Singularities of the temperature dependence of threshold voltages in nematic liquid crystals

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The difference between the domains produced in alternating and constant electric fields is revealed for the first time. It is shown that the threshold intensity of a constant electric field depends little on the temperature, so that domains can be observed in the entire temperature range. A photograph is presented of the domains existing at $t = -60°C$. In an alternating field, at definite frequencies, the threshold rises rapidly with decreasing temperature and no domains appear in nematics below these temperatures.

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We investigated the effects of temperature on the threshold voltage at which domains are produced in nematics. The threshold voltage was determined visually from the onset of domains[1] or of low-frequency electrohydrodynamic instability in a thin (15 μ) layer of the liquid crystal, and was measured with a VK-7-9 vacuum tube voltmeter. The sample was examined in a polarization microscope. At the steady-state temperature, an electric field of threshold intensity was applied and the picture of the appearance of the domains was observed, after which the field was turned off, the sample was cooled to the next temperature, and the observation of the appearance and vanishing of the domains was repeated.

The sample was cooled from room temperature with liquid nitrogen. The temperature was measured with a chromel-alumel thermocouple with the aid of a PP-63 bridge. The experiments were performed on the substance ZhK-440 (mixture consisting of two-thirds *p-n*-butyl-*p'*-methyloxyazoxybenzene and one-third *p-n*-butyl-*p'*-heptanoyloxybenzene), and on a mixture of MBBA with EBBA. In a large volume, the ZhK-440 had a nematic phase in the temperature range-20—75 °C. [2] We have established a heretofore unknown fact, that in sufficiently thin layers, $h \leq 30\ \mu$, ZhK-440 had a stable phase in the temperature region − 60—75 °C. Below − 60 °C, the substance became vitreous. This has made it possible to investigate the dependence of V_n on the temperature in this substance. In the mixture of MBBA with EBBA, the crystallization started at the usual temperatures near − 10 °C. The ZhK-440 had a conductivity, according to the data of[2], 10^{-12} $(\Omega\text{-cm})^{-1}$ and was doped with a conducting additive to 10^{-10} $(\Omega\text{-cm})^{-1}$, with conductivity ratio $\sigma_{\parallel}/\sigma_{\perp} \approx 1.8$, the dielectric anisotropy, according to[2], being ≈ -0.4. The mixture of MBBA with EBBA was also doped to $\sigma \approx 10^{-10}$ $(\Omega\text{-cm})^{-1}$.

We measured the temperature dependences of the threshold voltages V_n in constant electric fields and in low-frequency electric fields at frequencies 20, 40, 80, 200, and 400 Hz (Fig. 1). The measurements revealed a singularity in the behavior of the threshold voltage V_n when a nematic liquid-crystal layer was excited by a constant electric field (line of Fig. 1). Just as in ZhK-440, the threshold voltage of the mixture of MBBA with EBBA remains unchanged with decreasing temperature until the nematic goes over into the solid phase, and remains equal to 7—8 V for ZhK-440 and 5—6.5 V for the MBBA—EBBA mixture. The increased threshold of ZhK-440, by approximately 1 V, is

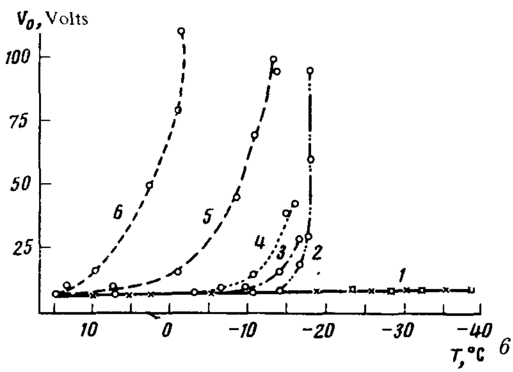

FIG. 1. Dependence of the threshold voltage V_n on the temperature t(°C): 1—constant electric field: ×—ZhK-440; ○—MBBA + EBBA mixture; 2—ZhK-440, alternating electric field f = 20 Hz; 3—MBBA + EBBA, f = 20 Hz; 4—MBBA + EBBA, f = 80 Hz; 5—ZhK-440, f = 200 Hz; 6—ZhK-440, f = 400 Hz.

