Low-frequency electrohydrodynamic instability in nematics

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A new low-frequency electrohydrodynamic regime in *p*-azoxy-anisole is described. The domains oscillate at double the field frequency, have an anomalously low threshold voltage, and their width exceeds the sample thickness. The empirical dependences of the threshold characteristics on the electric field frequency and sample thickness are determined.

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INTRODUCTION

It is known that in planar nematic textures there exists two regimes of electrohydrodynamic (EHD) instability[1,2]: with constant curvature of the orientational deformation ψ, and with oscillating curvature $\psi \sim \cos\omega t$. In the first case oscillation of the space charge q takes place and is due to the anisotropy of the electric conductivity. Williams domains are then observed with three different focal distances.[3] Therefore in the upper focusing position of the microscope the neighboring focal lines have different widths.[4] Usually the regime with $\psi = \text{const}$ is called the conduction regime.

In the case of the oscillating regime, the curvature ψ and the direction of the vortical flow vary with frequency ν of the electric field. The charge is practically constant. Therefore, light passing through the domains is modulated at double the field frequency, and the upper focal lines have identical widths. Such a regime was named dielectric.[1,2]

It was noted[4,5] that in nematic *p*-azoxyanisole (PAA) there exists a regime in which the threshold voltage V_{thr} is practically independent of the frequency (plateau). It can be assumed to be really the conduction regime ($\psi = \text{const}$), inasmuch as $\omega\tau < 1$ on the corresponding frequency interval from hundreds of Hz to several kHz, where $\omega = 2\pi\nu$ and τ is the time of the dielectric relaxation. It was noted earlier,[6] however, that in unoriented layers of PAA modulation of the transmitted light takes place with a frequency 2ν at precisely the lower frequency. The depth of modulation at 20 Hz and lower reached 90%, and decreased rapidly at higher frequencies.

Anomalous phenomena were observed also in methoxy-benzylidene-butylaniline (MBBA) at frequencies lower than 10 Hz. It was noted that the threshold voltage decreases rapdily with decreasing frequency,[7] and it was proposed[8] that both ψ and q depend on the time.

Thus, certain facts offer evidence of a nontrivial character of the EHD instability at low frequencies in ordinary planar textures. We have therefore undertaken an investigation of the characteristics of the low-frequency regime in nematic PAA.

EXPERIMENTAL RESULTS

The sample was placed in a cell having two elecrodes—glasses coated with SnO_2. The glasses were polished beforehand to produce a planar texture.

In the interval from 200–500 Hz to 2–3 kHz the threshold voltage V_{thr} remained practically unchanged with changing frequency ν and with changing sample thickness d (the plateau section). The period λ of the domains was somewhat smaller than double the thickness $2d$. For example, for $d = 30\,\mu\text{m}$ and $V_{\text{thr}} \approx 10$ V we have $\lambda = 50\,\mu\text{m}$ at 120 °C.

A decrease of the frequency below 200 Hz leads to an increase of λ. Below 120 Hz the period becomes larger than $2d$ and increases further to 178 μm at 20 Hz. Simultaneously, V_{thr} decreases from 10 to 2 V at 20 Hz. Thus, in the low-frequency regime one observes an anomalously larger period of the domain and an anomalously low threshold voltage. The threshold characteristics $V_{\text{thr}}(\nu)$ for samples with different thicknesses (Fig. 1) can be described by the relation

$$V_{\text{thr}}(\nu, d) = V_{\text{thr}}(\nu, 0) + cd.$$

The coefficient $c \approx 0.023\,\text{V}/\mu\text{m}$ at 120 °C. The threshold-voltage component that depends only on the frequency can be represented by straight lines when plotted in appropriate coordinates (Fig. 2). It is possible to choose the following empirical formulas:

$$V(\nu, 0) \approx A_1 \exp \alpha\nu \quad \text{for} \quad 20 \leqslant \nu \leqslant 50\ \text{Hz},$$
$$V^2(\nu, 0) \approx B_1(\nu - \nu_1) \quad \text{for} \quad 50 \leqslant \nu \leqslant 100\ \text{Hz},$$
$$V^2(\nu, 0) \approx B_2(\nu - \nu_2) \quad \text{for} \quad 100 \leqslant \nu \leqslant 200\ \text{Hz}.$$

It is similarly possible to present the $\lambda(\nu)$ dependence for different frequency intervals (Fig. 3). The corresponding empirical formulas are

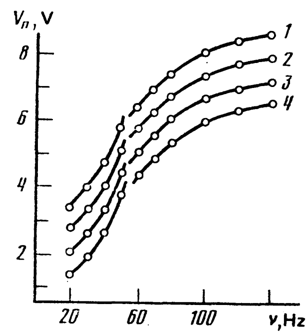

FIG. 1. Dependence of the threshold voltage on the frequency at different sample thicknesses: 90 μm (1); 60 μm (2); 30 μm (3); extrapolation to "zero" thickness (4) (120 °C).

