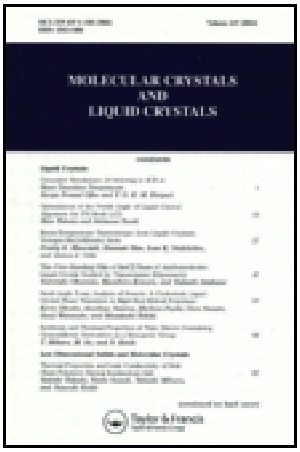

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On Measurement of Viscosity and Elasticity Constants

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ON MEASUREMENT OF VISCOSITY AND ELASTICITY CONSTANTS

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Abstract It is shown that it is possible to determine such NLC constants as viscosity, elasticity and thermoconductivity simultaneously by measuring the NLC eigenmode relaxation times using the probing beam diffraction on the refractive index grating excited by short laser pulses. The amplitudes of gratings have been calculated. Optimal conditions for excitation and detection of the gratings have been pointed out.

INTRODUCTION

Now there are enough experimental results showing that the disturbances of refractive index in liquid crystals due to temperature changes or director reorientation under action of short high power laser pulses can be detected effectively by probe laser beam[1-3]. The relaxation time of such disturbances depends on their characteristic length scale (cell thickness d, laser beam diameter 2a, etc.) and on the rheological constants of the substance.[4] In different versions this dependence is used for measuring material constants of different substances, including liquid crystals[5,6]. In this work we analyse the possibility of using the laser induced grating method for measuring elastic, viscous and thermoconductive coefficients of nematic liquid crystals. This method can be regarded as an extension of the forced Rayleigh scattering technique, which has been already used by Urbach W., Hervet H. and Rondelez F.[7] for measuring thermoconductive coefficients of NLC or as a forced version of the light scattering method. In this method, the interference field of the laser pulse, previously split into the two beams intersecting at an angle α, is the source of the refractive index disturbance. The relaxation of arising diffraction grating is investigated by means of a weak probe beam diffracted to the first order. We analyse two aspects of laser action: thermal – due to intrinsic or extrinsic absorption[3] and orientational – the director is rotated by the laser beam electric field[8].

BASIC EQUATIONS

We consider a small perturbation of the state parameters when the linearization of nematodynamic equations is correct[4]. This set of equations, referred to the basis in fig. 1, is divided into two independent parts.

$$\dot{\delta\rho} - i\,q\,\rho V_l = 0 \qquad (1)$$

$$\dot{V}_l + P_1 V_l + P_2 V_t - iq V_s^2 (\rho\gamma)^{-1}\delta\rho - iq a_p V_s^2 \gamma^{-1}\delta T + iq^3 b_1 G\,\delta n = -iq b_1 F_\pi/\lambda_1 \qquad (2)$$

$$\dot{V}_t + P_2 V_l + s_3 V_t + i b_2 G q^3 \delta n = -iq\, b_2 F_\pi / \lambda_1 \qquad (3)$$

$$\dot{\delta T} + iq\, V_l\, (1-\gamma)/a_p + \gamma s_4 \delta T = Q/\rho C_v \qquad (4)$$

$$\dot{\delta n} - G q^2 \delta n + iq\rho\, b_1 \lambda_1^{-1} V_l + iq\, \rho\, b_2 \lambda_1^{-1} V_t = F_\pi/\lambda_1 \qquad (5)$$

$$\dot{V}_\perp + s_6 V_\perp + iq^3 b_3 G_p \delta n_\perp = -iq\, b_3 F_\perp/\lambda_1 \qquad (6)$$

$$\dot{\delta n}_\perp - G_p q^2 \delta n_\perp + iq\, b_3 \rho \lambda_1^{-1} V_\perp = F_\perp/\lambda_1 \qquad (7)$$

where $V=\{V_l, V_t, V_\perp\}$ is the flow velocity, $\delta\rho$, δT, $\delta n=\{\delta n, \delta n_\perp\}$ are the deviations of the density, temperature and director from equilibrium values, V_s is the adiabatic sound velocity.

$$P_1 = [(\mu_4+\mu_7) + (\mu_5+\mu_6+2\mu_8+\lambda_2^2/\lambda_1)\cos^2\Theta + (\mu_1-\lambda_2^2/\lambda_1)\cos^4\Theta]\,q^2/\rho$$

$$P_2 = [-(\mu_1\cos^2\Theta + \mu_6 + \mu_8)\sin 2\Theta/2\rho + b_1 b_2 \rho/\lambda_1]\,q^2$$

$$b_1 = -\lambda_2 \sin 2\Theta / 2\rho; \qquad b_2 = \lambda_1 - \lambda_2 \cos 2\Theta / 2\rho; \qquad b_3 = \mu_2 \cos\Theta / \rho$$

$$b_4 = (-\mu_1\cos^4\Theta + (\mu_1+\lambda_2)\cos^2\Theta + (\mu_4-\mu_2+\mu_5)/2 - \lambda_2)/\rho$$

$$b_5 = ((\mu_5-\mu_2)\cos^2\Theta + \mu_4)/2\rho; \qquad s_4 = (k_\perp + k_a\cos^2\Theta))\,q^2/\rho C_p$$

