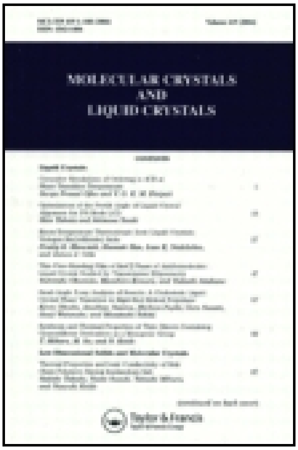

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OPTICAL INVESTIGATION OF THE VECTOR FIELD OF DIRECTORS IN THE L. C. BOUNDARIED NEMATIC MEDIUM UNDER ELECTRIC AND MAGNETIC FIELDS

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Abstract We have measured both phase difference decrease δ between ordinary and extraordinary rays passing through liquid crystal cell and dielectric constants ε of 4-trans-n-hexyl-cyclohekxyl-isothiocyanatobenzene (6CHBT). The results of the studies for different alignment and thicknesses under various electric measuring and magnetic fields are presented. .The exposed experimental technique and data processing allows K_{11} and K_{33} determination. Determination $\Theta(z)$ is derived from continuum theory so it is not purely experimental determination but semiempirical method.

INTRODUCTION

To every point within nematic volume a normalised vector **n** may be assigned, parallel to mean direction of long axes of molecules. Orientation of a nematic may thus be described by giving vector field **n**(r). Every deformation of director field homogeneous may be treated as a superposition of three types of deformation: splay, twist and bend. These deformations are described by elastic constants K_{11} , K_{22} and K_{33} introduced by Frank[1].Physical properties of ordered liquid crystal layer depend on relative positioning of molecules within the sample. Average direction of this positioning is described by the director **n**. Hence the determination of director field distribution **n**(r) is of fundamental importance. Ideal homogeneous sample has the structure characterised by homogeneous director field **n**(r). Molecules positioning within the sample is established as a result of: interactions between individual molecules, interactions between molecules and external fields and interaction between liquid crystal molecules and walls limiting the sample.

In real samples molecules almost always have some initial tilt in respect to base the (so-called tilt bias angle = TBA). This angle will, by convention, be referred to as an initial (boundary) angle Θ_B (see Fig.1). It may be measured by various methods[2, 3, 4, 5] ; however, the one based on conoscopic observations of the given liquid crystal cell seems most useful.

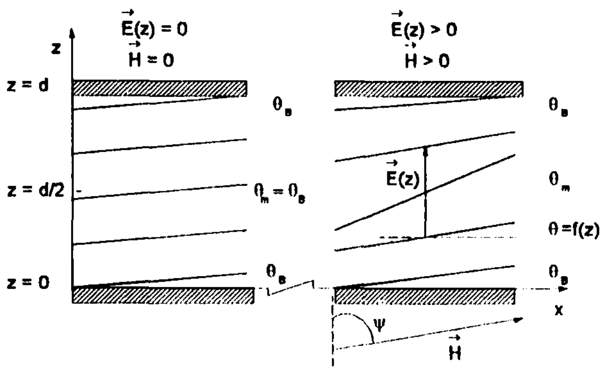

Figure 1. Schematic configuration of nematic liquid crystals in measurement cell.

It has already been mentioned that physical properties of liquid crystal layer depend on director field **n**(r). In our case we must only have the $\Theta = \Theta(z)$ function determined, i.e. we must know how the angle Θ changes when "z" coordinate is varied (see Fig.1).

THEORY

The concept of K_{ii} elastic constants determination on the basis of director field distribution may be described as follows:

A certain physical quantity W itself a function of director field distribution *must be chosen, which we can measure and calculate.*

W_M denotes the measured value of this quantity and W_L denotes its calculated value. These two values are next compared, in order to satisfy the W_M W_L condition. This may be achieved, for example, by changing the K_{ii} elastic constant value in the equation describing W_L, to achieve $W_L = W_M$. In this way the K_{ii} constant may be determined and our aim is achieved.

