Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Light Transmission Experiments with Nematic Liquid Crystals Showing Positive and Negative Dielectric Anisotropy

W. Haase [a] & D. Pötzsch [a]
[a] Institut fur Physikalische Chemie der Technischen Hochschule Darmstadt, Petersenstrasse 20, D-6100, Darmstadt, Federal Republic of Germany
Version of record first published: 28 Mar 2007.

To cite this article: W. Haase & D. Pötzsch (1977): Light Transmission Experiments with Nematic Liquid Crystals Showing Positive and Negative Dielectric Anisotropy, Molecular Crystals and Liquid Crystals, 38:1, 77-85

To link to this article: http://dx.doi.org/10.1080/15421407708084376

Mol. Cryst. Liq. Cryst., 1977, Vol. 38, pp. 77–85

Printed in Holland

Light Transmission Experiments with Nematic Liquid Crystals Showing Positive and Negative Dielectric Anisotropy

W. HAASE and D. PÖTZSCH

Institut fur Physikalische Chemie der Technischen Hochschule Darmstadt, Petersenstrasse 20, D-6100 Darmstadt, Federal Republic of Germany

(*Received October 14, 1976*)

We report on the light transmission of nematic liquid crystals with positive and negative dielectric anisotropy under a.c. electric fields. Using the twisted nematic effect we determined the frequency of dielectric isotropy f_0 as a function of temperature for the phenyl benzoates mixtures ZLI 518, WI and ZLI 612 (Fa. E. Merck). The results are in good agreement with those from dielectric measurements. The activation energies for this relaxation process were calculated. By tunable birefringence the temperature dependence of the refractive index difference was measured for 4′-*n*-pentyl-4-cyanobiphenyl (PCB). The results were compared with those from measurements with the Leitz-Jelly micro-refractometer.

INTRODUCTION

Nematic mixtures, which change sign of dielectric anisotropy at relatively low frequencies, are important for application in twisted nematic display devices, because the decay times of the display can be reduced drastically by a two frequency switching mode.[1]

Electrically controlled birefringence can be used in light valves or in tunable optical filters. Some electro-optic properties of nematic liquid crystals were studied by light transmission measurements with a spectrophotometer.

EXPERIMENTAL

The light transmission measurements were carried out in a spectrophotometer Cary 17. The experimental setup is shown in Figure 1. An oscillator connected with an amplifier supplied the a.c. voltage. The voltage was measured

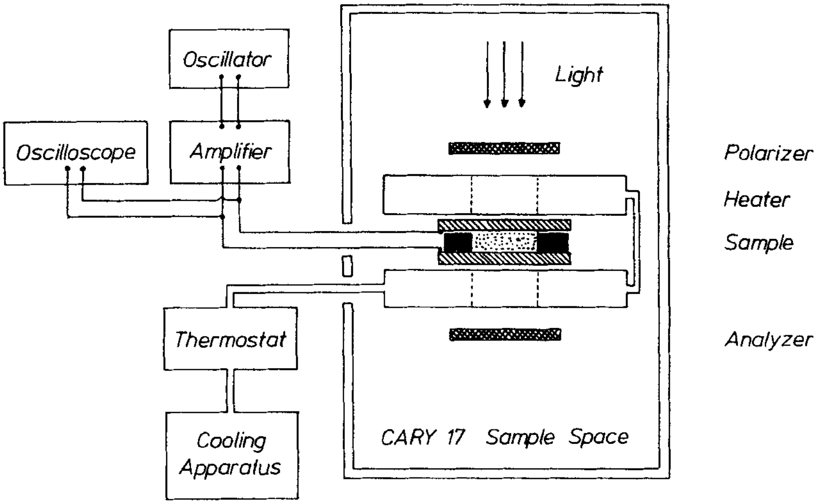


FIGURE 1 Experimental setup

by an oscilloscope or a vacuum tube voltmeter. A waterbath thermostat together with a cooling apparatus controlled the temperature within $\pm 0.5°C$. The cells consisted of two tin-dioxide coated and optically ground glass plates. The required starting orientation of the liquid crystal layers was obtained by pressing the electrode surfaces against a rotating styropor wheel. The thickness of the samples was controlled by Hostaphan spacers with a nominal thickness of 25 μm. Clamps fastenend the glass plates and provided the electrical terminals. The refractive indices were measured with a Leitz-Jelly micro-refractometer using sodium light. The temperature was held constant by a Mettler hot stage.