$$s_3 = (b_4 + b_2^2\rho/\lambda_1)q^2 = ((\lambda_2^2/\lambda_1 - \mu_1)\sin^2 2\Theta + 2(\mu_4-\mu_2+\mu_5) + 4\mu_2^2/\lambda_1)\,q^2/4\rho$$

$$s_6 = (b_5 + b_3^2\rho/\lambda_1)q^2 = (((\mu_5-\mu_2)/2 + \mu_2^2/\lambda_1)\cos^2\Theta + \mu_4/2)\,q^2/\rho$$

$$G = (K_{33}\cos^2\Theta + K_{11}\sin^2\Theta)/\lambda_1; \qquad G_p = (K_{22}\sin^2\Theta + K_{33}\cos^2\Theta)/\lambda_1$$

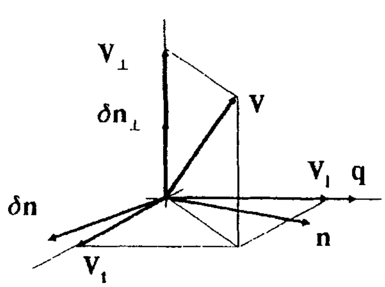

FIGURE 1 Basis.

μ_{1-6} – Leslie's viscosities $\lambda_1 = \mu_2 - \mu_3$, $\lambda_2 = \mu_5 - \mu_6$. It should be noted that Parody ralation $\mu_2 - \mu_3 = \mu_5 + \mu_6$ has been used. The terms $(\mu_7\delta_{ij}\delta_{km} + \mu_8(\delta_{ij}n_k n_m + n_i n_j \delta_{km}))\,d_{km}$ must be added to the dissipative part of the momentum flux tensor t_{ij} to take into account the compressibility of LC. (We use notations[4].) μ_7, μ_8 – additional viscosities. This question has been discussed in ref.[9]. K_{ij}, $k_\perp$, k_a – the elastic and thermoconductivity constants, a_p– volume expansion coefficient, C_p, C_v– specific heats, $\gamma = C_p/C_v$, Θ– angle between **n** and **q**. Eqns. (1-5) describe the motion in the plane (**n**,**q**), and (6,7) – that perpendicular to (**n**,**q**) direction. The action of the light electric field on LC is described by force $F=\{F_\pi,F_\perp\}=-\epsilon_a[e_1(ne_2)+e_2(ne_1)-2(ne_1)(ne_2)n]$ $(E_1E_2^* \exp(iqr)+conj.)/4\pi$. The heating is described by the heat source $Q=c(n_1n_2)^{1/2}$ $[g_\perp(e_1e_2)+g_a(ne_1)(ne_2)](E_1E_2^*\exp(iqr)+conj.)$. E_i, e_i and n_i – are the amplitudes of electric field, polarization vectors and refractive indices for two exciting waves. ϵ_a– the dielectric anisotropy, $g_\perp\delta_{ij}+g_an_in_j$ – absorption tensor. The interference term $\sim \exp(iqr)$ has only been retained in the expressions for the sources. The influence of uniform heating and reorientation will be considered later. The set (1-7) has been derived from Ericksen - Leslie equations[4] by eliminating $\delta\dot{n}$ and $\delta\dot{\rho}$ from the equations for the velocity and temperature. The set (1-7) has the form:

$$\dot{X} + L X = f \tag{8}$$

where $X = \{\delta\rho,\ V_l,\ V_t,\ \delta T,\ \delta n, V_\perp,\ \delta n_\perp\}$, L – is a linear operator, f – external disturbance vector. Common solution of (8) for zero initial conditions is a sum of eigenmodes:

$$X = \sum_i \exp(s_it)\ {}_0\!\int^t X_i(f_iY_i^*)\exp(s_it')\,dt' \tag{9}$$

where X_i and Y_i are normal eigenvectors of operator L and conjugate operator corresponding to eigenvalue s_i. It is seen that after external action ceases each mode relaxes exponentially with the relaxation time determined by the dispersive law $s_i=s_i(q)$. The modes amplitudes are determined by scalar product of external force vector and corresponding eigenvector of the operator conjugating to L.

NLC EIGENMODES

There are 7 modes in NLC. One can find eigenvalues in ref.10 and eigenvectors are given in the Table 1. There are longitudinal sound waves having dispersion law $s_{1,2}= i\Omega + P_1/2$. In P_1 we neglect the sound damping connected with thermoconductivity because it is $s_4/s_3 \approx k/C_v\mu \approx 10^{-3}$ times smaller than the main term. (for $k\approx$ 0.1 W/(m·K°), $C_v \approx 10^3$ j/(kg·K°), $\mu_1 \approx 0.1$ Pa·s). We find a thermal mode with dispersion law s_4 and 4 unspreading modes with dispersion laws s_3 and $s_5=-Gq^2 b_4/(b_4+b_2^2\rho/\lambda_1)$ (set 1–5), s_6 and $s_7=-G_p q^2\ b_5/(b_5+b_3^2\rho/\lambda_1)$ (set 6,7). The s_3 and s_6 modes are fast, s_5, s_7 are slow, and $s_5/s_3 \approx s_7/s_6 \approx K_{ii}\rho/\mu_i^2 \approx 10^{-4}$ (for $K_{ii}\approx$ $5\cdot10^{-12}$ N, $\rho \approx 10^3$ kg/m^3).Using the above estimation of s_i for typical LC parameters and $s_3/\Omega \approx \mu_l\, q/\rho V_s \approx 10^{-2}$ (for $q \approx 10^5$ m^{-1}, $V_s \approx 10^3$ m/s) one may conclude that $\Omega >> (P_1, s_3, s_6) >> s_4 >> (s_5, s_7)$. So, the ratios of these characteristic times are small parameters. All calculations in this work were performed in the main

