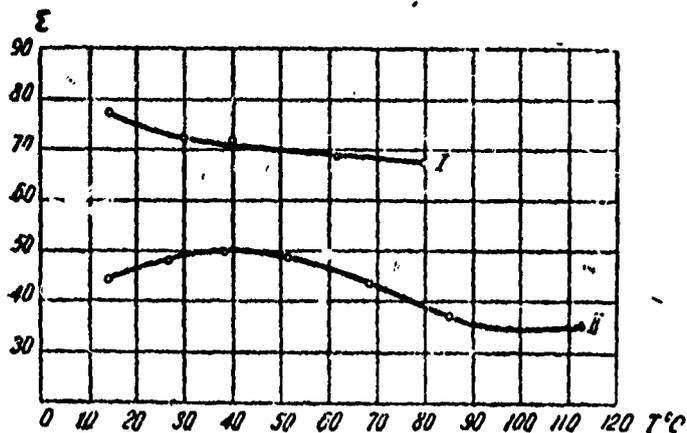


Figure 1.

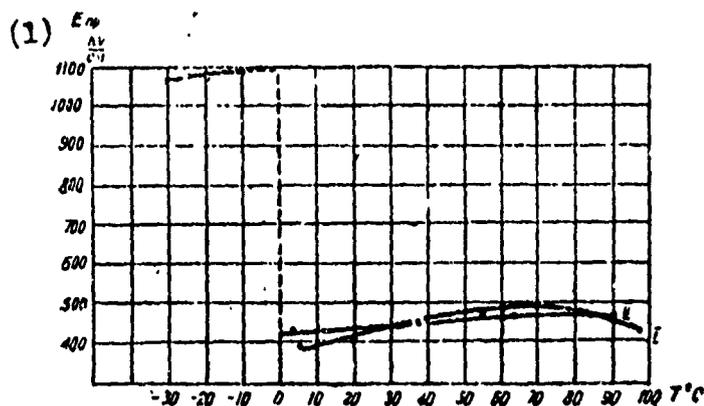


Figure 2. 1) Breakdown voltage, kilovolts per centimeter.

From Figure 1 it is apparent that the dielectric constant of water (curve I) drops insignificantly with an increase in temperature.

In glycerine (curve II) in the temperature interval of 35 to 40 degrees Centigrade, the dielectric constant has a maximum.

For this same temperature range, for the same substances, breakdown voltages in a homogeneous field were measured, as well as in a field close to homogeneous and in a heterogeneous field. The curves of the dependence of breakdown voltages for water are shown in Figure 2. Curve I is for distilled water, and curve II is for distilled water that was boiled for a long time.

In comparing these results with a fluctuation of the dielectric constant, and considering the assumptions expressed in Section 1, we should expect an increase in the breakdown voltage as the temperature rises for water. It is true that according to formula (1) this increase should not exceed five to ten percent, but since the errors of the experiment reached the same magnitude, with such small variations of the magnitude of the internal field we cannot speak of its effect in the given case.

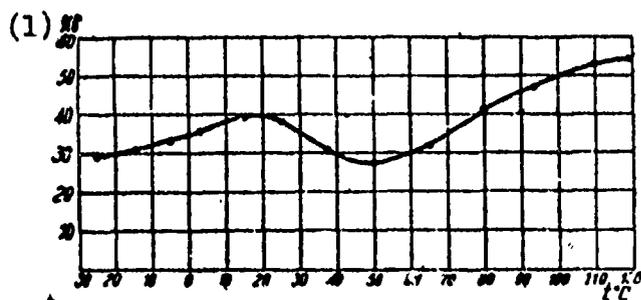


Figure 3. (1) kilovolts.

In Figure 3 the dependence of the breakdown voltage in pulses is presented for glycerine, taken in the interval from -25 degrees Centigrade to +120 degrees Centigrade. We will trace the fluctuation of this curve in the section of temperatures from minus 25 degrees Centigrade to +18 degrees Centigrade. At first we observe a growth of the breakdown voltage with an increase in temperature, and then it remains at a constant value; in the temperature range of 25 to 50 degrees Centigrade there is a maximum, and then a gradual increase of the breakdown voltage occurs, reaching an increase of 40 percent over the initial value at the end of the curve. In comparing the curve of breakdown voltages in Figure 3 with the curve of the fluctuation of the dielectric constant in Figure 1, taken in a temperature range of 14 to 113 degrees Centigrade at the same voltages, we see that in places where the curve of the breakdown voltages as a maximum value, the curve for the dielectric constant, on the contrary, has a maximum in the interval of 25 to 50 degrees Centigrade, i.e., with an increase in the dielectric constant the breakdown voltage falls.

