Orientational effect due to a change in the anisotropy of the interaction between a liquid crystal and a bounding surface

A. G. Dyadyusha, T. Ya. Marusiĭ, Yu. A. Reznikov, and A. I. Khizhnyak
Institute of Physics, Academy of Sciences of the Ukraine, 252650, Kiev, The Ukraine

V. Yu. Reshetnyak
Institute of Surface Chemistry, Academy of Sciences of the Ukraine, 252650, Kiev, The Ukraine

(Submitted 19 March; resubmitted 27 May 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **56**, No. 1, 18–21 (10 July 1992)

An orientational effect of a new type has been observed in a liquid crystal. Specifically, the direction of the planar orientation of the director changes upon a change in the magnitude and direction of the anisotropy of the interaction of the liquid crystal with a surface bounding it.

Effects involving a reorientation of the director in a nematic liquid crystal are widely used in systems for displaying and processing optical information. Several "bulk" effects, in which the reorientation of the director results from the application of an electric, magnetic, or sufficiently intense optical field to the entire volume of the liquid crystal, have been studied thoroughly.[1,2] There is the possibility in principle that orientational effects of a different type, in which the external fields act on the surface orienting the liquid crystal rather than on the liquid crystal itself, can occur. If this agent causes a change in the boundary conditions on the director, the director should undergo a reorientation to a new position throughout the volume of the liquid crystal in the cell. There are several mechanisms which might be used to alter the boundary conditions. The easy-orientation axis could be changed, for example, by photoisomerization of the orientant molecules[3] or by polarization-sensitive chemical reactions in this medium.[4]

In this letter we theoretically predict, and report the experimental observation of, one such effect: a change in the direction of the planar orientation of the director of a nematic liquid crystal upon a light-induced change in boundary conditions. This effect occurs once a threshold is reached.

1. Let us consider a simple model. A nematic liquid crystal is bracketed by two surfaces S_1 and S_2. In the initial state, the director in the volume of the liquid crystal is oriented uniformly along the Y axis by some external field, say, a magnetic field: $\mathbf{n}_0 = (0,1,0)$ (Fig. 1). Because of this external agent, the surfaces S_1 and S_2 become orienting agents, and the easy-orientation axes $\mathbf{e}_1$ and $\mathbf{e}_2$, which arise because of the anisotropy of the interaction of the liquid crystal with the surfaces, lie in the XY plane ($Z = 0$ and $Z = L$). They make an angle ψ with the direction of $\mathbf{n}_0$. A moment of force μ_s arises and acts on the director in the plane of the orienting surfaces. If the energy of the interaction of the liquid crystal with the orienting surfaces is described,

 0021-3640/92/130017-05$03.00

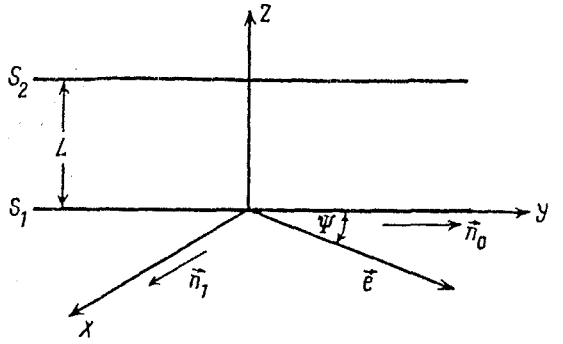

FIG. 1.

as usual, by the Rapini potential[5] $F_s = W_0(\mathbf{n}'\cdot\mathbf{e})^2$, where W_0 is the adhesion energy, then we have $\mu_s = \partial F_s/\partial\psi \sim \sin 2\psi$. The appearance of a moment of force should lead to a reorientation of the director in the **e** direction for all angles ψ except $\psi = 0$, $\pi/2$. No threshold is involved in this reorientation. The angle $\psi = 0$ corresponds to a stable equilibrium position of the director, and $\psi = \pi/2$ corresponds to an unstable one.

Let us examine the second case in more detail. Since we have $\mathbf{n}_0 \perp \mathbf{e}$ in the initial state, we have $\mu_s = 0$; a transition to a new, stable planar orientation $\mathbf{n}_1 \| \mathbf{e}$ can occur only as a result of thermal fluctuations of the director. A thermal fluctuation along the **e** direction lowers the surface component (F_s) of the elastic energy of the system and simultaneously increases the bulk component F_v. The condition for a reorientation of the director is determined by the balance between the changes in F_v and F_s upon the appearance of a thermal fluctuation. A comparison of the surface and bulk components of the elastic energy should be carried out for the lowest-index fluctuation modes, since they are the most sensitive to changes in F_s (Ref. 6).

