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Field hysteresis of the cholesteric-nematic phase transition

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Field hysteresis of the cholesteric-nematic phase transition in mixtures with a small (up to 2%) amount of optically active dopant was investigated. The relative value of the hysteresis loop was used to evaluate the transition hysteresis properties. It is shown that this value does not depend on the ratio of the cell thickness to the value of the pitch of the undeformed helix and is linearly dependent on the elastic constant ratio (K_{22}/K_{33}).

1. Introduction

The wide application of personal computers and text processors has led to the creation of a projection display with electric field erasing and recording. Liquid crystals panels based on the twist effect or on the supertwist double beam refraction effect may be used as such light valves. However, the presence of two polarizers, which absorb a large amount of light thus decreasing the screen brightness, are a drawback. In addition heat, absorbed by the screen, increases its temperature and disturbs the element addressing conditions, so leading to a decrease in information capacity of the screen.

This drawback can be removed by using a display, based on the cholesteric-nematic phase transition effect. This transition occurs in mixtures containing a small amount of optically active dopant (up to 5 per cent): it possesses an electric field hysteresis property or, in other words, has a bistability [1]. Due to the bistability characteristic, such a display has a high information capacity and the absence of polarizers increases the brightness. Matrix liquid crystal displays based on the cholesteric-nematic phase transition effect have been described earlier [2]. The nematic-cholesteric mixture, having a high cholesteric-isotropic transition temperature (372 K), with a pitch of $0.7 \mu\text{m}$ and providing a bistability range of 3 V for temperatures from 288 K to 343 K, was used. The stability of the hysteresis characteristic, in the authors' opinion [2], depends on the equilibrium between the specific rotation by the helical structure of the plane of polarization and its surface cohesion, i.e. it depends on temperature, which has an influence on the specific rotation of texture. Therefore the optimization of the material parameters, of the compounds used, was done aiming to reduce the temperature dependence of the pitch. As a result of experiments it was shown, that the decrease in the pitch makes the bistability range wider and the temperature dependence weaker.

In our opinion, evaluation of the cholesteric-nematic transitional hysteresis properties by such criterion as the absolute value of the hysteresis loop is one sided,

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because when we broaden the bistability range by reducing the pitch, we increase at the same time the transition threshold voltage. Further, knowledge of physical processes taking place during the transition, is necessary for a successful optimization of the cholesteric–nematic transitional parameters. The field hysteresis of mixtures with low concentrations (less than 2 per cent) of the optical active dopant content was investigated here.

2. Theory

It has been established [1, 3, 4], that the electrooptical and time parameters of the cholesteric–nematic transition depend on many factors. Of particular importance are the ratio d/P_0 , where d is the thickness of the layer, P_0 is the undeformed helical pitch, and the elastic constant ratio $\gamma^2 = K_{22}/K_{33}$. Further, in thin samples ($d/P_0 \approx 1$), the influence of the surface on the initial structure and of the device the cholesteric–nematic transition threshold voltage must be taken into account. The influence of the boundary conditions on the value of the critical electric field was considered for the first time by Greubel [4] for homeotropic orientation. For that case the threshold field for the reversed transition when

$$\gamma^2 \geq \frac{P_0}{2d} \quad (1)$$

can be obtained from

$$E_{\text{NC}} = \left(\frac{\pi_1}{P_0} \right) \{ [4K_{22}^2 - (K_{33}P_0/d)^2] / \varepsilon_0 \Delta \varepsilon K_{33} \}^{1/2}. \quad (2)$$

Goossens [5] has taken the boundary conditions into account by using the function

$$f(P, d) = \pm 2q^2 \cosh^{-2} \left(\frac{\gamma q d}{2} \right), \quad (3)$$

where

$$q = q_0 \left(1 - \frac{1 + 2 \log 2qa}{4\gamma d q_0} \right), \quad (3a)$$

The sign of $f(P, d)$ may be positive or negative, corresponding to planar or homeotropic boundary conditions, respectively. Thus the equation for the critical electric field obtained by Goossens, is

$$E_{\text{NC}} = (K_{22}/\varepsilon_0 \Delta \varepsilon)^{1/2} [\pi_1^2 / P_0 \pm f(P, d)]^{1/2}. \quad (4)$$

