ELECTRICAL STRENGTH OF PRESSED LEAD AZIDE

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Some results of an experimental determination of the electrical strength of lead azide in relation to several physical factors (density, crystal size, air pressure, electrode surface, etc.) are given. A particular model of pressed lead azide is considered.

The breakdown of solids, liquids, and gases continues to attract the interest of investigators [1-5]. The investigation of the breakdown of two-phase systems is of interest. A representative of a two-phase dielectric is pressed lead azide – it consists partly of lead azide crystals and partly of air. An investigation of the breakdown of lead azide and the determination of the mechanism of breakdown are also of interest for the study of its sensitivity to an electric spark.

Description of Experiments. We used polished steel electrodes with tip radius 1.5 mm and an interelectrode distance of 0.05 to 0.5 mm, which ensured an almost uniform field at the point of least thickness of the dielectric.

The mean electric field between spheres was calculated from the approximate formula [6]

$$E = 0.9 \frac{U}{d} \frac{r + \frac{1}{2}d}{r} \tag{1}$$

Here U is the voltage applied to the electrodes, d is the minimum distance between the spherical surfaces, and r is the radius of the sphere.

The difference in electric field between spherical surfaces separated by a distance d and the electric field between parallel plates separated by the same distance d when the same voltage is applied to the electrodes in each case does not exceed 5% for the electrodes and interelectrode distances used.

The electrical strength was calculated by formula (1) from the values of the breakdown voltage and the interelectrode distance.

The breakdown voltage of the specimens was determined in two ways: a) by applying a static voltage to the electrodes and then gradually increasing it at a rate of approximately 100 V/sec; b) by applying a square pulse of length $2 \cdot 10^{-7}$ sec to the electrodes. The method of producing such a pulse with a long line was described in [7]. The breakdown voltage in the first case was determined with a kilovoltmeter connected in parallel with the spark gap. In the second case it was determined with an oscillograph. The interelectrode distance was measured with a measuring microscope.

Experimental Results. The electrical strength of pressed lead azide was different for different interelectrode distances and decreased with increase in the interelectrode distance. Figure 1 shows plots of the electrical strength E (in kV/cm) of pressed lead azide with a density of 2.4 g/cm^3 and air at atmospheric pressure against the interelectrode distance d; 1) for lead azide with a static voltage applied; 2 and 3) for air with a static voltage applied [2) is from the data of [9], 3) is from the results of the present work], 4) for lead azide with a voltage pulse applied; 5) for air with a voltage pulse applied. A comparison of these relationships shows that the electrical strength of pressed azide in the case of static and pulsed voltages is less than the electrical strength of air at atmospheric pressure; the electrical strengths of lead azide and air at atmospheric pressure increase with reduction in interelectrode distance; the relationships E = f(d) for air and lead azide have the same shape; the electrical strengths of air and pressed lead azide are 2.5-3 times greater when a voltage pulse is applied than when a static voltage is applied.

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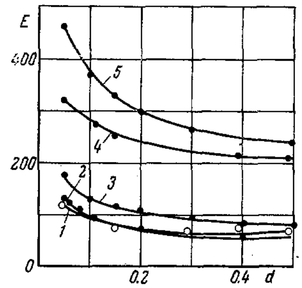

Fig. 1

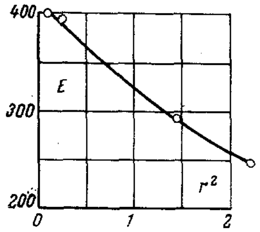

Fig. 2

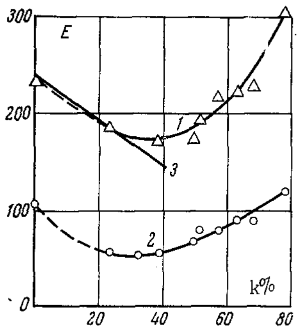

Fig. 3

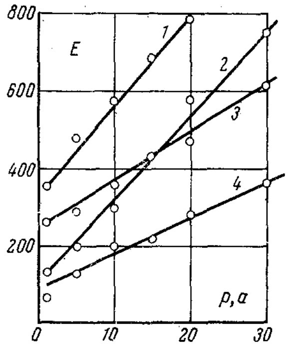

Fig. 4

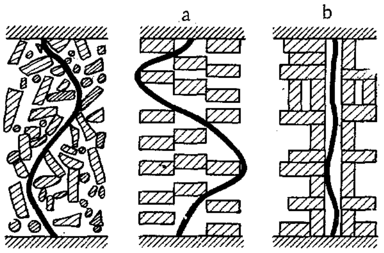

Fig. 5

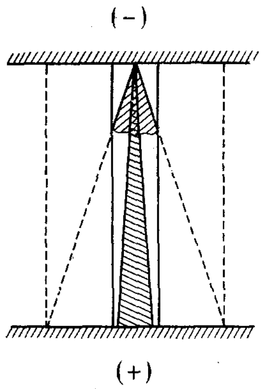

Fig. 6

We give data for the electrical strength of lead azide (density 2.7 g/cm^3) between electrodes with different tip radii (r) (d = 0.15 mm)

r = 0.3	0.5	1.2	1.5	(mm)
E = 400	390	290	250	(kV/cm)

The electrical strength of pressed lead azide decreases with increase in the tip radius of the electrodes.

