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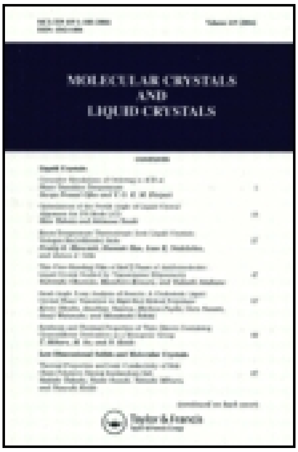

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Auto-Waves in Liquid Crystals. II. Uniform Fast Oscillating Flows

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AUTO-WAVES IN LIQUID CRYSTALS. II. UNIFORM FAST OSCILLATING FLOWS

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Abstract The nonlinear effects of interaction between shear acoustic wave and the director field in nematic liquid crystal have been investigated. The nonstationary vortex lattice formation has been found. The individual vortex centers are sources of orientational waves. The interference, diffraction by obstacle and reflection at interfational boundary were studied. It has been shown that the wave process has the properties of autooscillations.

Keywords: auto-waves, nematic liquid crystals, domain oscillation

INTRODUCTION

It is known[1] that the director reorientation occurs when the shear waves of small intensity propagate in nematic liquid crystal (NLC). The typical examples of such interaction are the director oscillation with double frequency of external perturbation[2] and the stationary reorientation of director[3] in the NLC. However, the director field distorsion damps with increase of the shear frequency sharply, as $\delta n \simeq \omega^{-2}$. Therefore, the nonlinear effects of interaction between the shear wave and the director field become considerable at the high frequency and the great intensity of acoustic wave.

In this paper, we study the nonlinear interaction between shear oscillations and the director field of NLC placed in external dc-electric field.

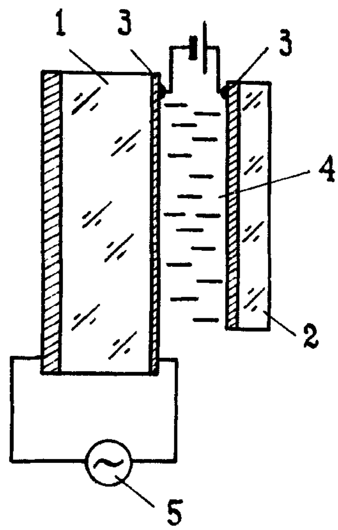

FIGURE 1. The scheme of experimental LC-cell. 1-the acoustic transducer; 2-quartz plate; 3-the conductive coating; 4-NLC; 5-the generator of ac-electric field.

EXPERIMENTAL

The sandwich-type LC-cells were used in our experiments (Fig.1). The NLC-layer was placed between the acoustic transducer and the transparant quartz plate with conductive coatings. The thickness of LC-layer h was $2 \div 5\times10^{-3}$ cm. This cell allows to act on the NLC by the acoustic and the electric field simultaneously. The crystal $Bi_{12}GeO_{20}$ with the piezocoefficient $e_{ii} \simeq 6\times10^{-6}$ $(dynes)^{1/2}$ was used as source of the shear waves. To observe these phenomena, the polarized-optical microscope with the spectrophotometric adapter has been used. The homeotropic and planar layers of MBBA with negative dielectric anisotropy have been studied.

