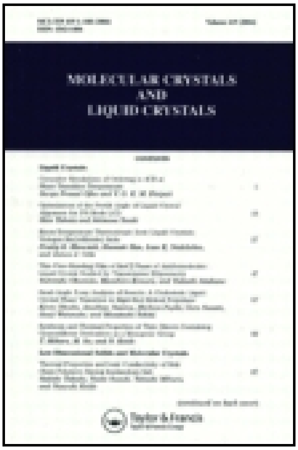

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Margareta Socaciu [a], Marcela Ursache [a], Violeta Calian [a], Cristina Sarpe-tudoran [a] & Liana-Daniela Socaciu [a]

[a] University of Craiova, Faculty of Sciences, Department of Physics, 13 A.I. Cuza, Craiova, 1100, Romania

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Multiple Layer Interference on TBBA-CM Liquid Crystal Mixture

MARGARETA SOCACIU, MARCELA URSACHE, VIOLETA CALIAN, CRISTINA SARPE-TUDORAN and LIANA-DANIELA SOCACIU
University of Craiova, Faculty of Sciences, Department of Physics,
13 A.I.Cuza, Craiova 1100, Romania

The new thermo-electro-optical effect consist of visible spectra colours changing under a d.c. electric field in a time periodical temperature variation around the given temperature value. This effect was remarked using a liquid crystal mixture TBBA-CM. In this paper we explain this effect by multiple layer interference. Analysing the theoretical results we obtained a good agreement with the experimental data.

Keywords: multiple layer interference; thermo-electro-optical effect

INTRODUCTION

The reorientation of the molecular director by an external field is an important feature of liquid crystals giving rise to a variety of electro-optic, thermo-optic and magneto-optic modulation effects. Many liquid crystal applications are based on these effects. The colour effects due to the addition of pleochroic dyes at the host liquid crystals have been reported in the case of nematic host[1], cholesteric host[2] and smectic host[3].

In 1970 Ferguson and Taylor[4] notified birefringence changes of $S_A \rightarrow S_C$ phase transition at TBBA cooling accompanied by interference colours.

We obtained these colours by a new thermo-electro-optical effect[5,6] without pleochroic dye in the smectic cholesteric mixture terephtal-bis-butyl-aniline (TBBA) and cholesteryl myristate (CM).

EXPERIMENTAL DATA

The thermo-electro-optical effect for liquid crystal[7] consists of the appearance of a sequence of colours when a liquid crystal mixture TBBA-CM was heated in a periodical temperature under a d.c. electrical field. The effect has been observed at the polarised light microscope with crossed polarisers in white light. It appears at the liquid crystal sample heating and it is produced near the $S_C \rightarrow S_A$ phase transition in the presence of a constant electric field. The birefringence of this mixture depends on the tilt angle of the molecules against the normal to the layer planes, which is modified by the temperature. The smectic phases are layered and the main difference between smectic C and smectic A phases being the value of the angle between the normal to the smectic layer and the long axe of the molecules. For the $S_C \rightarrow S_A$ phase transition, the tilting angle of the molecules depends on the temperature. By applying a sine-shape periodical regime of the temperature around a given temperature near the $S_C \rightarrow S_A$ transition temperature, the tilting angle of the molecules varies periodically, in phase with the temperature.

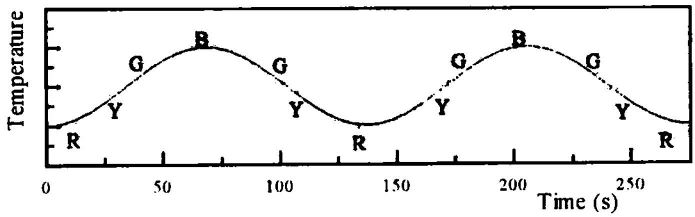

FIGURE 1 The time variation of the temperature.

Figure 1 shows the temperature time variation around a given temperature at heating of the liquid crystal mixture. In our case, the time period was 136.5s. In this Fig. 1. the points B, G, Y, R correspond respectively to the colours blue, green, yellow and red.