FREQUENCY OF DIELECTRIC ISOTROPY f_0

Electro-optic display devices using the twisted nematic effect[2] can be switched on rapidly (c. 100 μs) by applying a high electric field. The turn off times upon removal of the field are very slow (c. 100 ms) depending on the viscosity and the elastic constants of the material. The method of a two frequency switching mode takes advantage of the change of sign of the dielectric anisotropy: using low frequency voltages for switching on and high frequency voltages for switching off. Thus the turn off times are reduced to c. 1 ms.[3] For purposes of application one must know the temperature dependence of the frequency of

TABLE I

Some physical properties and activation energies of the mixtures.

	t_{N-I}(°C)	n_e[a]	n_0[a]	$W + W_{visc}$(eV)
ZLI 518	78.1	1.664	1.506	0.88
ZLI 612	45.3	1.646	1.509	0.87
WI	89.4	1.687	1.517	0.84

[a] $t = 25°C, \lambda = 589.3$ nm

dielectric isotropy f_0.[4] We investigated three nematic mixtures of phenyl benzoates ZLI 518, WI and ZLI 612 (Fa. E. Merck), which change sign of the dielectric anisotropy at relatively low frequencies (kHz range). Table I shows the clearing points and refractive indices of these mixtures. Using the fact that a twisted nematic layer can be unwound by an a.c. electric field, if the dielectric anisotropy is positive, and remains uneffected if the dielectric anisotropy is negative, we determined the frequency f_0 at different temperatures by light transmission measurements. The method is described in detail elsewhere.[5]

The light transmission of ZLI 612 and WI as a function of frequency at constant voltage is displayed in Figure 2a and 2b for different temperatures (ZLI 518 see Figure 2 in Ref. 5). By extrapolation we get the frequency f_0 at different temperatures. The semilogarithmic plot of f_0 vs. $1/T$ is shown in Figure 3. The agreement of the results with those from dielectric measurements for WI[3,4,6] and ZLI 518[7] is very good, there exist no data for ZLI 612. From the slope of the theoretically expected straight line in Figure 3 we calculated the activation energy $W + W_{visc}$ by the method of least squares, according to the formula[4] $f_0 \sim \exp - (W + W_{visc})/kT$. The results shown in Table I reflect the similiarity of the mixtures.

TUNABLE BIREFRINGENCE

The deformation of a parallel oriented liquid crystal layer induced by an electric field can be recorded by light transmission measurements.[8] The phase retardation δ of such a layer is

$$\delta = 2\pi d(n_e - n_0)\frac{\sin^2\theta}{\lambda} \tag{1}$$

with the film thickness d, the extraordinary and ordinary refractive index n_e and n_0, the electric field dependent angle between the optic axis of the liquid crystal layer and the direction of the propagation of light θ, and the wavelength of light λ. By increasing the strength of the electric field the transmitted

