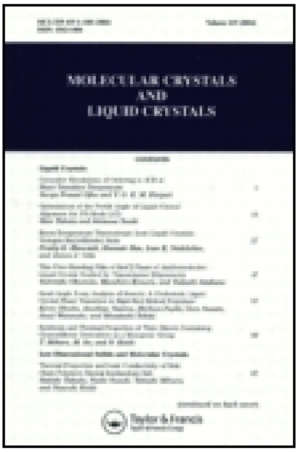

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Auto-Waves in Liquid Crystals. I. Nonstationary Electrohydrodynamic Instability

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AUTO-WAVES IN LIQUID CRYSTALS. I. NONSTATIONARY ELECTROHYDRODYNAMIC INSTABILITY

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Abstract It has been found that the coherent domain oscillations which perform stochastic auto-oscillations appear in nematic liquid crystals above the threshold of electrohydrodynamic instability in dc-electric field. In this case the oscillating domain block generates the nonlinear orientational waves. The voltage dependences of the wave length, velocity of propagation and period of wave process have been measured.

Keywords: domain oscillations, electrohydrodynamic instability, auto-waves

INTRODUCTION

Recently, self-organized spatial structures, which are connected with the formation of super-molecular order and observed in nonequilibrium systems[1] havê attracted great attention[2]. Bernard cell[3] and Williams domain[4] are famous patterns known as the "dissipative structures"[1]. The case of auto-oscillating mode, for instance, Belousov-Zabotinsky reaction[5] is of special interest. We have found that the domain auto-oscillation mode characterized by nonlinear wave generation may exist in nematic liquid crystals (NLC). We called these waves "orientational waves", because propagation of waves is provoked by periodic variation of domains orientation but not by their displacement.

In this paper, we present the investigation of the domain auto-oscillation mode in NLC in dc-electric field above the threshold of electrohydrodynamic instability (EHDI).

EXPERIMENTAL

The NLC with negative dielectric anisotropy (MBBA) have been used in our experiments. The planar LC-layers with strong boundary conditions have been studied. The LC-cell consisted of two SnO_2 coated glass plates separated by mylar spacers with $10<d<50$ μm thickness, was placed on the polarized-optical microscope stage. A coherent light with intensity being $J(t)$, transmitted through LC-cell and modulated by the local variation of birefringence $\langle \Delta n(t) \rangle$, was measured by a spectrophotometric adapter SFN-10 (Lomo, Leningrad). Obtained data were treated by computer.

RESULTS AND DISCUSSION

Recently, it has been observed that the pseudohexagonal domain lattice (grid pattern[6]) was formed in the dc-electric field above the threshold of EHDI at applied voltage U_{1c}=6.5 V. On increasing voltage beyong U_{1c} the grid pattern begins to oscillate. The LC-cell as a whole does not oscillate coherently but many local coherent regions (domain blocks) appear with slight

variation in shape. In our experiments the grid pattern appears at applied voltage $U_{1c}=8$ V.
It was found that the domain orientation in blocks varies according to the crystallographic axes of the initial pseudogexagonal grid pattern, which make an angle $\alpha \simeq 70^{\circ}$ with each other. Thus, α is amplitude of azimuthal domain oscillations and does not change with voltage.
To determine whether the single domain block oscillation is periodic or chaotic, the pseudophase space method[7] was used. A set of points in the pseudophase $\{(J(t), J(t+\tau)\}$-plane for light intensity $J(t)$ transmitted throught LC-cell and modulated by the oscillation of the single domain block was obtained (Fig.1).

