Nonlinear effects in nematics above the threshold of the electrohydrodynamic instability

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It is shown that by bringing nematic liquid crystals (NLC) with "weak" surface interaction to a state of advanced turbulence it is possible to obtain a stable reversible change of the initial homogeneous orientation.

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The behavior of NLC near the threshold of the electrohydrodynamic (EHD) instability U_0 at low frequencies ($\omega < \omega_c \sim 1/\tau$, where τ is the relaxation time of the space charges) depends significantly on the boundary conditions.[1,2] When the voltage is increased above the threshold value, the stationary flow is destroyed (dynamic scattering regime), and a transition to advanced turbulence [regime of secondary dynamic scattering (SDS)][3,4] takes place at $U_2 \approx 4U_0$. We deemed it of interest to ascertain the influence of the boundary conditions on the hydrodynamic behavior of the nematic above U_0.

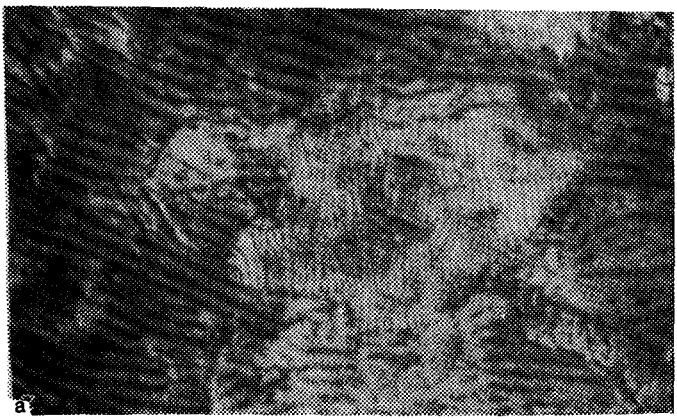
We have investigated the advanced turbulence regime (ATR) and its relaxation properties as functions of the character of the interaction of the NLC molecules with the surface.

We investigated MBBA samples and mixtures of azoxy-compounds (ZhK-440) with $d = 15$–$20\,\mu$m, doped by tetrabutylammonium-bromide ion impurity. The electric conductivity σ of the samples, measured with alternating current ($f = 1$ kHz), was 10^{-8}–$10^{-9}\ \Omega^{-1}\,\mathrm{cm}^{-1}$.

It is known[1,6] that chemical purification of the surfaces of current-conducting glasses contributes to homotropic alignment of the nematic and to reduction of the energy of the binding to the surface, whereas surface treatment by rubbing in leads to a planar orientation. Combining the two treatment methods in unequal degrees, we obtained cells with initial planar orientation but with different cohesion energy. As will be shown below, depending on the observed EHD effects, they can be subdivided into cells with "weak" and "rigid" anchoring.

It has been observed that if a planarly oriented NLC layer (state I) with "weak" surface anchoring is transformed to the SDS regime at low frequencies and the field is removed, then the sample relaxes to a new stable state (II) with the director having an oblique direction in space. This is evidenced by the changes of the capacitance and conductivity of the cell and by polarization microscopic observations. Thus, the change of σ amounts to $\sim 20\%$, which corresponds to a change of the molecule inclination angle by approximately 30°. The transparency of the sample in crossed Nicols is then decreased by a factor 2–3. In this case, at the threshold value $U_0' \approx U_0$, "longitudi-

nal" domains are produced, and they also attest to the oblique orientation.[2,6] We note that the propagation of the SDS over the sample has a finite velocity that depends on U.[7] Therefore, if the field is turned off at an instant when the SDS has propagated only over a fraction of the sample area, the individual regions are formed with differ-



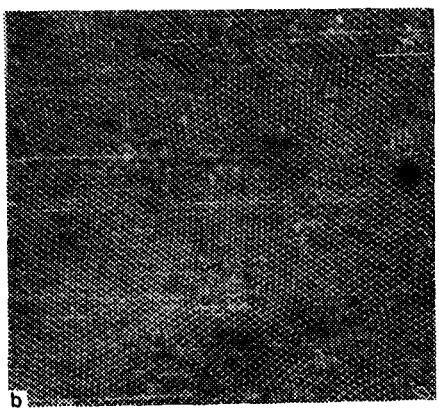


FIG. 1. Photographs of modulated structures: a) ZhK-440, $d=20\,\mu$m, $f=60$ Hz, $U=8$ V; b) MBBA, $d=15$ μm, $f=500$ Hz ($f_c=650$ Hz), $U=50$ V. $\mathbf{n}_0$ is the initial orientation of the director.

ent orientations (I and II). Figure 1(a) shows domains produced on sections with I (Williams domains) and II (longitudinal domains) with initial orientation.

