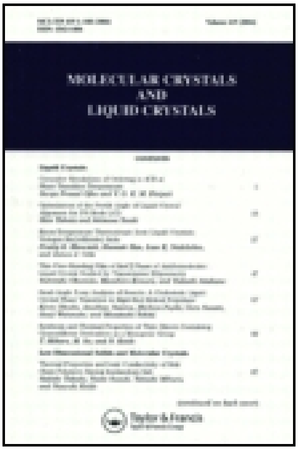

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ELECTRIC FIELD INDUCED CHANGES IN THE SELECTIVE REFLECTION BAND OF CHOLESTERIC LIQUID CRYSTALS

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ABSTRACT

This paper presents observations of the field induced changes in selective reflection from cells containing mixtures of cholecteric CB-15 in nematic E8. The considerably greater dielectric anisotropy of these materials over any in which this effect has previously been reported permits significant colour changes to be effected with voltages ~ 10 V before the onset of the planar to focal conic transition. The observations are discussed in relation to recent theoretical work on field induced pitch gradients in cholesterics.

INTRODUCTION

It was Fergason who, in 1966, first noted (1) that the colour of light reflected from a cell containing cholesteric liquid crystal could be modified by applying an electric field to the cell. The effect was further explored by Harper (2), Oron and Labes (3) and Gerritsma and van Zanten (4). Without exception, these authors used materials which have a low dielectric anisotropy and consequently a large applied voltage (~ 100 V) is needed to effect the colour change. This limits the usefulness of the device in practical applications. The reported shifts in the colour of reflection towards the blue imply a reduction in the helical pitch of the liquid crystal but few explanations of this change have been given. Gerritsma and van Zanten did observe a slight blue shift (~ 10 nm) in a cholesteric material, and linked this to the onset of a periodic gridlike deformation occurring when a field was applied (5). A recent application of continuum theory (6) has predicted a field-induced pitch gradient in a cholesteric cell which could give a shorter pitch either in the surface regions or in the centre of the cell and this may provide an alternative explanation of the field-induced shift in the selective reflection property. The optical effects of a pitch distribution in a cholesteric material have also been calculated (7).

This paper presents results obtained with cholesteric mixtures based on the cyanobiphenyl materials which exhibit a much larger dielectric anisotropy than any compound used in the references cited above. This permits a significant colour change to be achieved using much lower voltages (~ 10 V) before the onset of the planar to focal conic transition.

EXPERIMENTAL TECHNIQUE AND RESULTS

The cholesteric material used was CB-15 (BDH Ltd) which was diluted with E8 nematic (also from BDH) to increase its natural pitch and extend its cholesteric range to normal temperature. Two concentrations, one of 38.5% CB-15 (red reflection) and one of 44% CB-15 (green reflection) were used. These mixtures did not exhibit any significant thermo chromism. The cells were constructed from indium-tin-oxide-coated glass treated by the rubbed PVA method (8) to produce slightly tilted homogeneous alignment giving a transparent Grandjean texture in the liquid crystal. The cells were constructed using Mylar spacers (nominal thicknesses of 6, 12 and 25 microns), sealed with epoxy on two sides for mechanical strength and filled by capillary action.

A Unicam SP-800 spectrophotometer recorded the transmission spectra of the cells, which in the absence of absorption by the material are equivalent to the complement of the reflection spectra (Fig. 1a). The reflection effects at higher voltages were accompanied by the growth of regions of optically scattering focal conic texture. The fastest scan of the SP-800 over the region of interest proved to be too slow to record the initial observed colour change at these voltages before it became masked by the Grandjean to focal conic process, and therefore manual scanning was used. Successive scans of one undistorted cell gave a difference in λ_p of less than 2 nm., where λ_p, the peak wavelength of selective reflection, is defined as the midpoint of the line joining points where the reflection coefficient is at half its maximum value. For the mixture used $\lambda_p = \lambda_o = 650$ nm (red) and 540 nm (green). Circular polarisers of opposite sense were constructed from Polaroid 140 nm $\frac{1}{4}$ - wave plate and HN32 linear Polaroid material and placed in the spectrophotometer beam with the axis of linear polarisation vertical to give circularly polarised light incident on the cell. The vertical orientation of the linear polariser avoided any effect due to polarisation of the spectrophotometer beam. The ellipticity introduced by the retardation plate at wavelengths other than 560 nm causes slight changes in band shape, which are effectively cancelled out by the subtractive procedure outlined below. The main advantage, however, of circular polarisers is the change in transmission with wavelength as seen in Fig. 1a. Whereas the peak transmission in the circular dichroism band is 50% using unpolarised light, this approaches zero when the correct sense of circular polariser is inserted. As the scattered light produced by the disclination lines and by the growth of focal conic texture is largely unpolarised, its effect can be removed almost completely by sequentially inserting polarisers of the opposite sense and subtracting the resulting absorbance spectra. The electric field was supplied by a sinewave generator of 600 Ω output impedance, working at 10 kHz to avoid electro-hydrodynamic effects. The voltage applied to the cell was kept constant while the spectrum was recorded, and then switched off. The next spectral scan, at a higher voltage, was not taken until comparison of the transmittance of the 'off' state with that at the beginning of the experiment (i.e., at zero field) showed the cell had fully recovered. A series of spectra, at increasing voltage, was obtained for one cell with one of the circular polarisers in place. The procedure was then repeated for the same cell and voltages, but with the polariser replaced by one of opposite sense. The nature of the spectra obtained in this way is shown in Fig. 1b.

