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Temperature and concentration dependence of refractive index of cholesteric liquid crystal solution

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ABSTRACT

Average refractive indices of Cholesteric liquid crystal (Cholesteryl pelargonate: CP) dissolved in a soluble solvent were measured at various temperatures and concentrations. Multi-wavelength (visible range) refractometer made using hollow prism is used in the measurement. Due to variation in extra-ordinary and ordinary refractive index average refractive index changes with temperature for various concentrations of the solution. The changes in average refractive index were investigated for three wavelengths: 404 nm, 546 nm and 578 nm. Results so obtained are presented in this paper and are in accordance with claim by Hecht in his book.

KEYWORDS

Average refractive index;
Cholesteric liquid crystal;
Multi-wavelength refractometer;
Extra-ordinary and ordinary refractive index.

INTRODUCTION

Cholesteric liquid crystals (CLC) are one-dimensional photonic crystals with refractive index that is regularly modulated along the helix axis because of the director changing in helical manner from one layer to the other. This also cuts off propagation of light for a particular range of wavelength[1].

CLCs[2, 3] are mesomorphic phase in which molecules are parallel to each other within the plane of a layer. It is a type of liquid crystal with a helical structure and which is therefore chiral. They organize in layers with no positional ordering within layers, but a director axis which varies with layers. The variation of the director axis tends to be periodic in nature. CLCs are temperature sensitive and have colour changing ability at various temperatures. CLCs locally behave like uniaxial anisotropic media. The optical birefringence[4, 5], defined by $\Delta n = n_e - n_o$, can be easily controlled through the variation of the temperature. In the above, n_e represents the principal extraordinary refractive index, hence corresponding to a light beam polarization parallel to the optical axis, while n_o denotes the ordinary refractive index, associated with a light beam polarization orthogonal to the optical axis. Refractive index[6-8] is one of the most important optical properties of a medium. It plays key role in many areas of materials science especially in thin film technology and fiber optics. The average refractive index <n> of liquid crystals (LC) is of fundamental interest for liquid crystal electro-optical devices. It is a continuous function of wavelength and varies with temperature and concentration.

EXPERIMENTAL METHOD

The refractive indices of CLC solution were investigated using multi-wavelength refractometer. This refractometer is designed using a hollow prism and an ordinary spectrometer[9]. The sample is prepared by dissolving required quantity of CP ($C_{36}H_{62}O_2$) in toluene to get one to six molar solutions. Each solution is stirred continuously and then heated to form isotropic solution. The required solution is then filled in the hollow prism for measurement. Minimum deviation angles for various colours of mercury source are measured[10, 11]. Refractive indices are calculated using the Formula

$$\mu = \frac{\sin\left(\frac{A+\partial m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Refractive index measurements correct up to four and five decimal places are common using this technique with good control of the sample temperature. To identify ordinary and extra ordinary spectrum polarizer was used. Temperature variation is obtained using indigenously designed heating coil and thermometer. The same procedure is repeated for different concentrations of the mixture. For each concentration readings are taken by varying the temperature for different concentration solution.

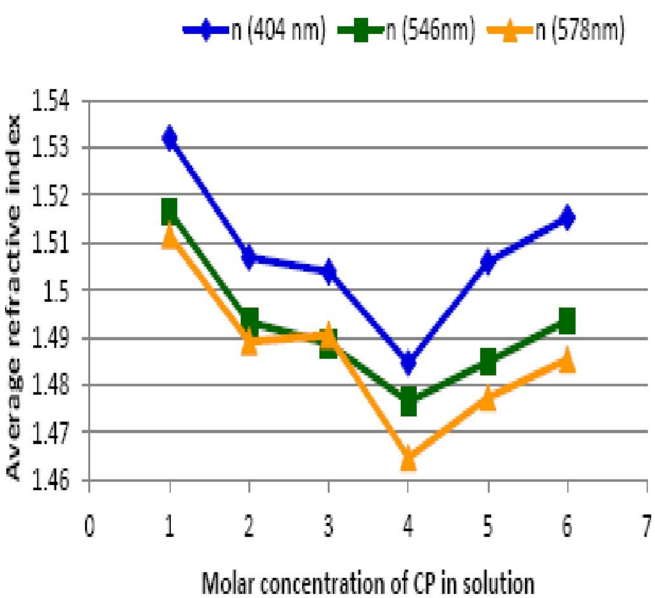


Figure 1 : variation in (*n*) for three different wavelengths (colour) with concentration of the solution.

