Optical rotation dispersion of cholesteric-nematic mixture

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Abstract. The dispersion of the specific rotation constant of a cholesteric-nematic mixture of 5CB and Ch17 at a low concentration was studied by optical spectroscopy. The dispersion of the anisotropy of the refractive index as a function of the wavelength is studied, and the helical pitch of the cholesteric-nematic mixture is calculated.

1. Introduction
The widespread use of cholesteric liquid crystals mixed with nematic materials in optics and photonics is due to the wide orientation-structural optical properties, in particular, such systems were used as resonators for the creation of microlasers [1]. The use of a cholesteric-nematic mixture allows us to significantly expand the range of existence of the mesomorphic state to the most commonly used temperatures (from 20°C to 90°C) [2,3]. In addition, by varying the chemical composition of LC mixtures, it becomes possible to fine-tune their physical and chemical properties, which makes it possible to improve the operational parameters of existing LC devices, as well as to find new applications for liquid crystals in science and technology [4,5]. For example, the use of mixtures of two-frequency liquid crystals can significantly speed up the response of LC devices [6–8].

Cholesteric mixtures are now used to create tunable diffraction optics [9,10], the possibility of electrical adjustment of selective reflection is found [11,13]. The use of CLC together with photoactive polymers makes it possible to create both transmitting and reflecting holographic lattices [14]. Recently, it has been proposed to use a cholesteric-nematic mixture as an optical biosensor for the determination of amino acids [15].

In this paper, the contribution of a cholesteric additive to the dispersion of the anisotropy of the refractive index of nematic liquid crystals is investigated. The data on the optical properties of the cholesteric-nematic mixture are compared with the resulting helix pitch. As you know [16], the continuous change in the step of the cholesteric helix is carried out in limitless samples. In cells whose size is comparable to the step of the undisturbed structure of the cholesteric, the external fields induce a stepwise unwinding of the helix [17]. The influence of various factors on the helix pitch in CLC droplets has not been sufficiently studied, as a rule, the helix pitch, and,
Figure 1. Phase cholesteric-nematic transitions. a – 25°C, b - formation of the ”grid” texture 33°C, c - texture formation at 36°C, d - 37°C

as a result, the characteristics of the CLC material can be controlled by temperature 18. The results obtained can be used to develop LC devices that operate in narrow ranges of the optical spectrum (for example, in the near IR), but have improved characteristics in comparison with classical solutions. Physical properties of the CLC in different Grandjean zones of wedge cells are described in 19,20.

2. The object of the study and the method of the experiment

The object of the study is a cholesteric-nematic mixture of nematic (5CB) and cholesteric LC (Ch17) with a concentration of 7% mass. Cholesteric liquid crystals are mixed with nematics and have their own packaging of molecules, twisted relative to each other. The prepared mixture is filled with a cell with a thickness of \(d=100\) microns and a planar orientation, after which it is uniformly heated to a temperature above 87°C (isotropic liquid). Next, this cell cools down to room temperature.

The non-oriented cholesteric liquid crystal has a confocal texture. A planar-oriented mixture under the influence of temperature, the cholesteric-nematic transition in the structure usually has three phases (fig. 1), which depend on the step of the helix. The grid (fig. 1b) is a two-dimensional spatial periodic deformation of a planar texture.

The study of the dispersion of the specific constant of rotation of the mixture can be carried out by the method of ”grooved” spectrum using a monochromator. At the beginning of the experiment, the calibration curve of the monochromator is plotted using the known mercury spectrum.

A diagram of the experimental setup is shown in fig. 2. Cell 1 is placed between the crossed
Figure 2. (a) Diagram of the experimental setup, (b) the fading lines in the blue part of the spectrum

polarizers 2 at an angle of 45° relative to the allowed directions of the polarizer. The lenses 3 focus the light on the input slit of the monochromator 4. The light source 6 is an incandescent lamp that emits white light. The radiation spectrum 6 is observed using the spectral nozzle of a monochromator. In the field of view, vertical black bands are clearly visible against the background of the spectrum (fig. 2b).

The spectrum has extinction bands for those wavelengths for which the sample is extinguished in crossed polaroids. The intensity of the light passing through the sample will be zero when the plane of light polarization rotates during the passage of the sample by an angle that is a multiple of $\pi$. That is, when moving from one fade band to another, the angle changes by the value of $\pi$.