The condition for a transition of the director to a new equilibrium position follows from the condition for an unbounded growth of the fluctuations $\delta\mathbf{n}(z)$. We have previously derived an expression [expression (10) in Ref. 6] for the spatial spectrum of such fluctuations in a bounded cell with a finite adhesion energy. Using that expression, and noting that the adhesion parameter $\epsilon = W_0 L/K$ (L is the thickness of the liquid-crystal layer, and K is the elastic constant of this layer) is negative in our case, we find that a fluctuation increases without bound under the condition

$$2 + \frac{2\epsilon_x}{\epsilon_x^2 + t_x^2} + \frac{1}{(\epsilon_x^2 + t_x^2)t_x}[(t_x^2 - \epsilon_x^2)\sin 2t_x - 4t_x\epsilon_x \cos 2t_x] = 0, \tag{1}$$

where $t_x = q_x L$ is the solution of the equation

$$\tan t_x = 2t_x\epsilon_x/(t_x^2 - \epsilon_x^2), \tag{2}$$

where $q_x(z)$ is the wave vector of the fluctuation. A numerical solution of Eq. (2) yields $\epsilon = -1.16$ as the critical value of the adhesion parameter, i.e., the value at which the director undergoes a reorientation to the new, stable position, with the boundary condition $\mathbf{n}_1 = (1,0,0)$. This result means that the transition $\mathbf{n}_0 \rightarrow \mathbf{n}_1$ requires

the attainment of a threshold, since it occurs only after a certain value of the adhesion energy, $W_c = -1.16\,K/L$, is reached in the direction set by the external agent. For the typical parameter values $K = 10^{-6}$ dyn and $L = 10\,\mu$m, the corresponding adhesion energy is relatively low, $W = 1.6\times 10^{-3}$ erg/cm^2.

The geometry which we are discussing here is the simplest of several possibilities for arranging a reorientation of a director once a certain threshold is reached during changes in boundary conditions. This effect can be observed if there are differences between the values of W_{x_1} and W_{x_2} at the surfaces S_1 and S_2, if there exists an initial adhesion energy W_{y_1} and W_{y_2}, etc. Calculations show that incorporating these parameters does not lead to qualitatively new results, the only change is in the threshold value of the adhesion energy.

2. As the medium for an experimental observation of this surface orientational effect we selected polyvinylcinnamate (PVC), which is an isotropic polymer in which an optical anisotropy can be induced by polarized UV light.[7] We showed in Ref. 4 that, when an illuminated PVC film is used as an orientant for several nematic liquid crystals and standard mixtures thereof, it establishes an easy-orientation axis $\mathbf{e}_{UV}$ perpendicular to the polarization vector of the illuminating light, $\mathbf{E}_{UV}$.

Most of our experiments were carried out at room temperature in some composite cells consisting of a quartz substrate covered by an isotropic PVC film and a second substrate which was either one with a microrelief, which gives rise to planar orientation (e.g., a coating of PAK varnish), or a quartz substrate without a coating. In the former case, a uniform planar orientation of the liquid-crystal layer, with $\mathbf{n}_0 = (0,1,0)$, was established by the substrate with a microrelief. In the latter case, it was set up by the known procedure of slowly cooling the liquid crystal from the isotropic state to the mesophase in a magnetic field directed parallel to the plane of the substrates.[8] Cells with thicknesses $L = 10$–$50\,\mu$m were filled with the standard mixtures NZhK-807 and NZhK-1285.

Illumination of the filled cells from the side of the substrate with the PVC orientant, for various angle $\varphi = 90°$ between $\mathbf{E}_{UV}$ and $\mathbf{n}_0$, resulted in a reorientation of the director in the illuminated regions in all cases except $\mathbf{E}_{UV} \perp \mathbf{n}_0 (\mathbf{n}_0 \| \mathbf{e}_{UV})$. The new direction of the director near the surface with the PVC orientant coincided with the induced easy-orientation axis for thick cells ($L = 50\,\mu$m), while it made an angle $\psi' < \psi$ in the case of thin cells ($L = 10\,\mu$m). The dependence of the new direction of the director on the nature of the second surface and the angle between $\mathbf{n}_0$ and $\mathbf{E}_{UV}$ for various samples of liquid-crystal cells requires further study. Nevertheless, the kinetics of the reorientation does not change from sample to sample. The change in the transmission of a cell between crossed polarizers reflects the change in the kinetics of the reorientation of the director. This change in transmission was monitored during the illumination and is shown in Fig. 2. We see that for all angles $\varphi \neq 0$ the reorientation begins at essentially the same time as the beginning of the illumination, t_0. If, on the other hand, the director and the induced easy-orientation axis are perpendicular, the reorientation begins at a certain time after t_0. This time varies from sample to sample, roughly over the range 10–150 s. It depends on the adjustment precision and the quality of the initial orientation. This time decreases with increasing duration of the illumination. The times involved in building up the anisotropy in the film at the UV

