The Study of Magnetic Rotation Light Effect of Liquid Crystal

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A matrix method for analyzing the optical rotation effect of a liquid crystal is presented, and the matrix expression of optical rotation of liquid crystal is given. The magnetic optical rotation characteristic of liquid crystal is studied by testing rotation angle and transmission of liquid crystal. The influence of magnetic field on molecular axis rotation angle and transmission of liquid crystal is analyzed. The curves of rotation angle and transmission of liquid crystal versus magnetic field are obtained. By altering the direction of magnetic field, the optical rotation induced by liquid crystal was tested again, and there was concluded that the optical rotation direction of liquid crystal is independent of the magnetic field direction. The obtained results are useful for the design, manufacturing and application of liquid crystal devices.

Keywords: Liquid crystal, Matrix, Rotation light, Magnetic field

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1. Introduction

Liquid crystal is a substance which is situated between true crystal and isotropic liquid. They are classified broadly into three types: nematic, smectic and cholesteric[1]. They are uniaxial and their molecular long axes are in accord with optic axis in general. The liquid crystals are composed of rod-like or disk-like molecules. There are fixed electric dipole moment in their high degree of long-range orientational order of the molecules. Because their molecular long-range are not exactly crystalline, they are easily affected by external conditions, such as electric field, magnetic field, temperature, stress and adsorbent impurity etc. Accordingly, their optical properties change. The molecular long axis of liquid crystal is rotated when the magnetic field (or voltage) is applied to the liquid crystal cell. Formerly, the rotation waveplates with voltage applied to the liquid crystal was studied by Yasuo Ohtera[2]. The effects of magnetic field-induced changes in molecular order and director structure within a nematic liquid crystal cell was examined in theory by N.J. Mottram[3]. The magnetic-field-induced birefringence in wedged homeotropic ferronematic liquid crystals was studied by Shu-Hsia Chen[4], and a particular kind of electro-optical light modulator for mid-infrared light has been investigated and tested by S Brugioni. In this paper the magnetic rotation optiucal characteristic of liquid crystal was researched by testing rotation angle and delustering ratio of liquid crystal, and it was discovered a new phenomenon: The d8irection of the optical rotation of the liquid crystal is independent of the magnetic field direction.

2. Theoretical analysis

The molecular axis of a liquid crystal rotates with magnetic field (or electric field). We suppose 'd' is the thickness of liquid crystal cell, directed vector of liquid crystal is range along glass plate, and the range of directed vector is interparallel (Fig.1). The Jones matrix of the liquid crystal cell is[6,7]:

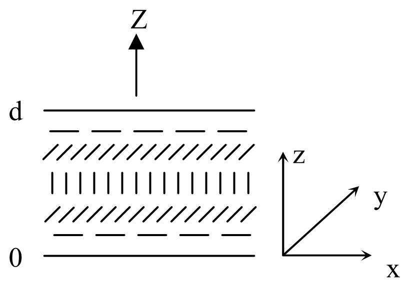


Figure 1 The liquid crystal cell

$$J=R(-\psi_d)\begin{pmatrix} \cos\Theta - \mathrm{i}\Gamma\dfrac{\sin\Theta}{2\Theta} & \psi_d\dfrac{\sin\Theta}{\Theta} \\ -\psi_d\dfrac{\sin\Theta}{\Theta} & \cos\Theta + \mathrm{i}\Gamma\dfrac{\sin\Theta}{2\Theta} \end{pmatrix} \quad (1)$$

Where: $R(-\psi_d)=\begin{pmatrix} \cos\psi_d & -\sin\psi_d \\ \sin\psi_d & \cos\psi_d \end{pmatrix}$,$R(-\psi_d)$ is a transform matrix of rotation -ψ_d angle.

$$\Gamma = 2\pi(n_e - n_o)d/\lambda \ ,\Theta = \sqrt{\psi_d^{\,2} + (\Gamma/2)^2} \quad (2)$$

We suppose that a polarized light which polarization state is $E_1=\begin{pmatrix}1\\0\end{pmatrix}$ vertically enter liquid crystal cell, so the polarization state of output light is

$$E_2=JE_1=\begin{pmatrix} \cos\psi_d & -\sin\psi_d \\ \sin\psi_d & \cos\psi_d \end{pmatrix}\begin{pmatrix} \cos\Theta - \mathrm{i}\Gamma\dfrac{\sin\Theta}{2\Theta} & \psi_d\dfrac{\sin\Theta}{\Theta} \\ -\psi_d\dfrac{\sin\Theta}{\Theta} & \cos\Theta + \mathrm{i}\Gamma\dfrac{\sin\Theta}{2\Theta} \end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix}$$

$$=\begin{pmatrix}\cos\psi_d & -\sin\psi_d \\ \sin\psi_d & \cos\psi_d\end{pmatrix}\begin{pmatrix}\cos\Theta-\dfrac{\mathrm{i}\Gamma\sin\Theta}{2\Theta} \\ -\dfrac{\psi_d\sin\Theta}{\Theta}\end{pmatrix}$$

$$=\frac{1}{2\Theta}\begin{pmatrix}2\Theta\cos\Theta\cos\psi_d-\mathrm{i}\Gamma\sin\Theta\cos\psi_d+2\psi_d\sin\Theta\sin\psi_d \\ 2\Theta\cos\Theta\sin\psi_d-\mathrm{i}\Gamma\sin\Theta\sin\psi_d-2\psi_d\sin\Theta\cos\psi_d\end{pmatrix} \quad (3)$$

From formula (2) we can know that Θ is related with ψ_d, and ψ_d is equal to rotation angle of the output polarized light, so the polarization state of output light is dependent on the rotation of liquid crystal axis.