TABLE 1 : Effect of variation in concentration obtained at room temperature of 30⁰C

Colour	Wavelength (nm)	n_e	n_o	(*n*)
For one molar (1M) solution at room temperature:-				
Violet	404	1.54408	1.5259	1.5320
Green	546	1.5299	1.5100	1.5166
Yellow	578	1.5219	1.5065	1.5116
For two molar (2M) solution at room temperature:-				
Violet	404	1.51892	1.50084	1.5069
Green	546	1.50865	1.48551	1.4932
Yellow	578	1.507	1.48014	1.4891
For three molar (3M) solution at room temperature:-				
Violet	404	1.515794	1.498008	1.5039
Green	546	1.507419	1.47936	1.4887
Yellow	578	1.506649	1.482586	1.4906
For Four molar (4M) solution at room temperature:-				
Violet	404	1.50251	1.47568	1.4846
Green	546	1.49685	1.46625	1.4765
Yellow	578	1.48658	1.45382	1.4647
For five molar (5M) solution at room temperature:-				
Violet	404	1.51788	1.499837	1.5059
Green	546	1.501326	1.476618	1.4849
Yellow	578	1.4977	1.467064	1.4773
For six molar (6M) solution at room temperature:-				
Violet	404	1.52343	1.5113	1.5153
Green	546	1.51186	1.48453	1.4936
Yellow	578	1.50321	1.47654	1.4854

***'M' stands for molar concentration**

OBSERVATIONS

First part of the experiment deals with measurements for various concentration of the solution. TABLE 1 shows how average refractive index[12] changes with the concentration of the CP in the solution. Average refractive indices (**(*n*)**) are obtained from the Vuks equation $(n)=(n_e+2n_0)/3$. Figure 1 shows the variation in average refractive index for three different wavelengths (colour) with concentration of the solution.

TABLE 2 to TABLE 6 show how extra ordinary, ordinary and average refractive indices change with the temperature for various concentration. Variation in the refractive indices is obtained for three different wavelengths. Figure 2 to Figure 6 show graphical representation of the variation.

TABLE 2 : Shows variation of n_e, n_o and (n) with the temperature for 1M concentrations.

Temp. (°C)	Violet (404nm)			Green (546nm)			Yellow (578nm)		
	n_e	n_o	<n>	n_e	n_o	<n>	n_e	n_o	<n>
70	1.5156	1.4726	1.4869	1.5037	1.4577	1.4730	1.501	1.4547	1.4701
60	1.5151	1.4767	1.4895	1.5061	1.4705	1.4824	1.5046	1.4632	1.477
50	1.5186	1.4861	1.4969	1.5044	1.4714	1.4824	1.5025	1.4684	1.4798
40	1.5188	1.4916	1.5007	1.5033	1.4775	1.4861	1.5018	1.4735	1.4829
30	1.5188	1.5027	1.5081	1.5013	1.4853	1.4906	1.5084	1.4834	1.4917

TABLE 3 : Shows variation of n_e, n_o and (n) with the temperature for 2M concentrations.

Temp. (°C)	Violet (404nm)			Green (546nm)			Yellow (578nm)		
	n_e	n_o	<n>	n_e	n_o	<n>	n_e	n_o	<n>
70	1.5137	1.4715	1.4856	1.5059	1.4627	1.4771	1.5045	1.4616	1.4759
60	1.512	1.4786	1.4897	1.5059	1.4725	1.4836	1.5017	1.4686	1.4796
50	1.5132	1.4873	1.4959	1.5008	1.4676	1.4787	1.4969	1.4656	1.4760
40	1.5134	1.4893	1.4973	1.5085	1.4766	1.4872	1.5028	1.4745	1.4839
30	1.5131	1.494	1.5004	1.5067	1.4774	1.4872	1.5019	1.4765	1.4850

TABLE 4 : Shows variation of n_e, n_o and (n) with the temperature for 3M concentrations.