The chosen W quantity must obviously satisfy a number of conditions, namely:

1° It must be an integral quantity,

2° It must depend on a director field distribution, i.e. on $\Theta(z)$ function,

3° It must depend on K_{ii} elastic constants values,

4° It must depend (among others) on Θ_B initial angle.

The most useful ones are: dielectric constant ε and phase difference decrease δ between extraordinary and ordinary rays of light passing through liquid crystal cell (see Figs. 2, 3, 4).

Let us assume that phase difference decrease δ is going to dealt with. With δ_L and δ_M values known, we may compare them. δ_L value is calculated for given K_{11} and K_{33} . The latter values are changed, $\delta_L$being recalculated each time, until become equal. This condition is satisfied for a certain director field *distribution $\Theta(z)$. Having determined this distribution through above described* procedure, we may call it self-consistent field as this procedure has the features of self-consistent field method, as known from calculations of quantum mechanical properties of atoms and molecules.

Consider a nematic layer of thickness d between planes (electrodes) z = 0 and z = d of a Cartesian coordinate system. The experimental geometry of this system is shown in Fig. 1. An external dielectric constant measuring field E is applied to the LC medium along the z axis. An external magnetic field H lies in the xz plane and forms an angle ψ with the z axis. The director **n** and the x axis at position z is denoted by $\Theta(z)$. In the absence of magnetic and electric fields,the director everywhere forms the same angle of $\Theta(z) = \Theta_B$ with the x axis.

On the basis of the Oseen and Frank elastic continuum theory of a nematic in the presence of a magnetic H and electric E fields, in the limit of small distortions, the balance of elastic, magnetic and elastic torques per unit volume requires [6]

$$[K_{11}\cos^2\Theta(z)+K_{33}\sin^2\Theta(z)]\frac{d^2\Theta(z)}{dz^2}=$$

$$=\Delta\varepsilon\varepsilon_o E^2(z)\sin\Theta(z)\cos\Theta(z)+\Delta\chi\mu_o H^2\sin[\Theta(z)+\Psi]\cos[\Theta(z)+\Psi] \qquad (1)$$

where K_{11} , K_{33} , $\Delta\varepsilon$ and $\Delta\chi$ are the LC elastic splay and bend constants and dielectric and diamagnetic anisotropies of the LC medium respectively. Here ε_0 is the electric permittivity and μ_0 is the magnetic permeability of the free space.

Due to the dielectric and diamagnetic anisotropies connected with local electric E(z) and magnetic H fields, the vector fields of directors n(Θ(z)) is formed in the LC medium. We must noticed that distortion of NLC layers by combinations of electric and magnetic fields is, in general, not uniform across the sample. In our case, when we apply a voltage U to the slab, the electric field E(z) has a component only in the z-direction.

If the LC-to-substrate anchoring force is the same for both electrodes (both electrodes have been treated in the same way), the solution of (1) is symmetric with respect to the z = d/2 plane. The angle Θ is a function of coordinate z, Θ(z) assuming the maximum value Θ_m at z = d/2 and the vale of Θ_B at the boundaries. After multiplying (1) by dΘ/dz and then integrating it and knowing that for z = d/2 Θ(z) = Θ_m and dΘ/dz = 0 one obtains

$$\frac{d\Theta(z)}{dz} = \tag{2}$$

$$= \left\{ 2\left[\int_{\Theta_m}^{\Theta} \frac{\Delta\varepsilon\varepsilon_0 E^2 \sin\Theta' \cos\Theta'}{K_{11}\cos^2\Theta' + K_{33}\sin^2\Theta'} d\Theta' + \int_{\Theta_m}^{\Theta} \frac{\Delta\chi\mu_0 H^2 \sin^2(\Theta' + \Psi)\cos^2(\Theta' + \Psi)}{K_{11}\cos^2\Theta' + K_{33}\sin^2\Theta'} d\Theta' \right] \right\}^{\frac{1}{2}}$$

For the dielectric displacement vector $\vec{D}(z) = \varepsilon(z)\varepsilon_0 \vec{E}(z)$ (3)

where $\varepsilon(z) = \varepsilon_\perp + \Delta\varepsilon \sin^2\Theta(z)$ (4)

We have the equation $\operatorname{div}\vec{D} = 0$ (5)

which requires the z-component D_z of $\vec{D}$ to be constant.

