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Study of the Faraday Rotation in a Nematic Liquid Crystal Doped with Methyl Orange

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Abstract

In this paper we report a comparative study of the magneto-optical effects which appear in a nematic liquid crystal doped with Methyl Orange when the magnetic field was applied parallel (Faraday configuration) and normally (Voigt configuration) with respect to the propagation direction of the optical beam from the probe laser. It was point out that the Faraday effect (linear dependence of the rotation angle on the magnetic field) appears only in the polar geometry at normal incidence, and is absent in Voigt configuration at normal incidence.. The quasiperiodical dependence of the rotation angle on the magnetic field was fitted by two empirical formulae.

1 Introduction

In the last decades, the „guest-host" liquid crystal (LC) systems were intensively studied due to their potential for applications in various domains as display industry and opto-electronics. It was found that such mixtures exhibit huge optical nonlinearities, even for a small amount of dye dissolved in the nematic matrix [1]-[4]. The magnetic field effects on the „guest-host" systems, which contain at least a LC, were recently investigated mainly to elucidate the type of the interaction between the nematic host and the nonmesogenic guests [5]-[7].

If the dye is an azoderivative compound, in the system appear conformational changes as a result of the azo-group *trans-cis* photoisomerization. These effects were studied both from theoretical and experimental point of view [8]-[11], but most of these studies are focused on molecular reorientation produced by electric or optical fields and less on the magneto-optical effects.

The magnetic field is an axial field, then, it induces a circular anisotropy and produce interesting optical effects as reported in previous works [12]-[14].

The magneto-optical effects could appear in transmission through a material (Faraday effects) or in reflection on a material surface (magnetic Kerr effects). In both cases there are three experimental geometries depending on the magnetic field orientation with respect to the incident surface and the optical beam: polar (Faraday configuration), longitudinal and transversal (both called Voigt configurations).

The magneto-optical effects are usually described in terms of the dielectric tensor of the medium in which the interaction between the light and the applied magnetic field takes place [15].

In a medium which has a ternary symmetry around z axis, in Faraday configuration, the dielectric tensor has the expression

$$\overline{\overline{\varepsilon}} = \begin{bmatrix} \varepsilon_{xx} & \varepsilon_{xy} & 0 \\ -\varepsilon_{xy} & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{bmatrix} \tag{1}$$

were we took into account that both **H** and **B**-fields are real, thus

$$\varepsilon_{ij}(-\omega) = \varepsilon_{ij}^{*}(\omega)$$

For a linearly polarized light passing through a nonmagnetic medium described by the dielectric tensor (1), the incident beam could be considered as a superposition of equal “amounts” of right- and left-circularly polarized beams.

These two components pass through the medium along **B** direction with different velocities [16],[17].

When emerging from the medium, the two components will recombine and the polarization direction will be rotated with the Faraday angle

$$\Phi_F = \frac{\omega d}{2c}(n_+ - n_-) \tag{2}$$

where ω is the frequency of the incident electromagnetic wave, d is the medium thickness, c is the light velocity in vacuum, and n_+, n_- are the refractive indices for the right- and left-circularly polarized beams, respectively.

By convention, the sign of the Faraday rotation angle is positive for a clockwise rotation of the polarization direction.

The equation (2) may be written as

$$\Phi_F = \frac{\omega d}{4nc}(n_+^2 - n_-^2) \tag{3}$$

were $n = \frac{n_+ + n_-}{2}$ is approximately equal with the refractive index in the absence of the magnetic field.

The aim of this paper is to compare the magneto-optical effects which appear in different experimental configuration, and to evaluate the rotation of the polarization plane in order to elucidate the origin of its oscillatory dependence on the magnetic field.

The paper is organized as follows:

After a short description of the experimental procedure, the results obtained when subjecting LC cells to magnetic fields are described and discussed. The studies were performed for cells with planar and homeotropic alignments, in Faraday and Voigt configurations, respectively. Experimental data referring to the rotation angles are presented and discussed. Finally, we suggest two empirical formulae for fitting the experimental data.

2 Experimental Section

The studied compound was a mixture of the nematic LC (Merck MLC-6601) with small amount of Methyl Orange (1.8% by wt.). The pure nematic MLC-6601 has the clearing point at 77^oC, the refractive indices $n_e = 1,5498$, $n_o = 1,4735$ and the birefringence $\Delta n = 0,0763$ (at $\lambda = 589.3nm$ and 20^oC). The chemical structure of the azo-dye is shown in Figure 1.

The LC cells were designed to have $180\mu m$ thicknesses (using glass spacers) and were filled by capillarity with the “guest-host” LC mixture. Before filling, the cells plates were chemically and mechanically processed to obtain either planar or homeotropic alignment.

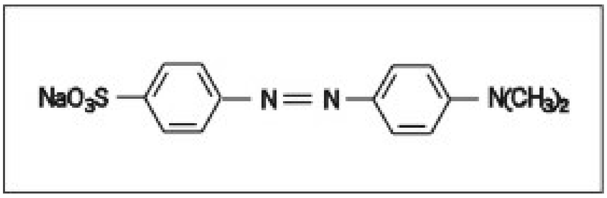

Figure 1: The chemical structure of Methyl Orange.

