TEMPERATURE DEPENDENCE OF BIREFRINGENCE IN LIQUID CRYSTALS*

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The temperature dependence of birefringence in the liquid crystal methoxybenzylidene-*n*-butylaniline has been obtained by measuring the birefringence of a thin sample placed between crossed polarizers. Measurements of transmitted laser light yield minima and maxima which can be related to the difference in refractive indices. A converging beam displays the orientation of the optic axis and is used in determining Δn. Wavelength dependence is measured in a similar way using white light and spectrograph.

Many organic materials have an ordered liquid phase between the solid phase and the isotropic liquid phase. Interest in this liquid-crystal phase has been revived in the past few years. It is well known that liquid crystals exhibit birefringence.[1] This paper reports research investigating the temperature dependence of the birefringence in the nematic liquid crystal methoxybenzylidene-*n*-butylaniline (MBBA).

If a thin sample is placed between crossed polarizers in a laser beam and the transmitted intensity is measured as a function of temperature, a curve similar to the one shown in Fig. 1 is obtained. As the temperature is increased, the intensity exhibits oscillations until the nematic-isotropic transition region is reached. Samples ranging from 0.2 mm to 2.0 mm thickness have been used and it is found that the separation of the minima in the curve is inversely proportional to sample thickness. These results are easily interpreted. The sample is similar to a "wave plate." If the laser light is transmitted through a region of the fluid where the molecular alignment is at some angle with respect to the polarization direction of the incident light, the transmitted intensity depends on the product of the sample thickness l and the difference in refractive indices, $n_o - n_e$. If $(n_o - n_e)l$ is an integral number of wavelengths, the transmitted intensity will be a minimum. As the temperature is increased, the quantity $n_o - n_e$ decreases and the transmitted intensity goes through a succession of minima. As the transition region is reached, however, the minima are not distinguishable. Were it not for this fading of the signal, one could simply measure the phase difference between the critical temperature and any temperature below critical to determine the quantity $2\pi(n_o - n_e)l/\lambda$ as a function of temperature. If $\psi = 2\pi(n_o - n_e)l/\lambda$ and ψ_m is the value of ψ at the subcritical temperature below which the signal is distinguishable in Fig. 1, then the temperature dependence of $\psi - \psi_m$ can be precisely measured for $T < T_m$. If ψ_m could be determined, the temperature dependence of ψ would be accurately measured. Several experimental techniques were used in increasing the precision of the measurement of

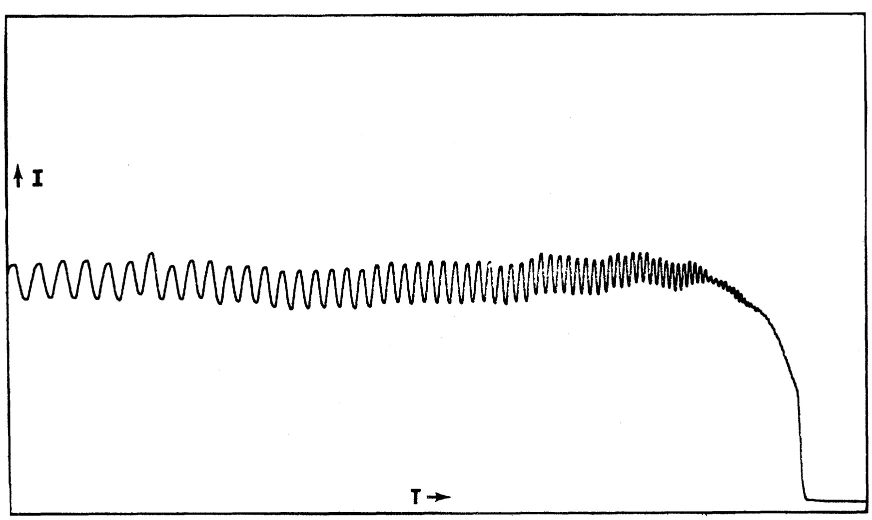

FIG. 1. Intensity of laser beam transmitted through liquid-crystal sample between crossed polarizers as a function of temperature.

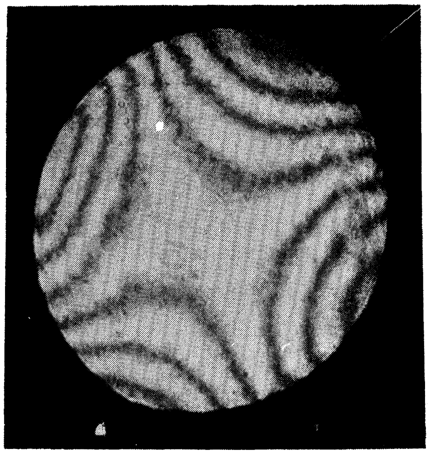

FIG. 2. Photograph of pattern obtained with converging beam and optic axis parallel to sample windows.