Optical properties of a nematic liquid crystal in the layout as shown in Fig.2 are described by two equations (1) and (6)[5,6,7] .

$$\delta = \frac{2\pi}{\lambda} \left| n_o d - \int_0^d \frac{n_o n_e dz}{\sqrt{n_o^2 \cos^2\Theta(z) + n_e^2 \sin^2\Theta(z)}} \right| \tag{6}$$

where n_o and n_e denote refractive indices for ordinary and extraordinary rays respectively, while δ denotes phase difference decrease between these two rays.

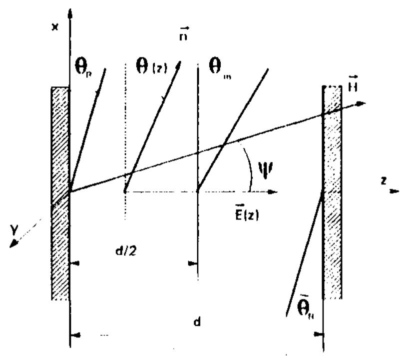

Figure 2. Illustration of the geometry of the system.

Applying measured voltage U to the cell filled with LC material characterised by K_{11}, K_{33}, $\Delta\varepsilon$, $\varepsilon_\perp$, $\Delta\chi$, n_o and n_e initially formed into a layer with d and Θ_B, under magnetic field described by H and Ψ, measured phase difference decrease δ_M can be written as

$$\delta_M = \frac{2\pi}{\lambda}|n_o d - \int_0^d \frac{n_o n_e \left[\frac{d\Theta(z)}{dz}\right]^{-1} d\Theta}{\sqrt{n_o^2 \cos^2\Theta(z) + n_e^2 \sin^2\Theta(z)}}| \qquad (7)$$

where dΘ(z)/dz is given by (2), and now the required function of E(z) in (2) may be calculated from (5) which becomes

$$\varepsilon^M(U,d,H,\Theta_B)\frac{U}{d} = \left\{\varepsilon_\perp + \Delta\varepsilon\sin^2\Theta(z)\right\}E(z) \qquad (8)$$

where ε^M is measured value.

Phase difference decrease δ given by Eq. (6) in which the dependence on electric field E(z) is implicit, appears as the quantity W in the self-consistency procedure.

EXPERIMENT

The investigated compound of 4-trans-4'-n-hexyl-cyclohexyl-isothiocyanatobenzene (6CHBT) was sythesized and described earlier [9, 10, 11]. The perpendicular $\varepsilon_{\perp}$ = 4.0 and parallel $\varepsilon_{\parallel}$ = 12.0 components of the permittivity tensor ε at 298 K were measured with a Tesla BM 484 bridge at 1592 Hz with a measuring voltage of 3 V. Refractive indices n_o = 1.5200 and n_e = 1.6720 at 298 K were measured by means of an Abbe refractometer[10]. The sample was studied in a double plane capacitor with silver electrodes. The thicknesses of liquid crystals layers were 2 mm. To orient the sample a magnetic field of 1T was used. Further optical and dielectric investigations were made with the measuring cells and setup previously described. Cells in the form of flat condensers were made from tin oxide (ITO) coated glass with the electrode area of 2 cm^2 and thickness varying from 30 to 120 μm. Boundary conditions were changed by coating the electrodes with 30 nm of different kinds of polyimides followed by suitable rubbing or by a lecithin. The sample alignment was checked and identified by conoscopic observation and measurements. The dielectric constants ε at 298.0 ±0.2 K were measured by Precision Component Analyzer WAYNE KERR 6425 with a measuring voltage from 10 mV to 5 V and a frequency of 1500 Hz. The magnetic induction was changed from 0.0 to 1.1 T.