Specific rotation of the mixture helix is calculated according to the equation

$$\rho = -\frac{2\pi}{P} \frac{\delta^2}{8\lambda^2\left(1 - \lambda^2\right)}, \quad (1)$$

$P$ – helix step, $\lambda' = \lambda/(\sqrt{\pi}P), \delta = (\varepsilon_2 - \varepsilon_1)/(\varepsilon_2 + \varepsilon_1)$.

If $\lambda' \ll 1$, i.e. $\lambda \ll nP$, the formula (1) is simplified:

$$\rho = -\frac{\pi P(\Delta n)^2}{4\lambda^2}. \quad (2)$$

Here $\Delta n$ is the optical anisotropy of the layer, $\lambda$ is the wavelength of the incident light, $P$ is the pitch of the helix. The pitch of the $P$ helix depends on the nature of the molecules and external influences.

The concentration of cholesteric is small, so the condition $\lambda < P$ is feasible, and the value of $\Delta n$ inside the cholesteric layer can be replaced by $\Delta n$ of the nematic component.

As can be seen from (2), the rotation angle of the polarization plane is inversely proportional to $\lambda^2$. Therefore, we can assume that the minimum for $\lambda=668$ nm corresponds to the rotation angle $\varphi = \pi + \varphi_0$, where $\varphi_0$ is some indefinite angle that will be constant for all other minima (fig. 3a), so it can be ignored.

The deviation of the experimental curve from the straight line is due to the variance $\Delta n=\Delta n(\lambda)$ NLC (fig. 3b). To account for this variance, another planar cell filled with pure nematic 5CB was made. The cell thickness $d_1=109 \, \mu m$. This cell was used to obtain the
Figure 3. (a) The dependence of the angle of rotation of the plane of polarization of the NLC 5CB on $1/\lambda^2$, (b) the dispersion of the anisotropy of the refractive index as a function of the wavelength dispersion curve using the transmission spectrum on the spectrophotometer. Based on the measurement results, the dispersion curves are plotted (fig. 3). The values of $\Delta n$ corresponding to the wavelengths of the extinction lines (fig. 3b).

Plot of the dependence of the rotation angle of the polarization plane on the value $(\Delta n/\lambda)^2$ is represented by fig. 3a. As follows from the theory of (2), the graph can be approximated with a sufficient degree of accuracy by a straight line, the angular coefficient of which makes it possible to calculate the step of the cholesteric helix.

The step of the helix, this is the period at which the director makes a complete revolution around the cholesteric axis, respectively, can be calculated from

$$P = \frac{4}{\pi d} \cdot \frac{\Delta y}{\Delta x} = 2.07 \mu m$$

The equation of the approximation line $y = -12.844 + 16202.4x$ determined from the data on fig. 4.

Knowing the pitch of the helix, we can calculate (1) the value of the specific rotation of the helix of the cholesteric-nematic mixture

$$\lambda' = \lambda/\sqrt{\varepsilon} P = \lambda/3.2,$$

$$\sqrt{\varepsilon} = n, \quad \Delta \varepsilon/2\sqrt{\varepsilon} = \Delta n,$$  

$$\delta = \Delta n/n \approx 0.125.$$  

The error in measuring the pitch of the cholesteric helix is due, on the one hand, to the error in determining the optical anisotropy and the accuracy of determining the coordinates of the wavelengths of the extinction lines, which is associated with the visual method of reference. In addition, the error in determining the cell thickness is taken into account

$$\varepsilon_P = 2\varepsilon_{\Delta n} + 2\varepsilon_\lambda + 2\varepsilon_d \approx 0.07.$$
Figure 4. Dependences of the rotation angle of the polarization plane taking into account optical anisotropy

Figure 5. Dispersion of the specific rotation constant of a mixture of cholesteric-nematic mixture (1) experimental data, (2) theoretical curve
On Fig. 5, the red curve is the theoretical dependence $\rho = \rho(\lambda)$, the black dots are the experimental values ($P=2$ microns). The discrepancy between the experimental data and the theory is probably due to the large variance of $\Delta n(\lambda)$ in the region of short wavelengths.

Conclusions

In the course of the work, the optical properties of the cholesteric-nematic mixture were investigated, various methods for determining the step of the cholesteric helix were described, and various factors on which this value depends were identified. The step of the cholesteric-nematic mixture was measured by the method of the grooved spectrum. From the experiment, the numerical parameters of the cholesteric-nematic mixture were determined, which are in good agreement with the theory.

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