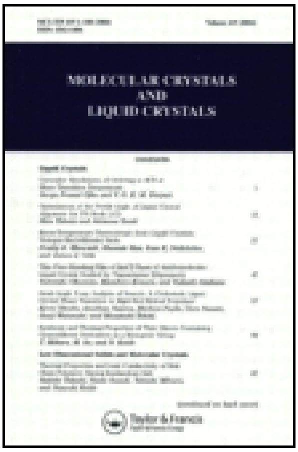

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TRANSMISSION SPECTRA OF NORMAL INCIDENT LIGHT ON PLANAR ORIENTED CHOLESTERIC LAYERS

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Abstract Transmission spectra of normal incident polarized light on planar oriented cholesteric layers of CE6 have been measured[1]. These measurements can be reproduced very well by the 4-wave model of Belyakov and Dmitrienko[2] using 6 adaptable parameters. A program is written which gives a graphical representation of the calculated spectra. By comparing the experimental spectra with the calculated ones, we determined the 6 adaptable parameters.

INTRODUCTION

Transmission and reflection spectra of normal incident polarized light on planar oriented cholesteric layers are very complex[1], due to, on the one hand, the interference of diffractive and dielectric reflection and on the other hand the wavelength dependence of the polarization of the incident light[2].

If the incident light is not completely circularly polarized, and the refractive index of the LC is different from the refractive index of the boundary material, the transmission and reflection spectra depend on the orientation of the director at the dielectric boundary with respect to the long axis of the polarization ellips of the incident light and on the ellipticity of the light. Usually when experiments are done with circularly polarized light, one uses a Glan-Thompson polarizer and a

1/4-wave plate to produce circularly polarized light. In reality one obtains elliptically polarized light and the ellipticity is wavelenght dependent.

In the model of Belyakov and Dmitrienko[2,4], all these effects are taken into account. It is therefore necessary to calculate the spectra by means of this model and compare with the experimental results.

EXPERIMENTAL

We have done transmission measurements on planar oriented layers of a 60% chiral/racemic mixture of CE6. The cholesteric structure of CE6 is righthanded[3]. The sample is held between two glass plates which are separated by spacers. The spacers are polymer spheres (Dynospheres) for the sample with thickness L = 4.8μm and glass fibres (Schott) for L = 18μm. The plates are coated with a 35nm thick transparant ITO film with a refractive index $n_{ITO} \approx 2$ and a 40 nm polyimide layer (Japan Syntetic Rubbers) for planar alignment. The sample is mounted in a temperature regulating system and can be rotated around the cholesteric axis. Light from a halogen light source passes through a monochromator with a resolution of 1 nm and is polarized by a Glan-Thompson prisma. To obtain circularly polarized light we used a 1/4 wave plate (Mica). The transmitted light, which is chopped is detected, via a photomultiplier, by a lock-in detector. In order to get the transmissivity, we divided the transmitted intensity by the averaged background intensity outside the total reflection region.

Figure 1 shows a series of experimental spectra measured at decreasing temperatures. The incident light is circularly polarized and the sample thickness L = 4.8μm. The temperatures are given in Tabel I.

TABLE 1 Temperatures for the spectra in FIGURE 1.

40.41 °C	40.39 °C	40.37 °C	40.34 °C	40.30 °C	40.27 °C

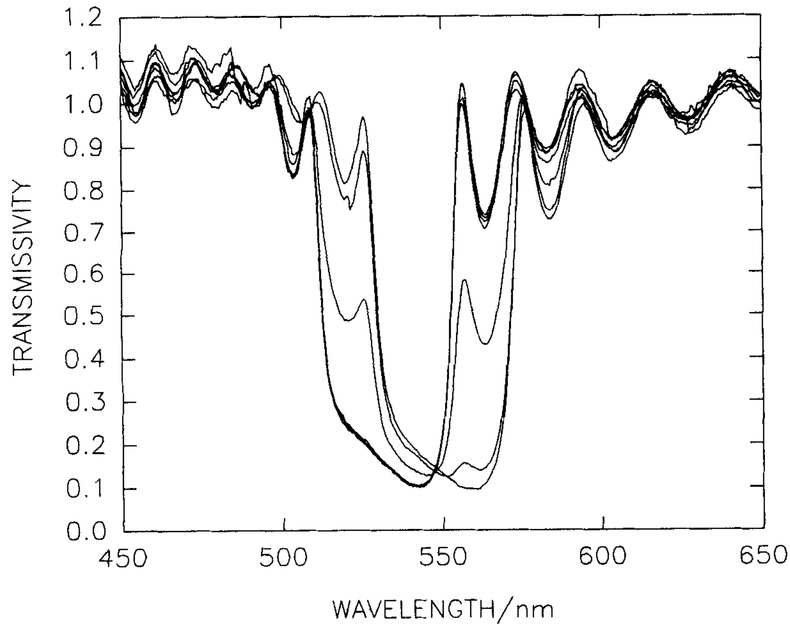


FIGURE 1 Experimental transmission spectra at 40.41°C; 40.39°C;40.37°C;40.34°C;40.30°C and 40.27°C