RESULTS AND DISCUSSION

Cells were prepared with planar alignment (P. C.) and homeotropic one (H. C.). In each cell the Θ_B angle was measured, with calibrated visual field. Accuracy of Θ_B measurement was 0.002. The cell was then placed in the measuring system described in [12]. Relevant dielectric constant ε^M and optical transmission T were measured simultaneously, employing electric field of the RLC bridge as field that induces certain deformation. In this way $\varepsilon^M = f(u)$ and T = f(U) (and hence $\delta_M = f(u)$). The parameter of this family of characteristics is the magnetic field H. *Typical experimental characteristics are shown in Figs. 3, 4 and 5.*

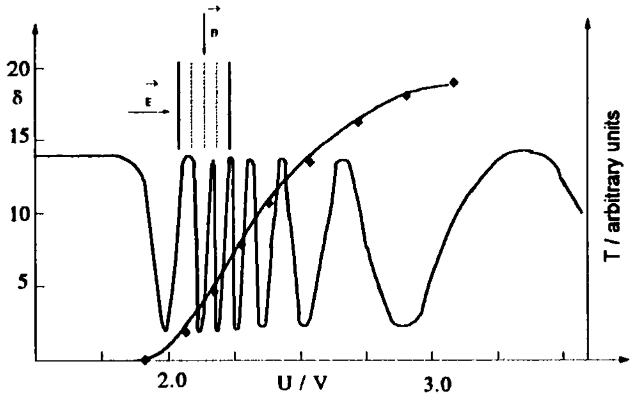

Figure 3. Measured optical transmission T (——) and phase difference decrease δ (♦♦♦) of 6CHBT versus voltage for d = 40 μm and Θ_B = 0.02 at 298 K under B = 0.69 T. .

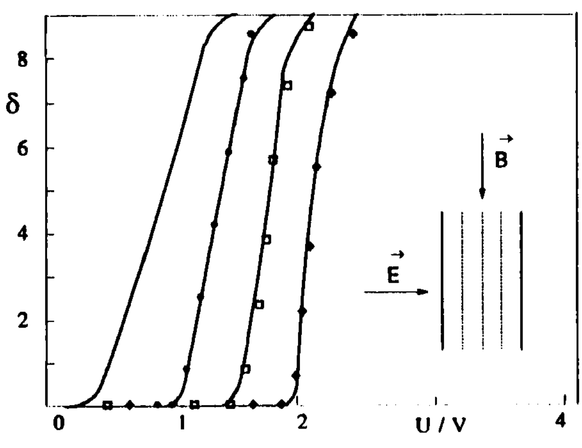

Figure 4. Phase difference decrease δ versus voltage U of 6CHBT for P. C. with d = 40 μm and Θ_B = 0.02 at 298 K under ( ) B = 0.00 T , (•••) B = 0.31 T , (□□□) B = 0.45 T , (♦♦♦) B = 0.69 T

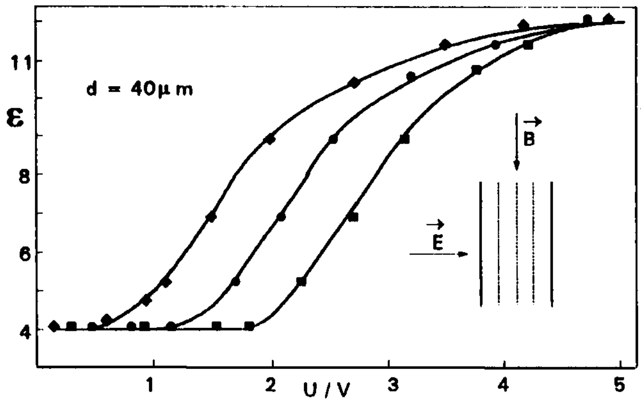

Figure 5. Dielectric characteristic of 6CHBT for P.C . with d = 40 μm and Θ_B = 0.02 at 298 K ; (•) B = 0.00 T , (•) B = 0.45 T , (▪) B = 0.69 T

Similar results may be obtained for homeotropic configuration. In this case, the electric field enhances the restoring elastic torque and the magnetic field, oriented in the layer plane, induces the deformation.