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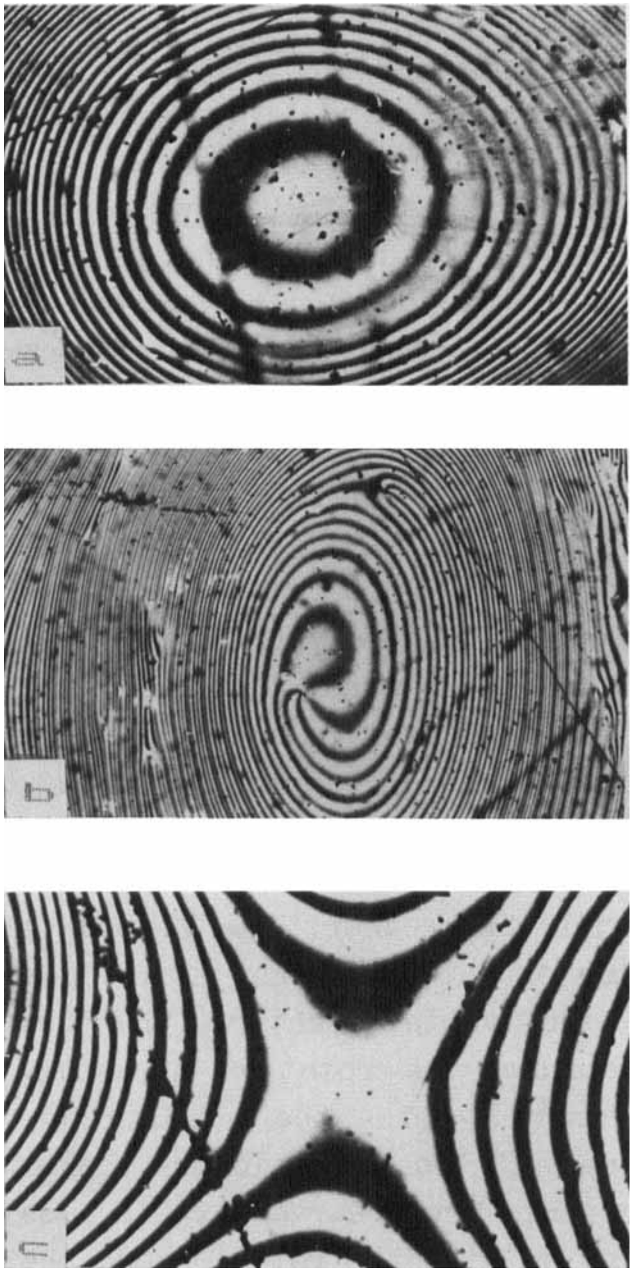

FIGURE 2. The micrographs of vortex centers: a) the leading center; b) the reverberation; c) the interaction of auto-waves, generated by the four leading centers.

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RESULTS AND DISCUSSION

It is well known[4] that due to Freedericksz transition in homeotropic layer of MBBA at applied voltage U_x=1,6 V the reorientation of director occurs. When dc-voltage U_k=40 V was applied to the acoustic transducer, the continuous generation of disclinations with Frank indices m=±1 has been observed. These disclinations have been found to move in the plane of the LC-sample coaxially with respect to each other bearing some resemblance to orientational wave. We have classified the wave sources as the leading centers and the reverberations (Fig.2a,b). The vortex sources form two-dimensional lattice with the average lattice spacing a=0,3 cm. The disclinations are generated over each period of director rotation. The annihilation of disclinations occurs in two ways. The first way is the annihilation of disclinations in the place, where four elements of lattice interact with each other. The second one is the annihilation of disclinations with opposite signs far from the vortex center. The next simple experiment shows the rotation of director. When the analizer and the polarizer rotate simultaneously the stationary pattern of concentric rings are observed. It is possible when the velocity of director rotation and the velocity of nicol rotation are equal to each other. It has been found that the velocity of director rotation depends on the amplitude and frequency of shear wave and on the applied voltage. The voltage dependence of the rotation frequency is shown in

