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EFFECT OF TEMPERATURE ON THE REFRACTIVE INDICES AND OPTICAL BIREFRINGENCE DISPERSION OF NEMATIC LIQUID CRYSTAL 4-CYANOPHENYL-4'-PENTYL BENZOATE

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abstract: The paper presents results of investigations on the temperature dependence of ordinary and extraordinary refractive indices and optical birefringence of the liquid crystal 4-cyanophenyl-4'-pentyl benzoate. The spectral dependence of the optical birefringence was determined from interferometric measurements. The theoretical expression for liquid crystal optical transmission, presented here, is in agreement with experimental results.

key words: refractive index; nematic liquid crystal; optical birefringence.

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1. Introduction

Liquid crystals are anisotropic fluids which show specific optical properties due to the anisotropy of molecular organization. As they are birefringent materials, they shows double refraction phenomenon, having two indices of refraction (extraordinary $n_{\rm e}$ and ordinary $n_{\rm o}$ indices) and birefringence $\Delta n = n_c - n_o$. Optical birefringence is strongly temperature dependent. This property is very important in building liquid crystal devices.

The work presents the results obtained in the optical birefringence study of the nematic liquid crystal 4-cyanophenyl-4'-pentyl benzoate. This compound passes from solid phase to isotropic liquid state at 60.5°C and presents the nematic state at the temperatures below 50.5°C, in cooling.

Several techniques for mesurement of the birefringence Δn were proposed, such as refractometric method [1,2,8,9] or intereference technique [3-6]. To find the spectral dependence of the birefringence we used the interferometric method and to interpret the results we need to use the refractometric measurements. The principle of the interferometric method is the next: a planar and uniaxial oriented thin film of liquid crystal is placed between crossed polarizers inside a spectrophotometer. The intensity of the transmitted

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light by the liquid crystal will be modulated because of the spectral dependence of the birefringence.

2. Experimental

The liquid crystal was encapsulated in a cell with plane-parallel glass plates, prepared to provide a planar and uniaxial alignment of the molecules. The cell with liquid crystal was thermostated using a special electric oven and temperature was measured with a digital thermometer with accuracy of 0.1°C. The optical transmission of the liquid crystal was recorded with a UV-Vis Zeiss Jena Spectrophotometer. The oven containing the liquid crystal sample was placed between crossed polarizers, in the probe channel of the spectrophotometer. The reference channel includes the same optical components, less the liquid crystal. The measurements were recorded for different temperatures. The refractive indices as function of temperature were measured with an Abbe refractometer (λ =589nm), using polarized light. The refractometer prisms heating was provided with o water circulation. The water temperature was ensured by a thermostat, within ±0.1°C.

3. Results and discussion

The optical transmission T(v) of the liquid crystal, placed between crossed polarizers, is presented in Fig.1. The transmission T(v) represents the ratio I_p/I_r , where I_p and I_r are the intensity of light transmitted through the sample channel and reference channel respectively. In Fig.1 the transmission was measured at a constant temperature of 30°C. Such interference spectra were also recorded for other temperatures in the nematic state of the liquid crystal. The transmission T(v) has a complex structure, being phase modulated due to liquid crystal birefringence dispersion.



Fig. 1 The optical transmission of the liquid crystal placed between crossed polarizers.

This transmission, presenting maximum and minimum values, can be expressed as function of wave number v, by:

$$T(\mathbf{v}) = A(\mathbf{v}) + B(\mathbf{v})\sin^2\varphi(\mathbf{v}) \tag{1}$$

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This expression can be obtained theoretically, considering the experimental conditions described in Fig. 2, where xOy represents the coordinate system attached to the liquid crystal sample, Oy is the liquid crystal optical axis, (P) and (A) represent the optical axis of the polarizer and analyser, respectively. Linear polarized incident light, of amplitude E, produced by the polarizer, makes an angle α relative to optical axis Oy. Because of birefringence, through the uniaxial liquid crystal are transmitted two waves, the ordinary (E_o) and extraordinary (E_e) . After passing through the liquid crystal, the phase difference between these components is:

$$\phi = \frac{2\pi}{\lambda} d\Delta n$$

where d is the thickness of the liquid crystal layer, Δn birefringence and λ the light wavelength.



Fig. 2 The coordinate systems associated to the liquid crystal with optical axis Oy, (A) and (P) optical axis of the analyser and polarizer.

