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N. éber^a & I. Jánossy^a

^a Central Research Institute for Physics, H-1525 Budapest, P.O. Box 49, Hungary

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AN EXPERIMENT ON THE THERMOMECHANICAL COUPLING IN CHOLESTERIC

N. ÉBER, I. JÁNOSSY

Central Research Institute for Physics
H-1525 Budapest, P.O.Box 49, Hungary

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ABSTRACT - The effect of the thermomechanical coupling on the homeotropic texture of a compensated cholesteric is investigated. The thermomechanical coupling coefficient is estimated from the deformation.

According to Curie's principle¹ the lack of center of symmetry in cholesteric liquid crystals may lead to the appearance of unique thermodynamic cross-effects. An example of them, the diffusomechanical coupling has been reported on recently.²

The heat conduction also may be coupled with the viscous flow or the rotation of the director of cholesterics. The phenomenological continuum theory of this thermomechanical coupling was given by Leslie³, but apart from some early and never reproduced observations of Lehmann⁴ it has never been studied experimentally.

In this letter we present a new experimental method requiring strong anchoring at the surfaces and give preliminary estimation on one of the

coupling coefficients.

THEORY

We chose a special geometry, where the thermo-mechanical coupling appears in a static deformation of the texture. A layer of a compensated cholesteric mixture, aligned homeotropically at the surfaces $z = \pm L/2$, was subjected to a heat gradient along the x direction, so that no heat convection could arise.

The distorted director field was calculated using Leslie's continuum theory.³ In the absence of flow and external fields the equation of motion for the director has the form

$$0 = \underline{g} + \text{div} \underline{\Pi}$$

where the director stress tensor $\underline{\Pi}$ and the intrinsic director body force \underline{g} contain the usual elastic terms coming from Frank's free energy, but \underline{g} includes an extra thermomechanical contribution of $\lambda_3 \underline{d} \times \text{grad } T$ too.

Assuming, that the heat gradient and consequently the distortion are small ($d_x \ll 1$; $d_y \ll 1$; $d_z \approx 1$) we can linearize the equations, so

$$\begin{aligned} \frac{\partial^2 d_x}{\partial z^2} + \frac{2K_2}{K_3} q_0 \frac{\partial d_y}{\partial z} &= 0 \\ - \frac{\partial^2 d_y}{\partial z^2} + \frac{2K_2}{K_3} q_0 \frac{\partial d_x}{\partial z} &= \frac{\lambda_3 + K_2 \frac{dq_0}{dT}}{K_3} \frac{\partial T}{\partial x} = \frac{\lambda_{\text{eff}}}{K_3} \frac{\partial T}{\partial x} \quad (1) \end{aligned}$$

Exactly at the compensation temperature the helical structure disappears ($q_0 = 0$ but $dq_0/dT \neq 0$)

nevertheless there is no reason for the λ_3 thermo-mechanical coupling coefficient to vanish. So in this case Eq.(1) yields

$$d_x = 0 ; \quad d_y = \frac{\lambda_{\text{eff}}}{K_3} \frac{L^2 - 4z^2}{8} \frac{\partial T}{\partial x} \quad (2)$$

i.e. the director declines perpendicularly to both the heat gradient and the original alignment.

This declination of the director results in the birefringence of the sample. The phase difference between the extraordinary and ordinary light components propagating in the z direction is

$$\phi = \frac{\pi}{120} \frac{L}{\lambda} \frac{n_e^2 - n_o^2}{n_e^2} n_o L \frac{4\lambda_{\text{eff}}^2}{K_3^2} \left(\frac{\partial T}{\partial x} \right)^2 \quad (3)$$

It can be seen, that measuring the birefringence we can get information about the coupling coefficient.

EXPERIMENTAL

Our apparatus for measuring small birefringences is similar to that of Lim and Ho.⁵ It has a resolution of 10^{-3} radian $\approx 0.05^\circ$.

We used the compensated mixture of cholesteryl-chloride and 4-cyano-4'-n-octyl-biphenyl (8CB) in 1:1 weight proportion with a compensation temperature of 36°C .

The birefringence, measured on $L = 114 \pm 1.5 \mu\text{m}$ thick sample at the compensation temperature is shown in Fig. 1. We have got, that the results are in good agreement with Eq.(3).