Discussion:

(1) When $\psi_d=0,\Gamma=2\pi(n_e-n_o)\frac{d}{\lambda}$, $\Theta=\frac{\Gamma}{2}=\pi(n_e-n_o)\frac{d}{\lambda}$, from formula (3) we can obtain the polarization state of output light

$$E_2=[\cos\pi(n_e-n_o)\frac{d}{\lambda}-\mathrm{i}\sin\pi(n_e-n_o)\frac{d}{\lambda}]\begin{pmatrix}1\\0\end{pmatrix} \quad (4)$$

This is agree with the polarization state of enter light, the liquid crystal cell is equivalent a phase retarder.

(2) When $\psi_d=\pi/4,\Gamma=2\pi(n_e-n_o)\frac{d}{\lambda},\Theta=\frac{\pi}{4}\sqrt{1+16(n_e-n_o)^2\frac{d^2}{\lambda^2}}$, then the polarization state of output light is

$$E_2=\frac{\sqrt{2}}{4\Theta}\begin{pmatrix}2\Theta\cos\Theta-i\Gamma\sin\Theta+\sqrt{2}\sin\Theta \\ \Theta\cos\Theta-i\Gamma\sin\Theta-\sqrt{2}\sin\Theta\end{pmatrix} \quad (5)$$

The polarization state of output light is changed, it is a elliptical polarized light.

(3) When $\psi_d=\pi/2$, the molecular axis of liquid crystal is accordant with z axis, namely entering light is transmitting along light axis, there is not birefringence[8,9], $\Delta n=n_e-n_o=0$,viz. $\Gamma=0$, $\Theta=\frac{\pi}{2}$, then the polarization state of output light is

$$E_2=\begin{pmatrix}1\\0\end{pmatrix} \quad (6)$$

The polarization state of output light is just the same polarization state of enter light.

Herein before concluding by theoretical matrix analyzing, other way is worth to be mentioned [8].

3 Experimental setup

The experimental setup is shown in Figure 2 [10]. A infrared laser is used as a light source, the experimental material are BL - 009 and E70 nematic liquid crystal. The rotation light angle and transmission of liquid crystal with magnetic controlled were measured by using JG-3 type continuous tunable magnetism device and angle dekko in room temperature 20°C.

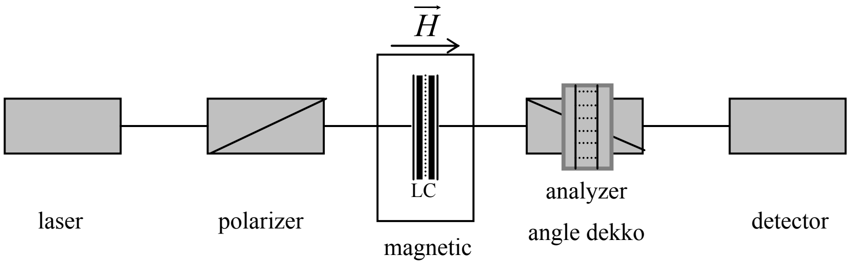


Figure 2 Experimental setup with iquid crystal

4. Analysis and discussion

The relation between rotation angle and magnetic field of BL - 009 nematic liquid crystal is shown in Fig.3. From Fig.3 we can know that liquid crystal molecular axis is not change until magnetic field intensity reaching a certain value which is the threshold of liquid crystal. The molecular axis of liquid crystal is rotated when magnetic field intensity exceeding 500 mT, and the molecular axis rotation angle of liquid crystal is increasing with the magnetic field ascending. The rotation of molecule axis of liquid crystal is not change after the magnetic field intensity reaching 1500mT. Then molecular range of liquid crystal is parallel the direction of magnetic field[11,12].