The spectra for the first three temperatures coincide completely. The next two temperatures give deformed and shifted spectra. Finally the last temperature gives a spectrum with the same shape as the first three spectra but the minimum has shifted to a longer wavelength. Lowering the temperature further will show a repetition of the cycle.

CALCULATIONS

Although in the general case the exact expression for the amplitudes of the reflected and transmitted waves are very complicated, their structure is fairly simple. The expression for the amplitude E_t^+ of the transmitted diffracting circularly polarized wave may be written as the following ratio of determinants (Belyakov[2] expression (1.16)):

$$E_t^+ = [\det D]^{-1} \begin{vmatrix} a_{11} & \cdots & a_{14} & E_e^+ \\ a_{21} & \cdots & a_{24} & E_e^- \\ a_{31} & \cdots & a_{34} & 0 \\ a_{41} & \cdots & a_{44} & 0 \\ t_{51}^+ & \cdots & t_{54}^+ & 0 \end{vmatrix}$$

where D is the matrix of the set of equations which determine the amplitudes of the eigenwaves E_j^+ excited in the sample.

$$D = \begin{vmatrix} a_{11} & \cdots & a_{14} \\ \vdots & \ddots & \vdots \\ a_{41} & \cdots & a_{44} \end{vmatrix}$$

$$t_{5j}^+ = \xi_j (1 + r\eta_j^+)$$
$$\eta_j^+ = \frac{K_j^+}{\kappa}$$
$$\kappa = \omega \frac{\sqrt{\epsilon}}{c}$$

j = 1,4 for the wavevector K^+ and j = 2,3 for K^-. These are the 4 wavevectors of the modes of the light wave in the sample.

$$r = \left(\frac{\overline{\epsilon}}{\epsilon_e}\right)^{1/2}$$

ϵ_e is the permittivity outside the CLC.

The calculations are done in function of the dimensionless wavelength $l = \frac{\lambda}{p}$, where p is the pitch and λ the wavelength in the CLC.

The following quantities are assumed to be parameters of the problem:

1/ Sample thickness t [in number of half-pitches $t = 2\ L/p$]

2/ Polarization of the incident light $e = \cos\alpha\ \chi_1 + i \sin\alpha\ \chi_2$.
χ_1 , χ_2 are the linear polarization directions, with χ_1 making the angle ξ with the director orientation at the entrance surface of the layer. α is the ellipticity of the incident light.

3/ Dielectric anisotropy $\delta = (\epsilon_1 - \epsilon_2)(\epsilon_1 + \epsilon_2)$, $\bar{\epsilon} = (\epsilon_1 + \epsilon_2) / 2$, where ϵ_1, ϵ_2 $= \epsilon_3$ are the principal values of the CLC dielectric tensor.

4/ r is the ratio of refractive indices of the external media and the CLC. $r = n_e/n$.

5/ E_+, E_- are determined by the following expression:

$$E_\pm = \frac{1}{\sqrt{2}} (\cos\alpha \pm i \sin\alpha)(\cos\xi - i \sin\xi)$$

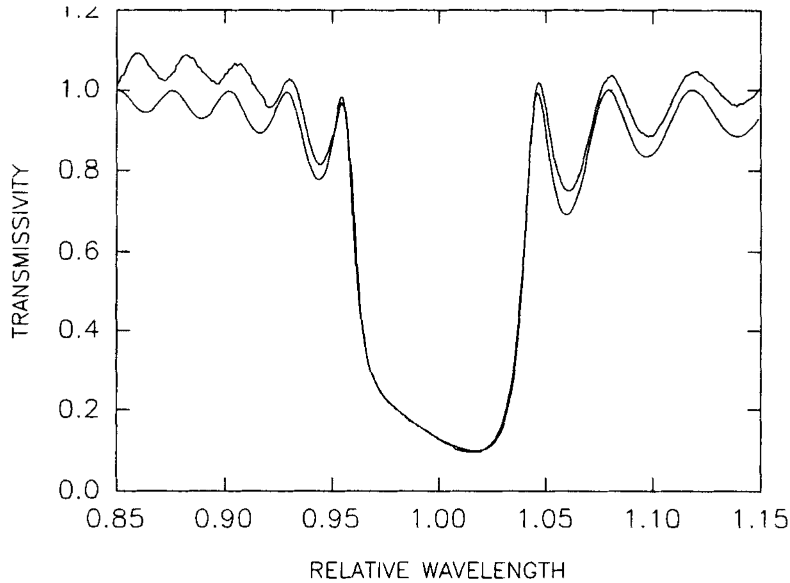
In the general case 6 parameters t, p, r, δ, α, ξ determine the characteristics of the transmitted and reflected beam.