RESULTS AND DISCUSSIONS

Any light interference phenomenon involves the division of the emission light beam by a source in two or more coherent beams. In anisotrope media two refracting waves correspond to each incident waves. These two refraction waves propagate with different velocities having rectangular oscillation directions between them. If we set between two polaroids a plane parallel plate illuminated with a white light, the interference polychromatic phenomenon appears.

In order to explain this effect, we consider the multiple layer interference which appears between the ordinary and extraordinary rays within the layered structure of the smectic liquid crystals. The components of these rays resulted after penetration of a single layer, become incidental rays on the next layer etc. The transmitted light intensity changes with the temperature and the tilt angle of the molecules, so that it depends on the layers number and their thickness.

We suppose that all the layers are biaxial. Let be α the angle between the polariser and the plane of the ordinary ray of the first layer. The wave incident to the first layer is divided into two linearly polarised waves in perpendicular planes respectively, heaving the amplitudes:

$$\begin{aligned} A_{o,1} &= A\cos\alpha \\ A_{e,1} &= A\sin\alpha \end{aligned} \qquad (1)$$

At the entering into the second layer, we obtain as follows:

$$\begin{pmatrix} A_{o,2} \\ A_{e,2} \end{pmatrix} = \begin{pmatrix} \cos\alpha_1 & \cos\Delta\varphi_1 \sin\alpha_1 \\ -\sin\alpha_1 & \cos\Delta\varphi_1 \cos\alpha_1 \end{pmatrix} \begin{pmatrix} A_{o,1} \\ A_{e,1} \end{pmatrix} \tag{2}$$

where α_1 is the angle between the vibration perpendicular planes of layers "2" and "1". Also, for the third layer, we have:

$$\begin{pmatrix} A_{o,3} \\ A_{e,3} \end{pmatrix} = \cos^2\frac{\Delta\varphi_2}{2} \begin{pmatrix} \cos(\alpha_1+\alpha_2) & \cos\Delta\varphi_1 \sin(\alpha_1+\alpha_2) \\ -\sin(\alpha_1+\alpha_2) & \cos\Delta\varphi_1 \cos(\alpha_1+\alpha_2) \end{pmatrix} \begin{pmatrix} A_{o,1} \\ A_{e,1} \end{pmatrix} \tag{3}$$

The transfer matrix for the N layers may be then written in this way:

$$\begin{pmatrix} A_{o,N} \\ A_{e,N} \end{pmatrix} = \cos^2\frac{\Delta\varphi_2}{2} \cdot \cos^2\frac{\Delta\varphi_3}{2} \cdot \ldots \cdot \cos^2\frac{\Delta\varphi_{N-1}}{2} \cdot \begin{pmatrix} \cos(\alpha_1+\ldots+\alpha_{N-1}) & \cos\Delta\varphi_1 \cdot \sin(\alpha_1+\ldots+\alpha_{N-1}) \\ -\sin(\alpha_1+\ldots+\alpha_{N-1}) & \cos\Delta\varphi_1 \cdot \cos(\alpha_1+\ldots+\alpha_{N-1}) \end{pmatrix} \begin{pmatrix} A_{o,1} \\ A_{e,1} \end{pmatrix} \tag{4}$$

or, in restrictive form:

$$\begin{pmatrix} A_{o,N} \\ A_{e,N} \end{pmatrix} = \left(\prod_{i=2}^{N-1} \cos^2\frac{\Delta\varphi_i}{2} \right) \begin{pmatrix} \cos\Sigma\alpha_i & \cos\Delta\varphi_1 \sin\Sigma\alpha_i \\ -\sin\Sigma\alpha_i & \cos\Delta\varphi_1 \cos\Sigma\alpha_i \end{pmatrix} \begin{pmatrix} A_{o,1} \\ A_{e,1} \end{pmatrix} \tag{5}$$

where $\Delta\varphi_i$ has the expression:

$$\Delta\varphi_i = \frac{2\pi}{\lambda}\Delta n \cdot d_i \tag{6}$$

In relation (6) d_i represents the thickness of "i "layer, only, and it has the expression:

$$d_i = l\cos\gamma_i\,; \qquad i = 2, \ldots, N-1 \tag{7}$$

where l is the length of a molecule and γ_i is the tilting angle of the molecules in the "i" layer respect to the normal at the layer surface.