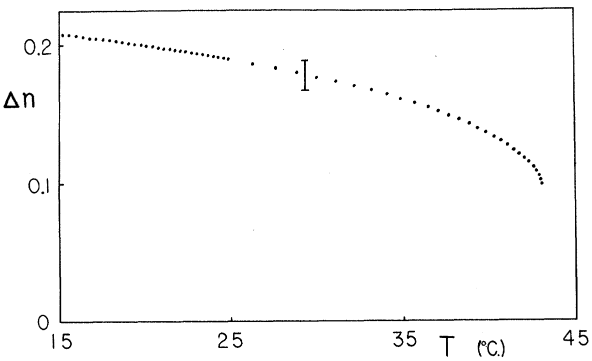

FIG. 3. Difference in refractive indices versus temperature.

$\psi(T)$ by decreasing the uncertainty in ψ_m.[2]

A channeled spectrum can be obtained if the laser is replaced with a white-light source and a spectrogram made of the light transmitted through the polarizer and analyzer. The spectrum exhibits minima and maxima. Minima occur at wavelengths for which $(n_o-n_e)l/\lambda$ is integral. If n_o-n_e were independent of wavelength, its value could be determined from the spacing of the minima in the spectrum. The spectrum was photographed continuously as the temperature was swept yielding the equivalent of Fig. 1 as a function of wavelength. Analysis of the results indicate that n_o-n_e is quite sensitive to wavelength. Further studies of the wavelength dependence are being made.

Rotation of the sample about an axis perpendicular to the laser beam provides a means of changing the path lengths for the *o* and *e* rays. As the sample is rotated, the transmitted intensity varies. If the direction of the optic axis were known, the value of n_o-n_e could be obtained from the angular spacing of the fringes. The direction of the optic axis can be obtained if the sample is placed between crossed polarizers in a convergent beam and the field viewed.

Figure 2 is a photograph made with a converging beam through a 1 mm sample. Similar photographs can be obtained with a thick slab of calcite or quartz cut parallel to the optic axis and can be found in standard texts.[3] The pattern in Fig. 2 can be monitored as the temperature is increased. The fringes change as the temperature is increased; the phase in the middle of the pattern corresponds to that measured in Fig. 1. It is also possible to obtain circular patterns characteristic of alignment of the optic axis perpendicular to sample vessel windows. This alignment was generally unstable except at lower temperatures. (Alignment can be attained at higher temperatures with applied fields.) The absolute value of ψ can be determined from the spacing of the fringes in the converging-beam patterns. The uncertainty in ψ from measurements for a given photograph is large, but making measurements on many photographs over a wide temperature range decreases the uncertainty.

A plot of n_o-n_e versus temperature is shown in Fig. 3. The meaning of the error bar is that the whole series of points can be shifted as a unit. The difference in refractive indices is proportional to $(T_c-T)^{0.22\pm0.05}$ over the temperature range $10^{-3}<(T_c-T)/T_c<10^{-1}$. Reduction in the uncertainties in Δn and T_c and data at temperatures closer to critical should improve the determination of the temperature dependence. The region near critical is being carefully investigated to improve the temperature range covered by the data and to determine if a sharp discontinuity exists. The effect on the transition of an applied field is being studied. Studies are also being made with other liquid crystals.

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[1]G. W. Gray, *Molecular Structure and the Properties of Liquid Crystals* (Academic, New York, 1962).

[2]A more detailed paper reporting this work will be submitted elsewhere.

[3]F. Jenkins and H. White, *Fundamentals of Optics* (McGraw-Hill, New York, 1957), 3rd ed.

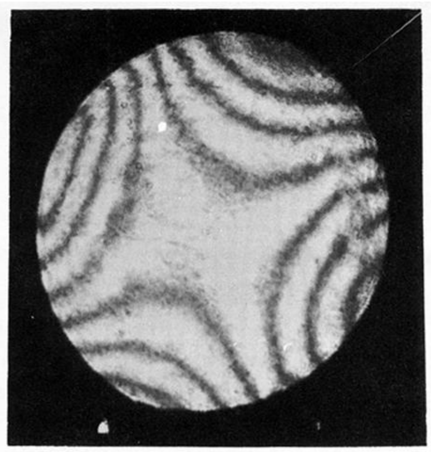

FIG. 2. Photograph of pattern obtained with converging beam and optic axis parallel to sample windows.