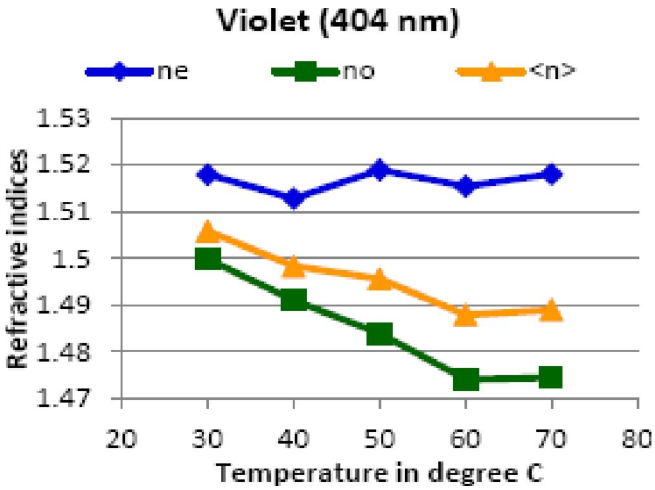
Temp. (°C)	Violet (404nm)			Green (546nm)			Yellow (578nm)		
	n_e	n_o	<n>	n_e	n_o	<n>	n_e	n_o	<n>
70	1.5222	1.4828	1.4959	1.5164	1.4663	1.4830	1.5012	1.4632	1.4759
60	1.5187	1.4934	1.5018	1.5094	1.4733	1.4853	1.5002	1.4655	1.4771
50	1.5165	1.494	1.5015	1.5074	1.4769	1.4871	1.5069	1.474	1.4850
40	1.5145	1.4924	1.4998	1.4993	1.4696	1.4795	1.4905	1.4607	1.4706
30	1.5157	1.498	1.5039	1.5074	1.4793	1.4887	1.5066	1.4825	1.4905

TABLE 5 : Shows variation of n_e, n_o and (n) with the temperature for 4M concentrations.

Temp. (°C)	Violet (404nm)			Green (546nm)			Yellow (578nm)		
	n_e	n_o	<n>	n_e	n_o	<n>	n_e	n_o	<n>
70	1.5189	1.477	1.4910	1.5128	1.4667	1.4821	1.4988	1.4567	1.4707
60	1.5143	1.4751	1.4882	1.499	1.4643	1.4759	1.4932	1.4553	1.4679
50	1.5135	1.4748	1.4877	1.4987	1.4641	1.4756	1.4921	1.4542	1.4668
40	1.5036	1.4751	1.4846	1.4987	1.4671	1.4776	1.4892	1.4545	1.4661
30	1.5025	1.4757	1.4846	1.4969	1.4662	1.4764	1.4866	1.4538	1.4647

TABLE 6 : Shows variation of n_e, n_o and (n) with the temperature for 5M concentrations

Temp. (°C)	Violet (404nm)			Green (546nm)			Yellow (578nm)		
	n_e	n_o	<n>	n_e	n_o	<n>	n_e	n_o	<n>
70	1.518	1.4745	1.4890	1.5104	1.4667	1.4813	1.5007	1.4567	1.4714
60	1.5154	1.4741	1.4879	1.5003	1.4617	1.4746	1.4965	1.4598	1.4720
50	1.5189	1.4839	1.4956	1.5118	1.475	1.4873	1.5075	1.4759	1.4864
40	1.5128	1.491	1.4983	1.5058	1.4775	1.4869	1.4989	1.4679	1.4782
30	1.5179	1.4998	1.5058	1.5013	1.4766	1.4848	1.4977	1.4671	1.4773



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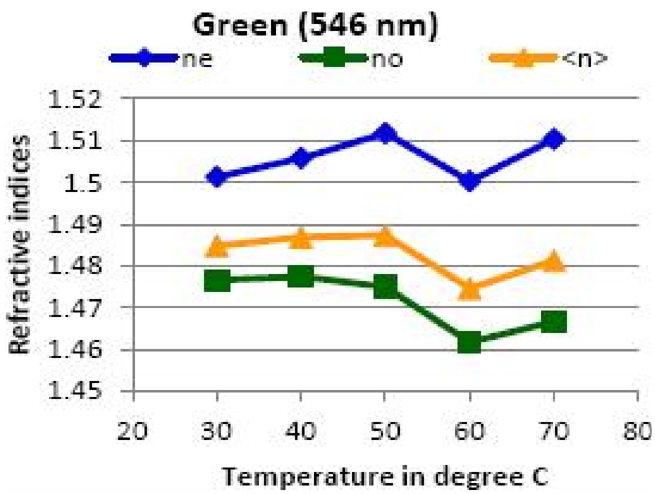

