Dissipative structure in the turbulent motion of liquid crystals

V. I. Khataevich and A. Kh. Zeĭnally

Azerbaĭdzhan State University
(Submitted 18 January 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **27**, No. 8, 434–438 (20 April 1978)

The behavior of liquid crystals far above the electrohydrodynamic (EHD) instability threshold is investigated. The appearance of new dissipative structures (DS) in the region of advanced turbulence is observed.

PACS numbers: 61.30.Gd

Much attention is being paid lately to the study of various types of dissipative structures (DS) that appear in systems that are far from equilibrium.[1] The simplicity of controlling the electrohydrodynamic (EHD) instability of liquid crystals,[2] and the feasibility of optical polarization observations of the produced DS, makes these structures convenient models for the study of nonequilibrium phenomena in crystals. It is known[2] that in nematic liquid crystals (NLC) in alternating fields there exist two EHD instability regimes, separated by a critical frequency $f_c \sim 1/\tau$, where τ is the relaxation time of the space charges. It was of interest to compare the behavior of the liquid crystal in both regimes considerably above the instability threshold. A number of DS that occur in NLC in the course of transition to turbulence have been reported in[3,4]. We have investigated here the behavior of a nematic MBBA and EBBA mixture (A) above the threshold of the secondary scattering of light.[5] No DS have been observed to appear in the region of advanced turbulence regardless of the frequency of the applied field.

A thin NCL layer ($d = 8$–$50\ \mu$m) was placed between glasses with non-conducting coating. The initial orientation of the molecules was planar. We used samples with low electric conductivity $\sigma \approx 10^{-11}\ \Omega^{-1}\ \text{cm}^{-1}$ ($t = 25\ ^\circ$C), and consequently low f_c, so that the investigations could be carried out at low frequencies and at voltages greatly exceeding the instability threshold in both regimes. The optical system made it possible to observe (photograph) simultaneously and to investigate the transmission of the polarized light.

Figure 1 shows the frequency dependence of the instability thresholds and of the secondary scattering for a sample with $\sigma \approx 1.3 \times 10^{-11}\ \Omega^{-1}\ \text{cm}^{-1}$. At high voltages we observed the appearance of formations darker than the background (the picture of turbulent motion) [Figs. 2(a), 2(b)]. The vertical lines on Fig. 1 show the regions of the observed structures for the given frequency f. The lower limit of the line corresponds to the appearance of a pattern of a still smeared and blurred pattern. With increasing voltage, the pattern becomes more distinct and contrasty, while the concentration of the resultant formations increases. Curve 3 of Fig. 1 corresponds to the most distinct pattern. With further increase of the voltage, the contrast of the picture decreases, and the dark regions smear out somewhat [Fig. 2(b)] and ultimately become indistinguishable from the background (upper limit and the lines on Fig. 1). The

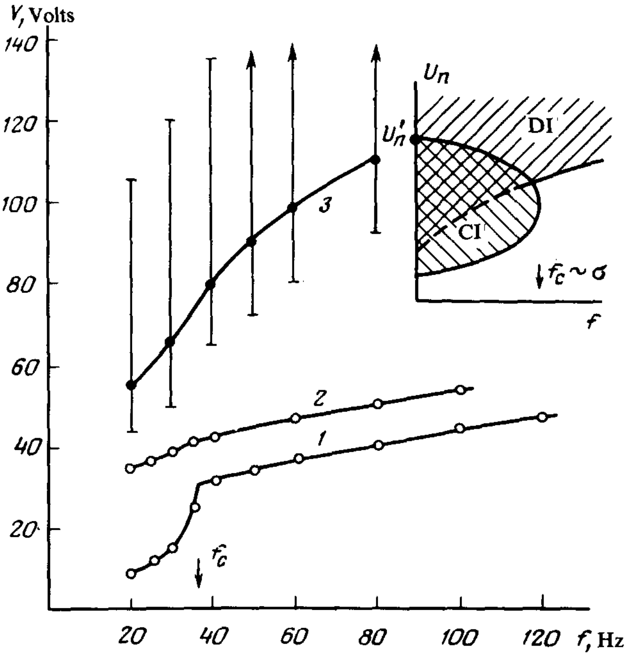

FIG. 1. Frequency dependence of the instability thresholds (1), of the secondary scattering (2), and of the region of new DS. Nematic A) $d=20$ μm. Insert—schematic dependence of the instability thresholds in accordance with[7]; CI—conducting instability, DI—dielectric instability.

resultant formations execute continuously pulsating motion. The linear dimensions depend little on the sample thickness, ranging from $\sim$40–50 μm at $d=8$ μm to $\sim$50–70 μm at $d=50$ μm. The small particles and air bubbles in the sample move randomly in the intervals between the produced formations, without crossing the latter.