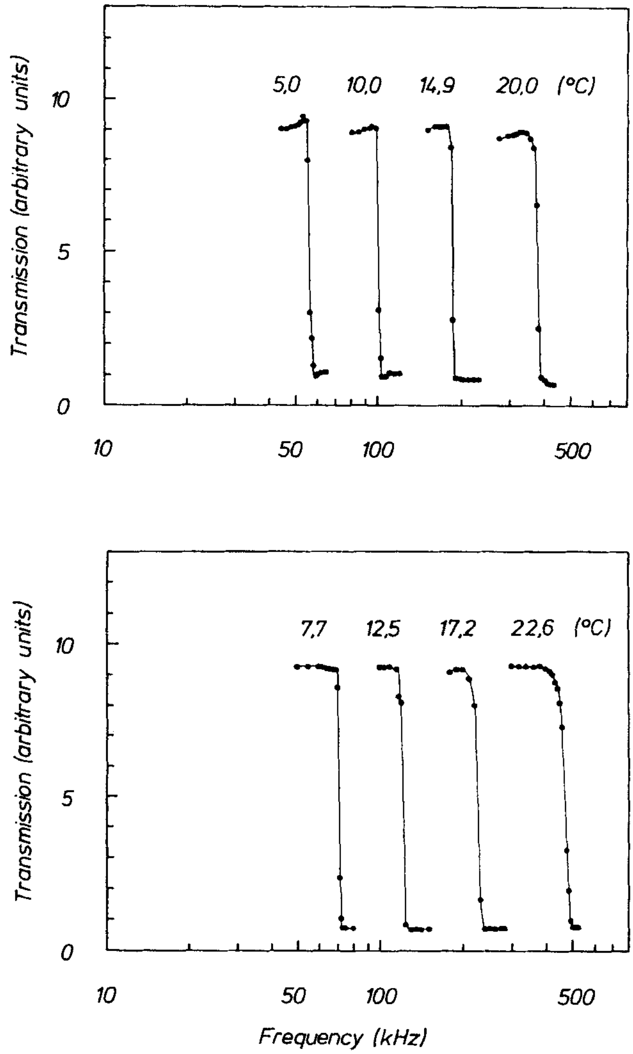
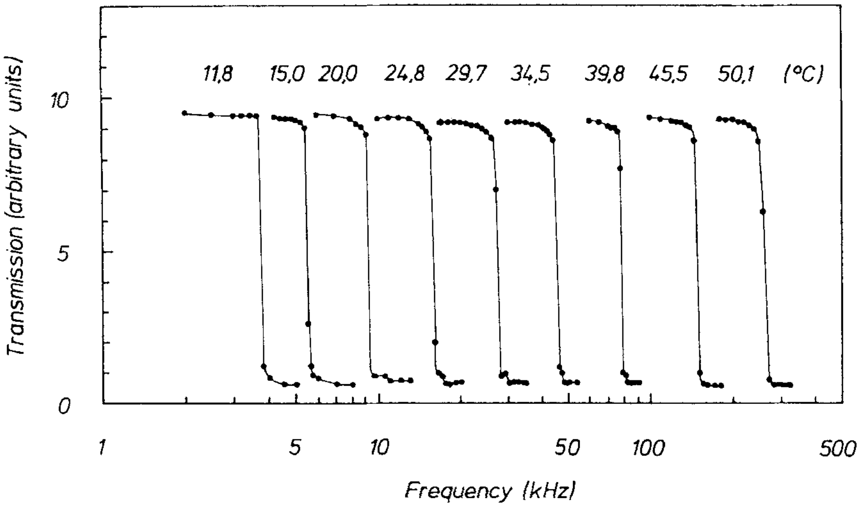


FIGURE 2a Light transmission vs. frequency for ZLI 612 ($d = 25\ \mu m$, $U = 40\ V_{eff}$, λ 700 nm, parallel polarizers)



