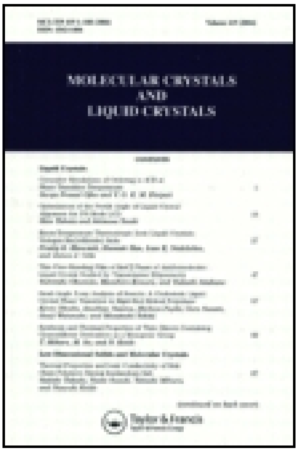

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Determination of Temperature Dependence of Kerr Constant for Nematic Liquid Crystal

M. H. Majles Ara [a] , S. H. Mousavi [a] , M. Rafiee [a] & M. S. Zakerhamidi [b]

[a] Photonics Laboratory, Physics Department, Tarbiat Moallem University, Mofateh, Tehran, Iran

[b] Research Institute of Applied Physics and Astronomy, University of Tabriz, Tabriz, Iran

To cite this article: M. H. Majles Ara, S. H. Mousavi, M. Rafiee & M. S. Zakerhamidi (2011): Determination of Temperature Dependence of Kerr Constant for Nematic Liquid Crystal, Molecular Crystals and Liquid Crystals, 544:1, 227/[1215]-231/[1219]

To link to this article: http://dx.doi.org/10.1080/15421406.2011.569662

Mol. Cryst. Liq. Cryst., Vol. 544: pp. 227/[1215]–231/[1219], 2011
Copyright © Taylor & Francis Group, LLC
ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2011.569662

Determination of Temperature Dependence of Kerr Constant for Nematic Liquid Crystal

M. H. MAJLES ARA,[1] S. H. MOUSAVI,[1] M. RAFIEE,[1]
AND M. S. ZAKERHAMIDI[2]

[1]Photonics Laboratory, Physics Department, Tarbiat Moallem
University, Mofateh, Tehran, Iran
[2]Research Institute of Applied Physics and Astronomy, University of
Tabriz, Tabriz, Iran

Nematic liquid crystals are the preferred materials for linear and nonlinear optics, where frequently required photosensitivity is provided by appropriate doping. This investigationis concerned with the determination of the Kerr constant of nematic liquid crystal (9CHBT). The temperature dependence of the Kerr constant B for azo dye doped nematic liquid crystalshas been studied. The sample has a positive Kerr constant which increases with decreasing of temperature. The linear dependence of the Kerr constant on $(T-T^*)^{-1}$*is found to be ingood agreement with the predications of the Landau-de Gennes model.*

Keywords Kerr constant; Kerr effect; nematic liquid crystal; temperature dependence

1. Introduction

The most studied and applied property of liquid crystals (LC) is their light-scattering ability. With the aid of an externally applied (usually electric) field, one cancontrol or realign the anisotropic liquid crystal axis, thereby controlling the effective refractive index and phase shift experienced by the light traversing the liquid crystal.Such electro-optical processes form a basis for various optical transmission, reflection, switching, and modulation applications.

Nematic liquid crystals are the most extensively studied LCs for their extraordinary linear, electro-optical and nonlinear optical properties [1–5]. In this work we are concerned with a new liquid crystal of the high nematic type birefringence with positive dielectric anisotropy and high chemical and thermal stability. The investigation reported here is concerned with the determination of the Kerr constant and the third order nonlinearity of this nematic liquid crystal. This effect is mainly due to the anisotropy of polarizability of molecules ordered by an applied electric field. Kerr established that the magnitude of this effect is proportional to the square of applied field strength (E^2) [6–9].