The first term of the right member of the (5) relation could be written as follows:

$$\prod_{i=2}^{N-1}\cos^2\frac{\Delta\varphi_i}{2} = \left(1-\sin^2\frac{\Delta\varphi_2}{2}\right)\left(1-\sin^2\frac{\Delta\varphi_3}{2}\right)\cdot\ldots\cdot\left(1-\sin^2\frac{\Delta\varphi_{N-1}}{2}\right)\cong$$

$$\cong 1-\left[\sin^2\frac{\Delta\varphi_2}{2}+\sin^2\frac{\Delta\varphi_3}{2}+\ldots+\sin^2\frac{\Delta\varphi_{N-1}}{2}\right]+\ldots \tag{8}$$

Replacing (6) in (8), we are able to write as follows:

$$\prod_{i=2}^{N-1}\cos^2\frac{\Delta\varphi_i}{2} = 1-\left[\left(\frac{\Delta\varphi_2}{2}\right)^2+\left(\frac{\Delta\varphi_3}{2}\right)^2+\ldots+\left(\frac{\Delta\varphi_{N-1}}{2}\right)^2\right]=$$

$$= 1-\left(\frac{\pi l\Delta n}{\lambda}\right)^2\left(\cos^2\gamma_2+\cos^2\gamma_3+\ldots+\cos^2\gamma_{N-1}\right) \tag{9}$$

The light polarisation plane is symmetrically twisted in two opposite directions for the first and the second half of the liquid crystal cell and as a consequence:

$$\gamma_i = i\frac{\gamma_{N/2}}{N/2} = i\theta, \quad i=2,\ldots,N/2 \tag{10}$$

We suppose that $\gamma_{N/2}$ is the maximum tilting angle of the molecules at the centre of the cell.

Therefore, from relation (9) we obtain:

$$\prod_{i=2}^{N-1}\cos^2\frac{\Delta\varphi_i}{2} = 1-2\left(\frac{\pi l\Delta n}{\lambda}\right)^2\left(\cos^2\gamma_2+\cos^2\gamma_3+\ldots+\cos^2\gamma_{N/2}\right) \tag{11}$$

$$\cos^2\gamma_2+\ldots+\cos^2\gamma_{N/1} = \frac{1+\cos 2\gamma_2}{2}+\ldots+\frac{1+\cos 2\gamma_{N/2}}{2} =$$

$$= \frac{1}{2}\left(\frac{N}{2}-1+\cos 2\gamma_2+\cos 2\gamma_3+\ldots+\cos 2\gamma_{N/2}\right) \tag{12}$$

$$\cos 2(2\theta)+\cos 2(3\theta)+\ldots+\cos 2\left(\frac{N\theta}{2}\right) = \mathrm{Re}\left(e^{i2(2\theta)}+\ldots+e^{i2\left(\frac{N\theta}{2}\right)}\right) =$$

$$= \frac{\cos\frac{\theta N}{2}\sin\frac{\theta N}{2}}{\sin\theta} = \frac{\sin\theta N}{2\sin\theta} = \frac{\sin 2\gamma_{N/2}}{2\sin\frac{2\gamma_{N/2}}{N}} = \frac{N}{4}\cdot\frac{\sin 2\gamma_{N/2}}{\gamma_{N/2}} \tag{13}$$

Finally, we obtain:

$$\prod_{i=2}^{N-1} \cos^2\frac{\Delta\varphi_i}{2} = 1 - \left(\frac{\pi l \Delta n}{\lambda}\right)^2 \cdot \frac{N}{2} \cdot \left(1 + \frac{\sin 2\gamma_{N/2}}{2\gamma_{N/2}}\right) \tag{14}$$