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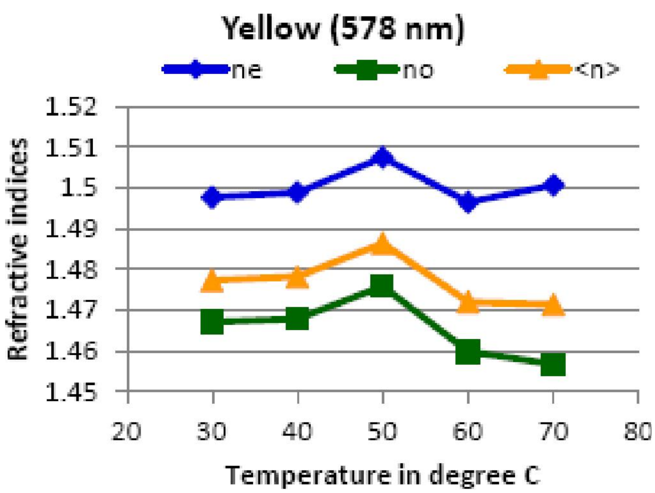
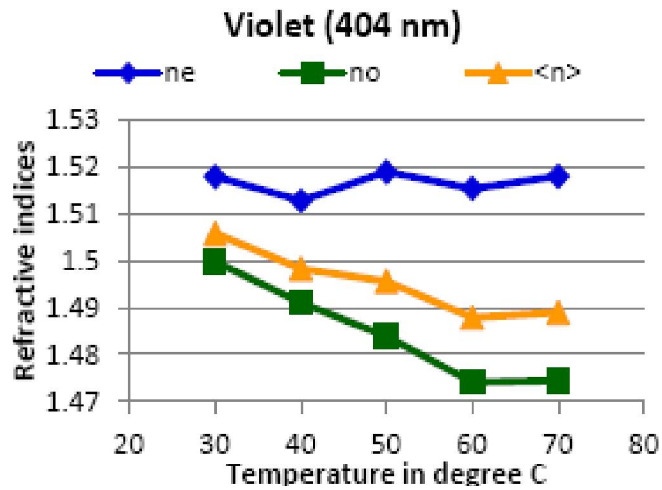


(c)

Figure 2 : a) Temperature variation of n_e, n_o and (n) for violet (404nm); b) Temperature variation of n_e, n_o and (n) for green (546nm); c) Temperature variation of n_e, n_o and (n) for yellow (578nm).



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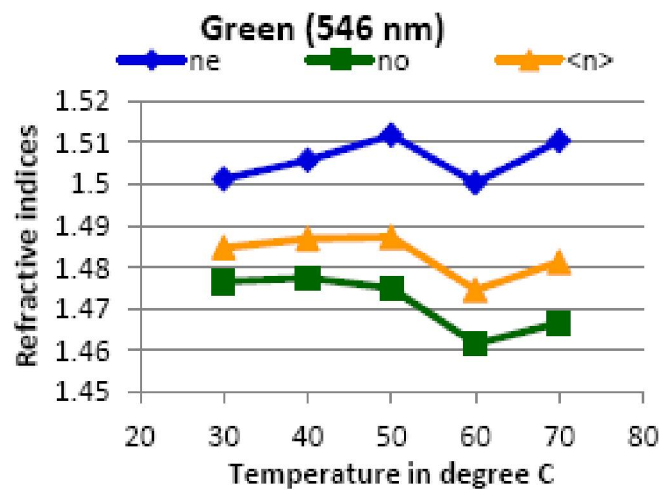