The dependence of the threshold voltages of the cholesteric–nematic and the reversed cholesteric–nematic transition on the ratio d/P_0 , calculated from equations (4) and (2), for definite values of γ , d , $\Delta \varepsilon$ give a linear dependence with the tilt angle of direct dependence $U_{\text{CN}} = f(d/P_0)$ proportional to the elastic constant K_{22} and the dependence $U_{\text{NC}} = f(d/P_0)$ is proportional to ratio K_{22}/K_{33} . To evaluate the hysteresis properties we choose as a criterion the relative value of hysteresis loop δU where

$$\delta U = \frac{\Delta U}{U_{\text{CN}}} = \frac{U_{\text{CN}} - U_{\text{NC}}}{U_{\text{CN}}} \quad (5)$$

and U_{CN} and U_{NC} are the threshold voltages of the direct and reversed transition, respectively. We now derive an analytical expression describing δU for the case when

$d/P_0 \gg 1$ and the influence of the surface on the cholesteric–nematic transition threshold voltage can be neglected. Expressions (4) and (2) can then be rewritten as

$$U_{\text{CN}} = \pi_1^2 \sqrt{\left(\frac{K_{22}}{\epsilon_0 \Delta \epsilon}\right) \left(\frac{d}{P_0}\right)}, \quad (6)$$

$$U_{\text{NC}} = \pi_1 \sqrt{\left(\frac{4K_{22} - K_{33}(P_0/d)^2}{K_{33} \epsilon_0 \Delta \epsilon}\right) \left(\frac{d}{P_0}\right)}. \quad (7)$$

Using the notation

$$\gamma = \left(\frac{K_{22}}{K_{33}}\right)^{1/2} \quad (8)$$

we obtain

$$\delta U = \left[1 + \frac{4\gamma^2}{\pi_1^2} - \frac{1}{\pi_1^2 \gamma^2} \left(\frac{d}{P_0}\right) - \frac{2}{\pi_1} \left(4\gamma^2 - \frac{1}{\gamma^2} \left(\frac{d}{P_0}\right)^{-2}\right) \right]^{1/2}. \quad (9)$$

According to [4], this expression is valid, when condition (1) is fulfilled.

It can be established by analysis of equation (9), that δU is a function of two parameters: γ and d/P_0 . The first of these is determined by the elastic properties of the liquid crystal and the second by the construction of the specific display device. For the case being considered ($d/P_0 \gg 1$) and in accord with [4] we find that the ratio of the threshold fields does not depend on d/P_0 . For that case expression (9) has the form

$$\delta U = \pm \left(1 - \frac{2\gamma}{\pi_1}\right). \quad (10)$$

That is we have a linear dependence of the hysteresis loop relative value on the elastic constant ratio.

3. Experimental

For our experiments we used liquid crystal materials, which have a nematic solvent consisting of mixtures of phenylbenzoates and cyanobiphenyls, cholesteryl esters (palmitate, undecilate, myristate, propionate) were used as the optical active dopants. The concentration of cholesteryl esters in the nematic–cholesteric mixtures varied from 0.2 to 1.6 wt%. The induced helical pitch was measured by the Cano wedge method and the diffraction of a laser beam on a confocal texture and a fingerprint texture. The pitch varied from 1 to 25 μm . The elastic constants were determined with the help of electrooptical measurements from experimental dependences $U_{\text{CN}} = f(d/P_0)$ and $U_{\text{NC}} = f(d/P_0)$. The hysteresis loop was determined from the voltage contrast characteristics of samples with a layer thickness of 25 μm . The experimental dependence of the cholesteric–nematic and nematic–cholesteric transition voltages on the ratio d/P_0 for mixtures investigated are shown in figures 1–4.

This dependence in d/P_0 range from 1 to 6 is linear and the slopes increase when the transition from mixtures with the propionate dopant to mixtures with myristate dopant occurs, indicating the growth of K_{22} and γ . For each mixture K_{22} and γ are approximately constant, when dopant concentration, determining the pitch P_0 , is small from 0.2 to 1.6 per cent). The value of $\Delta \epsilon$ also remains constant and is determined by dielectric anisotropy of the nematic solvent.

Analysis of the results obtained has also shown, that the relative hysteresis loop δU does not depend on the ratio d/P_0 , when $d/P_0 > 1$ and $\gamma > 1$.