The analyser transmits the components with amplitudes E_1 and E_2 , that are transmitted with different Fresnel coefficients by the interfaces between liquid crystal and glass plates of the cell [7]:

$$E_{1} = \frac{KE}{2} \left[\frac{n_{e}}{\left(n_{s} + n_{e}\right)^{2}} \right] \sin 2\alpha$$
(2)

$$E_2 = \frac{KE}{2} \left[\frac{n_o}{\left(n_s + n_o\right)^2} \right] \sin 2\alpha$$
(3)

and for the reference channel:

$$E_r = \frac{KE}{2} \left[\frac{1}{\left(n_s + 1\right)^2} \right] \tag{4}$$

where K-constant, n_s refractive index of the glass plates of the cell.

After analyser, the coherent and parallel polarized components E_1 and E_2 having the phase difference φ , will interfere and the resulted intensity I_p is:

$$I_p = \frac{K^2 E^2}{4} \left\{ \left[\frac{n_e}{(n_s + n_e)^2} - \frac{n_o}{(n_s + n_o)^2} \right]^2 + \frac{n_o n_e}{(n_s + n_e)^2 (n_s + n_o)^2} \sin^2 \frac{\phi}{2} \right\} \sin^2 2\alpha$$

and the light intensity in the reference channel is:

$$I_r = \frac{K^2 E^2}{\left(1 + n_s\right)^4}$$
(6)

Consequently, the transmission T(v) can be expressed as (1), where the terms A and B for $\alpha = \pi/4$ are:

$$A = \frac{(1+n_s)^4}{4} \left[\frac{n_e}{(n_s+n_e)^2} - \frac{n_o}{(n_s+n_o)^2} \right]^2$$
(7)

$$B = (1 + n_s)^4 \frac{n_o n_e}{(n_s + n_e)^2 (n_s + n_o)^2}$$
(8)

and

$$\phi = \frac{\pi d}{\lambda} \Delta n \tag{9}$$

In the above relations, the liquid crystal absorption and likely uncompensated absorption of the polarizers were neglected because they have no influence on determining the birefringence. Experimentally we found that A and B have a spectral dependence but are less dependent on temperature.

The transmission (1) will show maximum and minimum if the following condition are fulfilled:

$$\frac{\pi d}{\lambda} \Delta n = k \frac{\pi}{2} \tag{10}$$

and $T_{max}=A+B$, for k-odd number, $T_{min}=A$ for k-even number. According to relations (1) and (10), the liquid crystal transmission will be phase modulated as a consequence of the birefringence dispersion.

The intensity of the transmitted light is maximum if the condition (11) is satisfied:

$$\Delta n(\lambda_k) = k \frac{\lambda_k}{2d} \tag{11}$$

with k – odd number, $\Delta n(\lambda_k)$ is the birefringence corresponding to λ_k and k is the order of the interference maximum. The relation (11) shows that the factor k must be known to calculate the value of $\Delta n(\lambda_k)$. Without knowledge of an initial value k_0 , various authors

[3,4] have made assumptions about the wavelength dependence of birefringence to calculate the $\Delta n(\lambda_k)$.

We have calculated the value of an initial k_o using the temperature dependence of Δn , obtained from refractometric measurement at λ_o =589nm. Fig. 3 shows the temperature dependence of the refractive indices n_o and n_e of the compound 4-cyanophenyl-4'-pentyl benzoate, measured for λ_o =589nm, where n_{is} is the refractive index in isotropic state and n_o and n_e the refractive indices in the nematic state. In Fig. 4 is presented the temperature dependence of $\Delta n = n_e - n_o$ at $\lambda_o = 589$ nm. Using this results we could calculate the value of $k_o = 2d\Delta n(\lambda_o)/\lambda_o$ for different temperatures.



Fig. 3 The temperature dependence of the refractive indices n_o and n_e measured for λ_o =589nm.

Fig. 4 The temperature dependence of the birefringence Δn (λ_0 =589nm).



Fig. 5 The wavelength dependence of the birefrigerence for different temperatures.

Fig. 5 presents the wavelength dependence of the birefringence Δn for different temperatures. Birefringence has a normal dispersion in the visible spectral range, far from the absorption band of the liquid crystal. This may be due mainly of the increase of

extraordinary index with decreasing of the wavelengths. Also, it appears that the birefringence values decreases with increasing temperature. This decrease is due to degradation of the molecular ordering at high temperatures. The large values of Δn in the short wavelengths range recommend the studied liquid crystal as an anisotropic solvent only for the spectroscopic studies in the long wavelengths region of the visible spectrum and near IR.

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