A program has been written by means of "Mathematica" software, which gives a graphical representation of the calculated spectra.

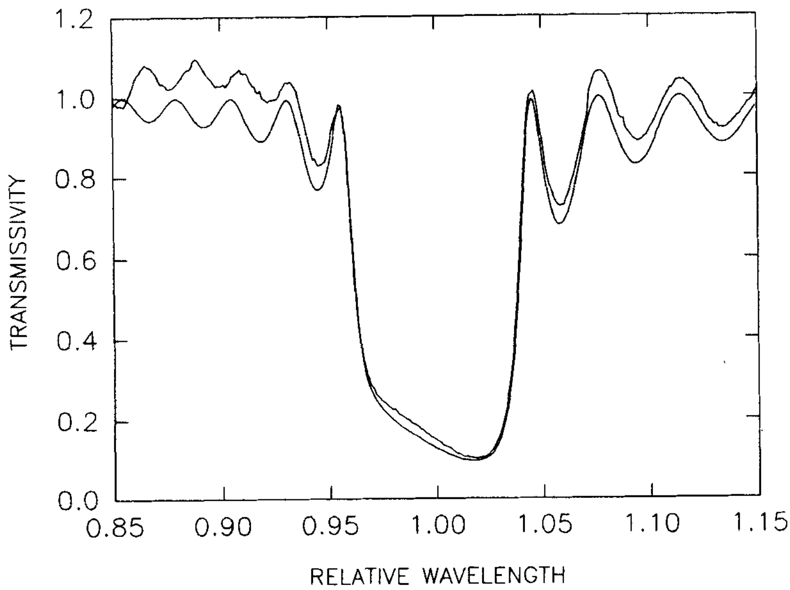
RESULTS

Circularly polarized light $L = 4.8\mu m$.

For the spectra of Fig. 1 at 40.27°C and 40.41°C, which are not deformed, we calculated the 6 parameters that give the closest correspondence with the experimental spectra. They are shown in Fig. 2a and Fig. 2b. One can see that the agreement is very good.



2a



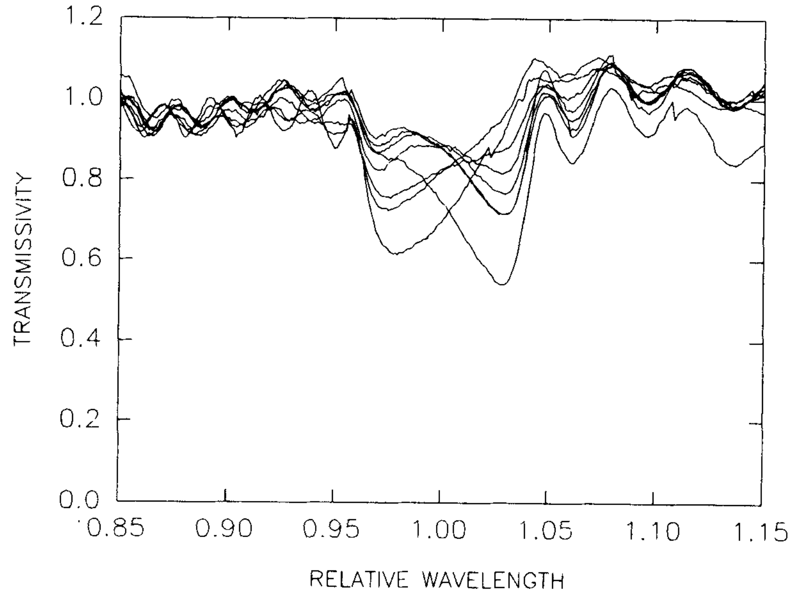
2b

FIGURE 2 (a) exp.- (....); calc. spectrum (–) T = 40.27°C
(b) idem for T = 40.41°C