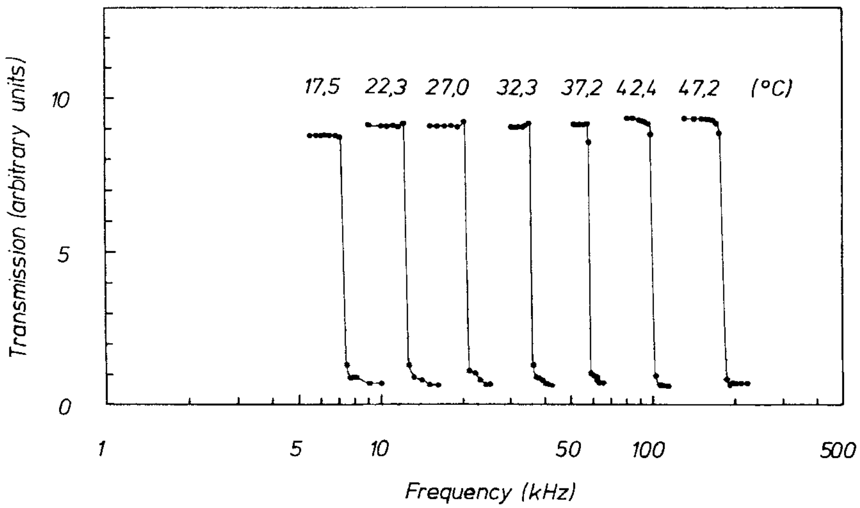


FIGURE 2b Light transmission vs. frequency for WI ($d = 25\ \mu m$, $U = 50\ V_{eff}$, $\lambda = 700$ nm, parallel polarizers)

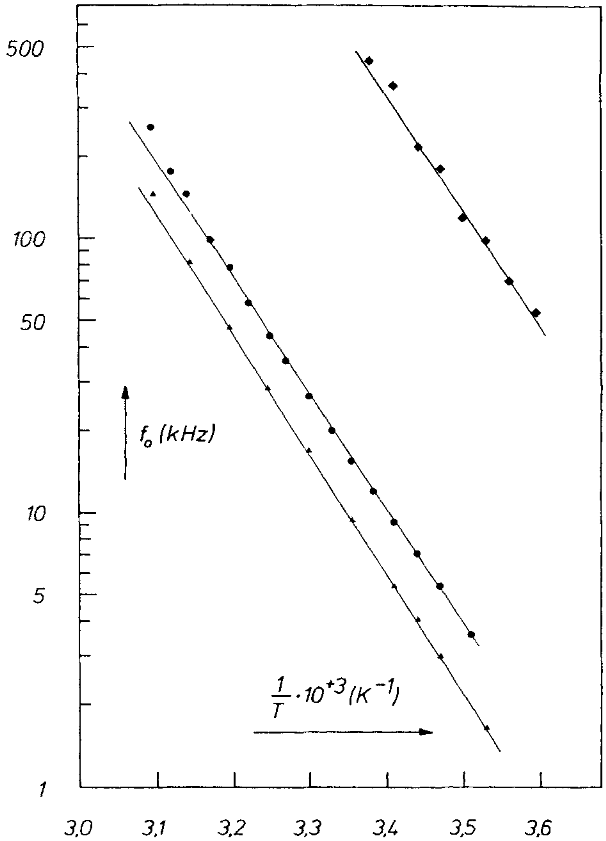


FIGURE 3 Frequency f_0 against $1/T$. Values are extrapolated from the curves of Figure 2a and 2b and Figure 2 of Ref. 5. ZLI 518 (▲), ZLI 612 (◆), and WI (●).

light goes through a series of maxima and minima. The condition for the maxima is

