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Verification of Leslie's Expression for the Threshold Field of a Twisted Nematic Cell

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By using an optical system sensitive to small changes in birefringence, we have measured the Leslie threshold field for distortion in a twisted nematic (TN) cell. The compound used in the measurement was 4′-*n*-heptyl-4-cyanobiphenyl (7CB) for which we have independently measured all the three elastic constants. With these data we have verified Leslie's expression for the threshold field for the TN cell.

INTRODUCTION

The twisted nematic cell consists of a nematic sample sandwiched between two glass plates whose surfaces have been treated to anchor the nematic director parallel to the surfaces. Further, the two plates are usually arranged with their easy axes of alignment orthogonal to each other so that the director "twists" uniformly by 90° between the two boundaries. If a magnetic field (or, if the medium has positive dielectric anisotropy, an electric field) is applied normal to the glass plates, a distortion in the orientation pattern of the director takes place above a threshold field H_L (or E_L). The theory of this distortion was worked out by Leslie.[1] The threshold magnetic field is given by the condition

$$\Delta\chi x_0^2 H_L^2 = \pi^2 k_{11} + (k_{33} - 2k_{22})\varphi_0^2 \qquad (1)$$

where $\Delta\chi$ is the anisotropy of the *volume* diamagnetic susceptibility of the medium, x_0 is the thickness of the sample, φ_0 is the angle of twist, k_{11}, k_{22} and k_{33} are respectively the splay, twist and bend elastic constants.

In display devices the incident light is polarized parallel to the director at one of the boundaries of a 90°-twist cell. The nematic medium has a strong

birefringence $\Delta n (\simeq 0.1\text{–}0.3)$. As a consequence, the phase retardation γ introduced by any thin section of the medium is $\simeq 2 \times 10^{-3}$ (if $\Delta n \simeq 0.2$ and the section is 20 Å thick) and is much larger than the rotation β of the director between two successive thin sections (typically $\beta \simeq 10^{-4}$ radian). Hence by the "adiabatic theorem," the direction of polarization is rotated by 90° as it emerges from the twisted cell and can be crossed out by a polarizer whose direction of polarization is set parallel to the first polarizer. Just above the threshold field H_L, the condition $\gamma \gg \beta$ still holds and hence the field of view remains dark. Only when the magnetic field is increased above an "optical" threshold H_0 such that the distortion is quite considerable and $\gamma \sim \beta$, does the field of view become bright. Thus the TN cell has a "bilevel" operation.

Gerritsma *et al.*[2] who noted that $H_0 > H_L$ also found that H_0/H_L increases as the sample thickness increases—a fact which can be easily understood in terms of the arguments given above (β decreases as the sample thickness increases). Hence Gerritsma *et al.* used capacitance measurements to detect H_L. Detailed calculations of the transmitted intensity of light as a function of the applied field have been made by van Doorn,[3] who also calculated the thickness dependence of $(H_0 x_0)$. Similar calculations have also been reported by Berreman.[4]

However, even just above H_L, the effective birefringence of the distorted medium will be reduced. There are two linearly polarized normal waves in the medium, one of them polarized parallel to the projection of the director in the plane normal to the direction of propagation (XZ plane in Figure 1) and another normal wave polarized perpendicular to this direction in the XZ plane. Just above H_L, the *phase difference* between these two normal waves *decreases* as a result of the decrease in the effective birefringence. Hence it will be possible to detect H_L if we have an optical set up sensitive to small changes in the birefringence. We have used a simple technique for this purpose.

EXPERIMENTAL

The experimental set up is shown schematically in Figure 1. The alignment of the director parallel to the glass plates was achieved by the oblique evaporation of silicon on the plates.[5] The cell was mounted in a suitable oven whose temperature could be maintained and measured to an accuracy of ± 0.02°C. A copper-constantan thermocouple was used to measure the temperatures. The oven was placed between the pole pieces of an electromagnet and its position was adjusted by means of screws so that the initial undistorted orientation of director was normal to the applied field. The

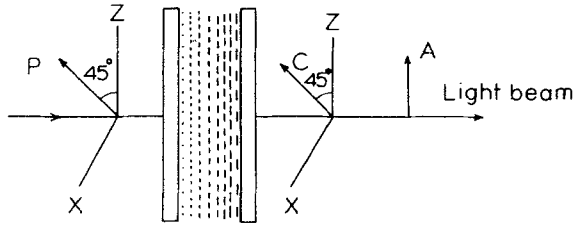

FIGURE 1 Schematic representation of the experimental set up. P: Polarizer, C: Quarter wave plate and A: Analyzer.

collimated light beam from a sodium vapour lamp was reflected by means of a mirror and allowed to pass through the cell. The incident light was polarized at 45° to the director at the boundary. It will be split into the ordinary and extraordinary waves in the medium both of which turn by 90° and develop a phase difference. The emergent beam is elliptically polarized and is allowed to pass through a quarter wave plate C (Figure 1). The orientation of C is adjusted to convert the elliptically polarized light to linearly polarized light which can now be easily detected by means of a linear polarizer A. Observations are made through a low power microscope into which the light beam is deflected by means of a suitable mirror. The azimuth of the linearly polarized light emerging from C is a measure of the phase retardation introduced by the cell. It is well known that this set up is quite sensitive to small changes in the phase retardation (see, for instance, reference 6). The analyser is set to get a dark field of view when the applied field is zero, so that when the distortion of the orientation of the medium occurs at H_L, the field of view becomes bright.

For the sake of comparison some measurements were also made with only the polarizer and analyzer set as in the display devices, to determine H_0.

In all experiments mylar spacers were used but the actual sample thickness x_0 was always measured by channelled spectra formed in air gaps deliberately left unfilled.