In order to record the transmitted light intensities and the rotation angles, we used the experimental set-ups, described in detail in [13], [14]. The magneto-optical effects were investigated for both Faraday and Voigt configurations using a He-Ne laser ($632.8nm$, $1mW$) as probe laser.

Doping small amounts of azo-dyes in a nematic matrix doesn't change the thermal properties of the nematic host in a significant manner [18]. This aspect was verified using the Polarised Optical Microscopy method and we found that, at room temperature, the mixture lies in the region of the nematic mesophase.

3 Results and Discussion

The plots of the transmited light intensities through the LC cells (Figure 2) and the variations of the rotation angle (Figures 3 and 4) were recorded for increasing magnetic field.

The dependence of the rotation angle on the magnetic field was find to be quasiperiodical and the values increased after UV irradiation of the samples [13],[14]. Since nor the pure LC nor the pure azo-dye show this behaviour in the presence of the magnetic field, it may be suggested that the rotation angle arises as a result of disturbing the nematic order by the azo-dye.

As we may see from Figures 3 and 4, the rotation of the polarization direction was clockwise for the planar cell and counterclockwise for the homeotropic cell. Still, for high magnetic fields the positions of the maxima and minima tend to overlap.

The net Faraday rotation angle given by the equation (3) is the average value of $\Phi(B)$.

In order to fit the experimental data, we propose the following empirical formulae for the rotation angle as function of the magnetic field

$$\Phi(B) = a + bB + c\exp\left(\frac{B}{2}\right)\sin\left[d\exp\left(-\frac{B}{f}\right)\frac{B}{g} + h\right] \tag{4}$$

for the planar cell in Faraday configuration, and

$$\Phi(B) = a' + c'\sin\left[\exp\left(-\frac{B}{f'}\right)\frac{g'}{B} + h'\right] \tag{5}$$

for the homeotropic cell in Voigt configuration.

In (4) the constants a, b, f, g and in (5) the constants f', g' depend on the cell thickness. This remark was proved by applying the fitting formula to the experimental data obtained for other thicknesses of the LC cells [19].

From eqs. (4) and (5) we can notice that the linear dependence of the rotation angle on the magnetic field (the Faraday Effect) appears only for the polar geometry. In Voigt configuration at normal incidence, the average rotation angle is constant.

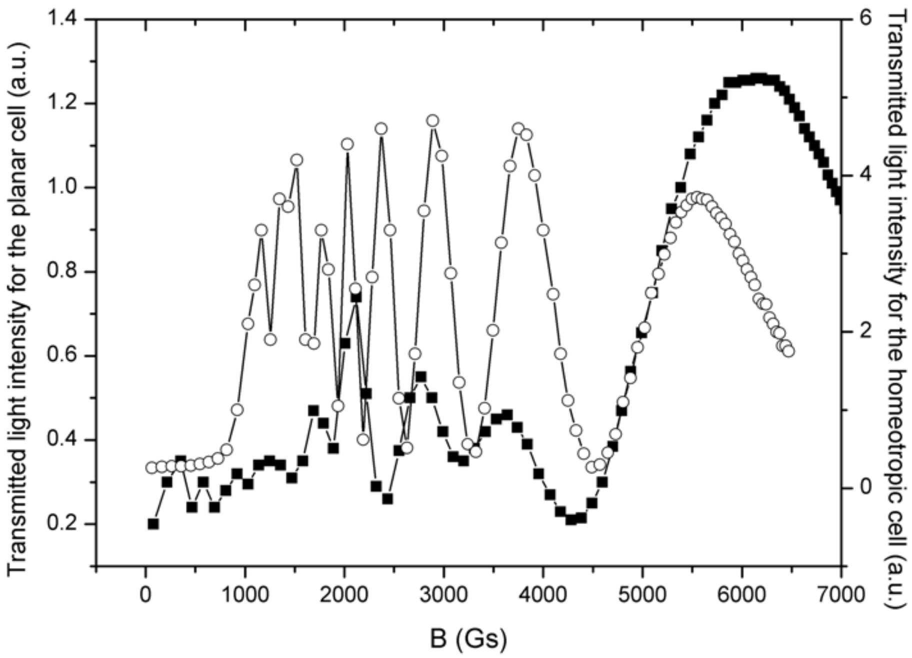

Figure 2: The intensities of transmitted light as a function of the magnetic field strength, for the planar cell (-■-) and the homeotropic cell (-O-).