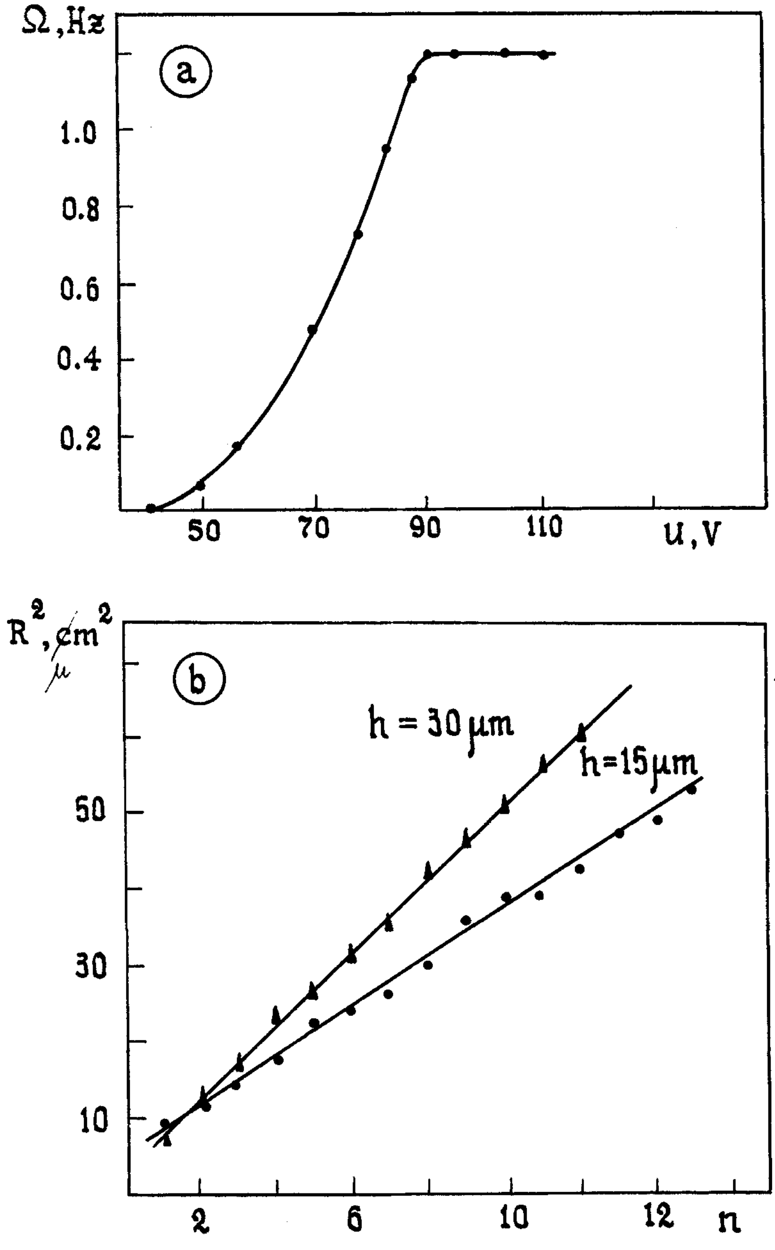

FIGURE 3. a) The dependence of the rotation frequency Ω for vortex sources on U_x+U_k applied voltage; b) the dependence of square radius R_n^2 on the ring number n, the thickness h of the LC-cell is parameter.

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Fig.3a. This dependence may be approximated by the square function of the voltage U_k. It should be noted that at the ultrasound frequency of the order of 10^4-10^5 Hz the frequency of director rotation is several Hz. These oscillations of director have a high degree of space-temporal coherence, i.e. they are undamped. Thus, the propagation of orientational oscillations in the nonlinear dissipative medium - NLC performs auto-oscillation process[5] and the orientational waves observed are auto-waves (AW)[6]. The energy source for auto-oscillation process is the acoustic field.

The interaction of orientational waves

In order to study the interaction between AW, small mica particles of different size were placed into LC-cell. The interaction of vortex centers of the topological indices m=±1 between each other and with interface has been investigated (Fig.4a). As on the boundary n_x=const, the orientational waves do not reflect but disappear at the boundary. During AW propagation along the boundary the "accumulation" of the phase value and "phase slip" by π, 2π, ..., $n\pi$ takes place. This leads to the formation of the reverberation system, as shown in Fig. 4b.