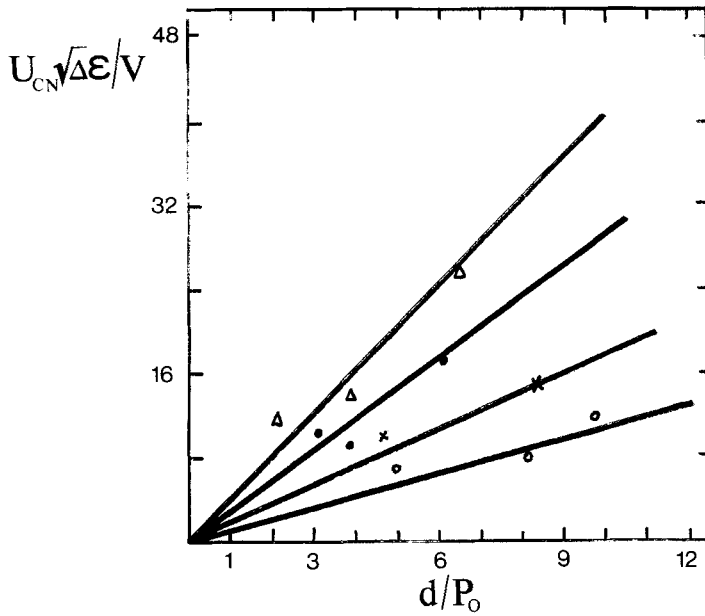


Figure 1. The dependence of U_{NC} on the ratio d/P_0 for NLC-I doped with: \times , propionate; Δ , undecilate; \circ , myristate; \bullet , palmitate.

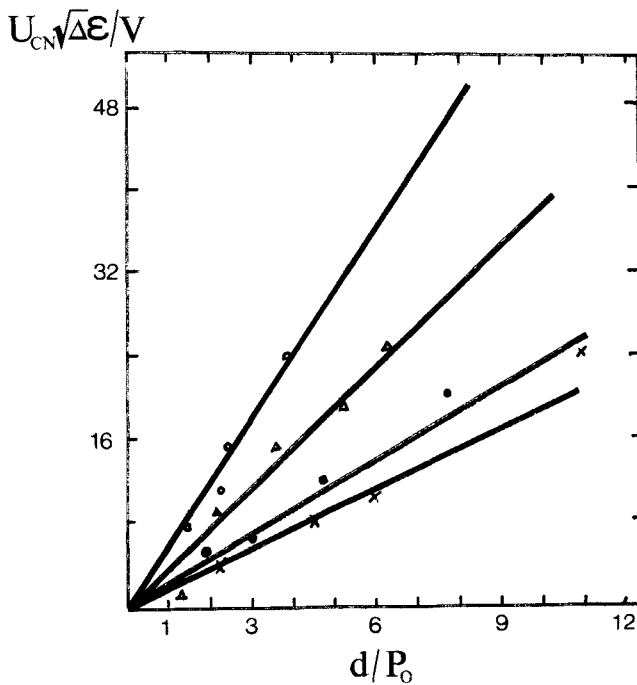


Figure 2. The dependence of U_{NC} on the ratio d/P_0 for NLC-II doped with: \times , propionate; Δ , undecilate; \circ , miristrate; \bullet , palmitate.

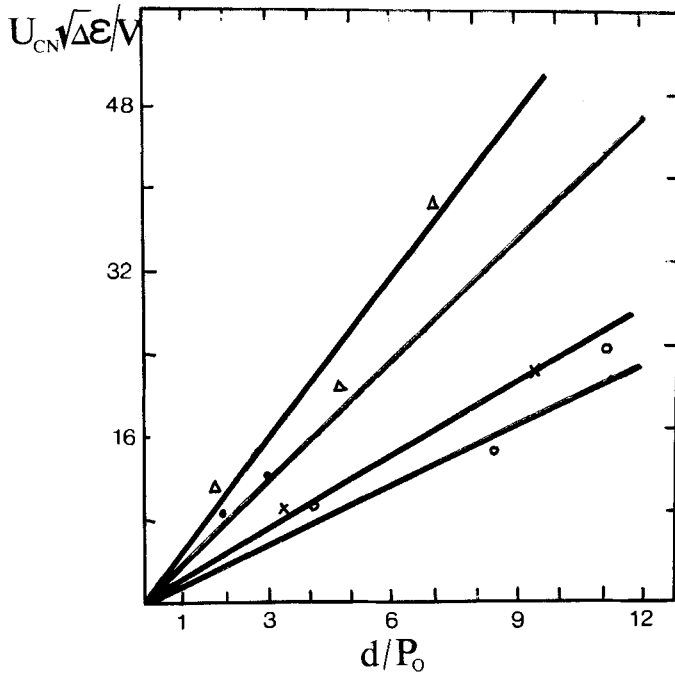


Figure 3. The dependence of U_{CN} on the ratio d/P_0 for NLC-I doped with: \times , propionate; Δ , undecilate; \circ , myristate; \bullet , palmitate.

