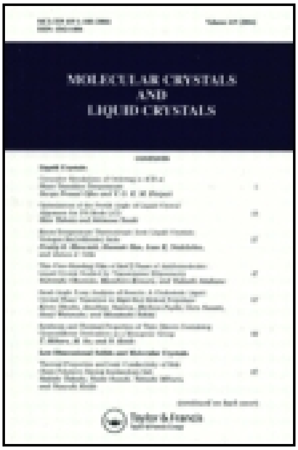

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Optical Observation of Freedericksz Transition in Wedged Homeotropic Nematics

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It is revealed that due to the initial bend in the molecular alignment of a homeotropic nematic wedge, there exists a relaxation in the reorientational degeneracy of the electrically induced Freedericksz transition. The reorientation of the weakly predistorted molecules takes place in a plane perpendicular to the refracting edge of the sample in the direction favoured by the wedge. The propagation vector **k** of the illuminating narrow beam is set in the plane of the molecular orientation and the angle β between the O- and the E-emergent beams has been taken to measure the director's orientation. For a finite angle of incidence $(\mathbf{k},\mathbf{n}_0) = \pm\,\theta_0$, the β vs. applied voltage curves show points of inflexion which correspond to molecular rotation through θ_0 and $\left(\frac{\pi}{2} - \theta_0\right)$ respectively. Further evidence of the lifting of the orientational degeneracy is provided by the conoscopy of the wedged nematics. A discussion of this optical approach to describe the Feedericksz transition along with experimental results will be given for MBBA samples having wedge angles up to 1° arc.

INTRODUCTION

The deformation of the optic axis of a thin nematic liquid crystal film under the influence of an electric field is caused by the dielectric torque. This momentum competes with the elastic torque generated by the interfacial forces between walls of the cell and the liquid crystals. This phenomenon has been extensively studied since the work of Freedericksz and Zolina.[1] The orientation of the sample director **n** with respect to the electric field **E** depends upon the sign of the dielectric anisotropy of the nematic. For a homeotropically aligned nematic sample with negative anisotropy, the electric field tends to reorient the director such that $\mathbf{n} \perp \mathbf{E}$. The distortion occurs above a certain threshold and it has been shown that the Freedericksz transition is a second order effect.

The invariance property of the director ($\mathbf{n} = -\mathbf{n}$) gives rise to a degeneracy in the Freedericksz transition which is dependent on the type and initial molecular alignment of the nematic. For a positive nematic with parallel configuration, the transition occurs with a twofold degeneracy.[2] The molecules are nucleated correspondingly into domains characterized by angles $(\mathbf{n}, \mathbf{n}_0) = \pm\phi$ and these are separated by walls over which the director changes orientation continuously from $-\phi$ to ϕ. The homeotropically aligned nematic with negative anisotropy have been shown[3,4] to exhibit the electric field induced Freedericksz transition with infinite degeneracy and hence the point singularities.

In a recent experiment[5] with homeotropic wedge shaped negative nematic, it was possible to obtain molecular reorientation reasonably free from these distortion singularities. The relaxation in the reorientation degeneracy is believed to be caused by the initial bend in the molecular alignment. In this paper we report on the optical observation of the Freedericksz transition in such wedge shaped nematic liquid crystals and discuss the optical visualization of the directors' orientation over the distortions which might result when the electric field is suddenly switched off.

DISTORTIONS IN WEDGED SAMPLES

We have employed MBBA (methoxybenzylidene-p-butylaniline) from Aldrich Chemicals, for which the dielectric anisotrpy $\epsilon_{\parallel} - \epsilon_{\perp} \cong -0.5$. The wedge was formed by using a variable thickness mylar spacer between two glass plates. Transparent electrodes formed of Sn_2O_3 are deposited on the inner sides of the glass plates and these were chemically treated to obtain homeotropic anchoring of the molecules. The wedge angles up to 1° were used while the thickness of the mylar spacer at the thin end was about 10 μm. The wedge was placed between two crossed polarizers and was illuminated with a plane wave of monochromatic light from a laser. When an a.c. electric field having a frequency of about 1000 Hz is applied, the Freedericksz transition occurs when the voltage exceeds 4.5 volts rms. If the polarization of the incident beam is suitably oriented to be at 45° with

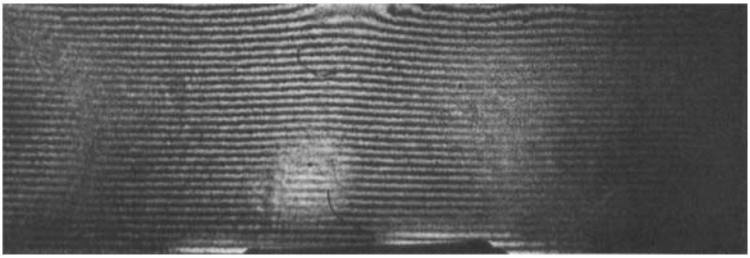


FIGURE 1 Interference fringes due to the optical path difference between the E- and the O-waves. The birefringence $\beta = 2 \times 10^{-3}$ radians obtained at 7 volts rms.