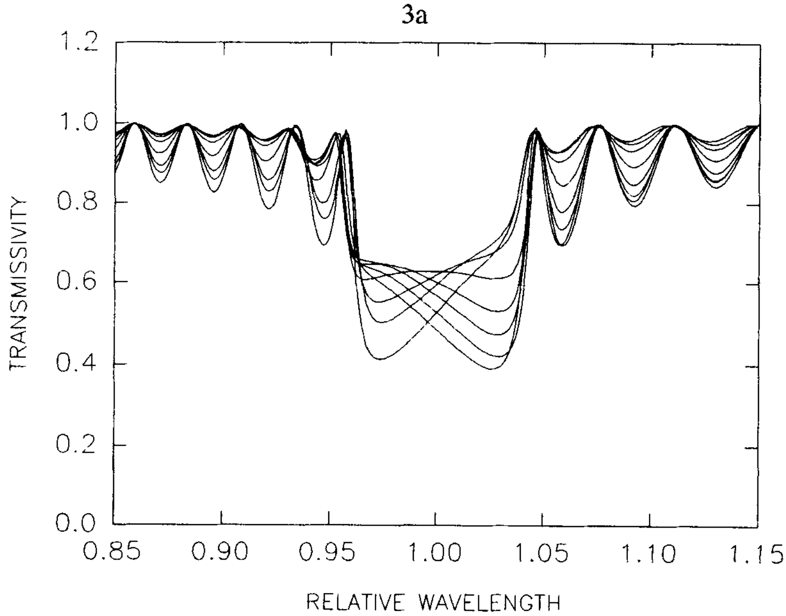
In Table 2 the values for the 6 parameters are given. Here $\alpha < \pi/4$ so the incident light is not circularly but elliptically polarized. This causes the asymmetry in the minima of the plots in Fig. 2 and is due to the fact that we used a mica 1/4-waveplate which gives only, up to a certain extend, circularly polarized light in the neighbourhood of 600nm. The value of ξ depends on the orientation of the sample and this was not changed during this temperature run. The number of half-pitches t increased by 1 due to the temperature dependence of the pitch. It is clear that the spectra are not deformed if an exact number of half-pitches fits into the sample thickness L.

TABLE 2 Parameters for spectra of FIGURE 2

α	$\frac{\pi}{8}$	$\frac{\pi}{8}$
ξ	$9\frac{\pi}{16}$	$9\frac{\pi}{16}$
r	1.25	1.25
δ	0.061	0.061
t	29	30
L	$4.8\mu m$	$4.8\mu m$
λ_p	550.5 nm	532.5 nm
T	40.27°C	40.41°C
Fig.	2a	2b



3a



3b

FIGURE 3 (a) experimental spectra for ξ = 0, 20, 30 , 45, 60, 70, 80, 90°
(b) calculated spectra for the same values of ξ.

Linear polarized light L = 4.8μm

We also measured the transmission spectra with linear polarized incident light. We removed the 1/4-waveplate. The incident light was vertically polarized and the sample was rotated around the optical axis over 90°. So the director orientation at the upper boundary rotated from the vertical to the horizontal direction. The experimental results are shown in Fig. 3a and the calculated spectra in Fig.3b. The overall shape of the spectra agree if we take the following parameters for the calculations.

$\alpha = 0$; $t = 31$; $\lambda_p = 503$ nm; $T = 41.33$°C are the parameters which are constant for the 8 measurements. The other 3 parameters are given in Table 3.

TABLE 3 ξ, r, δ values for spectra in FIGURE 3

ξ /°	r	δ
0	1.32	0.061
20	1.32	0.059
30	1.32	0.061
45	1.32	0.068
60	1.32	0.068
70	1.32	0.068
80	1.32	0.070
90	1.29	0.066

The value of the anisotropy parameter varies a little with the orientation. This is not expected and may be due to a relaxation of the sample to equilibrium.

