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Dependence of the Dielectric Strength of Some Alkali Halide Monocrystals on the Duration of the Applied Voltage

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Dependence of the dielectric strength of monocrystals of NaCl, KCl, KBr and KI on the duration of the applied voltage was studied experimentally. The effects of the formation and rate of growth of the discharge in the dielectric are studied. The assumption is made that the increase in the breakdown potential when the duration of the applied voltage is of the order of 10^{-5} sec relative to the breakdown potentials for voltages of shorter duration is caused by the ionic volume charge. When pulses are used, a proportionality is observed between the dielectric strength and the energy of the crystal lattice. Experimental data and oscillograms point to the existence of two stages in the breakdown process of the investigated dielectrics.

The dependence of the dielectric strength of solid dielectrics on the duration of the applied voltage has not been investigated very much. There are indications[1] that a time interval of 3 x 10^{-8} sec is sufficient for the development of the breakdown in solid dielectrics.

Valter and Inge[2] found in connection with the study of breakdown of glass in a uniform field that the dielectric strength is independent of the duration of the applied voltage within the limits of 10^{-7} sec and 1 sec.

Dittert,[3] using uniform fields for the breakdown, found an independence of the dielectric strength of paper base bakelite and ebonite on the duration of applied voltage in the interval from 10^{-8} to 10^{-1} sec.

Vorob'ev and Valter[4] observed an increase in the dielectric strength of porcelain in the field of a hemisphere against a plane surface with the decrease of the duration of applied voltage. With a pulse duration of 4 μ sec, the coefficient of the impulse was 1.33, and with a pulse duration of 3500 μ sec, 1.02 Such a dependence is apparently due to the influence of the porosity of porcelain.

Hippel and Alger[5] investigated the dependence of the dielectric strength of monocrystals of KBr on the duration of the applied voltage. For breakdowns with constant voltages or with pulses which persist up to the time of breakdown and are not less than 10^{-4} sec in duration, the dielectric strength was constant. With the decrease of the prebreakdown time, beginning with 10^{-4} sec, the dielectric strength decreases. At a duration of 5 x 10^{-5} sec the dielectric strength reaches a minimum (the decrease constitutes 12%), then increases and reaches the initial value at 10^{-6} sec. For the prebreakdown time of 1.7 x 10^{-8} sec, the dielectric strength is higher than for the constant field by 33%.

The dependence of dielectric strength on the duration of the applied voltage is important for the development of the theory of the breakdown. The information permits the evaluation of the rate of the processes involved in the breakdown and of the role of the various factors in the breakdown process. The insufficient and indefinite nature of existing data on the time dependence of the dielectric strength of solid dielectrics and the importance of this question prompted a systematic study in this field.

We have conducted an investigation of the time dependence of the electric strength of monocrystals of NaCl, KCl, KBr and KI. The monocrystals KCl, KBr and KI were grown from melts; rock salt was used in its natural state. Samples used in the experiments included machined spherical surfaces 8 mm in diameter. The thickness of the samples at the thinnest place, where the breakdown occurred, was 150 ± 10 μ. The spherically shaped portion and the opposite side were covered with tin by evaporation in a vacuum.

The breakdown of the samples was carried out in transformer oil. The amplitude of the applied voltage pulse was selected to be greater than the dielectric strength of the samples in order to produce the breakdown on the first rise of the applied pulse. To obtain a change in the order of magnitude of the time before the breakdown, the length of the wave front was changed. In parallel with the sample under test, there was included a voltage

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[1] A. P. Aleksandrov et al., *Physics of Dielectrics*, GTTI, 1932.

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[3] Dittert, Dissertation, Dresden, 1930.

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[5] A. Von Hippel and R. S. Alger, Phys. Rev. 76, 127 (1949).

divider, a portion of which supplied voltage to the plates of the cathode ray oscillograph. The displacement of the electron beam along the vertical and horizontal axes was calibrated. The accuracy of measuring the breakdown voltage was 5%.