It has been established that the sample can also be brought back from the state II to the state I by turning on the SDS regime at high frequencies.

When a cell in state I is acted upon by a definite field ($1.5U_0 \lesssim U_1 < 2U_0$), a stationary reticular pattern is produced [Fig. 1(b)]. This structure corresponds to coexistence of Williams domains and "longitudinal" domains. This possibility, which is connected with a finite inclination of the molecules in Williams domains, was noted in[6]. This structure, which corresponds to a transition to three-dimensional flow,[6,7] exists in a relatively narrow range of voltages and gives way to a turbulent-like flow. On cells with "rigid" anchoring, the effects described above are not observed, and after going over into the SDS regime the nematic relaxes to the initial state.

Important information on the character of the surface and volume orientation of the molecules in the dynamic regime is gained from a study of the relaxation time τ_p

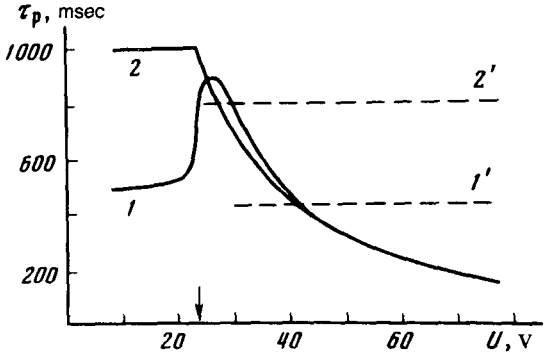


FIG. 2. Dependence of the relaxation time on the voltage ($f = 100$ Hz) for the case of "weak" anchoring to the surface: ZhK-440, $d = 15$ μm, 1,1'—initial state I; 2,2'—state II; 1',2'—plotted to the SDS. The arrow marks the instant when the field is turned on.

of the nematic to the equilibrium state after the field is turned off (Fig. 2). The value of τ_p measured prior to the transition to the SDS regime (curves 1 and 2) does not depend on U and is minimal in the case of state I. The initial orientation for both states is then restored. In the SDS regime for state II, the decrease of τ_p with increasing U is described by the relation $\tau_p \sim U^{-K}$, where $K \approx 1.6$. For state I, with increasing $U_0 > U_2$, the value of τ_p first increases, and then the $\tau_p(U)$ curves for both states coincide, with the NLC relaxing to state II.

This realignment of the molecular orientation can be explained by taking into account the singularities of the gas dynamic behavior of the nematic in the SDS regime[3,4,8] and the character of the interaction of the molecules with the surface. In the SDS regime at low frequencies, the flow consists of vortices that are elongated in the direction of the applied field and have a period that decreases with increasing U,[8] and this leads to an appreciable deviation of the director from planar orientation. The possibility of observing the orientations of the near-surface layers in the course of the transition to the SDS regime was noted in[4]. This should lead to the vanishing of the scale of the turbulent pulsations of order d, and the principal scale r in the SDS regime now becomes the quantity $r \sim K^{1/2}E^{-1}$, where K is the elastic modulus and $E = U/d$. Accordingly the time is $\tau_p \sim \gamma r^2/K \sim \gamma E^2$, where γ is the characteristic viscosity.

The difference in the character of the NLC relaxation is apparently due to the fact

that under conditions of "weak" anchoring it is possible to have in the surface layer two equilibrium molecule orientations, one of which is oblique. Therefore the orientation that is strongly perturbed in the SDS regime relaxes to the state II. At the same time, in a high-frequency field ($\omega \gtrsim \omega_c$) there is turned on a "dielectric" mechanism that contributes to an orientation close to planar, owing to the negative value of the dielectric anisotropy. Regardless of the initial state, when the SDS is turned off the sample relaxes to the state I.

Cells with "rigid" anchoring are characteristized by an increase of τ_p with increasing $U > U_2$[4] and by a resumption of the state I.

We have thus demonstrated the possibility of obtaining two homogeneous states having different transparencies (the "memory" effect).

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