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Study of Temperature effect on refractive indices for(5PCH) liquid crystals

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Abstract : Liquid crystals are state of substance possesses characteristics between traditional liquid and crystallization. For instance, perhaps liquid crystal away similar to the crystals. There are different types of crystal in the liquid phase. In this study, used nematic liquid crystals type(5PCH) and wavelength (632.8nm) for find the temperature effect on optical properties .This study shows the direct proportionality between the temperature and the ordinary refractive index (n_o), from one side and the indirect proportionality between the temperature with the extraordinary refractive indices (n_e),optical anisotropy (birefringence Δn).
Keywords : Liquid Crystals, Optical Properties, Birefringence.

1. Introduction

Generally, there are three basic states of matter, solid, liquid, and gaseous states. However, this is not true. Now, there exists other new states of matter in nature, such as the liquid crystal state, plasma state, amorphous solid, superconductor, neutron state, nanocrystal, 2D material etc.[1-7] Liquid crystals are wonderful materials that exhibit intermediate state between liquid and solid (crystal). They possess some typical properties of liquid as well as solid states. Crystalline materials or solids are materials characterized by strong positional order and orientational order. The positional and orientational orders have low values for liquids. The liquid crystal phase is amesophase, which occurs in the transition from solid to liquid (isotropic). As a result, positional order and orientational order of liquid crystals have values between solids and liquids[8,9]. There are three distinct types of liquid crystals accordance with physical parameters controlling the existence of the liquid crystalline in phases: thermotropic, lyotropic and polymeric[10-16]. The most widely used liquid crystals, and extensively studied are thermotropic liquid crystals[17]. Their liquid crystalline phases are controlled by temperature. The three main classes of thermotropic liquid crystals are: nematic, smectic and cholesteric[18].

Liquid crystals are found to be birefringent, due to their anisotropic nature. That is, they demonstrate double refraction (having two indices of refraction). Light polarized parallel to the director has a different index of refraction (that is to say it travels at a different velocity) than light polarized perpendicular to the director.

Thus, when light enters a birefringent material, such as a nematic liquid crystal sample, the process is modeled in terms of the light being broken up into the fast (called the ordinary ray) and slow (called the extraordinary ray) components. Because the two components travel at different velocities, the waves get out of phase. When the rays are recombined as they exit the birefringent material, the polarization state will be changed because of this phase difference[19].

The study of liquid crystals began in 1888 by Australian Botanist F. Reinitzer[1]. Liquid crystal materials are unique in their properties and uses. As research into this field continues and as new applications are developed, liquid crystals will play an important role in modern technology[20-24].

2. Theoretical background

When the laser beam is polarized at 45° to the director of the crystal, it will pass through the sample and splits itself in anordinary ray and an "extraordinary ray". Because of LC birefringence nature, the two beams will leave the cell in two different directions. By measuring the deviation angle of these two rays with respect to the situation in which the UCF liquid crystal is absent it will be easy to retrieve the two refractive indices of the liquid crystal by means of the refraction laws.

The point where reference ray R_{ref} (see Fig.1),emerges from the empty cell, encounters the observation plane π , which is perpendicular to R_{ref} ,is determined experimentally by translating the detector along the X axis by means of the millimetric translator until the peak of the spot is exactly in the center of the detector. After that the cell is filled with the liquid crystal and the two refracted beams R_O and R_e will appear (see Fig.1).The detector is now translated in order to bring the center of the peak corresponding to the ordinary beam. The displacement X_o from the reference point O is recorded.This procedure is 1 repeated for extraordinary light spot, recording its distance X_e from point O. The accuracy on the measurement of both X_o and X_e is estimated to be (1.6 mm). From the geometrical considerations (see Fig. 1) we can calculate the two refractive indices by the following formulas[25,26].

$$n_o = \frac{\sin(\theta + \theta_o)}{\sin(\theta)} \quad (1)$$

$$n_e = \frac{\sin(\theta + \theta_e)}{\sin(\theta)} \quad (2)$$

Where θ is the angle of the wedge formed by the two glass plates, θ_o and θ_e are the angles formed by the beams R_o and R_e with respect to the beam R_{ref} emerging from the wedge when the UCF is absent (Fig.1).Note that the lateral shifts of the beams R_o and R_e with respect to R_{ref} at the output of plate B are smaller. These shifts are much smaller than experimental accuracy on the measurements of X_o and X_e and, thus, can be neglected here. From elementary geometry, it follows that:

$$\tan\theta_o = \frac{x_o}{L} \quad (3)$$

$$\tan\theta_e = \frac{x_e}{L} \quad (4)$$

$$\therefore\ \theta_o = \tan^{-1}\left(\frac{x_o}{L}\right) \quad (5)$$

$$\theta_e = \tan^{-1}\left(\frac{x_e}{L}\right) \quad (6)$$

So that

$$n_o = \frac{\sin\left(\theta + \tan^{-1}\left(\frac{x_o}{L}\right)\right)}{\sin(\theta)} \quad (7)$$

$$n_e = \frac{\sin\left(\theta + \tan^{-1}\left(\frac{x_e}{L}\right)\right)}{\sin(\theta)} \quad (8)$$