It is important to note that these structures are observed in frequency regions both above and below f_c. With increasing frequency, the threshold of their appearance rises. No discontinuities occur in the optical observations on going through f_c. the light-scattering intensity in the regime corresponding to the sharp pattern of the observed DS is the same independently of f. It is known that in the dielectric regime ($f>f_c$) the transmitted light is modulated at a frequency $2f$ as a result of orientational fluctuations of the director. In the region of the existence of the new DS, the appearance of light modulation was observed also for frequencies $f<f_c$. When the field is turned off the DS vanish rapidly and only a slow (several seconds) contraction and vanishing of the filaments is observed, due to the secondary scattering.[5]

Similar structures were observed by us in the turbulent motion of cholesteric liquid crystals [nematic A + cholesteryl pelargonate (3%)] (B), thus evidencing the absence of a connection between their formation and the initial structure of the liquid crystal. In cholesteric liquid crystals it is convenient to observe the process of formation of DS from a turbulent medium, which is more prolonged than in NLC and lasts several seconds or dozens of seconds [Figs. 2(c) and 2(d)].

We note, however, that no such structures were observed in samples with high σ obtained by doping NLC with ion impurities, and also in a constant field independently of σ.

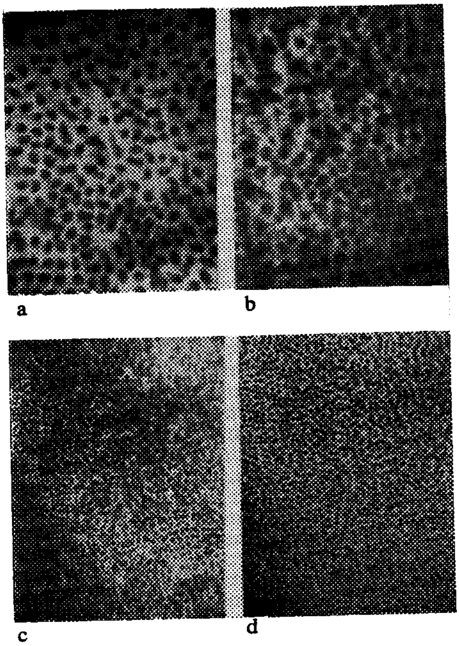

FIG. 2. Dissipative structures in turbulent motion of liquid crystals: a,b—nematic, A, $d = 20\,\mu$m, $f = 20$ Hz ($f_c = 36$ Hz); a—$U = 65$ V, b—$U = 90$ V; c,d—cholesteric B, $d = 15\,\mu$m, f = 150 Hz ($f_c \approx 120$ Hz), $U = 150$ V, c—10 seconds and d—20 seconds after applying the field.

Thus, optical investigations have shown that at appreciable voltages the difference in the behavior of NLC for different regions of f may disappear. There is no nonlinear theory describing the behavior of NLC far from the instability threshold. The possible existence of an upper branch of the threshold curve of the conducting regime, above which dielectric instability takes place was theoretically demonstrated in[7] (see insert in Fig. 1). The observed modulation of the light in the frequency region $f < f_c$ is obvious evidence of a transition to the dielectric instability. The onset of high-order DS is apparently due to a definite intensity level of the turbulent motion in the presence of orientational fluctuations of the director in the medium. The threshold for the upper branch of the conducting regime depends on σ[7]: if $\tau < T$, where T is the time of the viscous-elastic relaxation of the director, $U'_{\text{thr}} \sim \tau^{-1/2} \sim \sigma^{1/2}$ (see the insert). This can explain the observation of light modulation and new DS at low frequencies only in high-resistance samples, since the possibilities of increasing the voltage at limited by sample breakdown. Furthermore, an increase of σ leads to an increase of f_c[2] and consequently to a rise in the threshold of the new DS at frequencies $f > f_c$.

The authors thank S.A. Pikin for useful discussions.

[1]P. Glansdorff and I. Prigogine Thermodynamic Theory of Stability, Structure and Fluctuations, Wiley, 1971.

[2]P. de Gennes, *The Physics of Liquid Crystals*, Oxford, 1974.

[3]S. Kai and K. Hizakawa, Solid State Commun. **18**, 1573 (1976).

[4]S. Kai, N. Hoshitsune, and K. Hizakawa, J. Phys. Soc. Jpn. **40**, 267 (1976).

[5]V.N. Chirkov, V.I. Khataevich, and A.Kh. Zeĭnalli, Kristallografiya **22**, 809 (1977) [Sov. Phys. Crystallogr. **22**, 463 (1977)].

[6]G.H. Heilmeiz and W. Helfrich, Appl. Phys. Lett. **16**, 155 (1970).

[7]I.W. Smith, Y. Galerna, S.T. Logerwall, E. Dubois-Violette, and G. Durand, J. Phys. (Paris) Coll. **36**, C1-237 (1976).