apparently due to the orientation of the molecules in the liquid-crystal layer away from planar and closer to normal with decreasing sample temperature. When the liquid crystal is excited by an alternating electric field, a strong dependence of V_n on the temperature of the liquid-crystal layer was observed at each frequency f in a definite temperature interval (curves 2—6 of Fig. 1). A low frequency calls for a lower temperature (≈ − 15 °C), and in this case V_n rises steeply at practically constant temperature. The maximum value of V_n (95 V) is reached after approximately 2.5—3 min. With increasing frequency, the temperature interval of the variation of the threshold voltage expands and shifts towards higher temperatures, where the growth curve of the threshold voltage is less steep.

The theory of electrohydrodynamic instabilities of nematic liquid crystals have by now been sufficiently fully developed.[3] The rise of the threshold voltage with decreasing temperatures can be qualitatively explained by this theory. It appears that the jump of the threshold voltage at f = 20 Hz is due to the abrupt increase of the viscosity coefficient, and also to the anisotropy of the viscosity. As shown by Pikin and Shtol'berg,[4] the threshold voltage V_n depends strongly on the viscosity anisotropy, and at certain values of η_1 and η_1^* the domain texture may not appear at all, a fact observed in experiments with an alternating electric field. The less steep growth of the threshold voltage with decreasing temperature at f = 200 and 400 Hz is probably due not only to a change in the viscosity coefficients of the materials, but also to a decrease of the active current components with increasing frequency.

What remains unexplained is why the threshold voltage is constant when the temperature is varied and the sample is excited with a constant electric field. It is probable that in this case the domains are the result of accumulation of space charge inside the liquid-crystal layer. Then, owing to the anisotropy of the electric conductivity and the negative dielectric anisotropy of the liquid

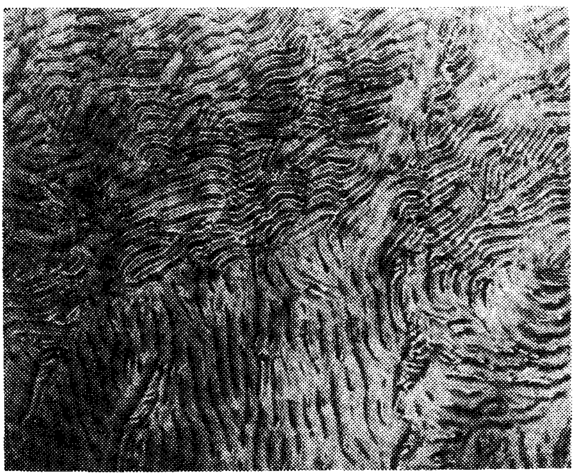

FIG. 2. Appearance of domains at t = − 60 °C. Crossed Nicol prisms. The narrow and broad domains correspond to parallel and perpendicular orientation of the polarization plane of the transmitted light, respectively.

crystal, the space charge becomes unevenly redistributed over the volume of the liquid-crystal layer. Contributing to this effect is also the fact that the current-conducting additive dissociates into ions, the radii of which are strongly different. Consequently, the ions have different mobilities in the electric field. The internal electric field which is unevenly distributed over the sample leads, as a result of the action of the inverse piezoelectric effect, to the onset of deformations in the liquid-crystal layer. These deformations visualize, in turn, the distribution of the space charge over the sample and take the form of the domains shown in Fig. 2. Thus, experiment demonstrates that the theory of electrohydrodynamic instabilities in liquid crystals[3] cannot be used when constant fields are employed, and the theory of the flexoelectric formation of domains, developed by Derzhanskiĭ *et al.*[5] is more valid here. This is confirmed also by the fact that at low temperatures there is no flow in the liquid-crystal layer, but domains are produced.

The main conclusion of our present paper should be taken to be the fact that we have obtained for the first time domains at low temperatures and have displayed the difference between the electrohydrodynamic and electrostatic behavior of a liquid crystal.

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