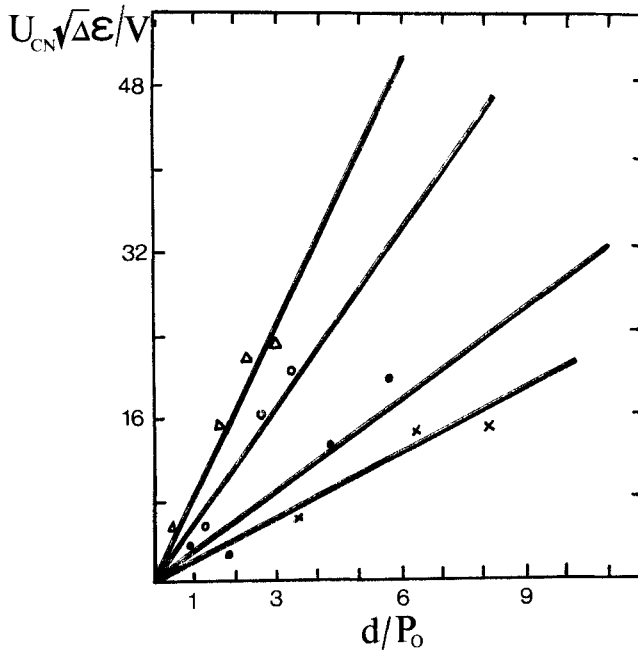


Figure 4. The dependence of U_{CN} on the ratio d/P_0 for NLC-II doped with: \times , propionate; Δ , undecilate; \circ , myristate; \bullet , palmitate.

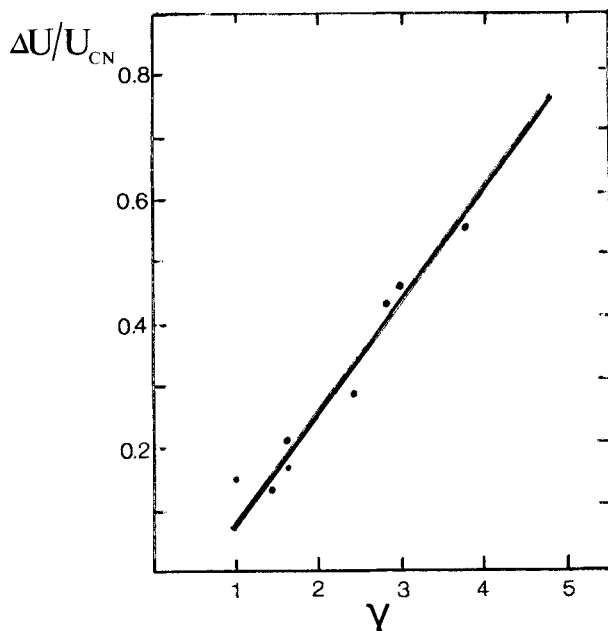


Figure 5. The dependence of the relative hysteresis loop on γ .

A curve, based on experimental data, is plotted in figure 5 showing the dependence described by

$$\delta U = 0.23\gamma - 0.15. \quad (11)$$

Comparing expressions (10) and (11), we can see that they differ only by their coefficients.

4. Conclusions

It has been established with the help of experimental data, that:

- (i) δU does not depend on d/P_0 in mixtures with a low concentration of the optically active dopant;
- (ii) the results obtained confirm the theoretically predicted linear dependence of δU on γ ;
- (iii) δU does not depend on the dopant concentration in the range from 0.2 to 1.6 w%, because δU does not depend on d/P_0 in the materials examined;
- (iv) the fact, that mixtures, having the same nematic solvent, differ by their elastic parameters, means, that the elastic properties of the mixture are not identical to the elastic properties of the nematic solvent.

Thus we conclude that a deeper investigation of the cholesteric–nematic transition properties will make possible not only the optimization, but also the reliable prediction of the parameters for specific liquid crystals devices, based on the cholesteric–nematic transition effect.

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