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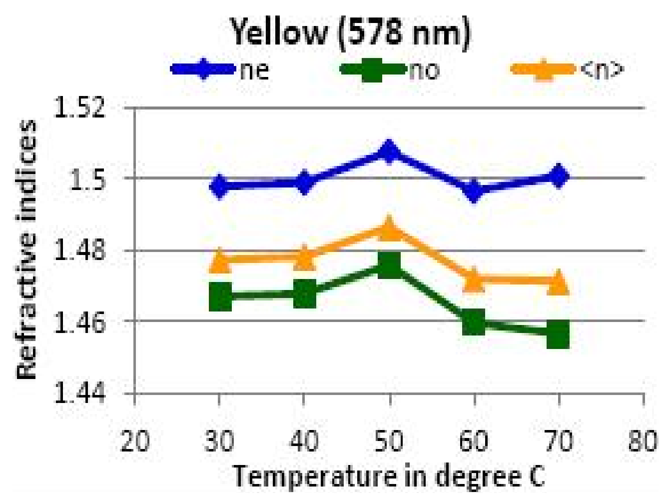

(a)

Figure 3 : a) Temperature variation of n_e, n_o and (n) for violet (404nm); b) Temperature variation of n_e, n_o and (n) for green (546nm); c) Temperature variation of n_e, n_o and (n) for yellow (578nm).

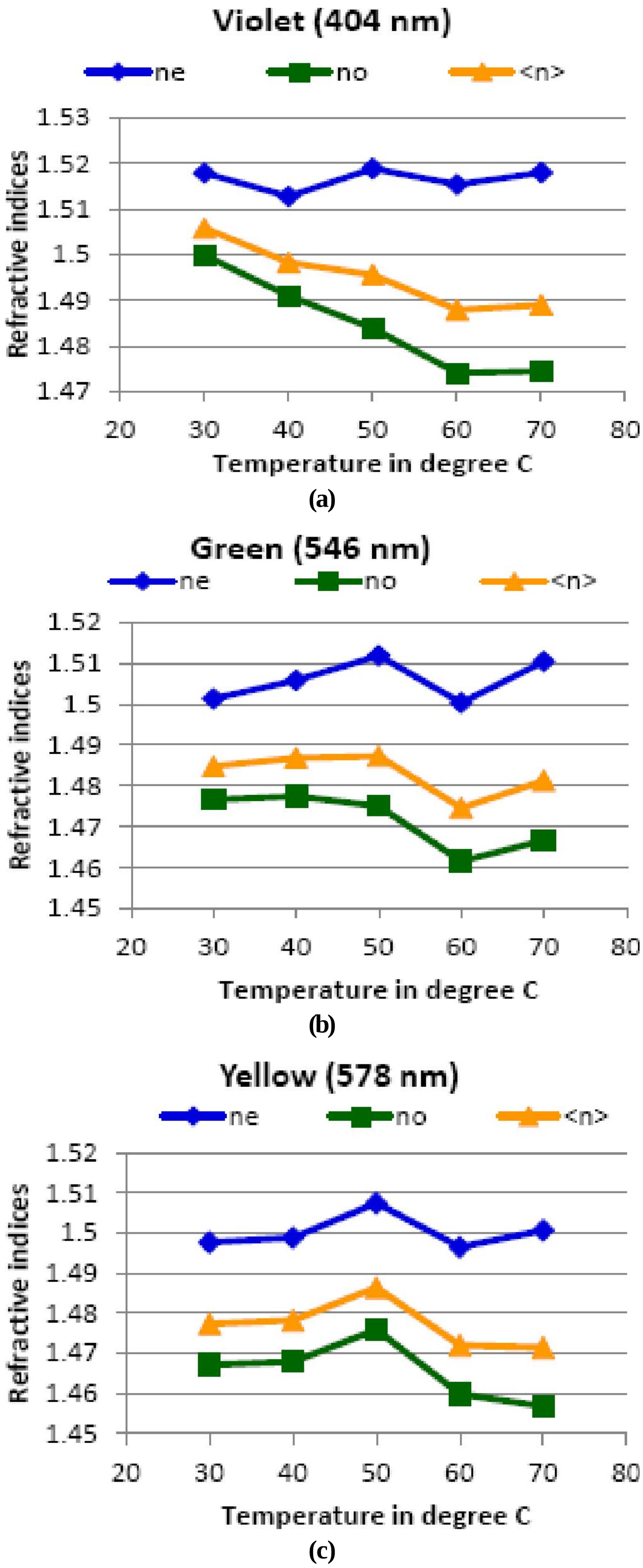

Figure 4 : a) Temperature variation of n_e, n_o and (*n*) for violet (404nm); b) Temperature variation of n_e, n_o and (*n*) for green (546nm); c) Temperature variation of n_e, n_o and (*n*) for yellow (578nm).