For a heterogeneous field approximately the same curves are obtained, only the end of the curve (at a high temperature) moves somewhat higher.

### 3. Experiments with Ice and with Seignette Salt

(a) Breakdown of ice. Out of the solids, two were investigated: ice and Seignette salt. Pure river ice was cut by means of a heated wire into pieces with dimensions of 2 x 2 x 1 centimeter. Breakdown was performed both in a homogeneous and in a heterogeneous field in pulsed voltage.

The experiment was conducted in the following manner: the pieces of ice were placed on a massive copper electrode, and then the upper electrode was forced into the specimen by pressure by means of a screw. The instrument was filled with dry cold oil and cooled in the open air to the temperature of the latter, where breakdown was also performed. The breakdown voltages were fixed at four temperatures: -31, -22, -17, and -10 degrees. For the frequency on which the experiment was performed the ice, according to the measurements of Errer (reference 3), does not change its dielectric constant in a variation of temperature, therefore we could not expect any great dependence of the breakdown voltage upon the change in temperature.

The high breakdown values obtained for ice in breakdown during pulses direct attention to themselves. Thus, in the breakdown of ice during pulses in a homogeneous field the ice turned out to be stronger than many solid dielectrics. The interval near zero degrees Centigrade, i. e., the interval of the transition from a solid state to a liquid state, is of interest. The breakdown strength of the ice in melting changes suddenly, and the strength decreases approximately to a third of its former value (Figure 2). If we consider that the dielectric constant of the ice at this frequency is only approximately a tenth as much as in water, then such a jump in breakdown voltages may be explained by working from formula (1).

(b) Breakdown of Seignette salt. The breakdown voltage of Seignette salt is of interest because its dielectric constant is not the same with respect to different crystallographic directions.

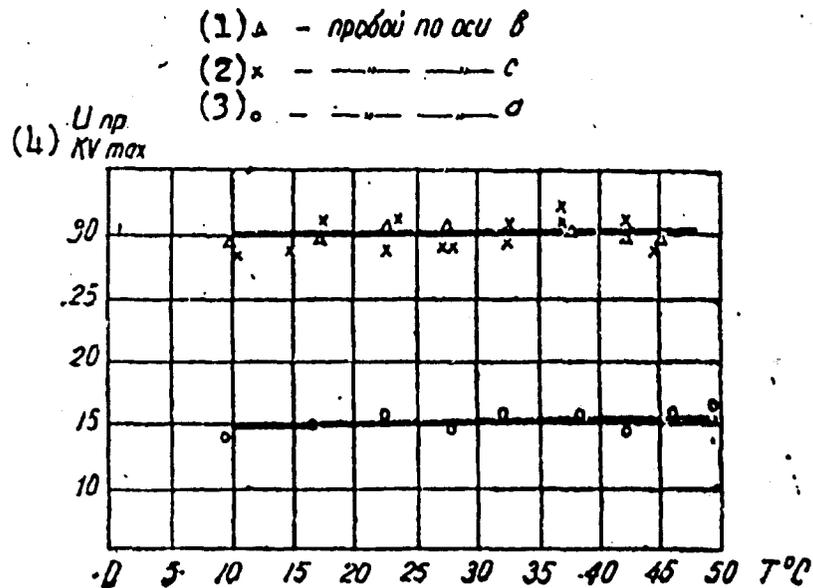


Figure 4. (1) breakdown along axis  $b$ ; (2) breakdown along axis  $c$ ;  
 (3) breakdown along axis  $a$ ; (4)  $U_{pr}$  [ $U_{np} = U_{pr} = U_{\text{breakdown}}$ ]  
 kv (kilovolts), maximum.