And the average refractive index < n > is[27]:

$$< n > = \frac{(2n_o + n_e)}{3} \quad (9)$$

For find the optical anisotropy use the equation[28]:

$$\Delta n = n_e - n_o \quad (10)$$

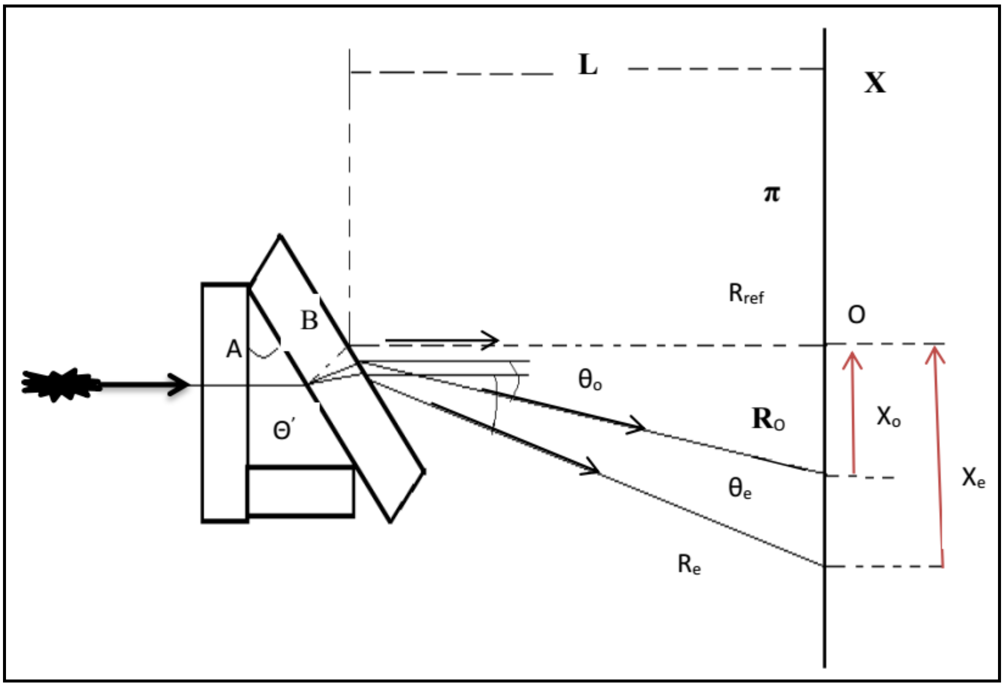

Figure 1: Liquid crystal wedged cell, the He – Ne laser beam encounters first the substrate A. When the cell is empty only ray R_{ref} emerges. When the wedge is filled the ordinary and extraordinary ray R_o and R_e appear.The angles formed by R_o and R_e with R_{ref} are called θ_o, θ_e)[25].

3. Experimental Part

To study the temperature effect on the refractive indices, put the LC cell in hot stage (Figure 2), the hot stage is controlled by thermometer and timer.

The ordinary and the extraordinary spots are shown as detected by the detector. Two different situation are presented in Figure 2, so that it is easy to find the position of the two beam maxima. The point where the ray reference (R_{ref})emerge from the empty wedge, the observation plane π , which perpendicular to(R_{ref}). This point is determined experimentally by moving the detector along the X – axis of the spot is exactly in the center of the detector. After that the cell is filled with the (5PCH) a the two refract beams (R_o) and (R_e) will appear. (θ') is the angle of the wedge formed by the two faces of the glass plates andθ_o, θ_e are the angles formed by the two beams (R_o)and(R_e)with respect to the beam (R_{ref}) (Figure 1).

The equations 7 and 8 are used to calculate the ordinary refractive indices (n_o) and (n_e) extraordinary refractive indices.

Each measurement has been repeated many times by changing the temperature of the sample in order to reconstruct the temperature dependence of the refractive indices, the time interval between two runs was (20 min), in order to reach a good stability.