Results that we obtained were used for numerical calculation of director vector field Θ(z) in given measurement cells. Now let us trace the self-consistent field procedure.

Let us choose , for example, the value of δ_M = 7.10 from Fig. 4. For the parameters the experiment U = 2.25 V, B = 0.69 T, d = 40 μm, Θ_B = 0.02, and for material constants of 6CHBT, i. e. $\varepsilon_\perp$ = 4.0 , $\Delta\varepsilon$ = 8.0, $\Delta\chi = 44\times10^{-8}$,n_o = 1.5200 and n_e = 1.6720 at 298 K , δ_L may be calculated for certain reasonably chosen "starting" values of K_{11} and K_{33}. Values of δ_L and δ_M are compared. Then K_{11} and K_{33} are changed and δ_L is calculated again. The angle Θ_B is kept constant all the time. This is why measurement of this angle is so important. Θ_B has very strong influence on the function Θ(z). Our procedure is continued until δ_L equals δ_M. . Self-consistency will be obtained for certain values of K_{11} and K_{33}. . This can be realised only in one way. In our case self-consistency was for: δ_L = 7.12, ε^M = 4.8, $K_{11} = 6.9\times10^{-12}$ N and $K_{33} = 9.8\times10^{-12}$ N. Θ(z) distribution, corresponding to the above values, is shown in Fig. 6.

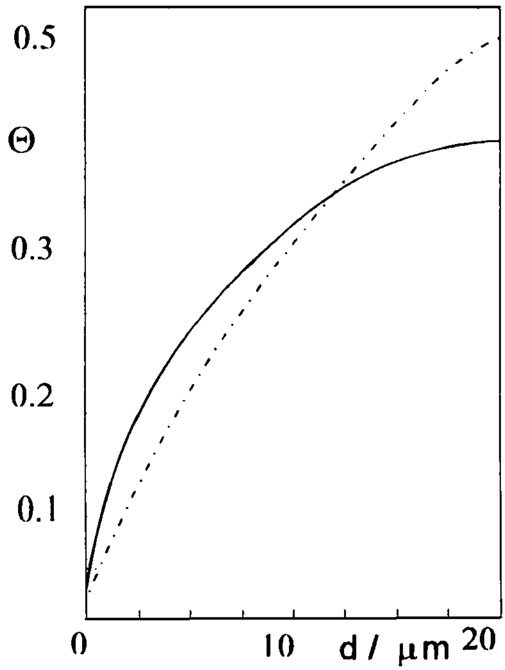

Figure 6. Plots of calculated distribution functions Θ(z) of the P.C. sample. $d = 40\ \mu m$, $K_{11} = 6.9\times10^{-12}$ N and $K_{33} = 9.8\times10^{-12}$ N., $\varepsilon_\perp = 4.0$, $\Delta\varepsilon = 8$; $\Delta\chi = 44\times10^{-8}$; (---) $\delta_L = 7.12$, $\varepsilon_L = 4.81$ when $\Theta_B = 0.02$, $B = 0.69$ T, $U = 2.25$ V with $E = E(z)$; (——) $\delta_L = 10.09$, $\varepsilon_L = 5.09$ when $\Theta_B = 0.02$, $B = 0.69$ T, $U = 2.25$ V with $E = U/d$.

CONCLUSION

The clue of our proposed method of K_{11} and K_{33} elastic constants determination is the fact that it is of no-threshold value. Threshold field is of no interest here. Deformation of ordered liquid crystal layer is investigated above threshold. Instead of determining threshold field with more or less sophisticated method employed, we investigate field-induced deformation itself. Next, expected value suitably chosen physical quantity W is calculated and above-described self-consistent director field method is employed to determine K_{11} and K_{33}.

Proposed method does not involve H_c or E_c explicitly.

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