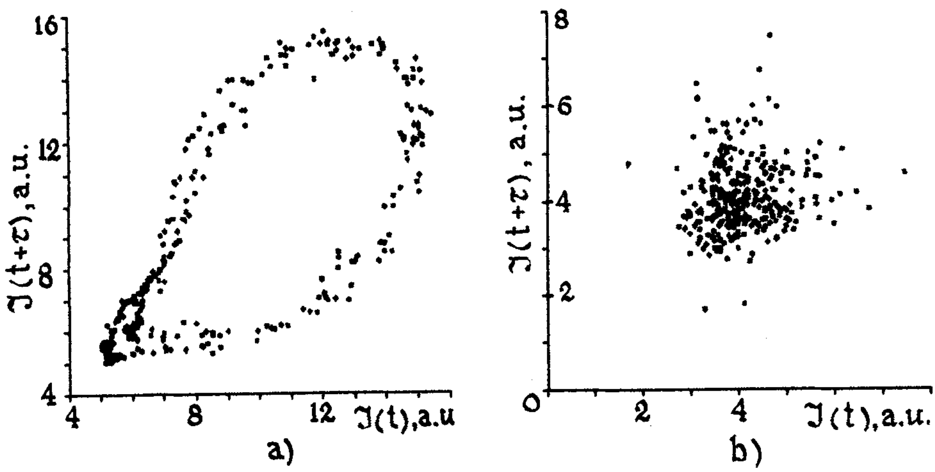

FIGURE 1. a) The trajectory of the domain block stochastic auto-oscillations in the pseudophase plane at applied voltage U=9.5 V, τ=80 ms. b) The trajectory of NLC chaotic oscillations near the threshold of dynamic scattering at applied voltage U=13.5 V.

As shown in Fig.1a, the domain block moves finitely near the limiting cycle that implies auto-oscillations. It is known[8] that the attracting set of points where stochastic dynamics is realized presents a stochastic attractor. Therefore, we believe that single domain blocks make stochastic auto-oscillations. We explain the stochastic motion of the domain blocks by the slow variation of its shape and by the fluctuations of the oscillation frequency[6]. The behaviour of NLC near the threshold of dynamic scattering mode is shown in Fig.1b. It should be noted that the transition from the ordering domain oscillation to the disordering one and turbulence occurs through the widening of the oscillation power spectrum. We found that the oscillating domain blocks generate the concentric waves of domain reorientation. The front of this wave is a boundary between areas with two directions of domain orientation . It follows from symmetry viewpoint the formation of the wave fronts connects with translational symmetry break of initial grid pattern. We assigned oscillating domain block as leading center. The interaction of the waves with each other, with boundary and with the obstacles has been studied. We have established the following properties of these waves: (i) the waves do not interfere with each other; (ii) the waves do not reflect at LC-sample boundary; (iii) the waves diffract by obstacle; (iv) the waves annihilate meeting each other. These properties are well known as auto-wave properties[8]. The micro-photographs of generation, propagation and interaction of orientational waves are shown in Fig.2a.