We performed the investigations with specimens cut along three crystallographic axes:  $a$ ,  $b$ , and  $c$ . Along axis  $a$  Seignette salt has a quite high value of the dielectric constant, and along axes  $b$  and  $c$  the value is considerably less. The result of the measurement is shown in Figure 4. The lower curve was taken for specimens polished along axis  $a$ . The breakdown values along axes  $b$  and  $c$  were obtained at coinciding values and with respect to strength lie at a point approximately twice as high. The fact of the very low breakdown voltages along axis  $a$  makes it possible to express the assumption here also that a decrease in breakdown voltage along this axis, in comparison with other directions, is associated with the variation of the dielectric constant, since all the other breakdown conditions were entirely the same.

#### 4. Dependence of the Breakdown Voltage of Liquid Dielectrics Upon the Magnitude of the Dipole Moments

For completeness of the picture of the dependence of breakdown strength upon the magnitude of the internal field, investigations were made of the electric strength of a number of liquids, the dipole moments of which were different. The basic investigations were performed with the following liquids: benzene, xylene, transformer oil, toluene, aniline, ethyl alcohol, and water. All the liquids (with the exception of oil) were thoroughly purified by double distillation. Breakdown was performed in a heterogeneous

field (needles against the plane) in pulses with different duration and different polarity. The curves of breakdown voltages as a function of the distance between the electrodes are shown in Figure 5. In Figure 5 curves are given for xylene (I), benzene (II), transformer oil (III), toluene (IV), aniline (V), ethyl alcohol (VI) and water (VII), broken down at pulses with a duration of  $6.2 \times 10^{-4}$  seconds. In Figure 6 the same curves are shown, but the breakdown occurred with a different polarity of the electrodes, namely: the negative electrode was sharp and the positive electrode flat. From Figure 6 it is apparent that the strength of benzene and xylene is almost the same, and curves of breakdown voltages lie above all the others for these. Following them, in order, are: transformer oil, toluene, and aniline. Alcohol and water occupy the lowest positions with respect to strength. Having arranged the liquids in a series according to the magnitude of the dipole moment, and also according to breakdown strength, we obtain Table 1.

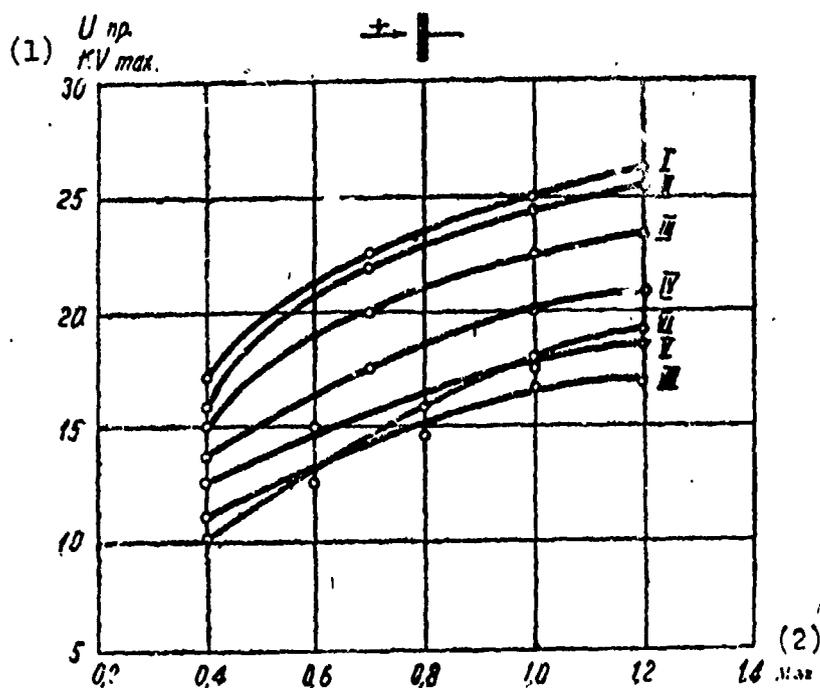


Figure 5. (1) breakdown voltage, kilovolts, maximum; (2) millimeters.