Replacing (14) in (5), we have:

$$\begin{pmatrix} A_{o,N} \\ A_{e,N} \end{pmatrix} = \left[1 - \left(\frac{\pi l \Delta n}{\lambda}\right)^2 \cdot \frac{N}{2} \cdot \left(1 + \frac{\sin 2\gamma_{N/2}}{2\gamma_{N/2}}\right)\right] \cdot \begin{pmatrix} \cos(\Sigma\alpha_i) & \cos\Delta\varphi_1 \sin(\Sigma\alpha_i) \\ -\sin(\Sigma\alpha_i) & \cos\Delta\varphi_1 \cos(\Sigma\alpha_i) \end{pmatrix} \cdot \begin{pmatrix} A_{o,1} \\ A_{e,1} \end{pmatrix} \tag{15}$$

Denoting by β the angle between the analyser direction and the perpendicular vibration planes, inside the "N" layer, being well-known that the light intensity I is proportional with A^2 , it results the amplitude wave after analyser as follows:

$$A^2 = \left(A_{o,N}\cos\beta + A_{e,N}\cos\Delta\varphi_N \sin\beta\right)^2 \tag{16}$$

We imposed for the birefringence variation the following expression:

$$\Delta n = \Delta n_0 + \delta n_1 \sin(\omega_T \cdot t + \varphi_n) \tag{17}$$

where ω_T has the same value as the temperature pulsation, assuming a slow time variation.

Introducing relation (17) in (15) and then replacing (15) in (16), the results was computed by multiple interpolation method. In this calculus we have taken into account the experimental values as follows: $\Delta n_0 = 0.12$; $\delta n_1 = 0.019$; $\omega_T = 4.6 \cdot 10^{-3}$ra ; $\varphi_n = \frac{\pi}{2}$; $l = 2 \cdot 10^{-9}$m ; $t \in (0s, 136.5s)$.

The 3-dimensional graphic representation from Fig. 2. shows the theoretical dependence of the transmitted light intensity (Oz) on time (Ox) and on wavelength (Oy). Analysing the above mentioned graphic, representation from Fig. 2 we conclude that the peaks of light intensity corresponding to

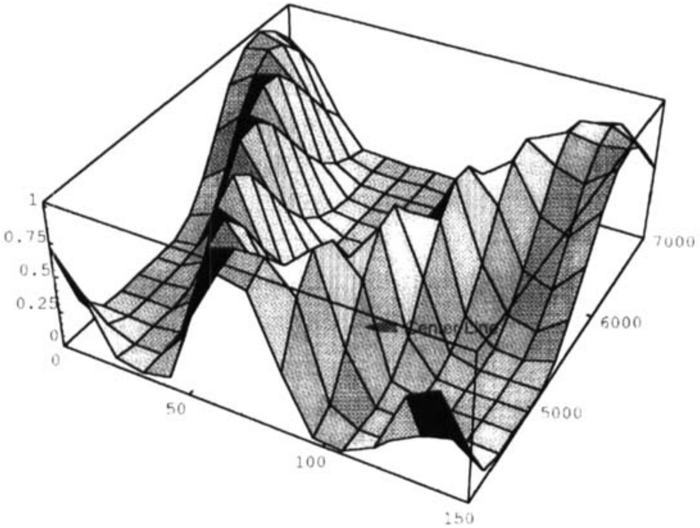

FIGURE 2. The theoretical dependence of the transmitted light intensity (Oz) on time (Ox) and wavelength (Oy).

different wavelengths recorded for different time moments are in good agreement with the experimental data presented in Fig. 1.

We can conclude that the theoretical model of the multiple layer interference is suitable enough to explain the sequence of colours R, Y, G, B, G, Y, R which appear in the same time moments of a single period of the time variation temperature as in our thermo-electro-optical effect.

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