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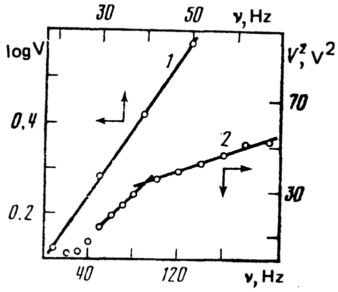

FIG. 2. Threshold voltage $V(\nu,0)$ plotted in different coordinates: $\log V(\nu)$—1, $V^2(\nu)$—2.

$$\lambda \approx B\nu^{-2/3} \quad \text{for} \quad 20 \leqslant \nu \leqslant 60 \text{ Hz},$$
$$\lambda^{-2} \approx A_1(\nu - \nu_1) \quad \text{for} \quad 60 \leqslant \nu \leqslant 100 \text{ Hz},$$
$$\lambda^{-2} \approx A_2(\nu - \nu_2) \quad \text{for} \quad 140 \leqslant \nu \leqslant 200 \text{ Hz}.$$

Visual observations have shown that segments of linear domains move constantly perpendicular to the focal lines. Therefore the period λ of the domains was determined from the diffraction pattern. In the upper focusing position of the microscope, the focal lines of the domains had equal widths. Light passing through the sample was modulated at a frequency 2ν. With increasing frequency, the ampltiude of the light-scattering peaks decreased, and on the "plateau" the modulation of the light vanishes. The amplitudes of the light-scattering peaks alternate in size. With increasing voltage above the threshold, the general level of the light scattering increases, and the ampltiude of the peaks decreases. At voltages approximately 10 V the modulation of the light vanishes in the entire frequency interval.

DISCUSSION OF RESULTS

The data obtained points to a new regime of EHD instability in the low-frequency region. The oscillation of the curvature makes it related to the "dielectric" high-frequency regime. Dependences of the type $V^2_{\text{thr}} \sim \nu$ and $\lambda^{-2} \sim \nu$ (for two frequency intervals) are similar to the frequency characteristics of the dielectric regime. On the other hand, the threshold voltage is not directly proportional to the thickness but is connected with the latter in a more complicated manner.

The appearance of an oscillating regime is directly connected with the increase of the period λ (or of the width $a = \lambda/2$ of the vortex tube of the domain). In the region of the plateau, the width a is always less than d. On the other hand, increasing the frequency leads to a decrease of the width of the Williams domain, but it always remains within the limits $d/2$. It is probable that the stationary vortical flow has a quasicylindrical shape, i.e., the dimensions along the x and z axes should be approximately equal. If $a > d$, the vortex tube loses its cylindrical shape. This should take place in practice already at values of a close to d, since the flow velocity near the walls cannot be maximal.

In contrast to the Williams-domain regime, the oscillating one is not rigorously connected with the sample thickness. It is known[2] that the width of the oscillating domains does not depend on the thickness and can be much less than d. Thus, the oscillating flow may not have a cylindrical shape.

The transition to the oscillating flow is actually accompanied in our case by an excess of λ above the value of the period on the plateau, and with further decrease of the frequency the domain width a becomes larger than d.

Usually the condition $\omega\tau < 1$ makes possible an anisotropic mechanism of Williams domains, but does not exclude fully the mechanism of oscillating domains. Indeed, the charge-oscillation process can take place only at sufficiently large voltages. If the threshold of the oscillating domains is lower than the threshold of the Williams domains on the plateau, they can precede the Williams domains. This is precisely the situation observed in experiment: when V increases to voltages typical of the plateau regime, the modulation gives way to a uniform rise of the light-scattering level.

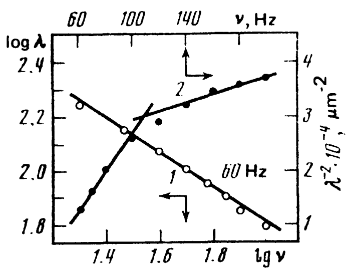

FIG. 3. Dependence of the period of the domains on the frequency in different coordinate axes: $\log \lambda$ ($\log \nu$)—1; $\lambda^{-2}(\nu)$—2; (120 °C, 30 μm).

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