Circular polarized light L = 18 μm

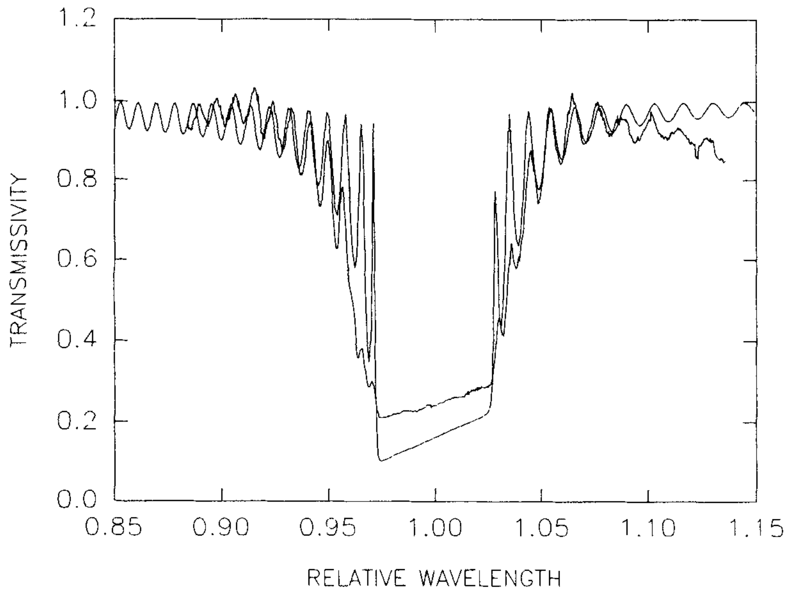
In Fig. 4 an example of 2 measurements in a 18μm thick sample is shown. In Fig. 4a the temperature equilibrium was obtained by cooling from a higher temperature and in Fig. 4b the same temperature was reached by heating from a lower temperature.

The parameters for these spectra are given in Table 4.

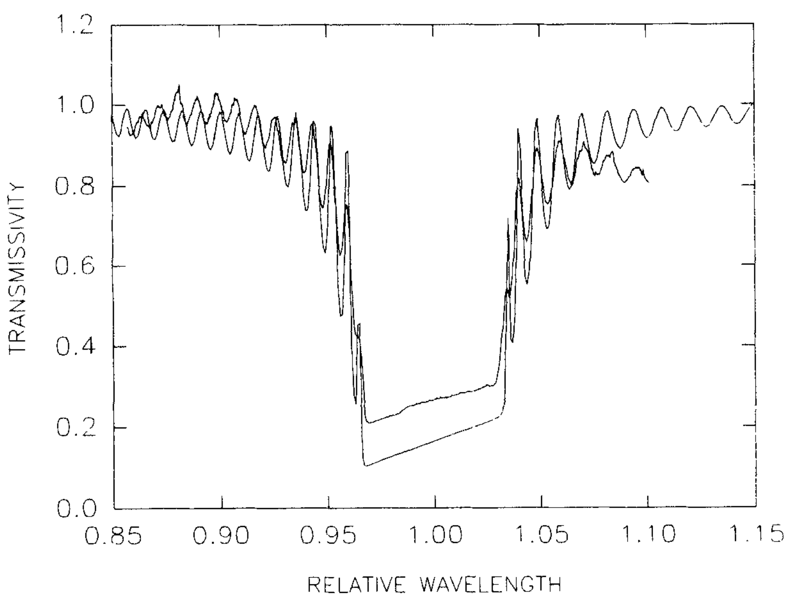
Also in this example the incident light is not completely circularly polarized. Here $\alpha > \pi/4$ because $\lambda_p > 600$ nm. The sign of the slope of the asymmetry of the spectra in comparison with Fig. 2 has changed. If we compare the parameters in Table 4a and 4b, we see a difference of 2 half-pitches. This means that the number of half-pitches lags 1 half-pitch behind on cooling as well as on heating. The same effect occurred in the L = 4.8μm sample. This effect is also visible in Fig. 1 where the first 3 spectra do not change when we lower the temperature and suddenly a jump with 1 half-pitch occurs. There also seems to be a difference in the anisotropy parameter δ but it is not clear where this comes from.

TABLE 4 Parameters for the spectra in FIGURE 4

α	$7\frac{\pi}{16}$	$7\frac{\pi}{16}$
ξ	$3\frac{\pi}{8}$	$3\frac{\pi}{8}$
r	1.19	1.19
δ	0.0525	0.066
t	88	86
L	18 μm	18 μm
λ_p	678.6 nm	700 nm
T	41.23°C	41.23°C
	Decreasing Temp	Increasing Temp
Fig.	4a	4b



4a



4b

FIGURE 4 (a) Temp. equilibrium after decreasing T.
(b) Temp. equilibrium after increasing T.

CONCLUSIONS

By comparing the experimental spectra with the calculations it is possible to get accurate values for various parameters as peak wavelength, pitch and anisotropy. It has been shown that the measured values of these parameters are influenced by the previous condition of the sample (higher or lower temperature) and probably the boundary properties. Even in thicker samples this effect is visible. This is of importance in determining the divergence of the pitch in the cholesteric phase[1]. It is not necessary to use a completely polarized light source in the experiments because the ellipticity can be taken into account in the calculations.

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