VISCO-ELASTIC PROPERTIES AND FIELD INSTABILITIES OF SMECTIC MESOPHASES*

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The results of theoretical and experimental investigations of rheological and elastic properties, and of light scattering phenomena in various liquid crystals, are reviewed. Special attention is paid to the mechanisms of the field-induced instabilities (Frederiks transition in the smectic-A and -C phases, Parodi instability, flexo-electric effect, phase transition from smectic-A to smetic-C phase). The physical aspects of the electrohydrodynamic instabilities appearing in the smectic-C phase and in nematic phases with a smectic ordering are also considered. Electro-optical properties of ferroelectric mesophases are discussed shortly.

1. Visco-elastic properties

One of the principal characteristics of smectic mesophases is the fact that the energy of intermolecular interactions responsible for translational ordering is much higher than the energy of external fields involved. The distance between smectic layers is practically independent of external fields. This fact explains why the elastic theory of smectic-A (S_A) phase allows the splay deformation ($K_{22}, K_{33} \to \infty$, K_{11} = finite) and very slight changes in inter-layer distance (the elastic modulus B of the order of that for the solid phase) only [1]. In a smectic-C (S_C) phase all Frank moduli diverge ($K_{11}, K_{22}, K_{33} \to \infty$) but the relative freedom of the rotation of director around the normal to the smectic planes is maintained. In fact, one can easily change the azimuthal angle of the director (Ω), but it is very difficult to change the tilt angle (Θ). These limitations of the freedom of the director motion account for the strong anisotropy of light scattering by S_A and S_C phases. For example, the high transparency of homeotropically oriented samples of the S_A phase was shown to be due to the lack of the director thermal fluctuations with a wave vector corresponding to the polarization vector of incident light [1].

The lamellar structure of smectic phases leads also to anomalously high "apparent" viscosity coefficients. The flow of the S_A phase out of a capillary, and the field rearrange-

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ment, both require that molecules are penetrating through smectic layers. This permeation effect [2] may be described in terms of the divergence of some viscosity coefficients of the nematic phase with temperature decreasing down to the point of transition into the S_A phase [3]. These coefficients can be, for instance, the Męsowicz $\eta_2 = \frac{1}{2}(\alpha_3+\alpha_4+\alpha_6)$ and the twist-viscosity $\gamma_1 = \alpha_2 - \alpha_3$ coefficients (α_i are Leslie viscosities).

2. *Field instabilities (at zero current)*

The threshold field of the Frederiks transition for the S_A phase was shown to coincide with that for the nematic phase [4]. However, the corresponding distortion is so small that up to now this effect has not been observed (ghost transition). The weakness of the distortion results from the low compressibility of the smectic structure.

In the case of very strong electric field the free energy minimum can be achieved by the formation of the non-uniform polydomain structure with a number of periodically located dislocations (the Parodi model [5]). Most of the molecules inside such a structure are oriented according to an external field. The threshold field for the Parodi instability must be proportional to $d^{-1/2}$, where d is a cell thickness, and this theoretical prediction agrees well with the experimental data obtained at the temperatures near the transition to the nematic phase [6].

An undulation instability [1], which is an analogy of a "grid" distortion pattern typical of the cholesteric mesophase, is another example of the static periodic deformation of the molecular distribution. There are no discontinuities in the spatial director variation. The threshold field in this case is rather high (about hundreds kOe for the magnetic field) and the undulation instability has been observed yet only as a result of mechanical tension[7].

It is possible to observe in the S_C phase a Frederiks transition which leaves unchanged both the inter-layer distance and tilt angle of the molecules. The threshold field for the director rotation around the normal to layers is again proportional to d^{-1} and, in addition, depends on the tilt angle ($H_{th} \sim d^{-1} \sin \Theta$) [4]. It has been shown theoretically that for some geometries such a transition is of the first order, i.e. the director must change its azimuth by jumps [8]. Unfortunately, up to now there are no reliable experiments with monodomain samples of the S_C phase exposed to a proper oriented field.

Very near the phase transition from the S_A to S_C phase one can even observe a field--induced change in the director tilt angle [1]. By slight tilting of the molecules of the S_A phase the $S_A \rightarrow S_C$ transition is induced and, in effect the transition temperature (T_c) is changed. The loss of the specific heat of the transition is compensated by the decrease in electric (or magnetic) energy [9]. Even a weak field ($H \approx 1$ kOe) can change T_c by several degrees [10].

3. *Electrohydrodynamic (EHD) instabilities*

As the anomalous (flow) orientation of the molecules, corresponding to negative anisotropy of the electrical conductivity ($\Delta\sigma$), has been observed in the S_A phase [11], one can expect, by analogy with nematic liquid crystals, the current-induced EHD instability due to the Carr-Helfrich mechanism in homeotropically oriented smectic samples. Such a possibility has been discussed by Geurst and Goossens [12]. On the other hand, by analogy with cholesteric liquid crystals, the anisotropy of the conductivity has to result in the same distortion as in the case of pure dielectric torque, i.e. to the undulation instability of the S_A phase. However, domain patterns are not observed usually, though the motion of the liquid can be seen under microscope using solid impurity particles [13]. Thus, despite the fluid motion, both the director and smectic planes are fixed because of specific visco-elastic properties of the S_A phase, and, in particular, because of the permeation effect [20].

In homogeneously oriented samples of the nematic phase with some smectic-A ordering the Carr-Helfrich EHD instability takes place only for $\Delta\sigma > 0$. When the temperature decreases near the transition to the S_A phase the anisotropy of conductivity changes its sign at a certain temperature T_c^*. The Carr-Helfrich mechanism is cut off below this critical temperature. Then only two mechanisms of the domain formation can play an important part, namely, the "isotropic" mechanism due to the electroconvective phenomena [14] and the flexo-electric mechanism [15]. The "isotropic" mechanism is observed practically for all the orientation geometries over a wide frequency range [16]. The crucial condition for the observation of flexo-electric instability is the weakness of dielectric anisotropy and the cut off of the EHD instability [17].

The EHD instability in the S_C phase is characterised by the (*i*) square-root dependence of the threshold field (E_{th}) on frequency, (*ii*) smallness of the domain width in comparison with the cell thickness and (*iii*) an increase in E_{th} with increasing thickness [18]. The experimental data can be accounted for by the "isotropic" mechanism due to the volume charge gradient directed along an external field [14]. However, so far, there is no quantitative consideration of the EHD instabilities in the S_C phase.

4. *Linear electro-optical effect in chiral smectic phases*

In principle, the complete set of the quadratic electro-optical effects typical of both the smectic and cholesteric mesophases should appear for chiral smectics (e.g. S_C(ch) and S_H(ch)). Their study is the matter of the nearest future. At present time, the linear electro-optical effect attracts great attention. This effect is due to the linear coupling between an external field and spontaneous polarization in the smectic planes. The average dipole moment of each layer has a tendency to be parallel with the field. As a result, the smectic helix becomes untwisted [19] and the spontaneous polarization can be calculated from the critical field of the untwisting (the order of E_{th} is 10^5 V cm^{-1}).

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