The wave diffraction by different obstacles has been investigated. It has been established that if the wave length λ is more than the size a of obstacle the wave is diffracted by it. However, disturbance of the wave front damps sharply. This

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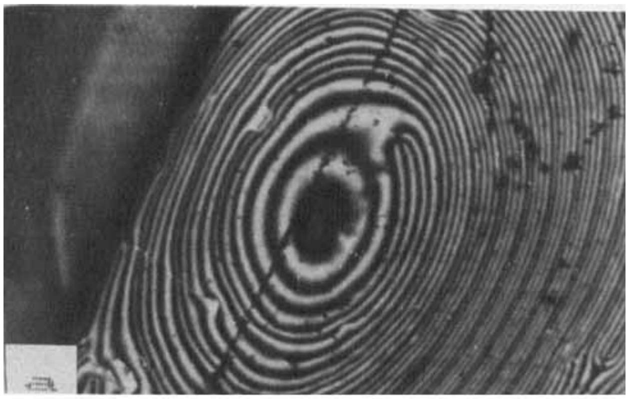

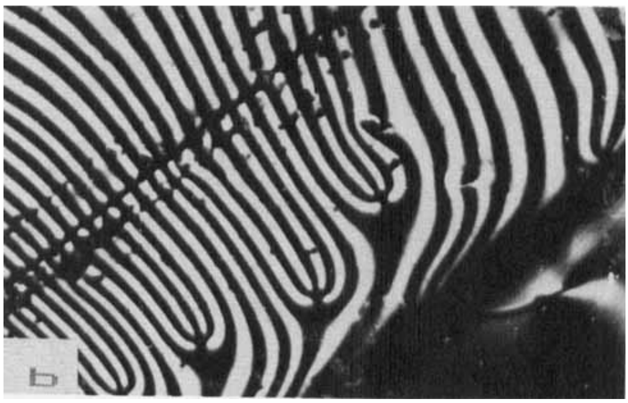

FIGURE 4. a) The interaction of leading center with the reverberation and with the LC-boundary; b) the propagation of auto-waves along LC-boundary.

is connected with the fact that the difference in phase of AW at the obstacle and far from it is considerably smaller than π. For this case the diffraction patterns are shown in Fig.5a. When $\lambda<a$ the diffraction differs from previous case and is similar to the propagation of AW along the boundary. The system of two reverberations with

Frank indices $m=\pm1$ appears (Fig.5b) due to the "phase slip" effect. The rotation directions of these reverberations are opposite. The interference of AW has been found to depend on the distribution of director field near every AW sources and the angular velocity of director rotation. When the AW sources of the same signs

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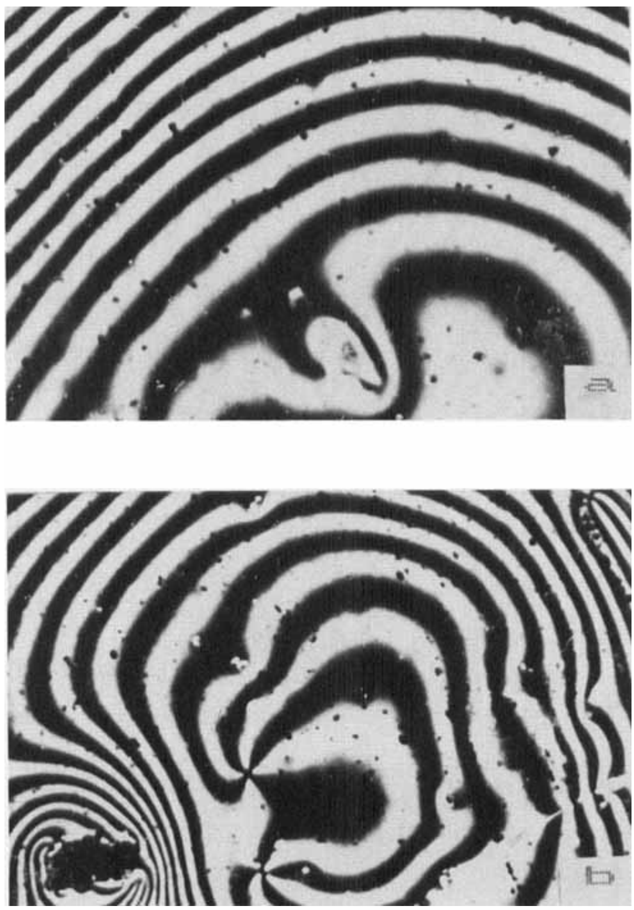

FIGURE 5. The auto-waves diffraction by different obstacles: a) $\lambda>a$; b) $\lambda<a$ (λ-the wave length and a-the size of obstacle).

