

Ferroelectric domains in liquid crystal

L. A. Beresnev, M. V. Loseva, N. I. Chernova, S. G. Kononov,
P. V. Adomenas, and E. P. Pozhidaev

A. V. Shubnikov Institute of Crystallography, Academy of Sciences of the USSR

(Submitted 5 March 1990; resubmitted 29 March 1990)

Pis'ma Zh. Eksp. Teor. Fiz. **51**, No. 9, 457–461 (10 May 1990)

Ferroelectric liquid crystals break up into domains with a period inversely proportional to the square of the spontaneous polarization.

The macroscopic spontaneous polarization breaks a solid ferroelectric up into domains, thereby lowering the energy of the electrostatic field of the spontaneous-polarization charge.¹ An analog of this breakup has been predicted theoretically for a liquid ferroelectric, but the ferroelectric nematic liquid crystal discussed in Ref. 2 has not yet been produced.

In the present study we have experimentally observed the breakup of a ferroelectric smectic C^* liquid crystal³ into domains. The thickness of these domains decreases sharply with increasing spontaneous polarization P_s .

For observation of the domains, a static electric field above the field required for untwisting the helicoid due to the chirality of the molecules was applied to a smectic liquid crystal in a good planar orientation. The field was turned off after 2–3 s. Figure 1 shows the typical appearance of the periodic structure which arose after the field was turned off. The period of the structure, D , was measured visually with the help of a microscope scale and was also determined from the angle through which the beam from a He–Ne laser was diffracted. Figure 2 shows the temperature dependence of D for one of the liquid crystals studied. The absolute value of D at a fixed temperature did not depend on the thickness of the liquid-crystal layer, D , over the interval 6–30 μm .

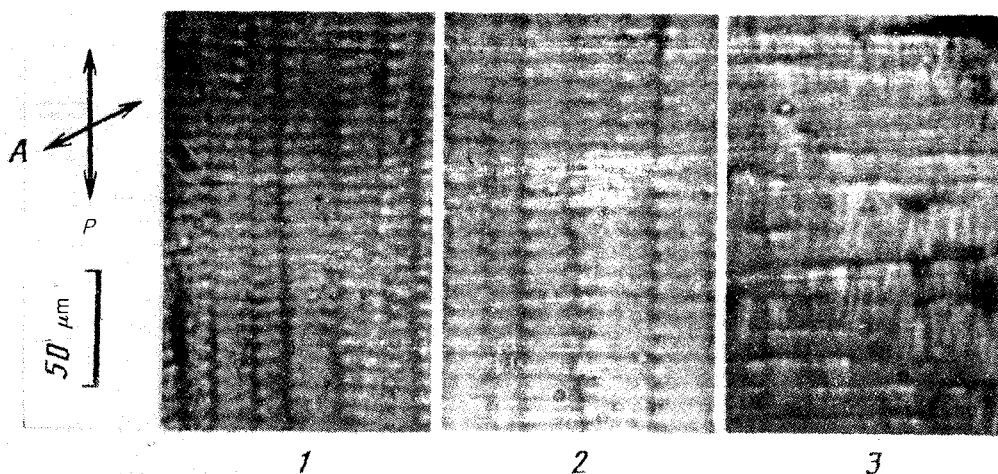


FIG. 1. Domain pattern in a ferroelectric liquid crystal, SZhK-218, at various temperatures. 1—24 °C; 2—30 °C; 3—34 °C. The cell thickness is 10.8 μm . $P_s = 120 \text{ nC/cm}^2$ (20 °C). The orientations of the polarizer (P) and the analyzer (A) are shown at the upper left. The rubbing direction is the same as the direction of P .

To prove that the observed domain patterns were of a ferroelectric nature, we measured the temperature dependence of the period D for a series of smectic liquid crystals in which the variable parameter was P_s . All the liquid crystals were formed by mixtures based on the same nonchiral (i.e., nonferroelectric) smectic C matrix and chiral (optically active) admixtures, which induced a spontaneous polarization. The total concentration of the admixtures [L -KhNL, (+)Luch-15, and (-)Luch-15] was fixed (35.0% by weight); the admixtures themselves were selected from the same chemical class. They differed only in a slight variation of the type of chiral fragment. By varying the relative concentrations of the admixtures, we were able to vary P_s over a wide range while holding constant the most important of the other thermodynamic properties [e.g., the elastic moduli, the inclination angle of the molecules; θ_0 ; and the phase transition points (at $T = 20$ °C, we have $\theta_0 = 30^\circ$ for all the smectic liquid crystals, and the temperature (T_{CA}) of the (smectic C^*)-(smectic A) transition ($S_C^* - S_A$) remains constant over the interval 51.6–53 °C].