Address correspondence to M. H. Majles Ara, Photonics Laboratory, Physics Department, Tarbiat Moallem University, 49 Mofateh Ave., 1571914911 Tehran, Iran. Tel.: +98 (21) 88309294; Fax: +98 (21) 88309294; E-mail: majlesara@gmail.com

2. Theory

The electric birefringence of the medium is defined as a difference between the refractive indices for light polarized parallel ($n_{\|}$) and perpendicular ($n_{\perp}$) to the orienting field direction, and is related to optical retardation or optical phase difference,

$$\delta = 2\pi lBE^2 = \frac{2\pi l(n_{\|} - n_{\perp})}{\lambda}, \tag{1}$$

where λ is the wavelength of the light, l is the optical pathlength, and B is called the "Kerr constant" of the substance, and is used to denote the magnitude of the Kerr effect. The electrically induced birefringence, Δn, may also be conveniently defined by (Kerr law):

$$\Delta n = \lambda BE^2. \tag{2}$$

For the nulled intensity method of measuring Kerr effect, which involves the nulling of an optical response resulting from the application of an external electric field across the Kerr cell [10], the rotation of the plane of polarization, α, is related to the phase difference, δ, by

$$\alpha = \frac{\delta}{4}. \tag{3}$$

Eliminating δ from Eqs. (3) and (4) and rearranging gives:

$$\alpha = \frac{\pi lBE^2}{2}. \tag{4}$$

If the Kerr law is observed, a plot of α versus thesquare of the applied electric field E^2 also should give astraight line passing through the origin with a gradient of $\pi LB/2$, from which the Kerr constant B may be determined.

The theory of Landau-De Gennes [11] has been used to describe the pre-transitional behavior in the isotropic phase of liquid crystals. According to this model, the Kerr constant in the isotropic phase is given by

$$B = \frac{\varepsilon_0 \Delta n_0 \Delta\varepsilon_0}{4\alpha\lambda\sqrt{\varepsilon}(T - T^*)}, \tag{5}$$

where α is the temperature independent coefficient; T^* isthe second-order pre-transitional temperature which is an extrapolated temperature just below the isotropic-nematic phase transition; $\Delta\varepsilon_0$ is the low frequency dielectric anisotropyin the completely ordered phase. From the aboveequation, there is a reciprocal relationship between the Kerr constant B, and the temperature, i.e., Δn is proportional to $(T - T^*)^{-1}$ [12,13].

3. Experiments

A nematic mixture of 9CHBT was synthesized in the Institute of Chemistry of the Military Technical Academy, Warsaw, Poland, and used as the host. The chemical

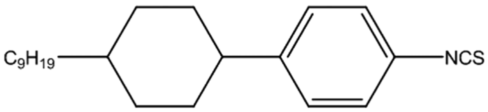

Figure 1. Chemical structure of the nematic liquid crystal (9CHBT).

structure of this liquid crystal is shown in Figure 1. The liquid crystal was poured at room temperature into a 10 mm quartz cell having only a negligible degree of absorbance in the visible range.

The stainless steel electrodes were inserted into the Kerr cell, leaving an active column of liquid 2 mm× 2 mm× 10 mm. A Teflon spacer was used to provide insulation between the electrodes and to maintain an electrode gap of 2 mm. The lower-part of the Kerr cell is fitted into a thermo-stated metal jacket, which was cut away to allow passage of the light beam. The temperatures were determined with a copper constantan thermocouple.

An experimental setup is used to measure the electro-optical properties of this liquid crystal as shown in Figure 2. A He-Ne laser emitting at a wavelength of 632.8 nm with a power of 5 mW was used as a probe beam. For the electro-optical investigation in the isotropic phase, a sample holder similar to that described by O'Konski and Haltner [14] was constructed.

The detection of the Kerr signal was achieved using a photo detector (Labmaster). The optical signal from the photomultiplier was displayed using a digital storage oscilloscope (Tektronix 300 MHz, model TDS3032B) and a personal computer. The polarizer and analyzer were Glan–Thompson double refraction type prisms of commercial origin and adjusted such that they crossed each other, making an angle 45° with respect to the applied AC field (1 kHz).

The quarter wave plate used in these experiments was micacut specifically for use at 632.8 nm and mounted between glassdiscs. The electric field is generated by means of a high-voltage power supply that was applied, as a short duration rectangular shaped pulse from a pulse generator, to the electrodes of the Kerr cell.