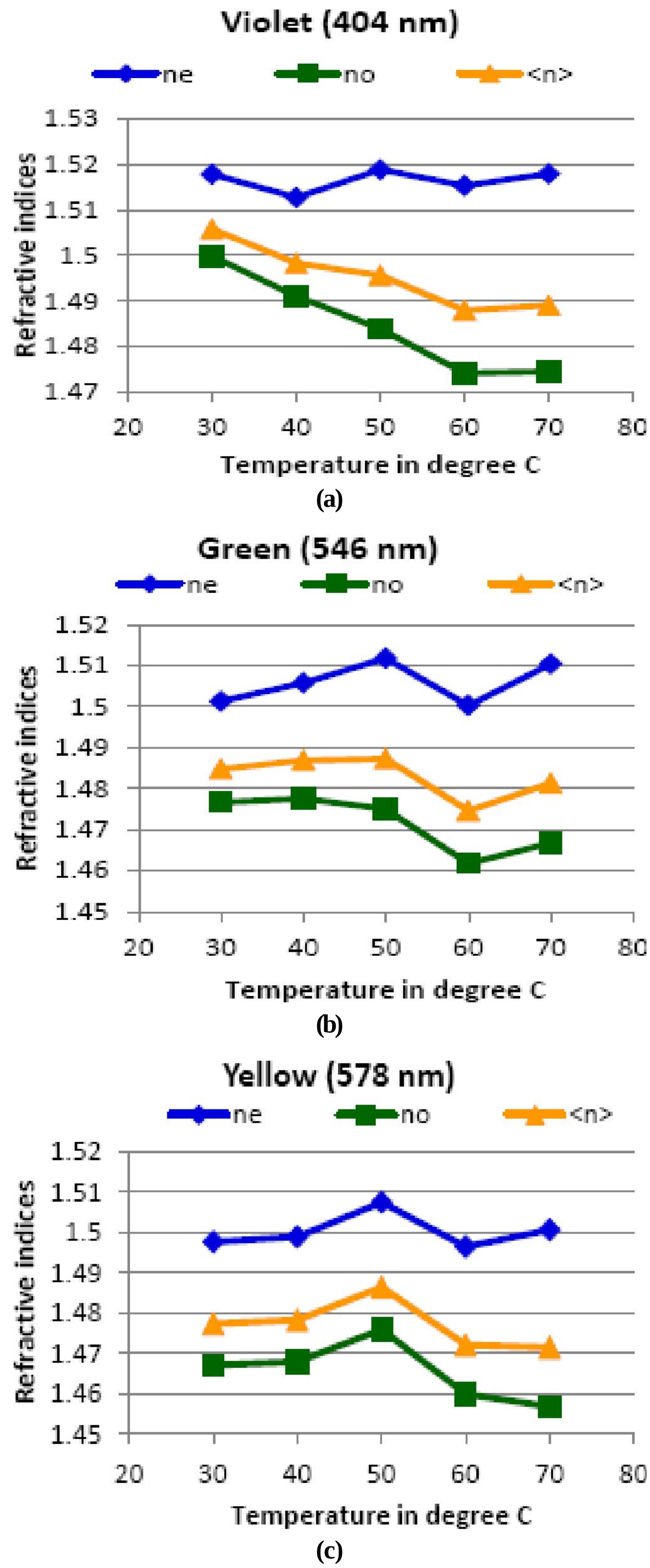

Figure 5 : a) Temperature variation of n_e, n_o and (*n*) for violet (404nm); b) Temperature variation of n_e, n_o and (*n*) for green (546nm); c) Temperature variation of n_e, n_o and (*n*) for yellow (578nm).