From superimposition of the two spectra, values of $A(\lambda)$ were obtained where:

$$A(\lambda) = A_{RHCP}(\lambda) - A_{LHCP}(\lambda).$$

$A_{RHCP}(\lambda)$ is the absorbance at one value of wavelength recorded with the RHCP polariser enhancing the change in transmission and $A_{LHCP}(\lambda)$ is the absorbance at the same wavelength with the LH circular polariser in place. A series of values of $A(\lambda)$ was derived in this way for each applied field value and cell.

The $A(\lambda)$ values were calculated as follows:
Six transmission coefficients $T_i(\lambda)$ were defined $(0<T_i<1)$ thus:

$T_1(\lambda)$ = transmission of RH circular polariser
$T_2(\lambda)$ = transmission of LH circular polariser
$T_3(\lambda)$ = transmission of cell to RHCP light
$T_4(\lambda)$ = transmission of cell to LHCP light
$T_5(\lambda)$ = transmission of cell and RHCP
$T_6(\lambda)$ = transmission of cell and LHCP

It was assumed that the properties of the RH and LH circular polarisers were similar and therefore that $T_1(\lambda) = T_2(\lambda)$. Absorption was neglected and hence $T_4(\lambda)$ was assumed to be unity.

Thus:

$$\begin{aligned} T_5(\lambda) &= T_1(\lambda)\, T_3(\lambda) \\ T_6(\lambda) &= T_2(\lambda)\, T_4(\lambda) = T_2(\lambda) = T_1(\lambda). \\ A(\lambda) &= -\log_{10} T_3(\lambda)\, T_1(\lambda) + \log_{10} T_1(\lambda) \\ &= -\log T_3(\lambda). \end{aligned}$$

The reflection coefficient $R(\lambda)$ for each value of λ was found from

$$R(\lambda) = 1 - \log_{10} T_3(\lambda).$$

Reflection coefficients were calculated for all wavelengths at 10 nm intervals, and reflection spectra were drawn, and the linewidths $\Delta\lambda_p$ (defined as the width of the reflection band at half the maximum reflection intensity) were obtained from each cell and value of applied field.

Graphs of λ_p against applied electric field were drawn for each cell thickness and cholesteric concentration studied and from these the average curve shown in Fig. 2 was derived in each case.

DISCUSSION

All the results show an initial shift of peak wavelength (λ_p) of selective reflection to shorter wavelengths with applied field. For small increments of voltage above the cell threshold voltage this decrease in wavelength appears to be approximately linear. The linewidth behaviour is shown in Fig. 3. The initial increase with field later becoming a decrease is consistent with the broad prediction of ref 6. In the case of the 25 micron cells it was found that the onset of the Grandjean to focal conic transition occurred before the region of decreasing linewidth was reached. Threshold voltages were obtained from graphs of λ_p against applied voltages by extrapolation to λ_o. The trend in V_T was found to be proportional to cell thickness (9) although some deviation was observed in the thinnest cells used where surface effects can alter the bulk behaviour of the material.

A practical estimate of the change in band wavelength due to environmental causes can be obtained from the zero field values of λ_p in different cells of the same material. These should give almost identical λ_p values in the absence of impurity or temperature effects (10). In practice the λ_p values varied by less than 4 nm for cells containing the same mixture. The upper limit of applied voltages was set by the magnitude of the Grandjean to focal conic texture change during one scan time. However, distortion in the graphs of reflection coefficient against wavelength was already apparent in most cases where the maximum coefficient (at λ_p) was below 70% of its value at λ_o. Since the Grandjean texture produces an essentially symmetrical reflection band (11), this effect points to a severe distortion of the structure. All of the above results were for fields at which the reflection coefficient at λ_p was at least 70% of its value at λ_o.