Some of the smectic liquid crystals studied had the helicoidal twisting which was discussed previously,^{3,4} which results from the chirality of the molecules, and which is unrelated to the breakup into ferroelectric domains. The period of this twisting, with the very small value $p_0 = 0.7\text{--}2 \mu\text{m}$, had the temperature dependence typical of a "classical" smectic liquid-crystal helicoid, with a maximum near⁵ T_{CA} . This period was observed either upon cooling from the S_A to the S_C^* phase in the absence of an electric field or after the application of a low-frequency alternating field with an amplitude of 10–15 V to the untwisted sample in the S_C^* phase, followed by a smooth reduction of this field amplitude to zero.

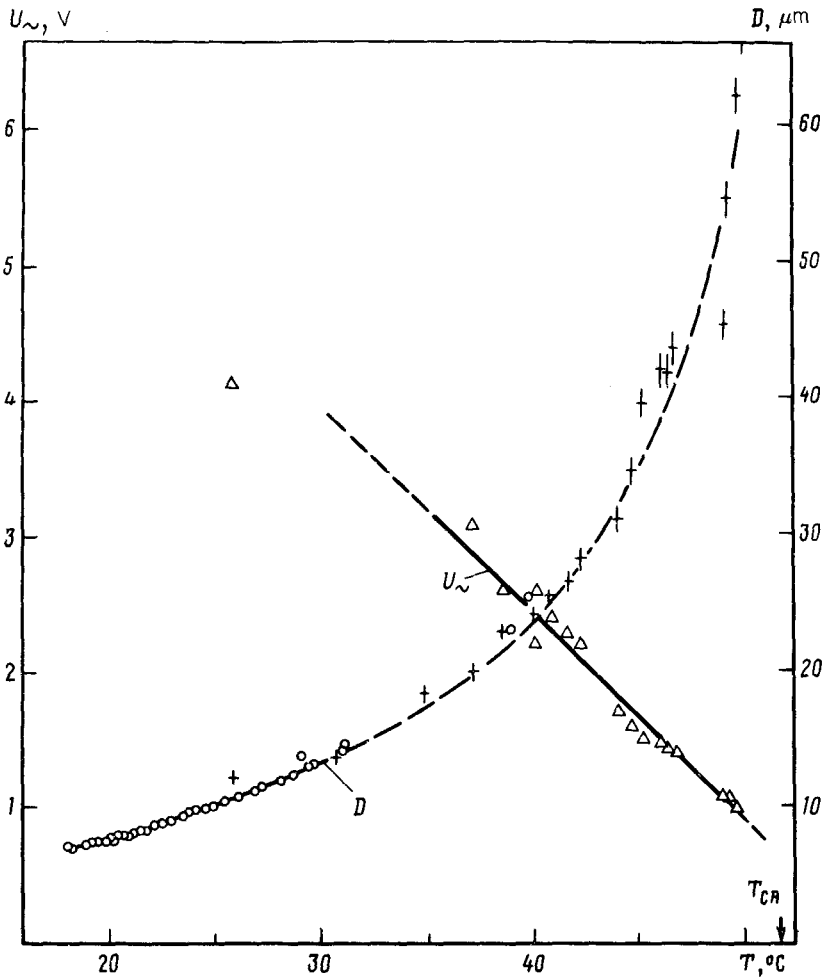


FIG. 2. Temperature dependence of the period of the domain structure in the liquid crystal SZhK-232. \circ —Static domains ($E_{\perp} = 0$); $+$ —dynamic domains in an alternating electric field U_{\sim} with a frequency of 25 Hz; Δ —the amplitude U_{\sim} at which dynamic domains are observed. The cell thickness is $16.9 \mu\text{m}$; $P_s = 105 \text{ nC/cm}^2$ (20°C); $T_{cA} = 51.8^\circ\text{C}$.