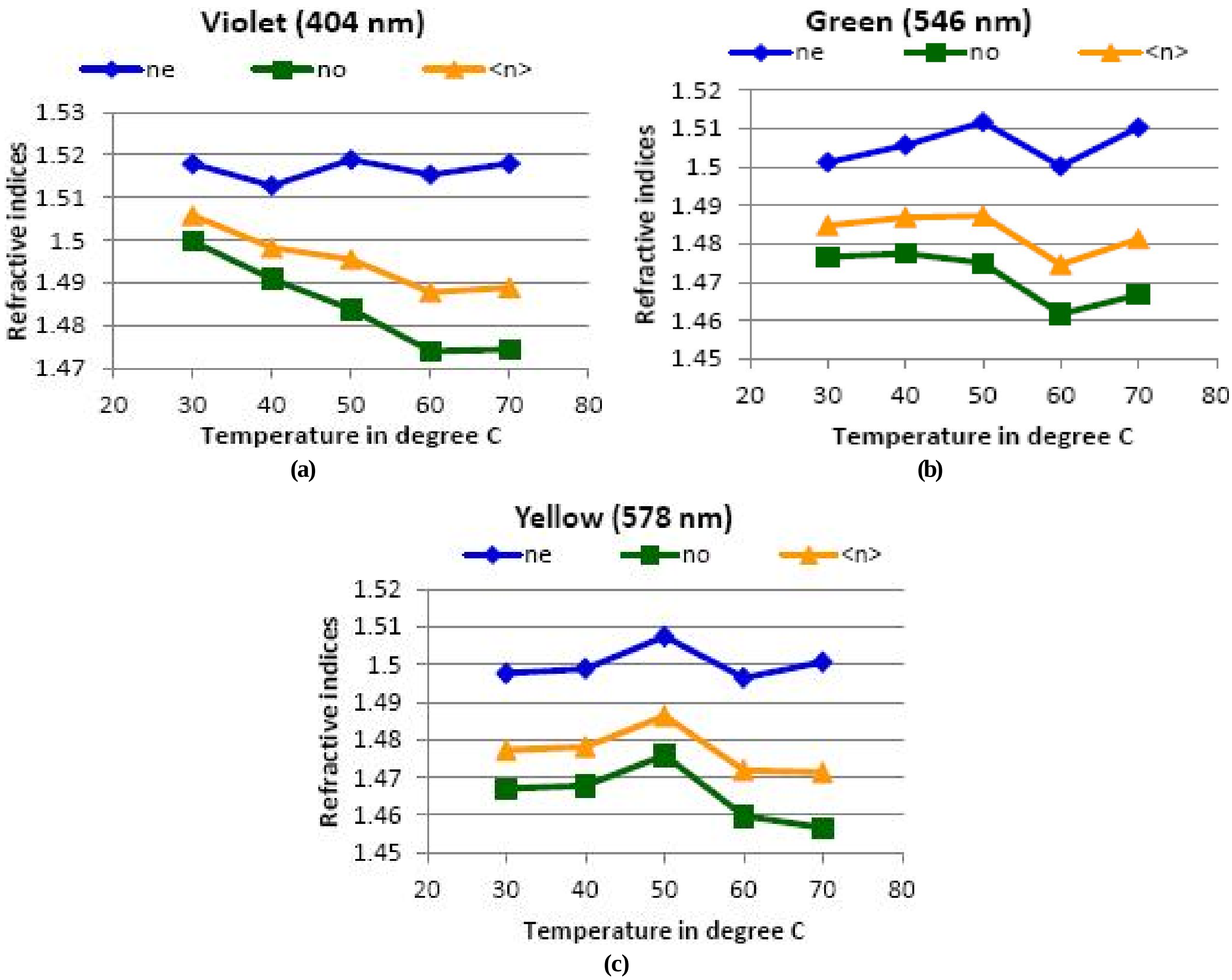

Figure 6 : a) Temperature variation of n_e, n_o and (*n*) for violet (404nm); b) Temperature variation of n_e, n_o and (*n*) for green (546nm); c) Temperature variation of n_e, n_o and (*n*) for yellow (578nm).

RESULT AND CONCLUSION

Here we have observed that the refractive index of extra ordinary and ordinary spectrum decreases as the concentration increases up-to 4 Molar concentration. Thereafter it shows increase. This happens due to changes in the molecular arrangement of the cholesteric in the solution[13]. For each concentration the refractive index of extra ordinary spectrum is greater than the ordinary spectrum indicating positive birefringence.

In the second experiment we observe that for each concentration as temperature increases the refractive index for extra ordinary spectrum and ordinary spectrum changes indicating changes in birefringence. It is interesting to see that as the average refractive index decreases with increasing temperature as specified by the Halller approximation and Vuks equation for refractive indices of liquid crystals.

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