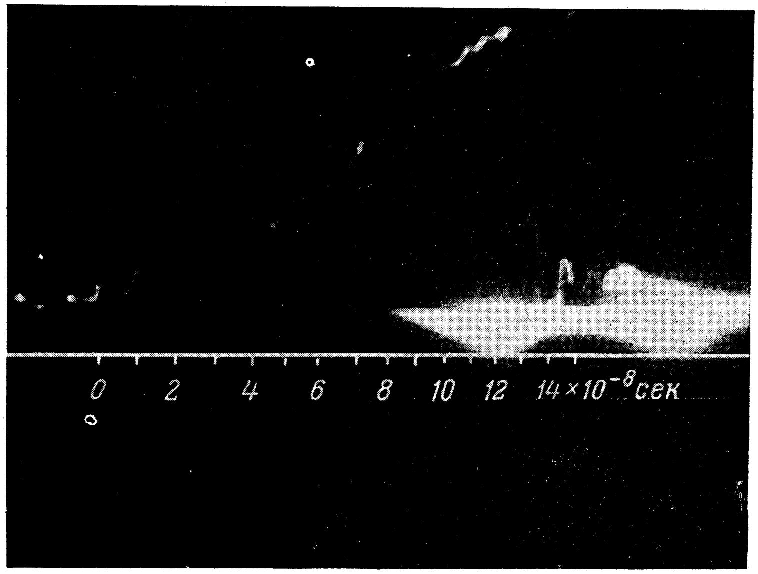


FIG. 1. Oscillogram of a Breakdown of NaCl

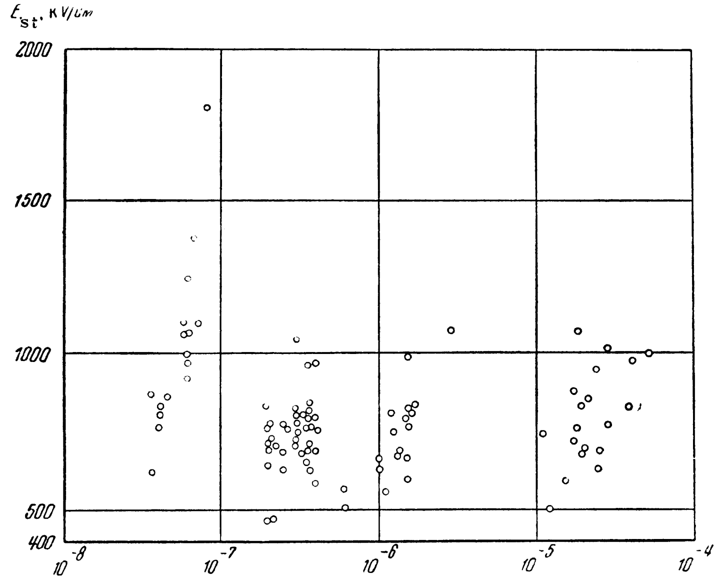
In Fig. 1 is shown a photograph of the oscillogram of a breakdown of NaCl for a time interval before the breakdown of 13 x 10^{-8} sec. For every time interval before the breakdown, and for each of the investigated dielectrics, we have obtained from 12 to 39 points. Figure 2 represents the dependence of the dielectric strength of KBr on the application time of the voltage. Figure 3 shows the statistically treated dependence of the dielectric strength of KI on the duration of applied voltage and Fig.4, curves of dependence of the dielectric strength of all the crystals investigated by us on the duration of the applied voltage for a probability of breakdown ψ=90%.

For all the investigated dielectrics, there was observed a considerable increase of dielectric strength at voltage duration of 6 to 9 x 10^{-8} sec, compared to the dielectric strength for longer duration of the applied voltage. For all the four salts, we have also obtained a somewhat greater dielectric strength for application times of the order of 10^{-5} sec, compared to that for application time of the order of 10^{-7} to 10^{-6} sec.

The increase in the dielectric strength of the investigated monocrystals for application time of 6 to 9 x 10^{-8} sec, is probably due to the delay in the discharge. The discharge time in solid dielectrics is practically equal to the time of discharge formation, since in a solid dielectric there always exists a certain number of free electrons. Experimental results are shown in Fig. 4 and the oscillograms permit the evaluation of the time of discharge formation. The times of discharge formation were determined from the oscillograms as shown in Fig. 5; E_t is the breakdown voltage for an application time of 6 to 9 x 10^{-8} sec; E_0 is the breakdown voltage for an application time for which no delay in the discharge is yet observed (in this case E_0 was taken as the breakdown voltage for an application time of the order of 10^{-7} to 10^{-6} sec); t_f is the time of charge formation which is to be determined. The curve of variation in the electric field strength with time was obtained from the oscillogram. Thereby it was considered that the formation of the discharge begins when the field strength in the dielectric reaches the breakdown value for the application time of the order of $10^{-7}$to 10^{-6} sec.