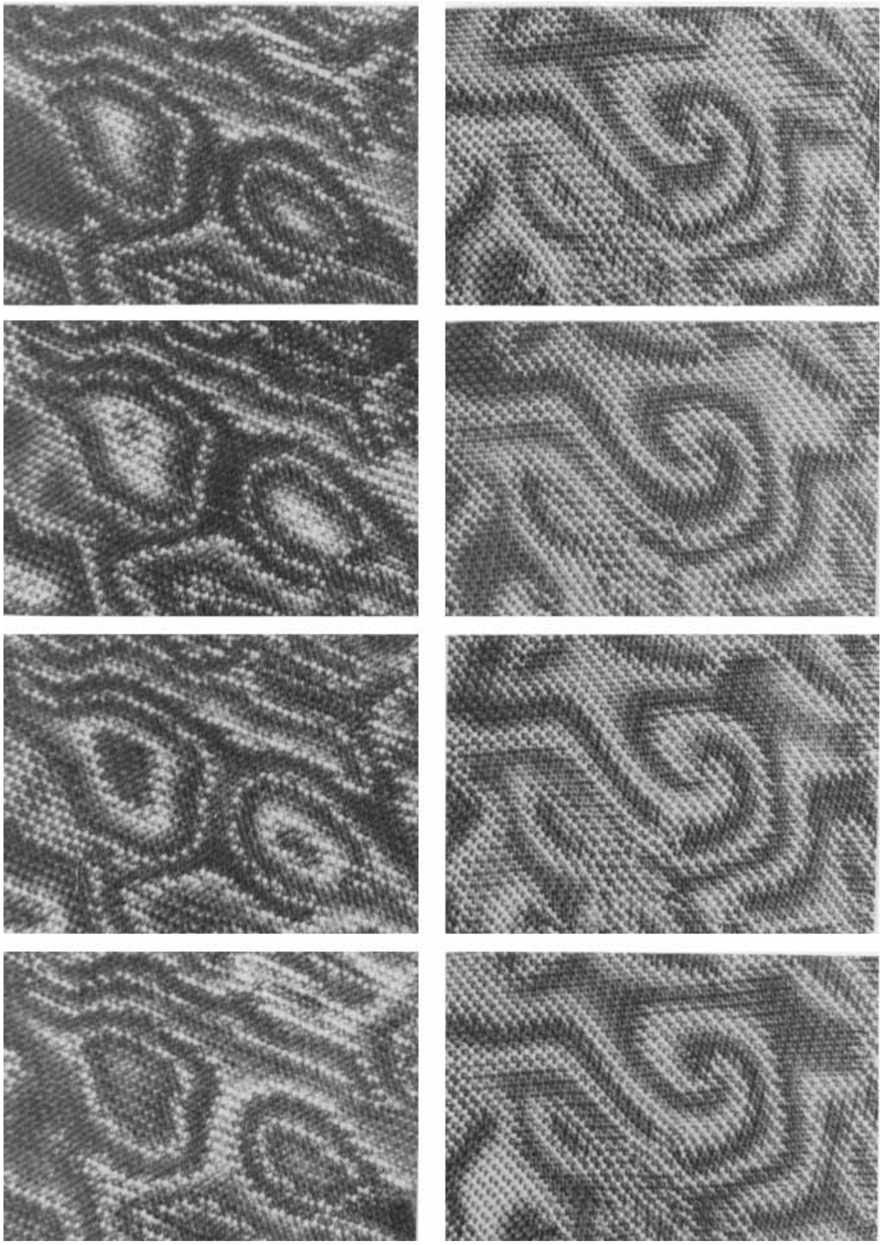

FIGURE 2. The orientational waves in NLC above the threshold of EHDI. a) The generation, propagaion and annihilation of concentric waves; b) spiral wave. The interval between frames is t=0.5 sec. Time passed from top to bottom.

Besides, we have observed the sources of spiral orientational waves - reverberations (see Fig.2b). The number of reverberations grows with voltage (i.e. with increasing the oscillation frequency). The reverberations with two sleeves (topological index N=2) are generated more frequently than reverberations with index N>2. It should be noted that the reverberations with only even topological indices are observed experimentally. We explain this fact as follows. Since two orientations of domains according to two crystallographic axes of initial grid pattern exist, it is impossible to cover a plane contained the rotation center by two types of domains with different orientation. We illustrate this by scheme in Fig.3. The clear region can be covered by the domains of type 1 or type 2 (see Fig.3a), then the boundary between domains with the same orientation disappears (see Fig.3b or Fig.3c). We have observed that the reason of spiral wave formation is rupture of wave front . This seems to be connected, for example, with separation of disturbance area from the obstacle.

