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Thermo-Optical And Phase Transitional Study Of Dielectric Material, A Liquid Crystal Mixture

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Abstract

We know that liquid crystal is of immense importance now-a-days. In the liquid crystal mixture, we have studied thermo optical properties as a function of temperature. The main feature of optical phenomena in liquid crystal causes due to thermo optical and phase transition procedure. Thermal effect is similar as in other materials. While the phase transition is the characteristic property which we find in liquid crystalline phases. The nonlinearity occurs due the reorientation effect in case of nematic phase that results to many other effects also which are not observed in any other type of nonlinearity. The nonlinearity depends on polarization of light within a wide range. It is independent of wavelength of light. It has slow response time which could be fasten by special optimization of the system.

Keywords: Thermal optical, Phase transition, dielectric material, Liquid crystal

Introduction: In liquid crystal, order is very important which is affected by number of microscopic properties like magnetic susceptibility, dielectric constant, refractive index and viscosity etc. When the light is allowed to pass through parallel to the director, the optical isotropy is found whereas when the light is allowed to pass through perpendicular to the director, the optical birefringence is observed. Different direction of polarized rays shows different refractive index. Many experimental setups show the anisotropy of nematic which arises due to the tendency of the rod like molecules in the fluid to align their long axis which are parallel to the director. Here, the director is shown by the symbol $\hat{n}$; the rod-shaped molecules are represented by the short lines (Goldmachr et al 1967, Heilmeier 1993, Oton et al 2020 and Shahina et al 2018)**.**

The director lies along the Z-axis of fixed rectangular coordinate system. When all the molecules are completely aligned with $\hat{n}$ for all permissible value of angle φ = 0 and $\langle Cos^2\theta\rangle$ = 1. On the other hand, when the molecules are randomly distributed in all possible directions, all the values of φ are equally likely and $\langle Cos^2\theta\rangle$ = ½.

In general, in any order disorder problem, the order parameter is always considered as one in case of perfectly ordered phase and vanishes for completely disordered phase. Examination of the average data as given above indicates that the proper order data for the nematic sample is given as follows:

$$\langle P_2\rangle = \tfrac{1}{2}(3Cos^2\theta - 1) \qquad \ldots\ldots\ldots\ldots\ldots$$

(1)

Obviously, $\langle P_2\rangle$ = 0 for the disorder isotropic phase and $\langle P_2\rangle$ = 1 for totally ordered nematic phase. The notation $\langle P_2\rangle$ is used for the order parameter because we identify the particular combination in the equation (1) to be the second order Legendre polynomial, given as under,

$$P_2\,(Cos\,\theta) = \tfrac{1}{2}(3Cos^2\theta - 1)$$

In some cases, the notation S is used in place of $\langle P_2\rangle$. The values of $\langle P_2\rangle$ are between 0 and 1 which describes degrees of ordering intermediate between totally isotropic and ordered. It is the task of order-disorder to determine the temperature dependence of $\langle P_2\rangle$ (Bahadur 1984, Chandrashekhar et al 1971, Heilmeier 1993, Kieser et al 2001, Nagham et al 2021, Sato 1999, Sutkowski et al 2000 and Zhao et al 2019).

Birefringence Behaviour: It has been observed that liquid crystals are birefringent. It is because of their anisotropic nature. It means they show double refraction i.e. having two refractive indices. The polarized light parallel to the director has different refractive indices while the polarized light perpendicular to the director not showing this behavior.

It is by the difference of refractive indices for the ordinary and extraordinary rays. As we know the refractive index is the ratio of the light speed in vacuum to that in the material. In present case, the refractive index for the velocities of a wave travelling parallel to the director is given by $n_e = \frac{c}{v_{\text{II}}}$ whereas the refractive index for the velocities of a wave travelling perpendicular to the director is given by $n_o = \frac{c}{v_\perp}$. The maximum value for the birefringence n = n_e - n_o. The condition $n_e > n_o$ specifies a positive uniaxial material, hence that nematic liquid crystals lie in

this category. For complex nematic crystals, the value of n_o is approximately 1.5 and the maximum difference of refractive indices (i.e., n) ranges between 0.05 to 0.5.

The birefringence of liquid crystal mixture plays a significant role in twisted nematic (TN) mode. This parameter is much sensitive in multiplexed display units where it should be matched with thickness of the liquid crystal layer by the following relation:

$$d. \Delta n = 2\lambda$$

where λ is the wavelength of visible light in the range 0.4 to 0.7μm, d is the cell spacing.

The relation d.Δn < 2λ leads to the color however the relation d.Δn > 2λ results to the narrow viewing angle mainly in multiplexed displays. Researcher have made many attempts to use dielectric material having low birefringence and use the relation $d.\Delta n = \sqrt{(3\lambda/4)}$ for high level multiplexed display units. Normally for direct drive displays, matching is not very critically assured and relation d. Δn ≥ 2λ.