The values of t_f obtained and also the values of E_t/E_0 and the mean velocity of the propagation of the discharge v for all the investigated dielectrics are given in the table. The data refer to a probability of breakdown $\psi = 90\%$.

Investigated dielectrics	NaCl	KCl	KBr	KI
E_t / E_0	1,27	1.3	1,55	1,57
t_f, 10^{-8} sec	1.7	1,6	2,2	2,1
V, 10^6 cм/sec	0.88	0,94	0.68	0.72



Duration of voltage action in secs

FIG. 2. Dependence of the dielectric strength of monocrystals KBr on the duration of voltage action for the case of uniform field.

For the voltage application time of 6 to 9 x 10^{-8} sec, 30 points were obtained for NaCl, 33 points for KCl, 16 points for KBr, and 12 points for KI.

The mean value of velocity of propagation of the discharge was computed according to the formula $V = d/t_f$ where $d = 0.15$ mm (the mean thickness of the samples at the breakdown point). The values of velocities obtained for the investigated solid dielectrics are a whole order of magnitude smaller than the velocities of propagation of electrons in air, while the field strength in the latter case is of the order of 10 times smaller. This can be explained by the fact that motion of electrons in a solid dielectric is considerably retarded by the high concentration of ions and their strong electrostatic influence upon the electrons.

As shown in Fig. 1, the time of the voltage drop at breakdown does not exceed 10^{-8} sec. We can refer to two stages of the breakdown in the investigated dielectrics. During the first stage of duration t the discharge is being formed. Conductivity during this stage is not high as indicated by the nonvarying form of the pulse. During the second stage, the conductivity rises very rapidly and the voltage across the sample drops.

Below are given values of the ratios E_t'/E_0 for the investigated monocrystals, where E_t' is the breakdown voltage for the duration of the order of 10^{-5} sec., and E_0 is the breakdown voltage for the duration of application of the order of 10^{-7}sec ($\psi = 90\%$)

	NaCl	KCl	KBr	KI
E_t' / E_0	1.13	1.18	1.11	1.01

We have also conducted experiments to determine the dielectric strength of rock salt for voltage pulses of duration of the order of 10^{-4} and 10^{-1} sec, and for constant voltages. The value of the dielectric strength for rock salt obtained in these experiments, within the limits of experimental error, turned out to be the same as for voltage durations of the order of 10^{-5} sec.

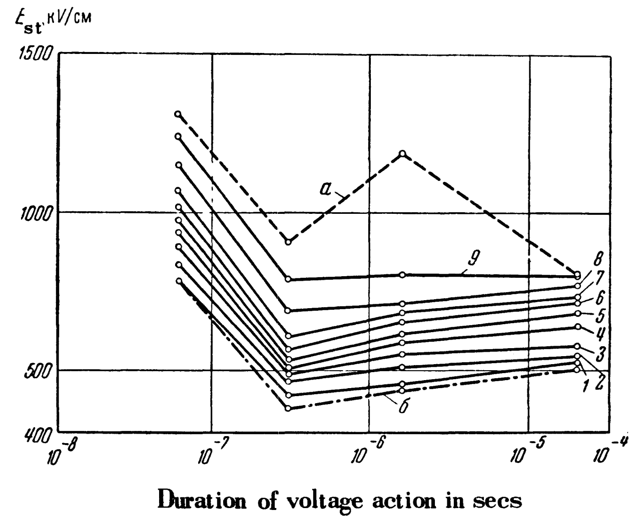


FIG. 3. Statistically treated dependence of the dielectric strength of monocrystals KI on the duration of voltage action for the case of uniform field: *a*-the boundary of maximum values; *b*-the boundary of minumum values; ψ is equal: *1*-10, *2*-20, *3*-30, *4*-40, *5*-50, *6*-60, *7*-70, *8*-80, *9*-90%.