The voltage dependence of the propagation velocity of the waves has been measured. The velocity increases with voltage linearly (Fig.4a). Fig. 4b shows the relation between the frequency of wave generation and the applied voltage. It has been found that period of the wave generation is equal to half-period of domain oscillation. The wave length is practically constant and equal to $\simeq 50$ μm. The general equations of nematodynamics that

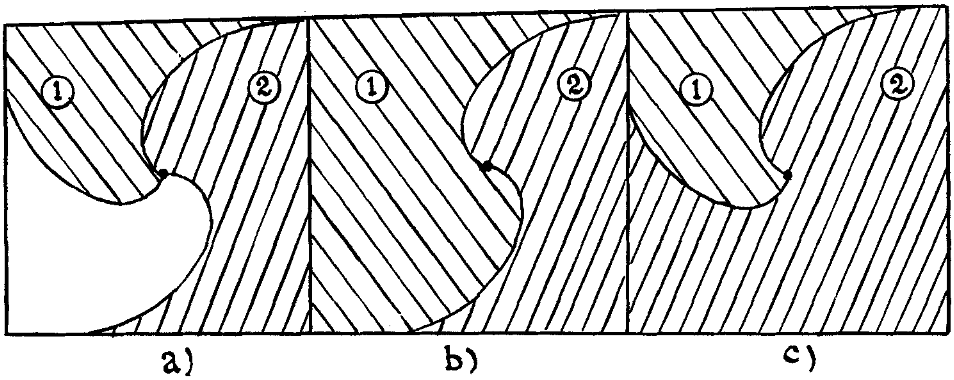

FIGURE 3. The scheme, which illustrates the impossibility of formation of the spiral wave with odd number of sleeves.

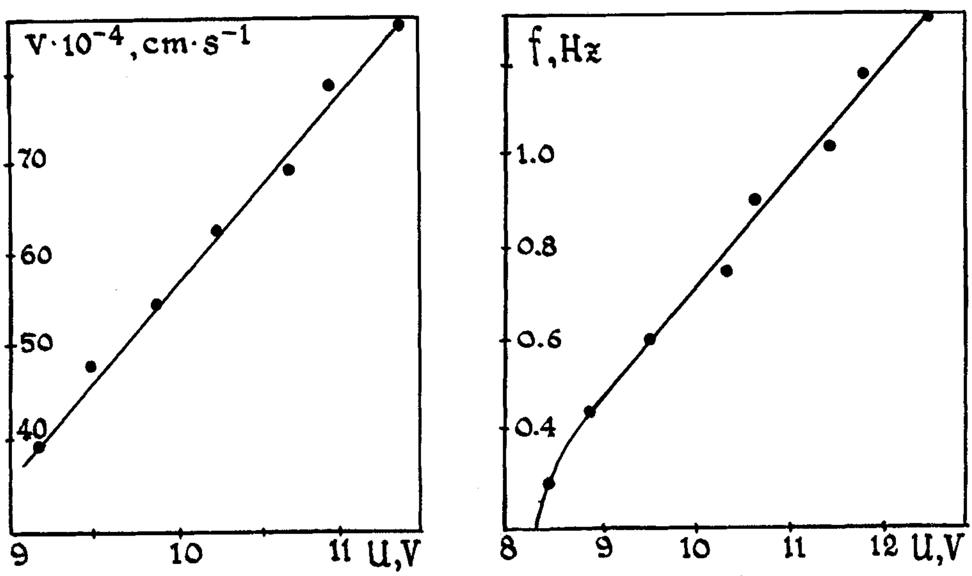

FIGURE 4. a) The voltage dependence of the propagation velocity v for orientational waves b) The voltage dependences of the wave generation frequency f .

describe the auto-oscillation mode in NLC are essentially nonlinear and can hardly be solved analytically. But our numerical solution of this problem will be published later.

CONCLUSION

It has been observed that the domain blocks of NLC oscillate coherently and concentric and spiral waves are generated in dc-electric field above the threshold of EHDI. The oscillations of domain block perform a stochastic auto-oscillations and the orientational waves have auto-waves properties. The wave sources are the leading centers and the reverberations. The generation period of waves is equal to half-period of domain oscillations. The propagation velocity of the waves increases linearly with the applied voltage and the wave length is practically constant.

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