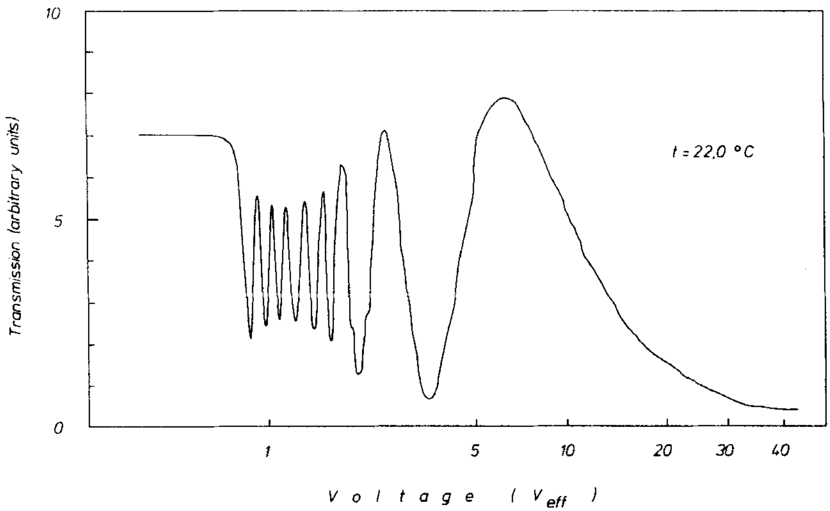
$$\sin^2\left(\frac{\delta}{2}\right) = 1, \quad \delta = (2r - 1)\pi, \qquad r = 1, 2, \ldots \tag{2}$$

and for the minima

$$\sin^2\left(\frac{\delta}{2}\right) = 0, \quad \delta = 2s\pi, \qquad s = 1, 2, \ldots \tag{3}$$

Then the refractive index difference is given by

$$n_e - n_0 = \left(r - \frac{1}{2}\right)\left(\frac{\lambda}{d}\right)\sin^2\theta \tag{4}$$



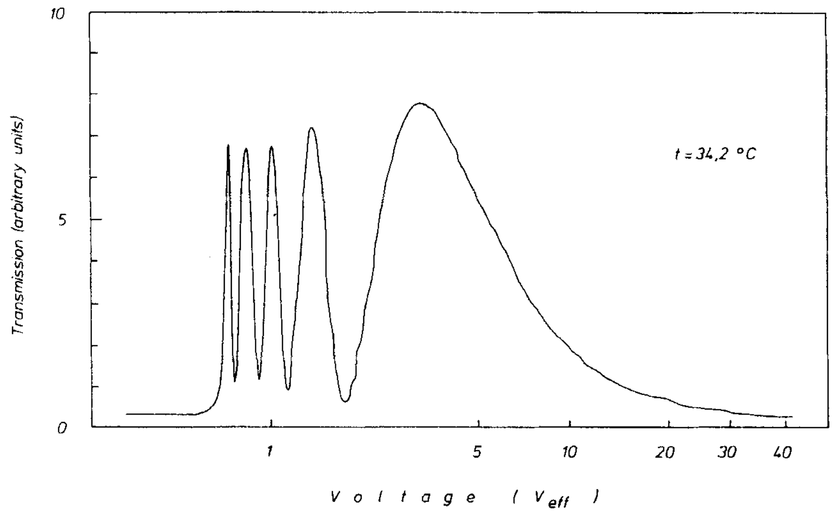


FIGURE 4 Light transmission vs. applied voltage (continuously increased). ($d = 26.8 \pm 0.8\ \mu m$, $\lambda = 589.3$ nm, $f = 10$ kHz, crossed polarizers, angle with direction of rubbing 45°)

for the maxima, and

$$n_e - n_0 = s\left(\frac{\lambda}{d}\right)\sin^2\theta \tag{5}$$

for the minima.

Assuming $\theta \approx 90°$ at high fields one can calculate the refractive index difference using the above equations. The saturation of θ can be checked by plotting δ vs. V using Eq. (2) and (3). We recorded the light transmission of 4′-n-pentyl-4-cyanobiphenyl (PCB) as a function of the applied electric field at different temperatures. Two records are shown in Figure 4. The wavelength of the light was 589.3 nm. The light beam had a dimension of 5×16 mm^2, this is large compared with the diameter of laser beams normally used in such experiments. The thickness of the cell was determined according to the formula[2]

$$d = \frac{\lambda_1\lambda_2}{2n(\lambda_1 - \lambda_2)} \tag{6}$$

by recording the transmittance of an empty cell ($n = 1$) as a function of wavelength. In this experiment the thickness of the cell was $d = 26.8 \pm 0.8$ μm. The results of the refractive index difference are shown in Table II and Figure

TABLE II

Refractive index difference of PCB by tunable birefringence ($\lambda = 589.3$ nm).