4. Results and Discussion

All measurements of the Kerr constant were made using the nulled intensity method. A parallel, plane-polarized beam of monochromatic light is passed through the Kerr cell such that the plane of polarization of the light is at an angle of 145° relative to the direction of the applied electric field. In the presence of an electric field the light

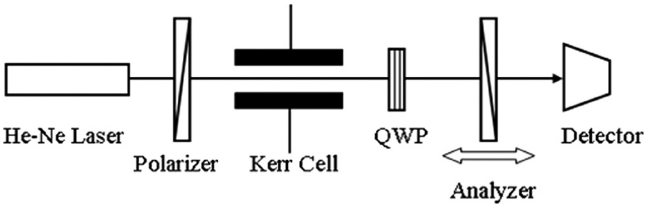

Figure 2. Electro-optical Kerr effect setup for measuring the Kerr constant (QWP: quarter-wave plate, laser wavelength = 632.8 nm).

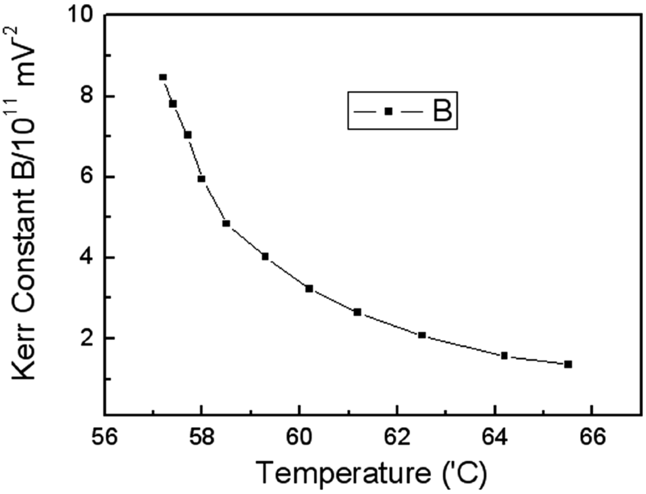

Figure 3. Temperature dependence of Kerr constant for 9CHBT.

leaving the cell is generally elliptically polarized. After passing through an oriented quarter-wave retarder the light can be extinguished by the analyzer.

The Kerr constant, B, of a material, at a given temperature may be obtained from the gradient of a graph of induced birefringence, Δn, plotted against the square of the applied electric field (i.e., $\Delta n = \lambda BE^2$). In the sample examined the electrically induced birefringence was found to be directly proportional to the square of the applied electric field (E^2), as it is positive ($\Delta n > 0$). The dependence of the Kerr constant, B, and the inverse of Kerr constant, B^{-1}, with temperature for 9CHBT in the isotropic phase are shown in Figures (3) and (4) respectively. This data show that the birefringence depends strongly on temperature.The high Kerr constant of this material in isotropic

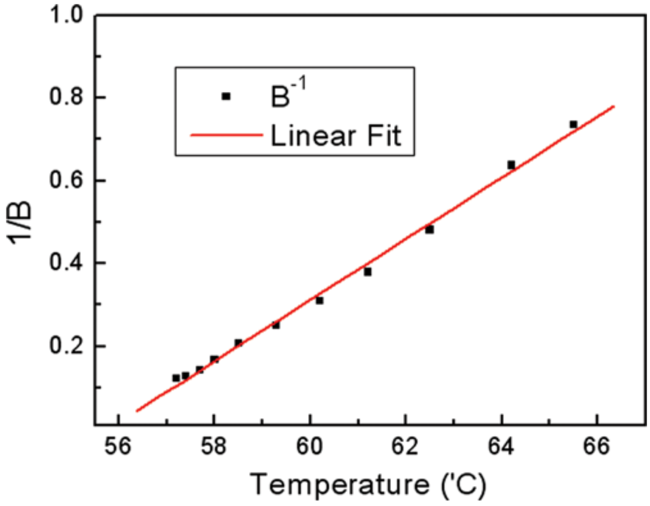

Figure 4. Temperature dependence of B^{-1} for the 9CHBT obtained using the pulsed a.c. field method. (Figure appears in color online.)

phase is due to the high polarizability tolane-based structure and polar head group (−NCS), which conducts to high optical anisotropy. However, the existence of lateral sulfurine substituent in this compound is very important and necessary in the nematic formation.