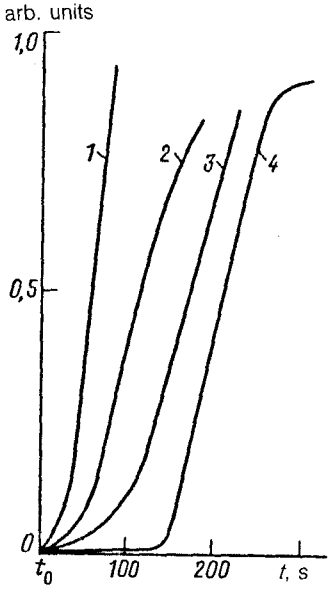

FIG. 2. Change in the transmission of a liquid-crystal cell between crossed polarizers during illumination by polarized UV light. *1*—$\varphi = 55°$; *2*—$\varphi = 35°$; *3*—$\varphi = 15°$; *4*—$\varphi = 0°$.

intensity levels used in these experiments are considerably longer than the time scales for the reorientation of the director. Consequently, the delay of the reorientation in the case $\mathbf{e}_{UV} \perp \mathbf{n}_0$ means that the process begins only when the adhesion energy reaches a certain critical value; i.e., a threshold is involved.

We should point out that we first observed a reorientation of the director in the geometry $\mathbf{e}_{UV} \perp \mathbf{n}_0$ involving a threshold in a cell consisting of two substrates coated with a PVC orientant (a PVC cell) which was put in a planar orientation by a magnetic field. The reason for the choice of a composite cell for the experiments is that in this case the parameters $\mathbf{e}$ and W_0 can be determined for both orienting surfaces. This is not the case for the PVC cell, in which these parameters are difficult to control for a surface which is illuminated through the liquid-crystal layer. The uncertainty stems from the weakening of the intensity of the light and the change in its polarization state which occur as the light propagates through the layer of oriented liquid crystal.

3. The orientation effect which we have observed is of considerable practical interest, since it opens up the possibility of controlling the direction of a planar orientation of a director by varying the polarization and intensity of light. This effect might also be used as the basis for new methods for studying the parameters of the interaction of nematic liquid crystals with orienting surfaces and for determining adhesion energies. In this "surface" orientational effect, in contrast with ordinary bulk effects, the director rotates through a large angle at the orienting surface. Consequently, one can work from the kinetics of the reorientation to determine, for example, the surface orientational viscosity coefficients—constants whose existence was pointed out in Ref. 9.

We are indebted to V. M. Kozenkov and V. G. Chigrinov for useful discussions and for furnishing the polyvinylcinnamate.

[1]L. M. Blinov, *Electro-Optical and Magneto-Optical Properties of Liquid Crystals*, Wiley, New York, 1983.
[2]B. Ya. Zel'dovich, N. V. Tabiryan, and Yu. S. Chilingaryan, Zh. Eksp. Teor. Fiz. **81**, 72 (1981) [Sov. Phys. JETP **54**, 32 (1981)].
[3]K. Ishimura, Y. Suzuki, T. Seki *et al.*, Jpn. J. Appl. Phys. **28**, Suppl. 28-3, 289 (1989).
[4]A. G. Dyadyusha, V. M. Kozenkov, T. Ya. Marusiĭ *et al.*, Ukr. Fiz. Zh. **36**, 1059 (1991).
[5]A. Rapini and M. Papolar, J. Phys. (Paris) **30**, 54 (1969).
[6]T. Ya. Marusiĭ, Yu. A. Reznikov, V. Yu. Reshetnyak *et al.*, Zh. Eksp. Teor. Fiz. **91**, 851 (1986) [Sov. Phys. JETP **64**, 502 (1986)].
[7]E. D. Kvasnikov, V. M. Kozenkov, and V. A. Barachevskiĭ, Dokl. Akad. Nauk SSSR **27**, 633 (1977).
[8]Zh. Kon'yar, *Orientation of Nematic Liquid Crystals and Their Mixtures*, Universitetskoe Izd., Minsk, 1986.
[9]M. E. Becker, R. A. Kilian, B. B. Sosnowski *et al.*, Mol. Cryst. Liq. Cryst. **132**, 167 (1986).

Translated by D. Parsons

Impedance of a type-II superconductor with a surface superconductivity

S. A. Govorkov, E. V. Il'ichev, and V. A. Tulin
Institute of Problems of the Technology of Microelectronics and Highly Pure Materials, Russian Academy of Sciences, 142432, Chernogolovka, Moscow Oblast

(Submitted 29 May 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **56**, No. 1, 22–25 (10 July 1992)

The surface impedance of a type-II superconductor with a surface superconductivity was studied experimentally. Small changes in the external magnetic field lead to a nonmonotonic behavior of the surface impedance. A qualitative model is proposed for the observed effect.

The impedance of type-II superconductors at $T < T_c$ and $H_{c2} < H < H_{c3}$ was studied in the late 1960s. Rothwarf *et al.*[1] worked from a numerical solution of the Ginzburg–Landau equation[2] and from the assumption of a uniform order parameter to propose a simple model for the behavior of the impedance, in particular, as a function of an external magnetic field. The experimental results found for a Pb–In alloy turned out to agree well with the model-based predictions.[1] We have returned to this question now because the sensitivity of the apparatus has been improved substantially by the use of computers and by the particular geometry which we have used. Our