Figure 3 shows the wave vector of the modulated structure, $q = 2\pi/D$, as a function of the spontaneous polarization P_s , measured at the same temperature by a polarization-reversal method,⁶ at $T = 20^\circ\text{C}$. The inset in Fig. 3 shows that the deformation caused by the electrostatic field of the spontaneous polarization in the liquid crystal is roughly proportional to P_s^2 . This behavior is typical of electrostrictive deformation in solid ferroelectrics.¹

On the basis of the electrooptic measurements and an analysis of the diffraction pattern, we propose the model in Fig. 4. This is a model of the distributions of the

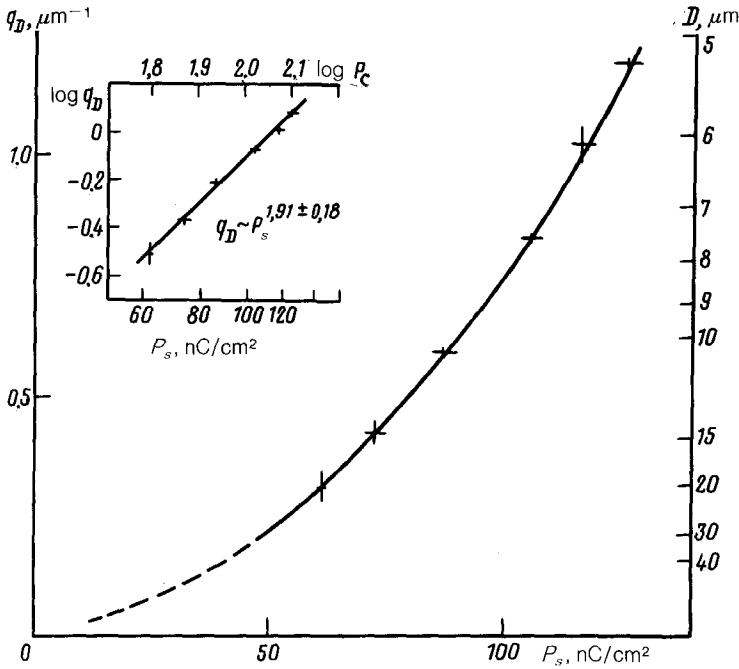


FIG. 3. The wave vector $q_D = 2\pi/D$ and the period D of the domain structure versus the spontaneous polarization P_s [$T = 20^\circ\text{C}$, cell thickness of $16.6\text{--}17.2 \mu\text{m}$, inclination angle of molecules $\theta_0 = 30^\circ$ (20°C)].

molecules and of the resultant dipole moment of the smectic layers before the static electric field is turned off [uniform states; Fig. 4(a) and 4(c)] and after it is turned off [modulated states; Figs. 4(b) and 4(d)]. At the centers of neighboring domains (regions A and B), the spontaneous polarization vectors are in opposite directions, and the thickness of the domain walls is essentially equal to the width of a domain itself.

It can thus be asserted that we are seeing a manifestation of intrinsic ferroelectricity in a liquid crystal with a high value of P_s , which leads to a breakup into domains with wide transition zones⁷ similar to the blurred Bloch walls in a ferromagnet.⁸ This breakup is similar to the breakup into ferroelectric domains which occurs in solid ferroelectrics, and it lowers the energy of the spontaneous-polarization electrostatic field.

From the changes in the period of the domain structure as a function of the duration and amplitude of the static electric field, we can easily see the effects of the screening of the spontaneous polarization by the space charge.⁹ As we increase the time over which the static field E_- is applied to the sample, for example, there is a noticeable decrease in the period of the modulated structure which arises during the first few seconds after E_- is turned off. This effect is attributed to an effective increase in the spontaneous polarization due to a decrease in the space-charge density and thus