The pre-transitional effect exhibited by liquid crystal materials has been found to influence the isotropic value close to the nematic–isotropic transition temperature. In the pretransitional region the residual short-range nematic orderingpersists well in the isotropic phase. According to the Landau–De Gennes model, the Kerr constant in the isotropic phase is given by $\Delta n \propto (T - T^{*})^{-\gamma}$. The second-order pre-transitional temperature T^{*}, which is slightly less than T_C, can be obtained by a linear extrapolation of the Kerr constant (B^{-1}) vs. temperature. For the samples studied the inverse of the Kerr constant varies linearly with temperature, i.e., $\gamma \approx 1$, as predicted by the Maier–Saupe mean-field theory for liquid crystals [15]. However, close to the T_C, a small deviation from the mean-field theory is observed [16]. In this liquid crystal, the second-order phase-transition temperature (T^{*}) is calculated about 56 degree centigrade.

5. Conclusion

The temperature dependence of the Kerr constant was obtained for 9CHBT. The sample had a positive Kerr constant which increased with decreasing of temperature. The second-order phase-transition temperature T^{*} were also determined for this compound. For the sample studied, the dependence of the Kerr constanton $(T-T^{*})^{-1}$ is found to be in good agreement with the prediction of the Landau-de Gennes model.

References

[1] MajlesAra, M. H., Mousavi, S. H., Salmani, S., & Koushki, E. (2008). *J. Mol. Liq.*, *140*, 21.

[2] MajlesAra, M. H., Mousavi, S. H., Koushki, E., & Salmani, S. (2008). *J. Mol. Liq.*, *142*, 29.

[3] Ghanadzadeh, A., & Beevers, M. S. (2004). *J. Mol. Liq.*, *112*, 141.

[4] Philip, J., & Prasada Rao, T. A. (1992). *J. Phys. D: Appl. Phys.*, *25*, 1231.

[5] Philip, J., & Prasada Rao, T. A. (1991). *J. Mol. Liq.*, *50*, 215.

[6] Kerr, J. (1875). *Phil. Mag.*, *50*, 337.

[7] Sinha, A., Prasada Rao, T. A., Murthy, V. R. K., & Dabrowski, R. (2000). *Liq. Cryst.*, *27*, 191.

[8] Coles, H. J., & Jennings, B. R. (1976). *Mol. Phys.*, *31*, 571.

[9] Ghanadzadeh, A., & Beevers, M. S. (2003). *J. Mol. Liq.*, *107*, 77.

[10] Beevers, M. S., & Khanarian, G. (1979). *Aus. J. Chem.*, *3*, 263.

[11] De Gennes, P. G., & Prost, J. (1995). *The Physics of Liquid Crystals*, 2nd ed., Oxcford University Press. New York.

[12] Khoshsima, H., Ghanadzadeh, A., Tajalli, H., & Dabrowski, R. (2006). *J. Mol. Liq.*, *129*, 169.

[13] Tajali, H., Ghanadzadeh, A., Khoshsima, H., & Zhalefar, P. (2008). *Opto-Eelectronics Rev.*, *16*, 386.

[14] O'Konski, C. T., & Haltner, A. J. (1956). *J. Am. Chem. Soc.*, *78*, 3604.

[15] de Gennes, P. G. (1971). *Mol. Cryst. Liq. Cryst.*, *12*, 193.

[16] Malraison, B., Poggi, Y., & Filippini, J. C. (1979). *Solid State Commun.*, *31*, 843.