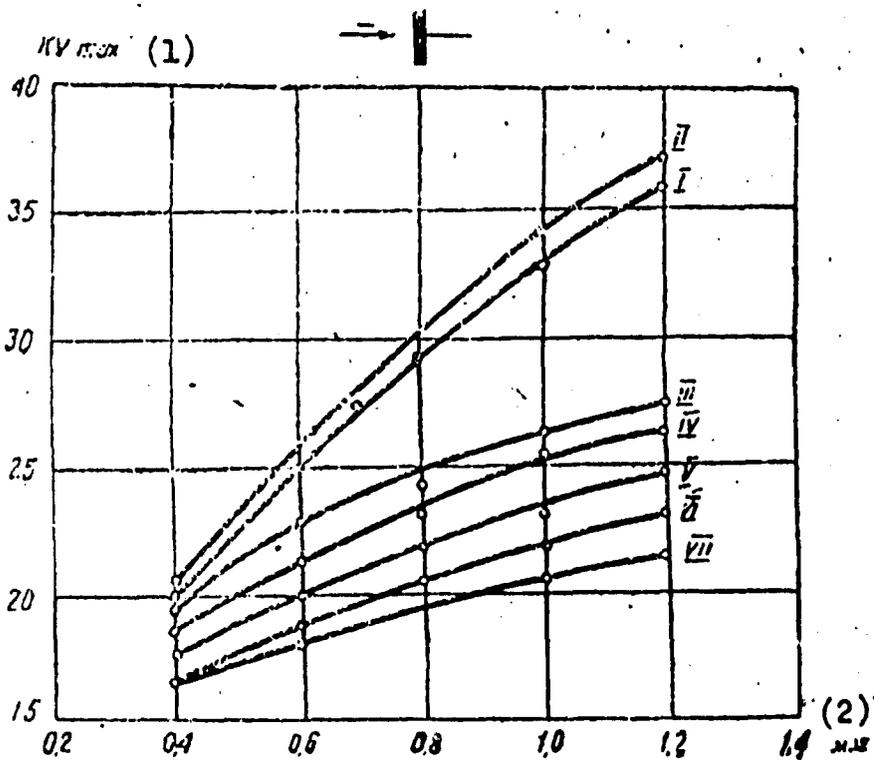


Figure 6. (1) kilovolts, maximum; (2) millimeters.

Table 1

| (a)<br>Вещество                     | (b)<br>Дипольный<br>момент | (c) Пробивное напряжение<br>на 1 мм в кв. |                                |
|-------------------------------------|----------------------------|---|--------------------------------|
|                                     |                            | (d) Острые положи-<br>тельные.            | (e) Острые отрица-<br>тельные. |
| 1. Ксилол . . . . .                 | 0                          | 24  | 32                             |
| 2. Бензол . . . . .                 | 0                          | 25  | 31                             |
| 3. Трансформаторное масло . . . . . | —                          | 22,5                                      | 26,5                           |
| 4. Толуол . . . . .                 | $0,52 \cdot 10^{-18}$      | 20  | 25,5                           |
| 5. Анилин . . . . .                 | $1,6 \cdot 10^{-18}$       | 17,5                                      | 23                             |
| 6. Спирт . . . . .                  | $1,64 \cdot 10^{-18}$      | 17,5                                      | 22                             |
| 7. Вода . . . . .                   | $1,94 \cdot 10^{-18}$      | 17  | 21                             |

Key: (a) substance; (b) dipole moment; (c) breakdown voltage per millimeter, in kilovolts; (d) sharp electrode positive; (e) sharp electrode negative; (1) xylene; (2) benzene; (3) transformer oil; (4) toluene; (5) aniline; (6) alcohol; (7) water.

Val'ter and Inge (reference 4) obtained approximately the same series with respect to strength in purely electrical breakdown for very pure liquids in conditions of a homogeneous field.

## 5. Conclusions

1. On the basis of data obtained in the breakdown of water and glycerine, as a function of the variation of the temperature, and also from data concerning breakdown voltages for ice, Seignette salt, and polar liquids, it follows that with the variation of the dielectric constant of the matter its breakdown voltage also changes. The variation of the breakdown voltage of a dielectric may be explained by the variation of the internal field.

2. It is demonstrated that in sharply heterogeneous fields liquids having large dipole moments have a considerably decreased electric strength in comparison with nonpolar liquid.

3. During breakdown in pulsed voltage dielectrics with a dipole structure show a temperature dependence of the breakdown voltage.

In conclusion, the author expresses his gratitude to Professor Doctor A. A. Vorob'yev for suggesting the subject and supervising the work.

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