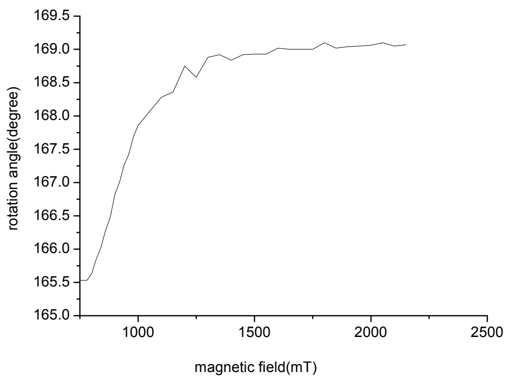


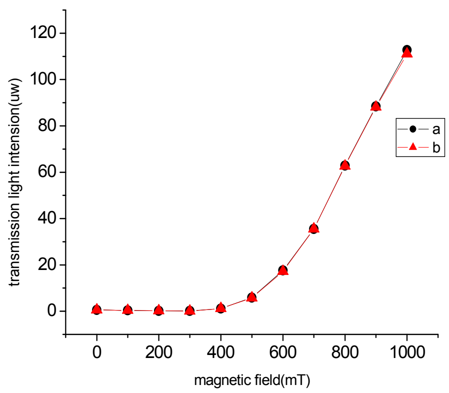
Figure3 Relation between rotation angle and magnetic field

The relation between least transmission light intensity (extinction position) and magnetic field of E70 nematic liquid crystal are shown in Fig.4. The least transmission light intensity of liquid crystal is not changed until the magnetic field intensity reaching about 400 mT, then delustering ratio is better. The least transmission gradually increasing with the magnetic field intensity ascending, and extinction position is disappear, this indicate that output light is not a linearly polarized light. Due to the output light intensity is not change by turning the polarization analyzer, so the output light is a elliptically polarized light.

Fig.5 is indicated that the molecule rotation angle of E70 nematic liquid crystal is dependent on magnetic field. From Fig.5 we can know that the molecular axis position of liquid crystal is without changing when magnetic field intensity from 0 to 350mT, then the molecular axis of liquid crystal is not rotated yet. The molecular axis rotation of liquid crystal is not evidence until magnetic field intensity reaching about 400 mT. Molecular axis rotation angle of liquid crystal is gradually augment along with the magnetic field intensity ascending. This is the same as magnetic rotation light effect of BL - 009 liquid crystal.

The molecule axis direction of liquid crystal is identical with the magnetic field direction if the magnetic field stronger enough, then the molecule axis direction is vertical to the surface of liquid crystal cell (namely ‘z’ direction in Fig.1). The input light is transmitting along the optical axis of the liquid crystal, then birefringence phenomenon disappears [4,5]. These agree with the conclusion by using matrix theory.

In figure 4 and figure 5, ‘a’ and ‘b’ are testing the results got by altering the direction of magnetic field fore-and-after. The two curves are basically superposed in double - condition. We can conclude that the molecular rotation of liquid crystal is independent of the direction of magnetic field.



Figiure 4 Relation between transmission and magnetic field

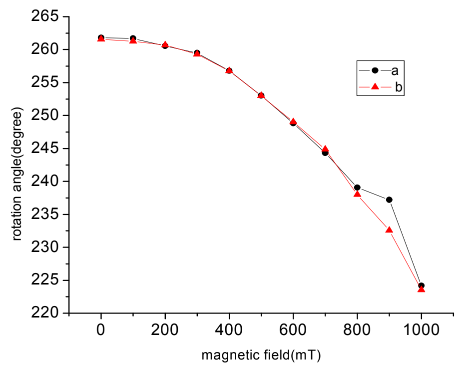


Figure 5 Relation between rotation angle and magnetic field

5 Conclusions

The magnetic rotation optical effect of liquid crystal was analyzed by using matrix method, the expression of rotation of polarization of the light in liquid crystal was gained, and the experiment is in agreement with the theory. The rotation angle of molecular axis of liquid crystal was tested by altering the direction of magnetic field, and we found that the rotation direction does not changes. The conclusion was drawn that the rotation direction of liquid crystal is independent of the direction of magnetic field. The optical deflector and optical modulator can be introduced by using this specific feature of the liquid crystal This could be a reference in the research of the liquid crystal characteristics and for the design of new liquid crystal devices

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References

[1] S. Chandrasekhar, F.R.S. *Liquid Crystals*(Cambridge Press, Cambridge,1992)
[2] Y. Ohtera, T. Chiba, and S. Kawakami. *IEEE Photonics Technology Letters*, 8, 390 (1996)
[3] N.J. Mottram, S.J. Hogan. Continuum Mech. Thermodyn.14, 281(2002)
[4] S.H. Chen ,C. W. Yang. Optics Letters,15,1049(1990)
[5] S Brugioni1 and R Meucci.J. Opt. A: Pure Appl. Opt. 6, 6 (2004)
[6] G.J. Ren, G.H. Li. *Chinese Journal of Liquid Crystals and Displays*, 18,357 (2003)
[7] F.J. Song. *Neoteric optical information disposal*(Beijing University Press, Beijing,1999)
[8] D.F. Wang, H.J. Sun. Trans. *The last technology of Liquid Crystals - Corporality·material·application -* (Chemical Industry Press, Beijing,1991)
[9] D.C. Wang. *Crystal Optics*.(Geologic Press, Beijing,1959)
[10] G.J. Ren, J.Q. Yao, P. Wang, et al. Journal of Optoelectronics·Laser,17,502(2006)
[11] J. Wang, C. Yu, Y, L. Chen, et al. *Journal of Materials Science: Materials Electronics*, 12,597 (2001)
[12] P. McIntyre. *J.Opt.Am.*, 68,869(1978)

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