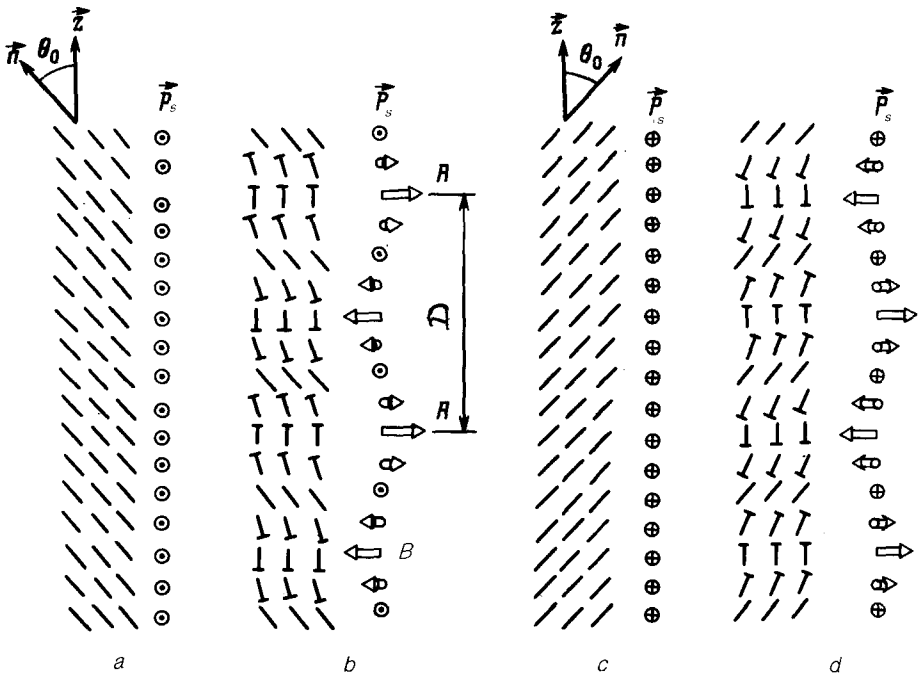


FIG. 4. Distribution of the director \mathbf{n} and of the spontaneous polarization vector \mathbf{P}_s in a ferroelectric liquid crystal with a high value of P_s at the center of a cell along its thickness. The planes of the electrodes are parallel; the smectic layers are oriented perpendicular to the plane of the figure. The ends of the molecules directed toward the observer have a short line segment. *a*—In an electric field directed toward the observer ($-E$); *b*—after the field $-E$ is turned off; *c*—in an electric field directed away from the observer ($+E$); *d*—after the field $+E$ is turned off.

a decrease in the screening effect of the space charge. On the other hand, tens of seconds after E_{\perp} is turned off, the charge returning from the electrodes to the interior reduces the effective electrostatic field of the spontaneous polarization. This decrease is manifested as an increase in the period of the domains.

We reported previously¹⁰ that at a certain amplitude of a low-frequency electric field a dynamic periodic structure arises in smectic liquid crystals with a high spontaneous polarization. The temperature dependence of the period of this structure measured at 25 Hz is essentially the same as the "static" dependence discussed above (Fig. 2). We are apparently dealing here with effects of an interaction of the electrostatic field of the spontaneous-polarization charge—a field which is modulated over the area of a cell—with space charge which is oscillating in time in the alternating field.

¹I. S. Zheludev, *Fundamentals of Ferroelectricity*, Atomizdat, Moscow, 1973.

²A. G. Khachatryan, *J. Phys. Chem. Solids* **36**, 1055 (1975).

³R. B. Meyer *et al.*, *J. Phys. (Paris) Lett.* **36**, L-69 (1975).

⁴S. A. Pikin and V. L. Indenbom, *Usp. Fiz. Nauk* **125**, 251 (1978) [*Sov. Phys. Usp.* **21**, 487 (1978)].

⁵L. M. Blinov and L. A. Beresnev, *Usp. Fiz. Nauk* **143**, 487 (1984) [*Sov. Phys. Usp.* **27**, 541 (1984)].

- ⁶Ph. Martinot-Lagarde, *J. Phys. (Paris) Lett* **38**, L-17 (1977); K. Miyasato, *Jpn. J. Appl. Phys.* **22**, L-661 (1983).
- ⁷V. L. Indenbom, *Kristallografiya* **5**, 115 (1960) [*Sov. Phys. Crystallogr.* **5**, 106 (1960)].
- ⁸I. E. Dzyaloshinskii, *Zh. Eksp. Teor. Fiz.* **46**, 1420 (1964) [*Sov. Phys. JETP* **19**, 960 (1964)].
- ⁹V. M. Fridkin, *Ferroelectric-Semiconductors*, Nauka, Moscow, 1978.
- ¹⁰A. Jakli *et al.*, *Mol. Cryst. Liq. Cryst.* **177**, 43 (1989).

Translated by Dave Parsons