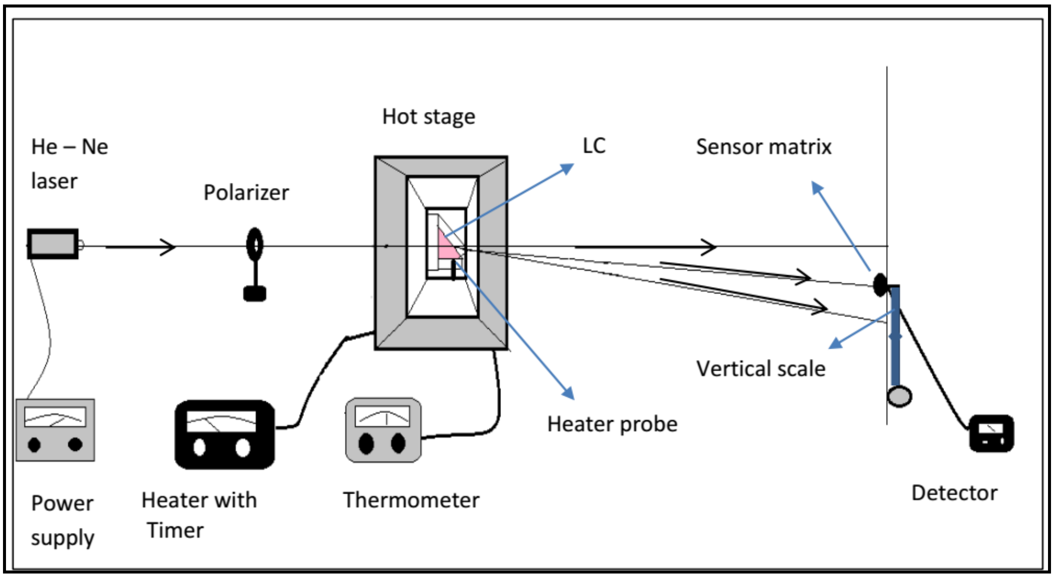

Figure 2: The thermo–optic system set up.

4. Result and discussion

4.1 The ordinary refractive index (n_o)

According equation 7, can be found the ordinary refractive indices, these data is representation in Figure 3 for liquid crystal (5PCH).

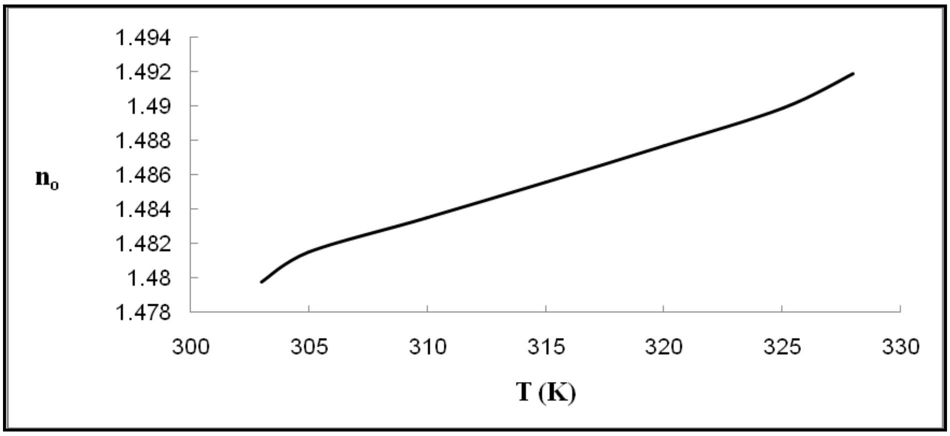

Figure 3: Temperature – dependent ordinary refractive index (n_o) for liquid crystal (5PCH), at wave length (632.8 nm).

The ordinary refractive index increase with increasing the temperature. To explain this behavior, the random motion of the rod like molecules increases when the temperature increase, therefore, the ordinary beam velocity decrease.

4.2 The extraordinary refractive index (n_e)

From applying equation 8, are can notice that the extraordinary refractive index (n_e) decreases with increasing the temperature Figure 4 for the liquid crystal (5PCH).

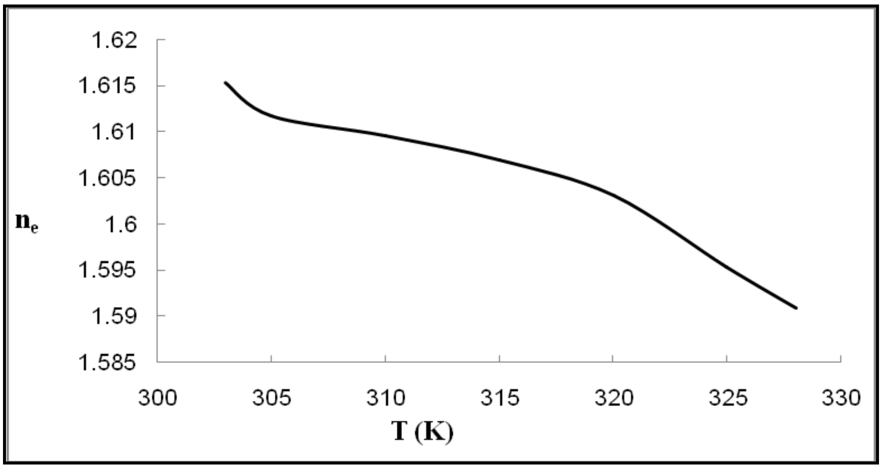

Figure 4:Temperature – dependent extraordinary refractive index (n_e) for liquid crystal(5PCH) at wavelength (632.8 nm).