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interact with each other (Fig.2c), the resulting velocity is equal to zero and annihilation of AW takes place. In the case of sources with the opposite signs the interference leads to the phase addition in resulting AW but the angular velocity of director rotation does not change. The interference pattern of interaction between leading center and the reverberation is shown in Fig.4a. The phase difference between 3th and 4th zones of leading center is 2π; this demonstrates the role of phase addition at interference of AW.

Theoretical interpretation

We consider that a cause of leading center formation during propagation of acoustic waves with great intensity in the NLC are forces quadratic in velocity. These forces remove the degeneracy of director orientation and leads to the local director rotation in the external electric field.

To observe the AW in NLC the following conditions should be realized. The surface force torques , the angle and the velocity at the boundary should be equal to zero. It is possible at homeotropic alignment of NLC with strong anchoring. Note that for planar NLC cell the AW generation is not revealed.

Let's consider the NLC layer, where the axis OZ is perpendicular to the layer surface and the direction of the shear oscillations coincides with axis OX. Director components are $n_x=\cos\varphi\cos\psi$, $n_y=\sin\varphi\cos\psi$, $n_z=\sin\psi$, where φ is the azimuthal angle, ψ is the angle between director and axis OZ. The process under study has two time scales: the first characterizes the fast-oscillating flow of NLC, the second describes the local rotation of director n. In this case the average velocity $\langle v \rangle_t = 0$. On the other hand, the surface force torques $\tau_{il}=0$. These conditions give at the NLC boundary $\partial\varphi/\partial z_{Z=\pm\sigma} = 0$. Taking into account that $n^2=1$, $q \gg k$, where q is the wave number of vortex lattice and k is the wave number of shear wave , the nematodynamics equations have the form:

$$\rho v_x \partial v_x/\partial x \simeq \gamma_2 (\partial^2 n_x^2/\partial x \partial t + \partial^2 (n_x n_y)/\partial y \partial t) \quad (1)$$

$$\partial^2 n_y^2/\partial y \partial t + \partial^2 (n_x n_y)/\partial x \partial t \simeq 0 \quad (2)$$

$$K \partial^2 \psi/\partial z^2 + \varepsilon_a/2\pi \, E^2 \psi \simeq 0, \ \sin\psi \simeq \psi, \quad (3)$$

where $\gamma_2 = \alpha_1 + \alpha_2$, $K=K_{11}=K_{33}$ is the elastic constant, and E is the external electric field. Since $v=v_0 \cos kx \cos\omega t$, then from the equations (1)-(3), one obtains:

$$\partial^2 n_x^2/\partial x^2 - \partial^2 n_y^2/\partial y^2 \simeq ct, \quad (4)$$
$$n_x^2 + n_y^2 \simeq 1, \ c = \rho v^2 k \gamma_2^{-1} \sin 2kx.$$

When $q \gg k$ the solution of equation (4) is

$$n_x = (Ctr)^{1/2}, \ n_y = (1 - Ctr)^{1/2},$$
$$r = [(x - na/2)^2 + (y - ma/2)^2]^{1/2}, \quad (5)$$

where $na/2$, $ma/2$ - the coordinates of vortex

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centers. Then, the angular velocity of director rotation is:

$$\Omega_{max} \simeq 2\rho\gamma_2^{-1} kqv_o^2 \; sin2kx \; cos^2\psi. \qquad (6)$$

As $cos^2\psi \simeq U^2/U_c^2$, then $\Omega \simeq kU^2$. This describes qualitatively the experimental situation well enough (Fig.3). For zones where the condition $n^2=1$ is realized in the vicinity of AW source, the relation between ring sizes is $r_l^2=l$, where l-ring number (Fig.3b).

CONCLUSION

In this paper we have studied the cooperative influence of the shear wave of great intensity and the external electric field on the NLC. It has been established that the local rotation of LC molecules takes place. The molecule oscillations are auto-oscillations. The auto-oscillations of director generate orientational waves in NLC layer. The diffraction, the interference and the reflection of waves at interface have been considered.

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