The results presented here appear to be in agreement with the theoretical work of Tough, Shanks and Fedak (6). The decrease in peak reflection wavelength with applied field suggests that the pitch in the cholesterics may be reduced at the edges of the cell consistent with a tendency for the pitch to be "unwound" near the centre by the action of the applied field. It is clear from the theoretical work that the relative magnitudes of two elastic constants (K_{22} and K_{33}) substantially determine the nature and extent of the observed colour change. Effort is currently being directed to the measurement of elastic constants of potentially suitable materials with the aim of extending the range of the colour change before the onset of the Grandjean to focal conic transition.

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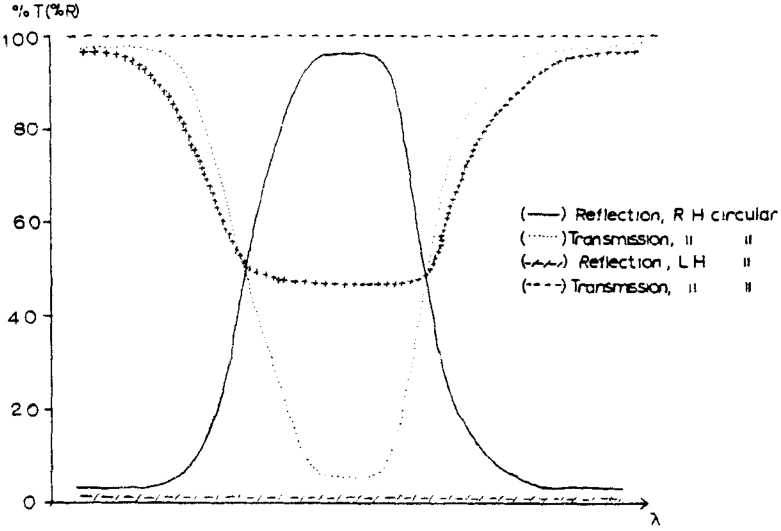

