AN EXPERIMENT ON THE THERMOMECHANICAL COUPLING IN CHOLESTERICS

N. ÉBER, I. JÁNOSSY

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

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 principle[1] 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 diffuso-mechanical 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 Leslie[3], but apart from some early and never reproduced observations of Lehmann[4] 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 choles-teric mixture, aligned homeotropically at the sur-faces $z = \pm L/2$, 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 $\underline{g}$ in-cludes an extra thermomechanical contribution of $\lambda_3 \underline{d} \times \text{grad } T$ too.

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

$$\frac{\partial^2 d_x}{\partial z^2} + \frac{2K_2}{K_3} q_o \frac{\partial d_y}{\partial z} = 0$$

$$-\frac{\partial^2 d_y}{\partial z^2} + \frac{2K_2}{K_3} q_o \frac{\partial d_x}{\partial z} = \frac{\lambda_3 + K_2 \frac{dq_o}{dT}}{K_3} \frac{\partial T}{\partial x} = \frac{\lambda_{eff}}{K_3} \frac{\partial T}{\partial x} \quad (1)$$

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

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

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

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 dif-
ference between the extraordinary and ordinary
light components propagating in the z direction is

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

It can be seen, that measuring the birefrin-
gence 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 reso-
lution of 10^{-3} radian $\approx 0.05^{\circ}$.

We used the compensated mixture of choles-
teryl-chloride and 4-cyano-4'-n-octyl-byphenil
(8CB) in 1:1 weight proportion with a compensation
temperature of 36 $^{\circ}$C.

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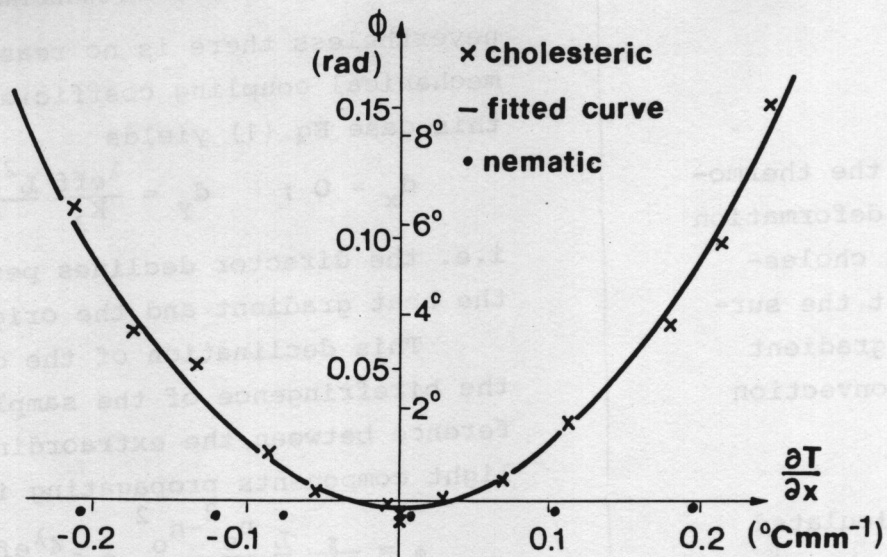in good agreement with Eq.(3).

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

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

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-

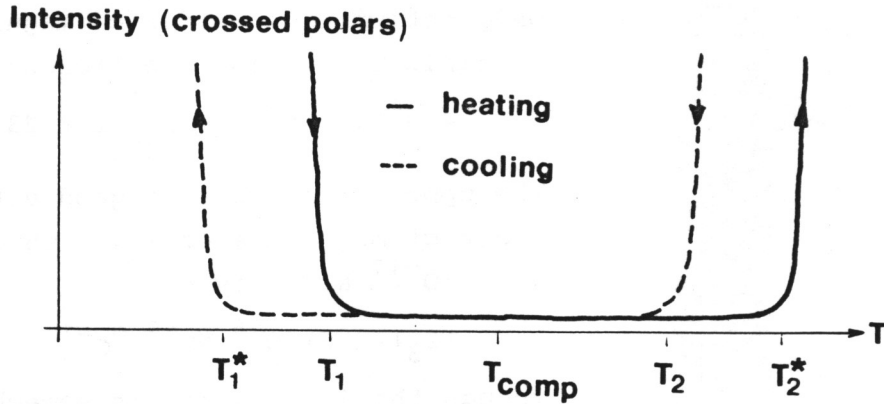**Intensity (crossed polars)**

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 $q_0 = dq_0/dT (T - T_{comp})$ we have got

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

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.

$$4.3 \overset{+}{-} 2.2 \; ^{\circ}C^{-1} < \frac{|\lambda_3|}{K_3} L < 23.1 \overset{+}{-} 2.2 \; ^{\circ}C^{-1}$$

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

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

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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