Infralow-frequency anomaly in the dielectric constant of a nematic liquid crystal

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An anomalous increase (up to 10^5) has been discovered in the dielectric constant of the nematic liquid crystal ZhK-440 in the frequency range 10^{-3}–1 Hz. A model of a diffusion-drift transport must be used in thin layers of liquid crystals.

The anisotropy of the dielectric constant of a nematic liquid crystal is known to be determined by the presence of a molecular order.[1] The dielectric properties of a nematic liquid crystal are not ideal because of the presence of ionized impurities, those which can be eliminated by purification and those which arise in the course of electron transfer at the interface between the nematic liquid crystal and the electrode. If ions are concentrated in bounded regions in the liquid crystal, strong electric fields arise; these fields are capable of influencing the local value of the order parameter.[2] The transport and clustering of current carriers in partially ordered media—a category including nematic liquid crystals—constitute an extremely interesting field of the physics of condensed matter, which requires far more experimental work.[3–5]

In the present letter we report the experimental observation of a sharp increase in the real part of the dielectric constant of ZhK-440, which is a mixture of azoxybenzenes. An alternating voltage with an amplitude no higher than the threshold for the onset of an electrohydrodynamic instability is applied to a thin layer of the nematic liquid crystal (30–100 μm thick) from a G6-15 oscillator. A stroboscopic measurement system is used to determine the amplitudes of the active and reactive components of the current. The total error of these measurements is less than 12%.

Figures 1 and 2 show the frequency dependence $\epsilon' = \epsilon'(\omega)$ for samples 30 and 90 μm thick, respectively. The results can be described quite well by a function $\epsilon' \sim \omega^{-\alpha}$, where α is in the range 1.1–1.7. At frequencies 1–10 Hz we observe a change in the slope of $\epsilon'(\omega)$. We denote the point of this change in slope as $\omega_{\max}$. We find the value of this frequency by extrapolating the straightened part of the curve to the point where it intersects the level of the rf value, $\epsilon'_{\rm rf} = 5$, for ZhK-440. The experimental results indicate that $\omega_{\max}$ is proportional to the average field in the sample, $E_{\rm av}$. What behavior of $\omega_{\max}(E_{\rm av})$ should we find in the case of an ion-migration polarization of the nematic liquid crystal? A simple calculation leads to the functional dependence

$$\omega_{\max} = (2/\pi d)(V_m n^{1/3}), \qquad (1)$$

where n is the concentration of ions in the nematic liquid crystal, d is the thickness of the crystal layer, and V_m is the amplitude of the sinusoidal signal applied to the sample. Clearly, the calculated field dependence $\omega_{\max}$ is in complete agreement with the experimental observations. It can therefore be asserted that the ion-migration po-

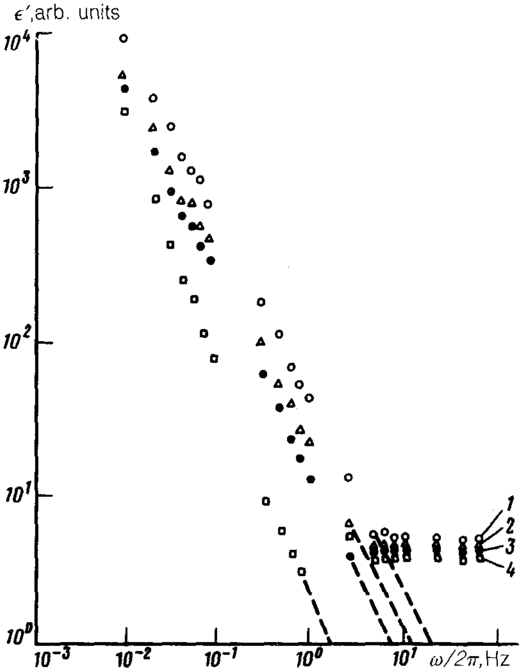

FIG. 1. Frequency dependence of the dielectric constant of the nematic liquid crystal ZhK-440 for a layer 30 μm thick in the following fields: 1—3.3×10^5 V/m; 2—6.6×10^5 V/m; 3—1.3×10^6 V/m; 4—2.6×10^6 V/m.

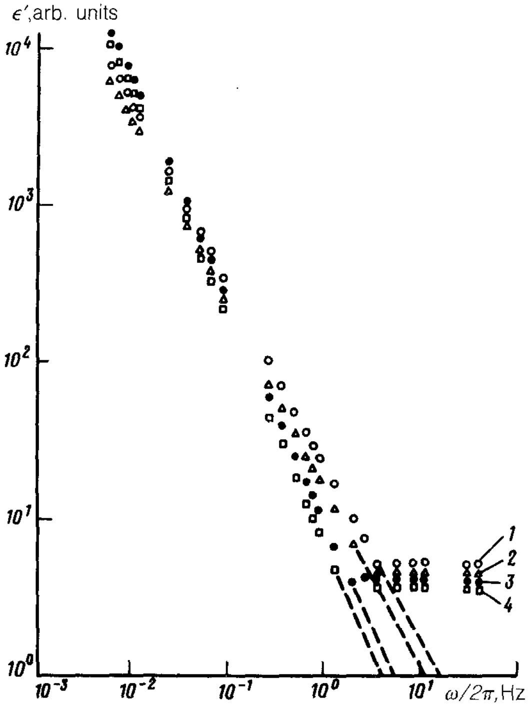

FIG. 2. Frequency dependence of the dielectric constant of the nematic liquid crystal ZhK-440 for a layer 90 μm thick in the following fields: 1—1.1×10^5 V/m; 2—2.2×10^5 V/m; 3—4.4×10^5 V/m; 4—8.8×10^5 V/m.

larization plays an important role in these samples. We can also use the results of these experiments and the known electrical conductivity of ZhK-440, $\sigma = 2.66 \times 10^{-9}$ S/m, to estimate the ion density. The ion mobility does not exceed 2.6×10^{-11} $m^2/(V \cdot s)$. The density which we are seeking lies in the range 6.3×10^{-20}–1.9×10^{23} m^{-3}. It is interesting to analyze these results on the basis of the Gritsenko-Moshel' model, which is used in describing the polarization of nematic liquid crystals.[6] The time dependence of the current in this model is written in the form

$$I(t) = qn(t)\mu S[V(t) - Q(t)/C], \tag{2}$$

where $Q(t)$ is the charge which is concentrated in a part of the nematic liquid crystal near a contact. This expression holds at frequencies $\omega < \omega_{\max}$. In the limiting case of a low carrier density and a significant capacitance of the electrode region, we should observe no polarization at infralow frequencies—in contradiction of experiment. Furthermore, the absence of a diffusion term from (2), despite the need for such a term at infralow frequencies, as stressed by Klimontovich,[7] demonstrates that the Gritsenko-Moshel' model is incomplete.

We believe that an alternative approach to the problem should include a numerical simulation of the complete system of equations consisting of the Poisson equation and the equations of a diffusion-drift equilibrium.

The results if this study show that it is possible to observe an anomalously large dielectric response of a nonideal nematic liquid crystal, with the result that regions of an elevated field may arise. Such regions are capable of serving as centers of a local reorientation of the director. It has also been shown here that a rigorous approach must be taken in a description of transport phenomena and charge buildup in thin layers of nematic liquid crystals.

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