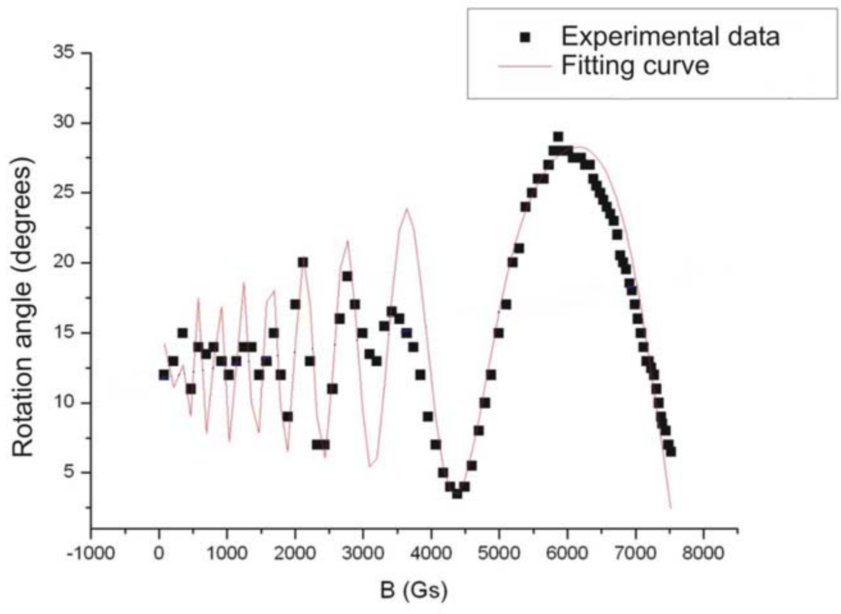

Figure 3: Experimental data and fitting curve for the rotation angle in the planar cell, $180\mu m$ thickness.

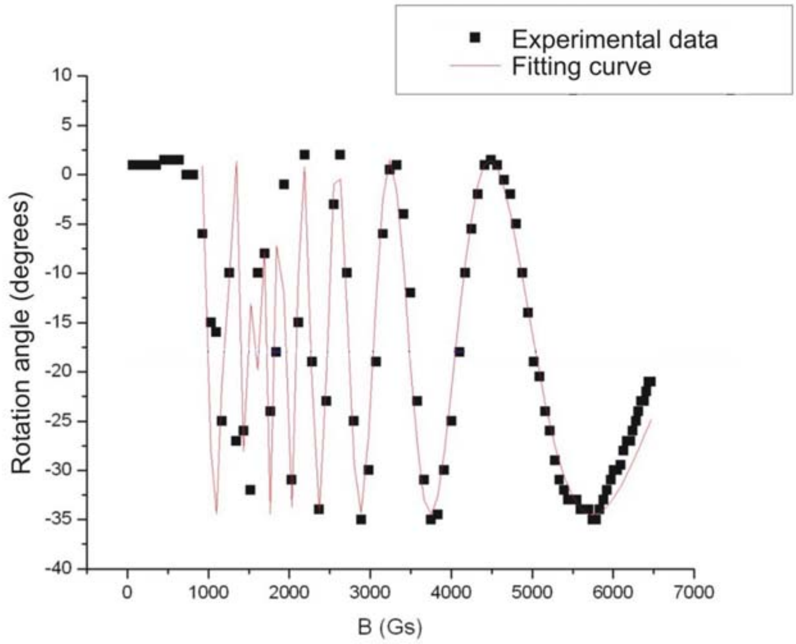

Figure 4: Experimental data and fitting curve for the rotation angle in the homeotropic cell, $180\mu m$ thickness.

The rotation angle at zero magnetic field, in Figure 4, arises as result of UV irradiation of the sample which increased the proportion of *cis* isomer of Methyl Orange and enhanced the rotational effect [14].

A similar quasiperiodical variation of the rotation angle, but at constant magnetic field and different angles of incidence, was reported for a $20\mu m$-thick slab magnetized along the Z-axis [20], [21]. The oscillations in the transmitted amplitudes and in the polarization angles were ascribed to the interference among the multiply-reflected beams at the facets of the slab. Aside from the interference effects, in this case, the Faraday Effect does not show any signs of abatement with the increasing angle of incidence. The reason is that, while the direction of propagation of the beam increasingly deviates from the direction of the **B**-field, the propagation distance simultaneously increases, keeping the net interaction between the magnetic material and the beam of light at a constant level.

In our case, the interference could be produce by the beams passing through the cell at different angles due to the molecular reorientation of the LC molecules which act as wave guides. The nematic LC molecules have the tendency to orient with their long molecular axis along the magnetic field direction, thus the initial alignment of the mixture molecules is disturbed, except for two very thin layers in contact with the glass substrates. The effect is enhanced by the dye molecules and could be further enhanced by UV irradiation. The magnetic field direction is kept constant, while the propagation distance increases, thus the rotation angle linearly increase at increasing magnetic field, in polar geometry.

4 Conclusion

The phenomena described in this paper have a high degree of complexity. The interaction between the host nematic molecules and the molecules of the azoderivative dye, even in the rod like *trans* form are not yet elucidated. The torques induced by the *trans* and *cis* isomers on the nematic director and those performed by the magnetic field on both the nematic director and on the dye give rise to a three-dimensional rotation of the LC molecules. This geometry could generate at its turn the rotation of the polarisation plane of the linear polarized incident light.

The results of our study are significant for applications since the azo-dye doped LC may be used as Faraday rotators and the rotation angle could be controlled by UV irradiation.

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