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# Birefringence of azo-dye doped nematic liquid crystals

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Changes into the birefringence of an azo-dye doped nematic liquid crystal, subjected to magnetic fields, were investigated using a transmission technique. Liquid crystal cells, with planar/homeotropic alignment, were examined under both Faraday and Voigt configurations, i.e. the magnetic field direction was parallel and perpendicular to the incident light (He-Ne laser beam, 632.8 nm), respectively. The rate of decreasing/increasing birefringence under magnetic field is discussed, as well as the influence of UV irradiation.

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## 1. Introduction

The birefringence, $\Delta n$, of liquid crystals (LC) is of fundamental interest for liquid crystal electro-optical devices. $\Delta n$ is a continuous function of wavelength and varies when the liquid crystal film is subjected to electric or magnetic fields.

Several techniques for measurement of $\Delta n$ were proposed, such as total reflection method [1,2], hollow prism method [3,4], interference technique, giving $\Delta n$ values in the visible region [5], or voltage dependent transmission techniques [6,7]. An improved method based on determination of phase difference, occurring when monochromatic polarized light passes through a LC cell with an anisotropic refractive index, was proposed by Wu et al. [8]. This method, giving $\Delta n$ as a continuous function of wavelength in the ultraviolet, visible and infrared spectral regions, is based on a voltage-dependent transmission technique.

In our previous paper [9] we have shown the influence of UV radiation on magneto-optical effects in azo-derivative doped nematic liquid crystals.

In this paper we have calculated the birefringence of an azo-dye doped nematic liquid crystal using a magnetic field-dependent transmission technique. In order to obtain the dependence of $\Delta n$ on magnetic field strength we used a procedure similar to that described in [8].

## 2. Experimental

Liquid crystal cells, with Mylar (*50 $\mu m$, 60 $\mu m$*) or glass (*180 $\mu m$*) spacers, were filled by capillarity with a mixture of nematic liquid crystal (Merck MLC-6601) and Methyl Orange (1.8 % by weight). Before filling, the cells plates were processed to obtain either homeotropic or planar alignment.

Transmission measurements of a linear polarized He-Ne laser beam (*$\lambda$=632.8 nm, 1 mW*) were performed when subjecting the LC cells to an increasing magnetic field. We used both Faraday and Voigt configurations, i.e. the magnetic field direction was parallel and perpendicular to the incident light, respectively. The experimental equipment was described in detail in Refs. [10,11].

## 3. Results and discussion

When the magnetic field strength exceeds the threshold value for magnetic Freedericksz transition, the light passing through the LC cell varies quasiperiodically when increasing magnetic field values. This phenomenon occurred for both Faraday and Voigt configurations. Changes in the light transmission when increasing magnetic field strengths are shown in Fig. 1.

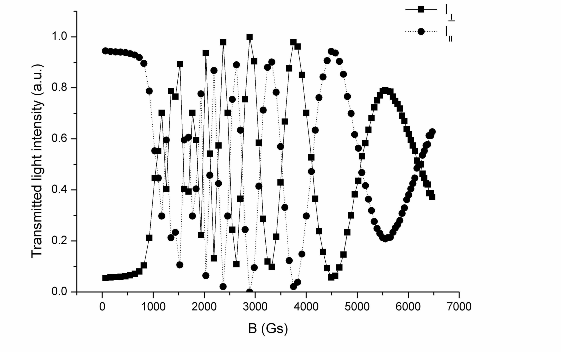


*Fig. 1. Magnetic field dependence of transmitted light intensity corresponding to perpendicular ($I_\perp$) and*

*parallel ($I_{||}$) orientations of the analyzer relative to incident light polarization direction, for a homeotropically aligned LC cell (180 μm), when using Voigt configuration.*

As it has been shown [8], the transmitted light intensities $I_{\perp}, I_{||}$, corresponding to perpendicular and parallel orientation of the analyzer with respect to the polarizer, are

$$I_{||} = I_0 \exp(-\alpha_o d)\left[1 - \sin^2 2\varphi \sin^2 \frac{\delta}{2}\right], \quad I_{\perp} = I_0 \exp(-\alpha_o d)\sin^2 2\varphi \sin^2 \frac{\delta}{2} \tag{1}$$

where $d$ is the cell thickness, $\alpha_o$ the absorption coefficient of ordinary ray, $\varphi$ the angle between the molecular director and the direction of incident light polarization and $\delta$ the phase difference between the ordinary and extraordinary rays.

The relations (1) hold when assuming negligible absorption anisotropy, i.e. $(\alpha_e - \alpha_o)d << 1$.

