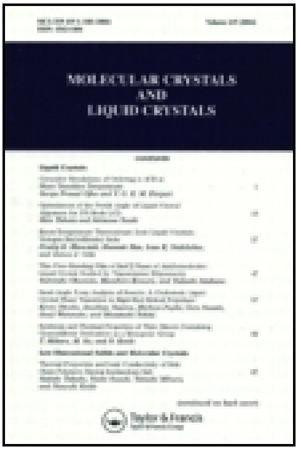

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FIELD INDUCED TWIST PROFILES IN VOLTAGE CONTROLLED CIRCULAR DICHROISM LIQUID CRYSTAL CELLS

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INTRODUCTION

The vivid reflection colours resulting from the circular dichroism exhibited by short pitch cholesteric liquid crystals are well known(1), as are the thermally(2) and impurity(3) induced shifts in the peak wavelength λ_m of the reflection spectrum. Electrochromic effects in which an electric field induces a blue shift in λ_m for cholesterics showing a positive dielectric anisotropy have also been reported and exploited in voltage controlled circular dichroism (VCCD) devices patented by Fergason(4). In this note experimental results demonstrating the low voltage operation of such a device are presented and a mechanism for the pitch contraction implied by this blue shift is proposed and contrasted with the distortion of the twist profile in a twisted nematic cell.

EXPERIMENTAL RESULTS

The spectral absorbance of a 12 μm layer of 38.5% CB15* in E8* subjected to several different voltages is shown in Figure 1. These results were obtained using a Pye Unicam SP800 spectrophotometer in conjunction with a right hand circular polariser incorporating HN32 'Polaroid' sheet and a 140 nm 'Polaroid' retardation ($\frac{1}{4}$ wave) plate.

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* Materials supplied by BDH Ltd, Poole.

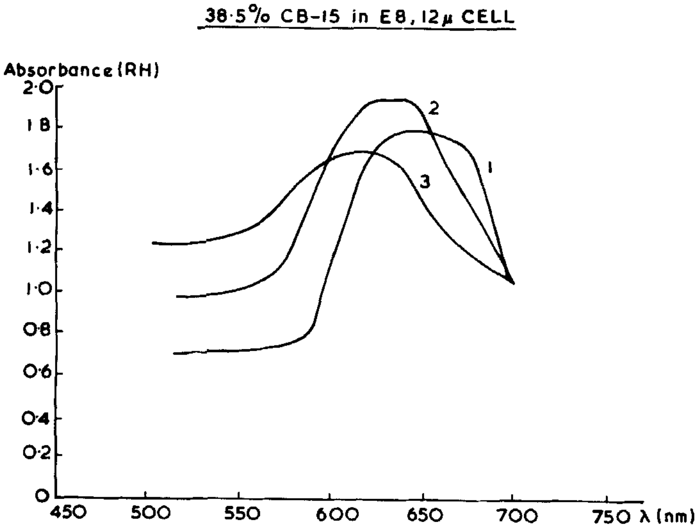

FIGURE 1 Spectral absorbance of 12 μ planar cholesteric cell (RH circular polaroid in place) at different applied voltages: (1) zero field, (2) 15 volts, (3) 30 volts.

The cholesteric liquid crystal was aligned by unidirectional rubbing on a thin layer of polyvinyl alcohol on ITO glass and showed no discernible thermochromic effects. The shift in λ_m is quite marked (the corresponding colour change is readily detected by eye) and, through the use of modern high positive dielectric anisotropy materials(5), is obtained at relatively low voltages. Further experimental details and data are contained in the companion publication of Fedak, Pringle and Curtiss(6).

THEORY

To discuss the deformation of the twist profile of n turns of cholesteric across the cell we recall that the rate of change of twist angle ϕ with distance z across the cell, where as a result of the application of an electric field the director makes an angle θ with the plane of the cell, is given by(7)

$$\frac{1}{\tau}\frac{d\phi}{dz} = \frac{\rho + \cos^2\theta}{\cos^2\theta(1 + a_2\sin^2\theta)}$$

where τ is the rate of change of twist in the undistorted cholesteric,

$$a_2 = (k_{33} - k_{22})/k_{22} \quad ,$$

k_{22} and k_{33} being liquid crystal twist and bend elastic constants respectively, and ρ is a constant related to K, the torque per unit acting on the body of the liquid crystal, through

$$\rho = \frac{K}{n\pi\, k_{22}} \quad .$$

On making a small θ expansion we find that

$$\frac{1}{\tau}\frac{d\phi}{dz} = 1 + \rho + ((1 - a_2)\rho - a_2)\theta^2 + O(\theta^4) \quad .$$

Thus there will be a pile up of twist at the edge of the cell (ie $d\phi/dz > \tau$) if $\rho > 0$. As twist is conserved across the cell (the cholesteric director is assumed to be firmly anchored by the surface treatment) there is at least one value of θ for which $d\phi/dz = \tau$.

From (1) we see that this implies that such a value of θ satisfies the equation

$$\frac{\rho}{a^2} = \cos^2\theta\,\sin^2\theta$$

and so

$$0 < \frac{\rho}{a^2} < \frac{1}{4} \quad ,$$

implying that ρ has the same sign as a_2. Consequently there will be a build up of twist at the edge of the cell if $k_{33} > k_{22}$. This result is in accord with Leslie's analysis(7) of a cholesteric not anchored at the surfaces (ie $\rho = 0$ in (1)) which unwinds in an applied field if $k_{33} > k_{22}$. In our firmly anchored situation we would expect the cholesteric at the centre of the cell to unwind in an applied field, giving rise to a build up of twist at the cell edges and inducing a positive torque acting on the body of the cholesteric.

The distortion of the twist profile in a conventional twisted nematic cell by an electric field has been determined numerically by several authors(8,9,10). A formal treatment similar to that used by Leslie and others(11,12,13) to analyse the coupling of twist and tilt in a nematic in the absence of an electric field shows that field induced twist pile up at the edge of the cell can only occur if $k_{33} > 2k_{22}$. Should θ_m, the maximum tilt angle in the distorted layer, exceed

$$\theta_e = \sin^{-1}\left[(k_{33} - 2k_{22})/2(k_{33} - k_{22})\right]^{1/2}$$

then there is also a pile up of twist at the centre of the cell. These results refer to distortion of a twist profile imposed on the liquid crystal by surface effects while the foregoing analysis of the cholesteric describes the distortion of its natural twist. Viewed in this light the difference between the conditions for surface pile up in the two cases is not surprising.

DISCUSSION

The non-uniform twist profiles described above contain regions in which the pitch is less than its undistorted value. The optical behaviour of such structures has been analysed by Hajdo and Eringen(14) and we believe that the selective reflection band must both broaden and extend towards the blue since shorter wavelength light will be selectively reflected by some range of depths within the layer. It is expected that in all cases, as in the twisted nematic, the twist will accumulate in the centre of the cell at high enough applied fields; the effective birefringence is at a minimum in this region and could lead to a decrease in the half width of the reflectance and absorbance spectra. Although our theory is developed for a perfect planar layer with no disclinations, we believe that it holds locally even in their presence and provides a plausible mechanism for the VCCD effect. The total free energy of such distorted structures will be high and a discontinuous transition to a distorted focal conic texture via a nucleation process occurs if the free energy of the focal conic texture is less than that of the distorted planar texture. This transition will reverse only slowly if the field is removed and may be considered irreversible in practical terms. Thus the transition to the focal conic texture in the presence of high fields may define the limits of the usable electrochromic colour shift.

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