respect to the optic axis of the crystal, an interference fringe pattern characteristic of the optical path difference between the O- and the E-waves is obtained. These fringes are rectilinear in nature and run parallel to the refracting edge of the wedge. For a typical value of the maximum birefringence $\mu_e - \mu_0 = 0.2$ and taking the wedge angle $\alpha = 1°$, one obtains about 5 fringes/mm in the plane of the wedge.

Figure 1 shows the interference fringe pattern for an MBBA wedge with $\alpha = 1°$ and observed with monochromatic light at $\lambda = 632.8$ nm. Obviously, there are no point singularities, showing complex distortion of the director as have previously been reported in the case of constant thickness samples, visible over the entire field of view. This shows that the bulk of the molecules constitutes a single domain and that the molecules have undergone reorientation over a given plane in a preferred direction determined by the initial long-range bend distortion of the molecules. The wedge behaves like a weakly distorted system and at any point the local optical properties are still those of a uniaxial crystal. The magnitude of the anisotropy remains unchanged and it is only the director **n** which has been rotated. The rotation of the director in this case takes place about the refracting edge of the sample and is contained in a plane perpendicular to it. Now, this direction of rotation will be preferred if the director is subjected to further distortions due to the external electric field. If this coincides with one of the permissible orientational directions, it will be favoured over the others resulting in a complete removal of the degeneracy. This has been further elaborated in the subsequent sections.

MODIFIED FREEDERICKSZ TRANSITION CURVES

The nematic wedge behaves like a tunable polarization prism[6] dividing the incident light into two beams with orthogonal polarizations.

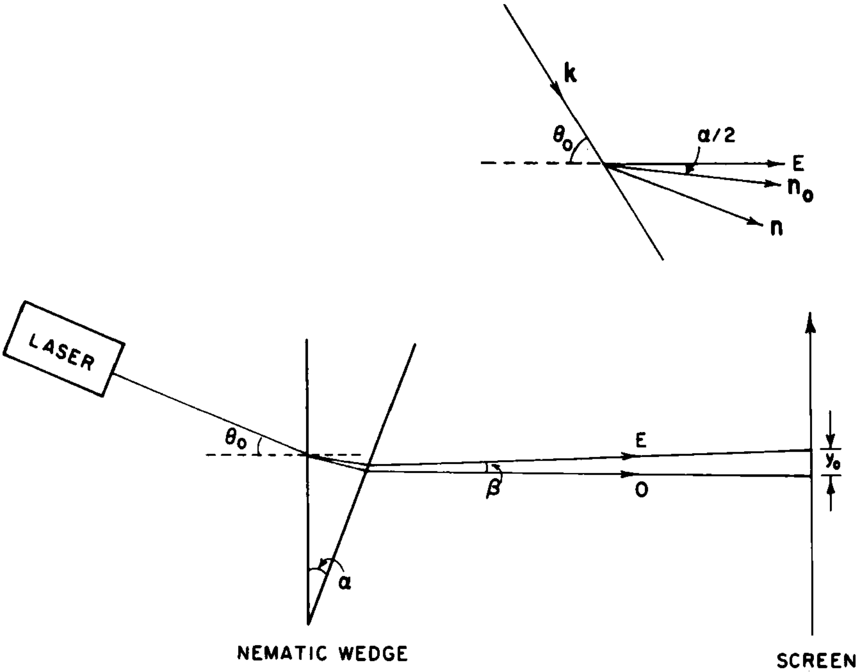


FIGURE 2 Optical setup for measuring the Freedericksz transition.

The angle β between the O- and the E-rays has been taken to be a measure of the birefringence of the sample. The optical setup has been shown schematically in Figure 2, where the refracting edge of the sample is taken to coincide with the Z-axis. The director $\mathbf{n}_0$ and the electric field $\mathbf{E}$ are then contained in the plane (x, y) which is perpendicular to refracting edge. The plane (x, y) is also the plane of incidence of a narrow probe beam from a He-Ne laser. Let $(\mathbf{k}, \mathbf{n}_0) = \theta_0$ be the angle between the propagation vector $\mathbf{k}$ of the probe beam and the director $\mathbf{n}_0$ at the wall. The orientation $(\mathbf{n}_0, \mathbf{n}_0') = \alpha/2$ of the distorted director due to the initial bend in the middle of the sample is very small. The birefringence parameter β is determined by measuring the beams separation y_0 along the y-axis on the screen at a distance L from the sample. Figure 3 shows the plot of the angle β against the applied voltage and it corresponds to the standard tunable birefringence curve of the nematic wedge at $\theta_0 = 0$.