The compound used was 4′-*n*-heptyl-4-cyanobiphenyl (7CB) for which we have determined the temperature variation of all the elastic constants independently.[7,8] The nematic–isotropic transition point (T_{NI}) of 7CB was 41.9°C.

RESULTS AND DISCUSSION

The experiments were done on two sample thicknesses ($\simeq 25\ \mu$ and $\simeq 50\ \mu$), with several independent trials for each thickness. Since we want to compare the experimental data with the theoretical values (Eq. (1)), we have collected the elastic constants of 7CB[7,8] in Figure 2. The experimental values of ($H_L x_0$) are plotted as functions of the relative temperature ($T_{NI} - T$) in

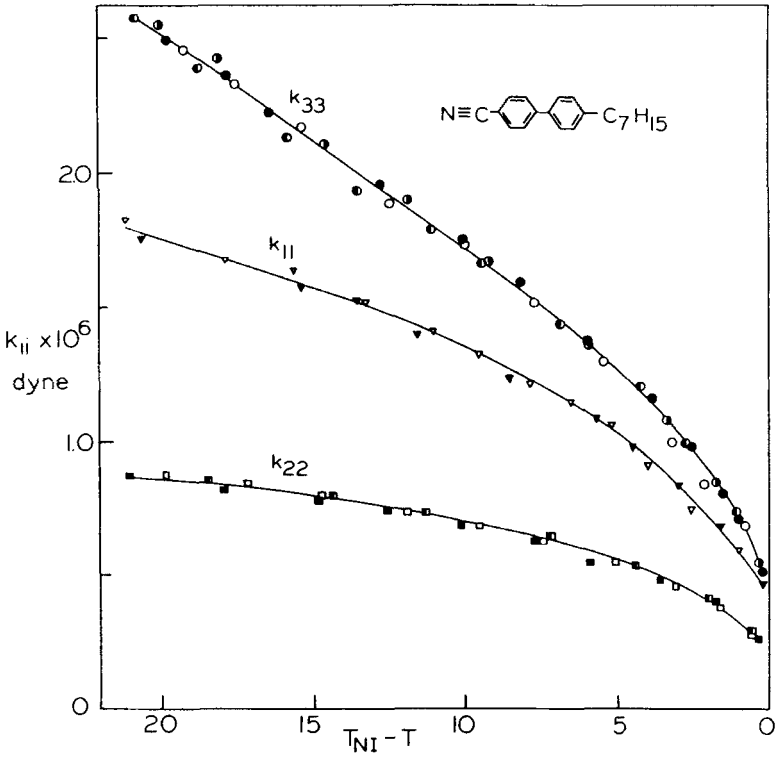

FIGURE 2 Splay (k_{11}), twist (k_{22}) and bend (k_{33}) elastic constants of 4′-*n*-heptyl-4-cyanobiphenyl as functions of the reduced temperature ($T_{NI} - T$).

Figure 3. The values calculated on the basis of Eq. (1) are also shown (continuous line in Figure 3). It is obvious from the figure that at any given relative temperature ($H_L x_0$) is constant to $\pm 2.5\%$. Further, the calculated values agree extremely well with the experimental data on the 25 μ samples. However, the data on the 50 μ samples are somewhat lower (by about 5%) than the calculated values. We believe that this discrepancy arises mainly because of the uncertainty in the measurement of the magnetic field. Since H_L is lower for the thicker samples, the error in measurement is larger. Hence we can say that Leslie's equation has been verified within the experimental errors.

On the other hand, in the experiments with the usual arrangement of the polarizer and analyzer, we get at $T_{NI} - T = 1°C$ the following results: $H_0/H_L = 1.24$ for $x_0 \simeq 25$ μ and $H_0/H_L = 1.39$ for $x_0 \simeq 50$ μ. It is interesting to note that the latter number is close to the value calculated by van Doorn[3] ($H_0/H_L \simeq 1.4$) for a 50 μ thick sample of MBBA.

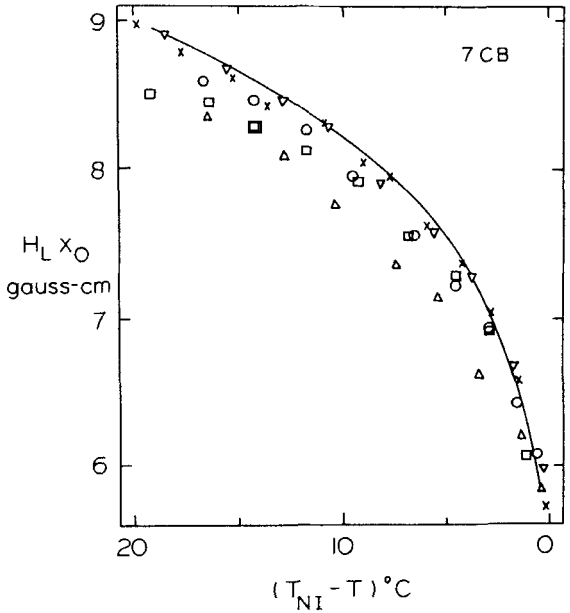

FIGURE 3 The product of the threshold field (H_L) and sample thickness (x_0) as a function of the reduced temperature in 4′-*n*-heptyl-4-cyanobiphenyl. The values calculated on the basis of Eq. (1) and data of Figure 2 are plotted as the continuous line. X, ▽ and ○ are data for $x_0 \simeq 25\ \mu$ and □, △ are for $x_0 \simeq 50\ \mu$.

In conclusion, we may note the advantages of using the optical method to determine H_L, compared to the capacitance technique. We can choose a small, well aligned area of the specimen, thus avoiding any temperature gradients and edge effects.

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