Low birefringence materials having high positive dielectric anisotropy and order parameter are required for dye phase change type display unit (Cole et al 1978 and Magham et al 2021).

Wavelength Dependent of Refractive Index: In normal dispersion, "The refractive index increases as the wavelength of the light decreases." It means the slope of the curve is greater at shorter wavelengths. Also, we can say that the dispersion increases as the wavelength of the light used decreases. That's the region for the violet end of the spectrum by prism is spread out on a larger scale than the red end of the spectrum by the prism (Billard 1972, Landau et al 1958, Nagham et al 2021and Singh et al 2004).

Determination of Refractive Index of dielectric material: In the present paper, we are reporting the results of the measurements taken of extraordinary refractive index (n_e), ordinary refractive index (n_o) in an isotropic phase of a liquid crystal sample E48 in terms of temperature by using Abbe refract meter by using a monochromatic light source. From the experimental data, we have calculated different useful parameters e.g. birefringence, normalized polarizabilities (α_e/α, α_o/α) and order parameter S (Billard 1972, Kieser et al 2001, Landau et al 1958, Nagham et al 2021, Shahina et al 2018 and Singh et al 2004).

Results and Discussion: Vuks gave a semi-empirical relation that relates the refractive indices and the molecular polarizabilities in case of anisotropic materials.

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$$\frac{n^2_{e,o}-1}{<n^2>+2} = \frac{4\pi}{3}N\alpha_{e,o}$$ ……………

(2)

Where n_o and n_e are the refractive indices for ordinary and extra ordinary ray respectively, α_{eo} are the corresponding molecular polarizabilities and N is the number of molecules per unit volume, and $<n^2>$ is given by the following relation:

$$< n^2 >= \frac{n_e^2+2n_o^2}{3}$$

……………(3)

In the above equation (2), n_e and n_o are coupled together such that the relation between the refractive indices and the corresponding molecular polarizabilities is not evident. To reveal this relationship, we should decouple n_e from n_o by solving equation (2). Substituting the value of $<n^2>$ from equation (3) in equation (2) and separating n_e and n_0, we have

$$n_e = (1 + \frac{4\pi N\alpha_e}{1-\frac{4\pi}{3}N<\alpha>})^{1/2}$$ ……………(4)

$$n_0 = (1 + \frac{4\pi N\alpha_e}{1-\frac{4\pi}{3}N<\alpha>})^{1/2}$$ ..……………(5)

Where $<\alpha>$ is average polarizability of the liquid crystal molecules which is given by the following relation:

$$< \alpha >= \frac{\alpha_e + 2\alpha_0}{3}$$

The birefringence of the liquid crystal sample is given by $\Delta n = n_e - n_o$. Now by using above equation's we have the following relation:

$$\Delta n \approx \frac{\sqrt{2}\pi NS(y_e-y_0)}{1-\frac{4}{3}\pi N<\alpha>}$$ …………(6)

However, the average refractive index $< n >$ of liquid crystal is defined as

$$< n >= \frac{n_e+2n_0}{3}$$ ….…..…… (7)

On putting the values of the n_e and n_o in above equation, we drive

$$< n >= \frac{3\sqrt{2}}{4} + \frac{\sqrt{2}\pi N<\alpha>}{1-\frac{4}{3}\pi N<\alpha>}$$ …………(8)

Putting the values of Δn from equation (6) and that of $< n >$ from equation (7) in equation (4) and (5), then the refractive indices have the following simple expression

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$$n_e = <n> + \frac{2}{3}\Delta n$$

………………(9)

$$n_0 = <n> - \frac{1}{3}\Delta n$$

………………(10)

Order Parameter: The calculation of microscopic order parameter in the liquid crystal sample by optical birefringence's is done by using Vuks direct extrapolation method. The refractive indices n_e and n_o have been analyzed by the method of Haller and Horn, this method uses Vuks relation.

$$S\left(\frac{\delta\alpha}{\alpha}\right) = \frac{3(n_e{}^2 - n_o{}^2)}{(n_e{}^2 + 2n_o{}^2 - 3)}$$

………….(11)

