Effect of electric field on the phase transition from an isotropic liquid to a liquid crystal

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A study of the phase transition from an isotropic liquid to a liquid crystal in a strong pulsed electric field reveals deviations of the behavior of the induced anisotropy from the Kerr law. It is shown that the point of the phase transition may be altered by an electric field.

Experiments on the effect of strong external fields on liquid crystals run into definite difficulties. The reason is that it is necessary to use magnetic or electric fields strong enough to make the energy of the interaction of the liquid crystal with the external field comparable to the energy of the intermolecular interactions which are responsible for the long-range orientational order in a mesomorphic substance. This condition cannot be met by using the magnetic fields which are actually attainable experimentally.[1] Electric fields are far more promising.[2,3] In the case of a static or alternating (sinusoidal) field, however, fundamental difficulties arise because of the electrical conductivity of liquid crystals, the influence of hydrodynamic flows,[4] their dielectric heating,[5] and the possibility of electric breakdown in strong fields.

In this letter we are reporting the first use of pulsed fields to study the influence of strong electric fields on the phase transition from an isotropic liquid to a liquid crystal. The pulsed fields have made it possible to eliminate the influence of the parasitic factors listed above on the effects of interest. The experimental method was based on the Kerr effect (electric birefringence), which made it possible to study both (a) the behavior of the birefringence as a function of the electric field at temperatures just before the transition region, under conditions with clearly defined fluctuations in the orientational order in the isotropic phase,[6,7] and (b) the effect of an external field on the temperature (T_0) of the transition from the isotropic state to the liquid-crystal state.

Single electrical pulses with a length of 0.1 ms and a field strength E up to 2×10^5 V/cm were applied to the Kerr cell. The cell temperature was held constant within 0.05 °C.

For measurements of the phase difference δ which arises in the Kerr cell during the application of an electric field (this difference reaches several tens of wavelengths at the field strengths used), we used an electrical pulse with a special shape: an exponentially rising leading edge and a short trailing edge (Fig. 1a). The voltage rise at the leading edge of the pulse was accompanied by the appearance of maxima and minima in the light flux, corresponding to a change of 2π in the phase difference between the interfering ordinary and extraordinary rays (Fig. 1b).

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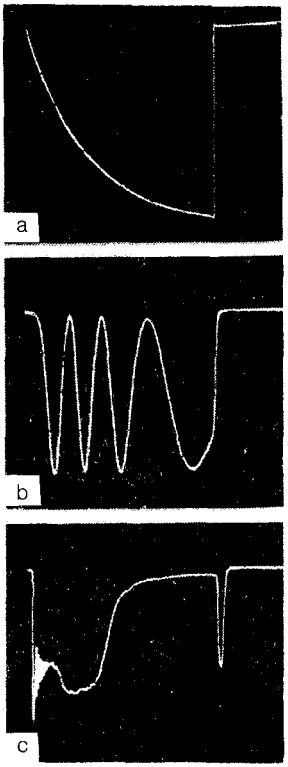

FIG. 1. a—The electrical pulse; b, c—oscilloscope traces of the light flux transmitted through a Kerr cell holding 6CB for $\Delta T = 0.4$ °C and for various electric strengths; b—$E = 2.0 \times 10^4$ V/cm; c—5.9×10^4 V/cm.

The number of observed minima, m, determines the magnitude (Δn) of the birefringence which arises in the substance under study: $\Delta n = m\lambda / l$ ($m = 1,2, \ldots$) at the various electric fields. Here $\lambda = 628$ nm is the wavelength of the light source, and $l = 0.5$ cm is the length of the Kerr cell.

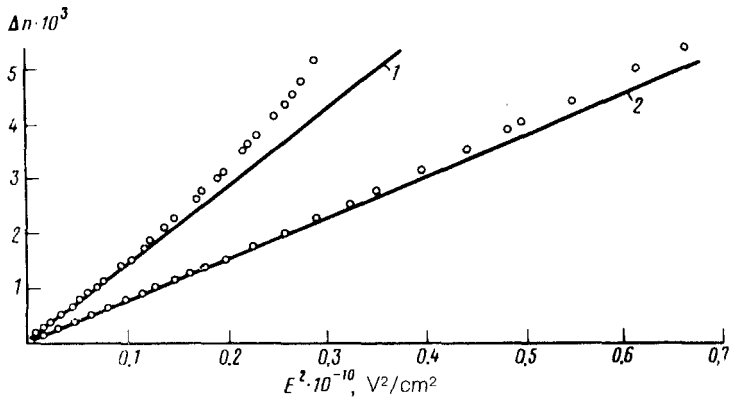

FIG. 2. Magnitude of the birefringence, Δn, versus the square of the electric field, E^2, in the isotropic phase of 6CB at various temperatures ΔT: 1—0.1 °C; 2—0.8 °C.