As it has been found [10,11], when the LC cell was subjected to a magnetic field, the molecular director experienced a rotation and, consequently, $\varphi$ is changed. Considering this case, one obtains for the phase difference

$$|\delta| = (m+1)\pi - 2\tan^{-1}\sqrt{\frac{I_{\perp}}{I_{||}\sin^2 2\varphi - I_{\perp}\cos^2 2\varphi}}, \qquad m = 1,3,5,... \tag{2a}$$

$$|\delta| = m\pi + 2\tan^{-1}\sqrt{\frac{I_{\perp}}{I_{||}\sin^2 2\varphi - I_{\perp}\cos^2 2\varphi}}, \qquad m = 0,2,4,... \tag{2b}$$

Using the equations (2a and b) and the well known formula of the phase difference

$$\delta = \frac{2\pi d \Delta n}{\lambda}, \tag{3}$$

We may calculate the birefringence, $\Delta n$, of the studied LC mixture.

For planar aligned LC cells, examined under Faraday configuration, we recorded the magnetic field dependences of the transmitted light intensities for perpendicular ($I_{\perp}$) and parallel ($I_{||}$) orientations of the analyzer relative to the polarization direction of the linear polarized He-Ne laser beam. The first maximum of the $I_{\perp} = I_{\perp}(B)$ plot, starting from high magnetic field end, is ascribed to a phase retardation of $\pi$, the second maximum to $2\pi$ and so on. Using Eqs. (2) and (3) we have determined the phase retardations and the birefringences for two LC cells, with *50 μm* and *180 μm* thicknesses. The results are shown in Fig. 2.

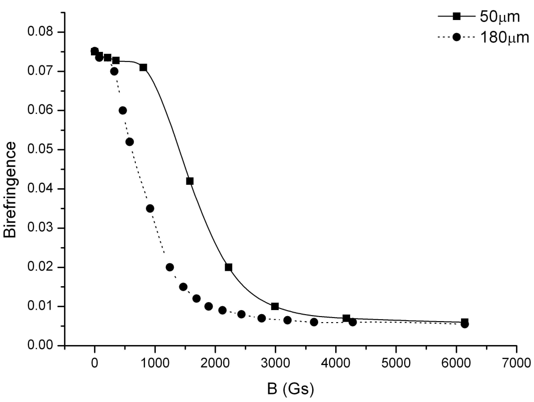


*Fig. 2. Magnetic field dependence of birefringence, for two LC cells with planar alignment.*

When the magnetic field strength exceeds the threshold value for the Freedericksz transition, the birefringence abruptly decreased, and then reached a minimum value for higher field strengths. The maximum phase difference (and maximum birefringence) is obtained in absence of the magnetic field. We get $(\Delta n)_{max} = 0.075$ and $(\Delta n)_{max} = 0.0751$ for the cells with *50 μm* and *180 μm* thicknesses, respectively.

For homeotropically aligned LC samples, examined under Voigt configuration, the magnetic field dependence plots of $I_{\perp}$ and $I_{||}$ were recorded for two cells with *60 μm* and *180 μm* thicknesses. In order to obtain the birefringence, we used Khoo and Wu method [12].

First, the phase retardation as a function of magnetic field and then, by linear extrapolation, the critical fields, $B_{th}$, for magnetic Freedericksz transition were determined. We get $B_{th} = 2880Gs$ and $B_{th} = 970Gs$ for the LC cells with *60 μm* and *180 μm* thicknesses, respectively.

Second, from the plots $\delta = \delta(B_{th}/B)$ we have determined, by linear extrapolation at $B_{th}/B = 0 \quad (B \to \infty)$, the maximum value for the phase retardation. We obtained $\delta_{max} = 11.4\pi$ and $\delta_{max} = 41.54\pi$ for the LC cells with $d = 60\mu m$ and $d = 180\mu m$, respectively.

Finally, using Eq. (3) we have obtained the maximum birefringences: $(\Delta n)_{max} = 0.0721$ for the cell with $d = 60\mu m$ and $(\Delta n)_{max} = 0.073$ for that with $d = 180\mu m$.

The magnetic field dependence of the birefringence is shown in Fig. 3, for the LC cell with *180 μm* thickness. It may be seen that the birefringence abruptly increases within the range of low fields; the increasing rate is slower at higher fields and the birefringence reaches its maximum value at very high magnetic field strengths (practically, for $B \to \infty$). In the same figure we give the results obtained when the LC cell was subjected, for *15 min*, to UV irradiation (*λ=365 nm*). It may be seen that $\Delta n$ decreased as a result of UV irradiation; this phenomenon is more evident within the range of high fields and originates from the generation of radiation-induced "cis" isomers, which disturb the nematic order.