Here, $\delta\alpha(= \alpha_e - \alpha_1)$ is the anisotropy of polarizability and α is mean molecular polarizability. The logarithmic of the R.H.S. of above equation is plotted against $\log(T/T_C)$ and the straight line so obtained is extrapolated to $T = 0^0$ K. The intercept at $T = 0^0$ K where $S = 1$ led to the scaling factor δα/α in equation (11), we can obtain the value of order parameter at various temperatures. Figure 1 and 2 respectively after clearing point the birefringence becomes zero. The ordinary refractive indices (n_o) increases slightly while the extraordinary refractive index decreases sharply with increases in temperature the SmA to isotropic point i.e. at 104°C refractive index values changes and becomes almost constant. It is in accordance with the results obtained by others on different samples. The reason for this kind of behavior is due to birefringent nature of liquid crystal phase. As we increase the temperature, the molecular ordering decreases and this birefringent nature becomes less significant and after the isotropic temperature, the □n vanished and the sample behave like any ordinary organic liquid.
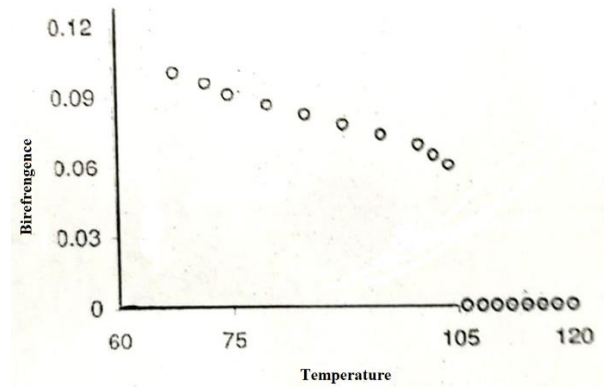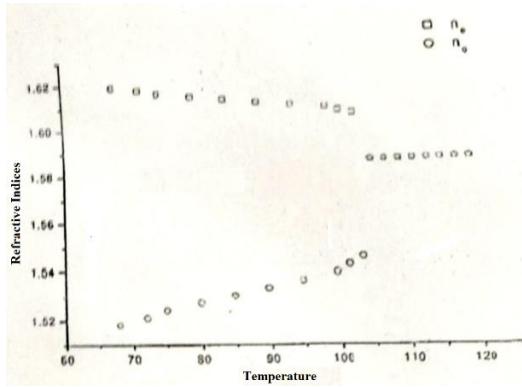
Figure 1: Variation of Refractive indices with temperature

Figure 2: Variation of Birefringence with temperature

To calculate the order parameter, we have used birefringence values of the sample and Vuks approach. The variation of microscopic order parameter with temperature is shown in Figure 3. It is maximum in crystalline phase and as we increase the temperature the order parameter (S) decreases and becomes zero after the SmA to isotropic phase transition temperature i.e. the molecular order in the sample gets extinguished.
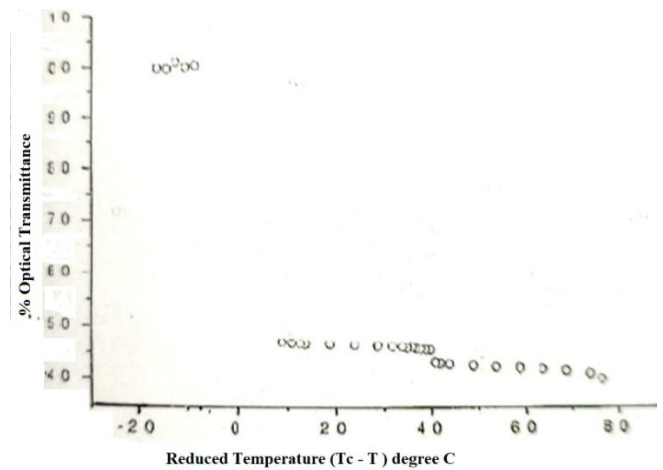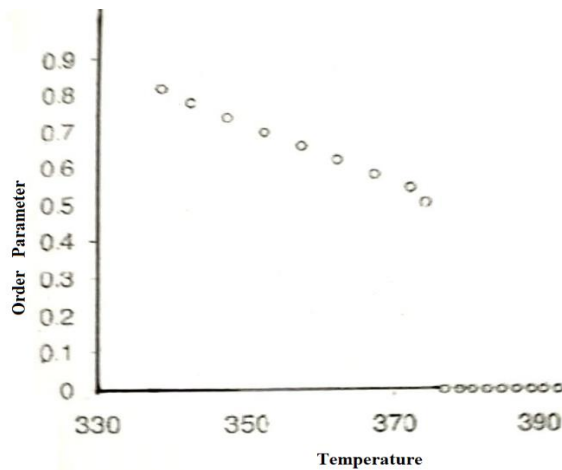

Figure 3: Variation of order parameter with temperature

Figure 4: Variation of % optical transmittance with reduced temperature

Figure 4 indicates the variation of % optical transmittance with the reduced temperature (T_C-T). Initially the optical transmittance rises slowly with temperature and when the sample became isotropic in phase, the optical transmittance reaches to its peak value i.e. nearly 92% and after that it becomes constant with respect to increment in temperature.

Conclusion: The order parameter decreases as we move from crystalline to isotropic phase by increasing temperature. The variation of order parameter 0.788 to 0.444 in smectic phase while

its value is zero in isotropic phase. However, some liquid crystal phases are relatively recent discoveries and are more rarely encountered. Although such novel liquid crystal phases can usually be identified by optical microscopy accordingly, just as the field of liquid crystals draws on the expertise of scientists from many disciplines, the identification of mesophases requires a wide range of techniques to identify and classify fully the different structure of the various mesophases. As the identification techniques become more sophisticated, more novel mesophases will be discovered, possibly paving the way for the development of more technological applications.

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