Many investigators have obtained values for dielectric strength of solid dielectrics with constant voltages higher than with short pulses. The authors explain this fact by the action of volume charges. Thus Hippel and Alger[5] explain the increase in the dielectric strength of KBr for voltage duration of the order of 10^{-4} sec compared with shorter periods by the compensating effect of the negative volume charge formed by capture of electrons by the "knots" of the crystal lattice on the positive volume charge formed by

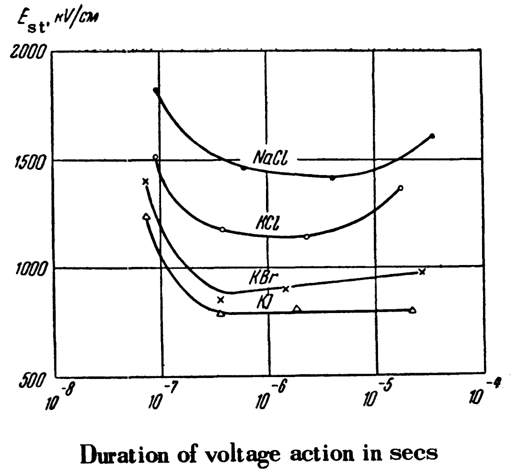


FIG. 4. Dependence of dielectric strength of monocrystals NaCl, KCl, KBr and KI on the duration of voltage action for the case of uniform field and for the probability of breakdown $\psi = 90\%$.

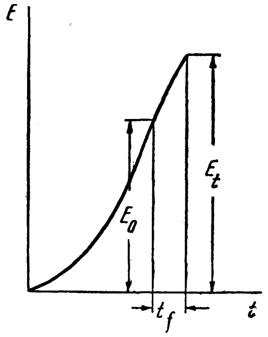


FIG. 5. A graph for the determination of the time of discharge formation.

the movement of positive ions. The negative volume charge by itself, according to these authors, lowers the breakdown voltage. Gochberg and Ioffe[6,7] consider that the volume charge produces in the dielectric a field opposite to the applied field. The mean voltage in the dielectric must thereby decrease and this, according to the authors, should lead to a rise in the dielectric strength of the dielectric. Fauler[8] supposes that the volume charge facilitates the removal of electrons from the cathode which should, according to Fauler's theory, lead to a lowering of the breakdown voltage. However, a lowering of the breakdown voltage with the increase of the duration of the applied voltage was observed only for calcite[9,10], where the volume charge is concentrated in the layers close to the electrodes.

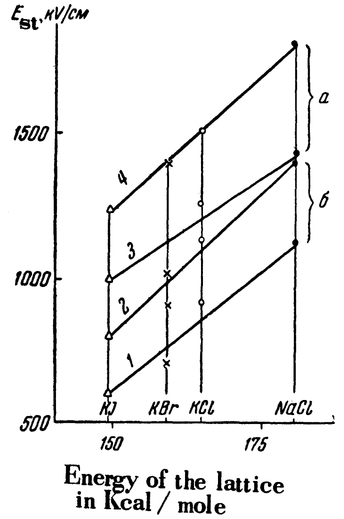


FIG. 6. Dependence of the dielectric strength on the energy of the lattice for NaCl, KCl, KBr and KI for breakdown with pulses. Duration of voltage application: *a*-order of 10^{-8} sec; *b*-order of 10^{-6} sec; ψ is equal: *1* and *3*-50%; *2* and *4*-90%.

The influence of volume charges is confirmed by the fact that the dielectric strength of solid dielectrics, in the case of simultaneous action of a steady and pulsed voltages of the same polarity, is greater than for the case of pulsed voltages alone.[11] The question arises: Is the time interval (of the order of 10^{-5} sec) sufficient for the formation of the volume charge? Is the rise in the breakdown voltage for application time of the order of 10^{-5} sec actually due to the influence of the volume charge? It is known that in air the mobility of ions is about a thousand times smaller than the mobility of electrons. If this relation is preserved in the investigated dielectrics, then, for an electron charge formation time of the order of 10^{-8} sec, the corresponding time required for the ions to move across the thickness of the dielectric is of the order of 10^{-5} sec, which is in agreement with our experiments.

In Fig. 6 there is shown the dependence of the dielectric strength of indicated crystals on the energy of the lattice for two different durations of applied voltage and for two values of probability of breakdown. The general type of this dependence agrees with what has been previously observed by Vorob'ev[12] for breakdown of crystals under constant voltage.

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