Figure 2 shows the electrical strength E (kV/cm) of lead azide (density 2.7 g/cm^3) as a function of the square of the tip radius r^2 (mm^2) for an interelectrode distance of 0.15 mm. Figure 2 shows that an increase in the surface area ($S \sim r^2$) of electrodes near which a strong electric field is created leads to a reduction of the electrical strength of pressed lead azide.

Figure 3 shows the electrical strength E (kV/cm) of pressed lead azide as a function of the filling factor k (%): 1) for pulsed voltage; 2) for static voltage; 3) calculated from the formula. The broken line joins points corresponding to the electrical strengths of air and lead azide powder. Figure 3 shows that the electrical strength of pressed lead azide is lower if the filling factor is less than 70%, and higher if the filling factor is greater than 70%, than the electrical strength of air. With increase in the filling factor the strength first decreases a little (to k=38%) and then increases (the curve has a minimum); in the case of pulsed voltage the electrical strength is 2-2.5 times greater than in the case of static voltage.

To find out the effect of crystal size on the electrical strength, we prepared three precipitates of lead azide with different crystal size, which was determined from photomicrographs. For these three precipitates we give the electrical strength of pressed lead azide (density 2.7 g/cm^3) with different crystal size $\delta(\mu)$ for static (E^0) and pulsed (E^*) voltages (kV/mm)

$$(1)\ \delta = 0.3\text{—}1.0, \quad E^0 = 160, \quad E^* = 260$$
$$(2)\ \delta = 1.0\text{—}3.0, \quad E^0 = 140, \quad E^* = 240$$
$$(3)\ \delta = 4.0\text{—}7.0, \quad E^0 = 110, \quad E^* = 170$$

These figures show that the breakdown voltage decreases with increase in crystal size (for specimens of the same density).

With increase in air pressure in the range p=1 to p=30 atm the electrical strengths of air and pressed lead azide (density 2.4 g/cm^3) increase linearly for pulsed and static voltages. Figure 4 shows the relationships for: 1) air (pulsed voltage); 2) air (static voltage); 3) lead azide (pulsed voltage); 4) lead azide (static voltage). The electrical strength of air is greater than that of lead azide with density 2.4 g/cm^3.

Model of Pressed Lead Azide. Pressed lead azide consists of lead azide crystals of varying shape and size. The interstices between the crystals are occupied by air at the same pressure as the surrounding atmosphere. The solid phase of pressed lead azide occupies 20-90% of the volume, depending on the pressing pressure, crystal size, and size of the specimen; the rest of the volume consists of air. The fact that the electrical strength of pressed zinc azide increases with increase in air pressure indicates that breakdown takes place via the gas phase (via the air channels).

Breakdown probably takes place via a zig-zag air channel between crystals of different size randomly scattered throughout the volume, as Fig. 5, left, shows. For simplicity we will consider two models, each of which represents particular aspects of the true picture of breakdown: a) the crystals are in the form of parallelepipeds with their faces parallel to the electrode surface and to one another; a continuous air channel passes from one electrode to the other (Fig. 5a); b) the air channel is in the form of a cylinder with its walls formed by the crystals (Fig. 5b).

An increase in the filling factor (or density) due to an increase in pressing pressure will reduce the gaps between the crystals in model *a*, and will reduce the cross section of the air channel formed by the crystal walls in model b. We will consider how this will alter the field in the air channels in models *a* and b.

When the crystals are arranged as in model *a*, pressed lead azide can be regarded as a composite dielectric. For pulsed or alternating voltage (low dielectric loss) the electric field E_l in layer l of a complex dielectric consisting of n layers of thickness $d_1, d_2, \ldots, d_n$ with dielectric constants $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n$, respectively, will be

$$E_l^* = U\left(\varepsilon_l \sum_{i=1}^{n} \frac{d_i}{\varepsilon_i}\right)^{-1} \tag{2}$$

where U is the voltage applied to the electrodes.