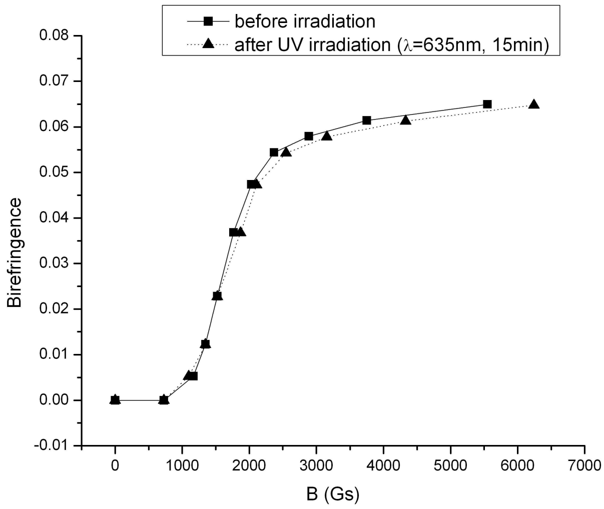


*Fig. 3. Magnetic field dependence of birefringence, for a LC cell ($d = 180\mu m$) with homeotropic alignment, before and after UV irradiation.*

As shown in [10,11], by adding azo-dyes (such as Methyl Orange) to nematic liquid crystals, an optical activity was noticed. When the LC cell is subjected to a magnetic field, using Faraday configuration, the mean value of the rotation angle, $\Phi_F$, depends linearly on the magnetic field. The rotation angle is given by

$$\Phi_F = \frac{\pi d}{\lambda}\left(n_+ - n_-\right) = \frac{\pi d}{\lambda}\Delta n^{rot}, \qquad (4)$$

where $\Delta n^{rot}$ is the circular (rotatory) birefringence.

We have found: $\Delta n^{rot} = 0.02$ and $\Delta n^{rot} = 0.013$ for the planar aligned LC cells, with *d = 50 μm* and *d = 180 μm*, respectively.

The magnetic field dependence of circular birefringence is shown in Fig. 4.

There are also noticed in Refs. [10,11] that the light emerging from the LC cell is elliptically polarized. This is an indication for the presence of circular dichroism, as the circular polarized waves display different absorption coefficients.

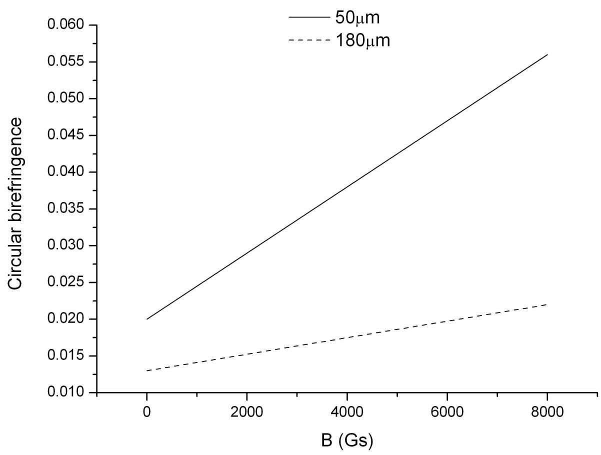


*Fig. 4. Magnetic field dependence of circular birefringence, for planar aligned LC cells with two different thicknesses.*

The ellipticity is given by

$$e = \frac{\pi d}{\lambda}\left(\kappa_+ - \kappa_-\right), \qquad (5)$$

where $\kappa_+$, $\kappa_-$ are the extinction coefficients for right-handed and left-handed circular polarized waves, respectively.

We obtained: $\kappa_+ - \kappa_- = 0.0021$ and $\kappa_+ - \kappa_- = 0.00033$ for the planar aligned LC cells, with *d = 50 μm* and *d = 180 μm*, respectively.

For the homeotropic aligned LC cells, examined under Voigt configuration, $\Phi_F$ keeps a constant value when increasing/decreasing magnetic field strength. Using the relation (4), we have computed the circular birefringence in the absence of magnetic field. It resulted: $\Delta n^{rot} = 0.06$ for the LC cell with *d = 60 μm* thickness and $\Delta n^{rot} = 0.018$ for that with *d = 180 μm*.

In both cases, the rotational birefringence is higher when the cell thickness is lower. It may be suggested that the main contribution to the rotational birefringence is due to a surface layer.

## 5. Conclusions

A magnetic field dependent transmission technique was used in order to study the birefringence of a nematic liquid crystal doped with azo-dye (Methyl Orange). As the LC mixture exhibits rotatory power, an appropriate formula for the phase retardation was used. The magnetic field dependence of birefringence and its maximum values were calculated using two experimental configurations (Faraday and Voigt), for LC cells with different thicknesses (50 μm, 60 μm, 180 μm) and different molecular alignments (planar and homeotropic). For the homeotropic aligned sample, examined in Voigt configuration, the magnetic field dependence of the birefringence was investigated before and after UV irradiation ($\lambda$ = 365 nm). A decrease of the birefringence in the range of high magnetic fields was noticed after UV irradiation.

The circular (rotatory) birefringence and the anisotropy of the extinction indices were computed for the LC mixture analysed in both configurations. It was found that, in certain circumstances, the circular birefringence may be controlled by the magnetic field.

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