FIGURE 1 Transmission and reflection by a "left handed cholesteric

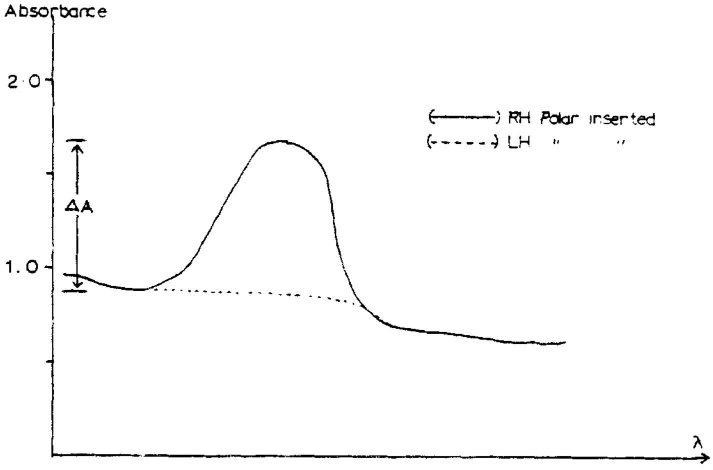

FIGURE 1b Typical experimental observation of the reflection

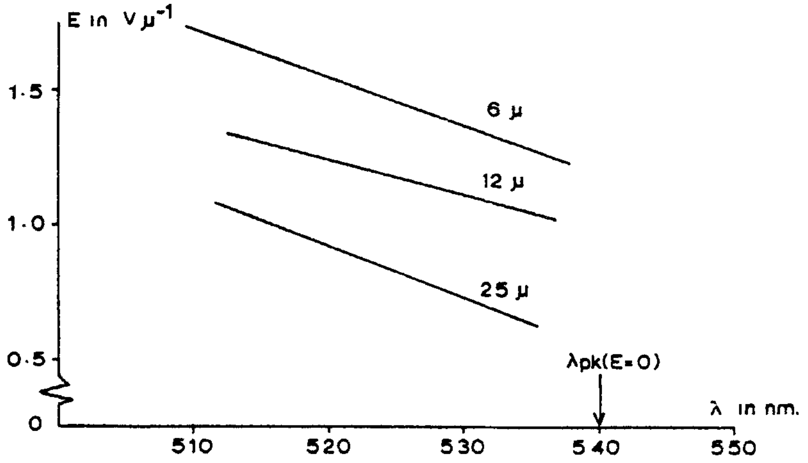

FIGURE 2a Graph of λpk against applied field 4.4% CB-15 in E 8

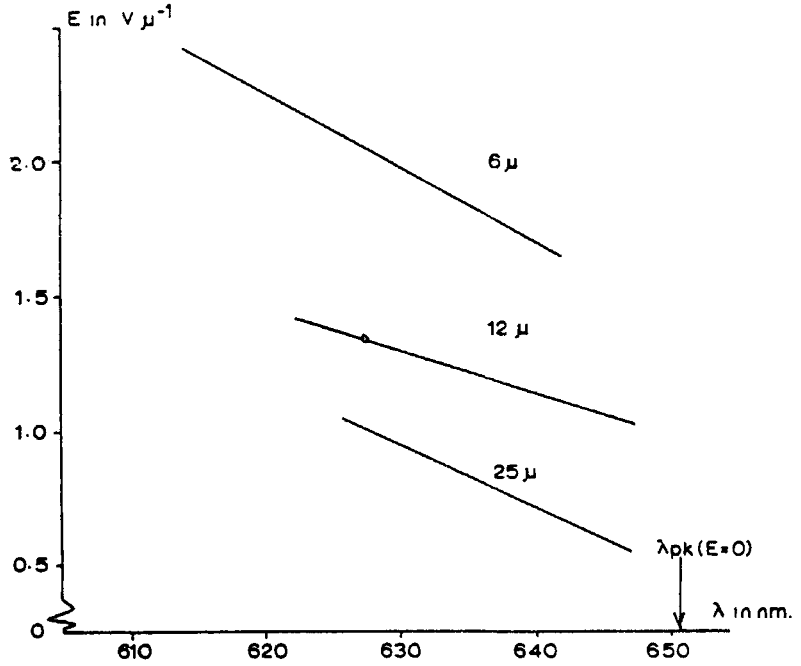

FIGURE 2b Graph of λpk against applied field : 38·5 %

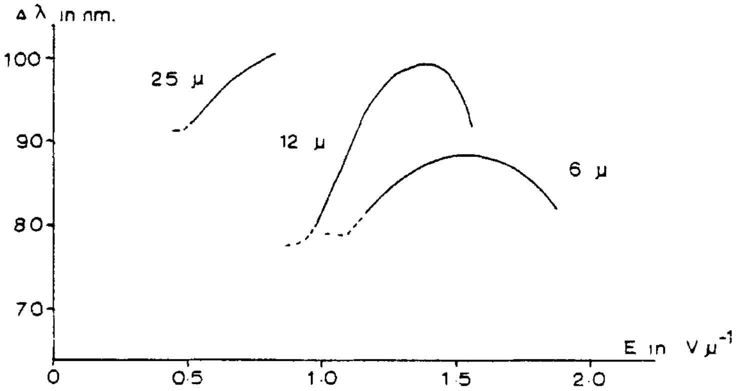

FIGURE 3a Examples of linewidth changes with applied field (44 % mixture)

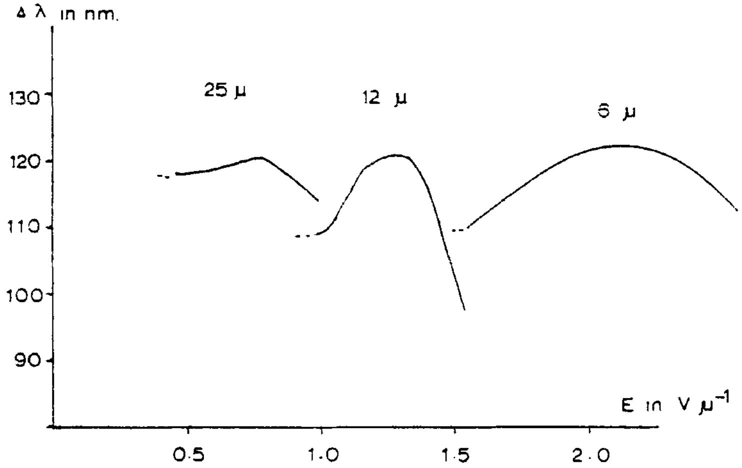

FIGURE 3b Examples of linewidth changes with applied field (38.5 % mixture)