Let the pressed lead azide consist of n lead azide layers and n air layers. We denote air layers by the subscript 1 and lead azide layers by the subscript 2. The field in air layer l will then be

$$E_{1l} = \frac{U}{\varepsilon_1}\left(\sum_{i=1}^{n} \frac{d_{1i}}{\varepsilon_1} + \sum_{i=1}^{n} \frac{d_{2i}}{\varepsilon_2}\right)^{-1} = \frac{U}{\varepsilon_1}\left(\frac{d_1}{\varepsilon_1} + \frac{d_2}{\varepsilon_2}\right)^{-1} \tag{3}$$

Here d_1 and d_2 are the total thicknesses of the air and lead azide layers, respectively. In the case of plane-parallel layers

$$\frac{d_1}{d_1 + d_2} = 1 - k, \qquad \frac{d_2}{d_1 + d_2} = k, \qquad d_1 + d_2 = d \tag{4}$$

where k is the filling factor of the lead azide.

Using (4) we find from formula (3) that

$$E_{1l} = \frac{U}{\varepsilon_1 d}\left(\frac{1-k}{\varepsilon_1} + \frac{k}{\varepsilon_2}\right)^{-1} \quad (5)$$

Taking

$$\varepsilon_1 \approx 1, \ \varepsilon_2 \approx 20, \ U / d = E$$

we obtain

$$E_{1l} = E(1 - 0.95k)^{-1} \quad (6)$$

The value of E is determined experimentally. If we assume that breakdown occurs when the field in the air channels reaches the breakdown value, then the electrical strength E of pressed lead azide will be given by the formula

$$E = E_0(1 - 0.95\ k) \quad (7)$$

where E_0 is the electrical strength of air for the particular pressure, interelectrode distance, and nature of the applied voltage.

In the case of model *a* the electrical strength of pressed lead azide will decrease with increase in the filling factor, which is actually observed experimentally up to $k = 32\%$.

In the air channel in model b the field is independent of the cross section of the cylindrical channel if the channel walls are oriented in the direction of the field, and is given by $E = U/d$. A reduction of the cross section of the air channels should, however, lead to an increase in electrical strength for the following reasons. The breakdown of air is due to individual elementary avalanches formed from a single electron. An electron avalanche is a cone with its base at the anode. From the point of appearance of the parent electron the avalanche expands due to diffusion of the electrons. The radius of the cross section is given by the equation

$$r = \sqrt{2Dt} \quad (8)$$

where D is the diffusion coefficient, and t is the time of propagation of the avalanche. The radius of the avalanche depends on the field: It decreases with increase in the field. If the channel radius becomes less than the avalanche radius, the further development of the avalanche will be inhibited, since the electrons will give up all, or part, of their kinetic energy to the walls (Fig. 6). In such conditions breakdown will require an increase in field to reduce the diameter of the elementary avalanche. Thus, a reduction in the cross section of the air channels leads to an increase in electrical strength. An increase in electrical strength due to an increase in the filling factor was experimentally observed for $k > 35\%$.

In fact (Fig. 5, left), an increase in the filling factor (or density) will lead to narrowing of the air channels and to an increase in the electric field. The electrical strength will be determined by the combined effect of these two factors.

A consideration of the model of pressed lead azide and a calculation of the electric field indicate that the experimental relationship between the electrical strength of pressed lead azide and the filling factor (curve with a minimum) can be attributed, firstly, to the fact that the field in the air channels is greater than the field which would be produced in the same spark gap with the same potential difference if the lead azide crystals were absent and, secondly, to the effect of the cross section of the air channels on the breakdown voltage. When $k < 33\%$, the electrical strength of pressed lead azide decreases with increase in k, with the result that the electric field in the air channels increases. When $k > 33\%$, the electric field continues to increase with increase in k, but the predominating factor is the increase in breakdown voltage due to reduction of the cross section of the air channels, which leads to an increase in the electrical strength of pressed lead azide. An increase in breakdown voltage with reduction of the cross section of the air channels was observed by A. Gemant [8], who conducted experiments with paraffin plates in which air channels of known section were made. The reduction of the cross section of the air channels is responsible for the increase in electrical strength of pressed lead azide with reduction in crystal size (specimens of same density).

The electrical strength of pressed lead azide decreases with increase in electrode area or interelectrode distance, which increases the volume of dielectric with a high prebreakdown electric field. The greater the volume of dielectric between the electrodes the greater the probability of appearance of a weak spot, which leads to a reduction of the electrical strength of pressed lead azide. A relatively wide air channel can be regarded as a weak spot when the electric field is increased.

A comparison of the experimental and calculated data indicates that the breakdown of pressed lead azide takes place via the air channels when the electric field in them is increased.

The established relationships for the electrical strength of pressed lead azide will obviously apply also to several other two-phase dielectrics (pressed powders, nonimpregnated paper, porous ceramics, etc.).

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