In Figure 4 we show the results obtained when the probe beam was incident at a finite angle on the wedge. As shown in the figure inset, the probe beam is directed from the top towards the refracting edge such that $\theta_0 = -50°$. The system shows a residual birefringence equal to the angle β_0. As an electric field is applied, β remains constant

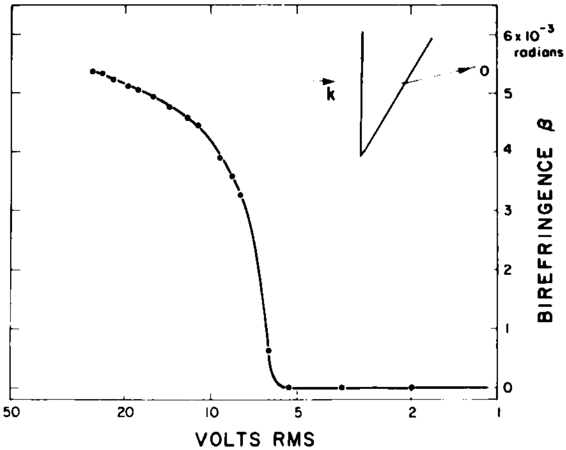


FIGURE 3 Birefringence β versus the applied voltage: the probe beam angle θ_0 = 0 as shown in the inset.

until the threshold for the Freedericksz transition is reached. The birefringence parameter β is found to decrease with the increasing voltage reaching a zero value at about 5 volts rms. Afterwards it increases steadily to reach a maximum saturated value. Such a behavior signifies that the director has undergone a rotation about the refracting edge in the clockwise direction. The zero birefringence ($\beta = 0$) then corresponds to the instant when the director lines up with **k**. The curve shown in Figure 5 corresponds to probe beam incident from the below at angle $\theta_0 = +50°$. Unlike in the previous case, the residual birefringence β_0 now increases as the applied voltage is increased beyond the threshold. The maximum birefringence occurs when the angle (**k**, **n**) between the probe beam and the director is equal to $\pi/2$. The director's rotation with respect to its undistorted position now corresponds to $(\pi/2 - \theta_0)$. A further increase in the voltage produces a steady decrease in the birefringence until a saturation is reached. Evidently, the above behaviour is caused by the director tilting once again towards the refracting edge of the prism.

CONOSCOPIC OBSERVATION

The conoscopic figures for the wedged sample viewed between crossed polarizers and in convergent white light in the normal direction are shown in Figure 6. The typical cross of isogyers, located in symmetrically in the field of view, is obtained for the case when the electric

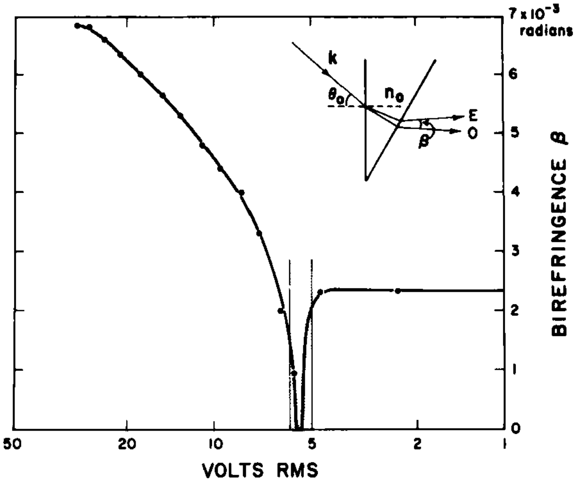


FIGURE 4 Birefringence β versus the applied voltage; the probe beam angle θ_0 = 50° as shown in the inset.