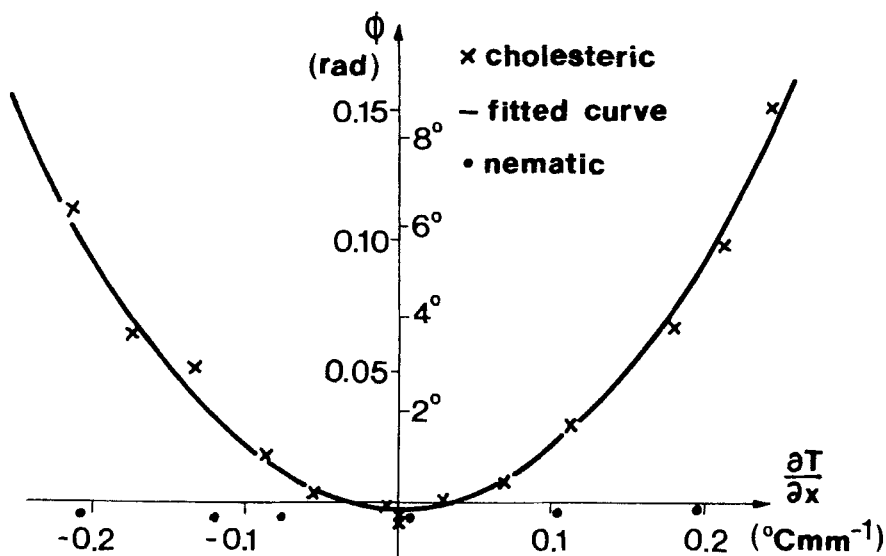


FIGURE 1. The birefringence of the sample as a function of the heat gradient

For the effective coupling coefficient we have got by curve fitting

$$\frac{|\lambda_{\text{eff}}|}{K_3} = \frac{|\lambda_3 + K_2 \frac{dq_0}{dT}|}{K_3} = 13.7 \pm 1.2^\circ \text{C}^{-1}$$

Unfortunately only the absolute value of the coefficient could be obtained since the birefringence is its quadratic function.

As comparison, the same measurements were carried out on a nematic liquid crystal (8CB). No distortion was observed, just as it was expected for a centrosymmetric substance.⁶

THE THERMOMECHANICAL COUPLING COEFFICIENT λ_3

The deformation and the birefringence depend on an effective coupling coefficient λ_{eff} . Its appearance in Eqs.(1-3) shows, that the thermo-

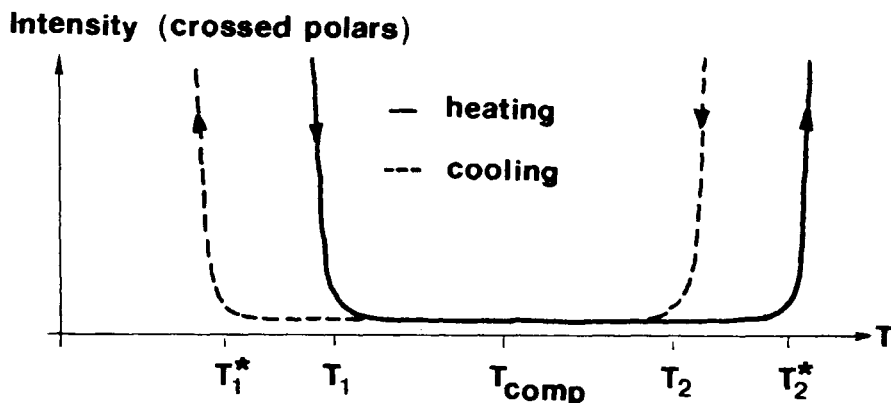


FIGURE 2. The intensity of light passing through the sample as the function of temperature

mechanical coupling has the same effect as the temperature dependence of the helical pitch. In order to separate them the latter has to be measured independently.

We observed a hysteretic behaviour of the homeotropic-fingerprint texture transition (Fig.2). Starting from the homeotropic one the fingerprint texture can develop only through a homogeneous (depending on z only) deformation at temperatures T_1^* , T_2^* respectively, satisfying the instability condition

$$\frac{K_2}{K_3} |q_0| L = \pi$$

Since near the compensation point $q_0 = dq_0/dT(T - T_{\text{comp}})$ we have got

$$\frac{K_2}{K_3} \left| \frac{dq_0}{dT} \right| L = \frac{2\pi}{T_2^* - T_1^*} = 9.4 \pm 1.0 \text{ } ^\circ\text{C}^{-1}$$

As the sign of λ_{eff} is not yet known, we can only estimate the order of magnitude of the thermo-mechanical coupling coefficient λ_3 .

$$4.3 \pm 2.2 \text{ } ^\circ\text{C}^{-1} < \frac{|\lambda_3|}{K_3} L < 23.1 \pm 2.2 \text{ } ^\circ\text{C}^{-1}$$

The upper limit gives a good estimation for the order of magnitude of λ_3 . With a typical value of $K_3 = 10^{-11} \text{ N}$ it gives

$$|\lambda_3| < 2 \cdot 10^{-6} \text{ Nm}^{-1} \cdot ^\circ\text{C}^{-1}$$

Though the lower limit is somewhat uncertain being close to the margin of error, it indicates λ_3 not to be zero.

CONCLUSION

We have found experimentally the distortion predicted by the theory and could estimate the value of the coupling coefficient λ_3 .

With a slight improvement this method seems to be applicable even for the determination of the sign and the exact value of the coupling coefficient.

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