According to the equation ($n_e = c/v_e$) , the extraordinary velocity increases with increasing the temperature causing reducing the value of the (n_e).

4. 3 The average refractive index < n >

Usingequation 9,and the ordinary and the extraordinary refractive index values, the average refractive index values can be calculated, these data are represented in Figure 5 for liquid crystal (5PCH).

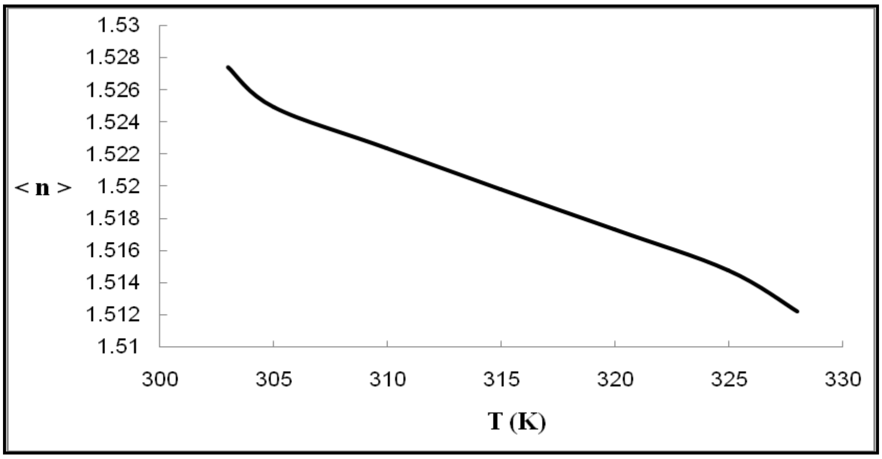

Figure 5: Temperature – dependent on average refractive index for liquid crystal (5PCH) at wavelength (632.8 nm).

This figure showsthat; the average refractive index is decrease direct as the temperature increase. Also from above figure , are can predict the value of the refractive index in the liquid phase .

4.4 The birefringence (Δn)

According the values of extraordinary refractive index (n_e) and ordinary refractive index (n_o) in equation 10, one can find the optical anisotropy(birefringence) values at different temperatures value, the data is presented in Figure 6 for the liquid crystal (5PCH).

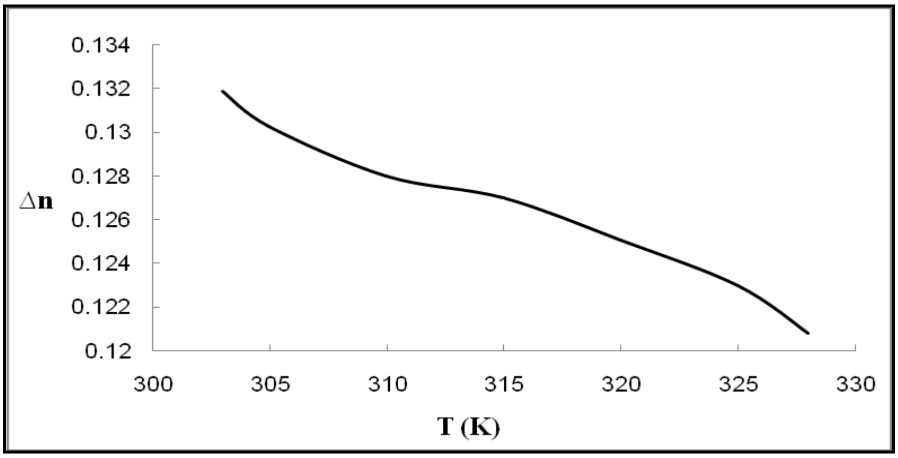

Figure 6: Temperature – dependent on birefringence (∆n) for liquid crystal (5PCH), at wavelength (632.8 nm).

The above figure which show that birefringence (∆n) decreases with increasing the temperature value, and because of this sensitivity, the liquid crystals used as thermal sensors.

Conclusions:

The studyfinds the ordinary refractive index (n_o) increased when the temperature increased, but the extraordinary refractive index (n_e) and birefringence (∆n) are decreased as the temperature is increased. Also find the average refractive index < n > decreased linearly when the temperature increased.

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