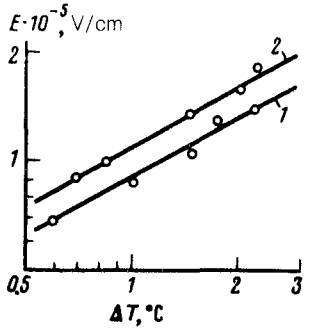

FIG. 3. Change in the temperature of the phase transition versus the electric field, in logarithmic scale. 1—6CB; 2—8CB.

As test samples we used three homologs of para-alkylcyanobiphenyls: the sixth (6CB, $T_0 = 29.5\,^\circ\mathrm{C}$), the eighth (8CB, $T_0 = 40.0\,^\circ\mathrm{C}$), and the tenth (10CB, $T_0 = 50.5\,^\circ\mathrm{C}$). These substances have a large positive dielectric anisotropy in the mesaphase ($\Delta\epsilon \sim 10$) and differ significantly in the heat (q) of the transition from the isotropic state to the liquid-crystal state: $q = 0.07$ kcal/mole (6CB), $q = 0.16$ kcal/mole (8CB), and $q = 0.64$ kcal/mole (10CB).[8]

Figure 2 shows the measured birefringence versus E^2 for various temperatures $\Delta T = T - T_0$ for 6CB. The linear dependence of Δn on E^2 at weak fields is characterized by a deviation from the Kerr law, in the direction of an increase in the measured anisotropy in strong fields E. The deviations observed correspond to a phase difference δ of several wavelengths. A detailed study of the characteristics of the observed deviations is a task for future work. A further increase in the field revealed the value of E at which the cell holding the substance became opaque in the transmitted beam (Fig. 1c). We attribute the disappearance of the light flux to a transition of the substance from the isotropic phase to the nematic phase caused by the electric field. The field which causes the transition of the samples to the liquid-crystal state is shown as a function of the same temperature ΔT in Fig. 3. The slope of the straight lines is 2. This slope corresponds to a proportionality between the change in the phase-transition temperature and E^2. It can be concluded from the experimental data that the values of E required for the phase transition depend on q. At a fixed temperature ΔT, a progressively greater field strength E will bring about a phase transition as the heat of the transition of the sample from the isotropic state to the liquid-crystal state is raised (Fig. 3). In the case of 10CB, which has the largest heat of transition from the isotropic state to the smectic state, we were not able to reach a phase transition even at the strongest fields E used in the present experiments.

In summary, an electric field can substantially influence the order of the isotropic phase of a nematic liquid crystal. The effect is manifested in the observed deviation of the electric-field-induced optical anisotropy from the Kerr law and in the possibility of a transition of the substance from an isotropic state to an ordered nematic phase under the influence of an external field.

[1]C. Rosenblatt, Phys. Rev. A **27**, 1234 (1983).
[2]A. J. Nicastro and P. H. Keyes, Phys. Rev. A **30**, 3156 (1984).

[3]W. Helfrich, Phys. Rev. Lett. **24**, 201 (1970).
[4]A. J. Nicastro and K. G. Inman, Mol. Cryst. Liq. Cryst. **90**, 111 (1982).
[5]M. Shadt, Phys. Lett. **A81**, 355 (1982).
[6]Ya. I. Frenkel', Zh. Eksp. Teor. Fiz. **9**, 952 (1939).
[7]V. N. Tsvetkov and E. I. Ryumtsev, Kristallografiya **13**, 290 (1968) [Sov. Phys. Crystallogr. **13**, 225 (1968)].
[8]H. J. Coles, Mol. Cryst. Liq. Cryst. **49**, 67 (1978).

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