Tunable birefringence			Micro-refractometer			
t(°C)	No. of Minimum	$n_e - n_0$	t(°C)	n_e	n_0	$n_e - n_0$
22.0	9	0.198	22.0	1.727	1.528	0.199
24.8	8	0.176	25.0	1.721	1.530	0.191
28.1	8	0.176	28.0	1.709	1.532	0.177
30.6	7	0.154	31.0	1.699	1.534	0.165
31.6	7	0.154	32.0	1.692	1.538	0.154
32.4	6	0.132	33.0	1.685	1.540	0.145
33.4	6	0.132	34.0	1.670	1.545	0.125
34.2	5	0.110	35.0	—	—	0.0

5. The meaning of the error bar is that the whole series of points can be shifted as a unit because of the error in the thickness of the cell. They are in agreement with results from measurements with the Leitz-Jelly micro-refractometer. The stepwise decrease of the refractive index difference obtained by the method of tunable birefringence results from the fact, that one counts only integers for the extrema.

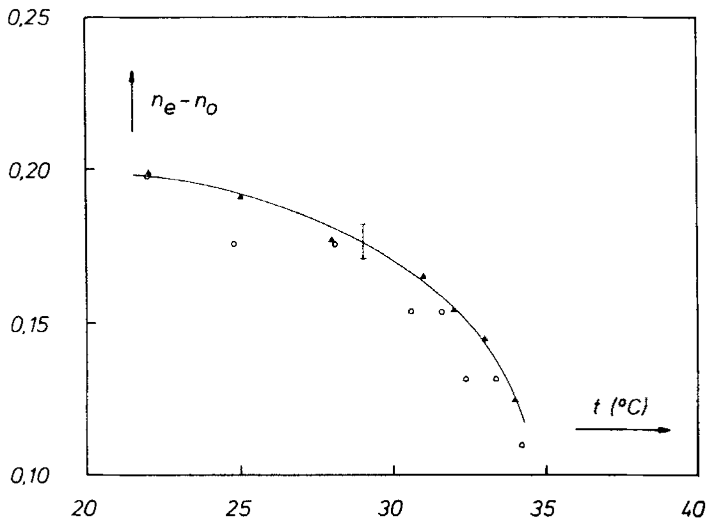


FIGURE 5 Refractive index difference of PCB vs. temperature. Tunable birefringence (○) and micro-refractometer (▲).

Acknowledgement

We would like to thank Dr. J. Krause (Fa. E. Merck) for supplying us with the nematic mixtures. This work was supported by the Deutsche Forschungsgemeinschaft and the Fonds der Chemischen Industrie.

References

1. G. Baur, A. Stieb, and G. Meier, *Appl. Phys.*, **2**, 349 (1973).
2. M. Schadt and W Helfrich, *Appl. Phys. Lett.*, **18**, 127 (1971).
3. E. P. Raynes and I. A. Shanks, *Electronic Lett.*, **10**, 114 (1974).
4. W. H. de Jeu and Th. W. Lathouwers, *Mol. Cryst. Liq. Cryst.*, **26**, 225 (1974).
5. D. Pötzsch and W. Haase, *Phys. Lett.*, **57A**, 343 (1976).
6. G. Baur, A. Stieb, and G. Meier, Liquid Crystals and Ordered Fluids 2 (Plenum Press, New York, 1974) p. 645.
7. L. Pohl (Fa. E. Merck), communication.
8. R. A. Soref and M. J. Rafuse, *J. Appl. Phys.*, **43**, 2029 (1972).
9. J. J. Wright, *Amer. J. Phys.*, **41**, 270 (1973).