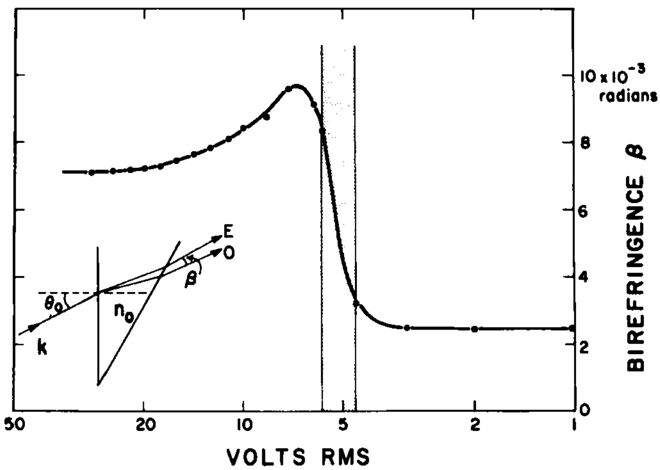
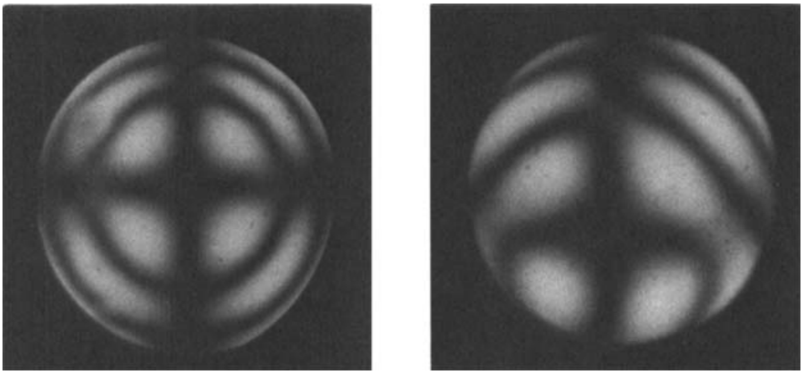


FIGURE 5 Birefringence β versus the applied voltage; the probe beam angle θ_0 = +50° as shown in the inset.

field is absent (Fig. 6a). As the predistortion of the molecules caused by the wedge is very small, the asymmetry is not quite apparent from this conoscopic figure. The asymmetry, however, becomes visible if the pretilt of the molecule is lage.[7] The electric field induced reorientation of the director just above the threshold is shown in Figure



(a) (b)

FIGURE 6 Conosopic figures of wedged homeotropic sample. (a) $E = 0$ (b) $E \cong E_{\text{threshold}}$.

6(b). It is revealed that the cross of isogyers always tends to move towards the refracting edge. This observation conforms to that made in the previous section.

EFFECT OF SUDDEN REMOVAL OF THE ELECTRIC FIELD

In this experiment we have examined the behaviour of the wedge when the electric field is suddenly switched off. The molecules under the influence of the elastic torque due to the cell walls revert to the original homeotropic structure. The instantaneous observation of the sample between crossed polarizers as before, now shows complex molecular disorders indicating formation of molecular domains. Figure 7 shows an example of the distortion obtained upon removal of the electric field. As the mechanism of the directors realignment under the elastic torque is rather slow, the interference fringes due to the birefringence still persist and these decay slowly with time. The period of these fringes is given by

$$p = \frac{\lambda}{(\mu_{\text{eff}} - \mu_0)\alpha}$$

and becomes variable due to the variation of the refractive index μ_{eff} over the wedge. The interference fringes are further modified depending upon the distortion in the molecular structure. In effect one would see the contours of equal phase represented by the fringes and an

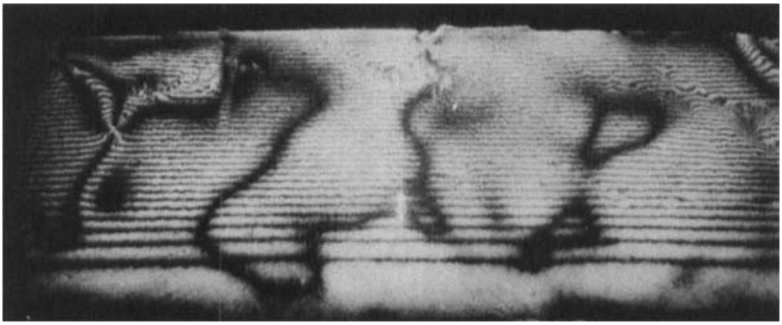


FIGURE 7 Interference fringes in presence of the distortions caused by sudden removal of the electric field.

analysis of the interferograms would help characterize these distortions.

DISCUSSION

The Freedericksz transition in wedged homeotropic nematics has been measured by using a probe beam whose plane of incidence coincides with that of the directors' rotation. The initial bend in the molecular structure caused by the wedge helps lift the degeneracy of the electric field induced molecular reorientation. The curves showing the evolution of the birefringence with the applied voltage now show points of inflexion demonstrating that the directors' rotation takes place in a particular direction. In the voltage range shown by shaded areas on the Figures 4 and 5, we have obtained an excessing scattering in the emergent beams. The points of high intensity concentration on the screen corresponding to the directions of the emergent beams, were, however, distinctly visible. Furthermore the distortions in the molecular structure can be measured by analysing the interference fringes characterizing the optical path difference between the E- and the O-waves.

Acknowledgements

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