TABLE 1 Eigenvectors

	$X_{1,2}$	X_3	X_4	X_5	X_6	X_7
$\delta\rho$	$2^{-1/2}\rho$	$-i\gamma\rho P_2\Omega$	ρ	$\rho s_5 s_3 B\Omega^{-2}$	0	0
V_l	$\pm 2^{-1/2}V_s$	$V_s\gamma P_2 s_3\Omega^{-2}$	is_4/q	$iV_s s_5^2 s_3 B\Omega^{-3}$	0	0
V_t	$\frac{iV_sP_3}{\Omega\sqrt{2}}$	V_s	$\frac{-iV_sP_3s_4}{s_3\Omega}$	$\frac{-iV_sb_2s_5}{b_4\Omega}$	0	0
δT	$\frac{(\gamma-1)}{a_p\sqrt{2}}$	$\frac{i\gamma(1-\gamma)P_2}{a_p\Omega}$	$-1/a_p$	$\frac{(1-\gamma)s_5^2s_3B}{a_ps_4\Omega^2}$	0	0
δn	$2^{-1/2}L_1$	$i\Omega L_2/s_3$	A	1	0	0
$V_\perp$	0	0	0	0	1	$-iq^3b_3G_p/s_6$
$\delta n_\perp$	0	0	0	0	$iqL_3s_6^{-1}$	1

Conjugate eigenvectors

	$Y_{1,2}$	Y_3	Y_4	Y_5	Y_6	Y_7
$\delta\rho$	$2^{-1/2}/\rho\gamma$	$iP_2/\rho\gamma\Omega$	$(\gamma-1)/\rho\gamma$	$-A/\rho$	0	0
V_l	$\pm 2^{-1/2}/V_s$	$\frac{P_3s_3}{V_s\Omega^2}$	$\frac{i(1-\gamma)s_4}{V_s\Omega}$	$\frac{i\gamma As_5}{V_s\Omega}$	0	0
V_t	$\frac{2^{-1/2}iP_2}{V_s\Omega}$	V_s^{-1}	$\frac{-i(1-\gamma)s_4P_2}{s_3V_s\Omega}$	$\frac{iL2\Omega}{V_ss_3}$	0	0
δT	$2^{-1/2}a_p/\gamma$	$ia_pP_3/\gamma\Omega$	$-a_p/\gamma$	a_pAs_5/s_4	0	0
δn	$\frac{-2^{-1/2}b_1G_\pi q^2}{\rho V_s^2}$	$\frac{-is_5b_2}{b_4\Omega}$	$\frac{(1-\gamma)s_5s_3B}{\gamma\Omega^2}$	1	0	0
$V_\perp$	0	0	0	0	1	iqL_3/s_6
$n_\perp$	0	0	0	0	$-iq^3b_3G_p/s_6$	1

$A = (L_1s_3 + L_2P_3)/s_3$; $\quad B = \gamma(s_3b_1 - P_2b_2)/b_4s_3$; $\quad L_1 = b_1\rho/\lambda_1$

order with respect to the small parameters.

In principle, five constants can be determined by measuring slow mode relaxation times s_5^{-1}, s_7^{-1} as a function of the angle Θ. This is used in the light

ON MEASUREMENT OF VISCOSITY AND ELASTICITY CONSTANTS

scattering methods[11]. But s_5 and s_7 are the ratios of polynomials of $\cos^2\Theta$ whose coefficients contain not only μ_i but also K_{ii}. That is why this method demands a great number of accurate measurements of s_5 and s_6 for different Θ, complicated analysis and independent data about K_{ii}. The active LC mode excitation gives additional opportunity to measure fast modes relaxation times s_3^{-1} and s_6^{-1}. For known ρ and given q by measuring $s_3(\Theta)$ and $s_6(\Theta)$ one can determine directly three independent combinations of μ_i as polynomial coefficients of $s_{3(5)}$ $(\cos^2\Theta)$: $\lambda_2^2/\lambda_1 - \mu_1$ from s_3, $(\mu_5 - \mu_2)/2 + \mu_2^2/\lambda_1$ and μ_4 from s_6. We shall show later that another two independent combinations of μ_i can be derived from the ratio of fast and slow mode amplitudes. For known μ_i, K_{33} and K_{11} can be determined with high accuracy from s_5 and K_{33}, K_{22} from s_7 by using only $\Theta = 0$ and $\pi/2$ respectively. Measuring the sound decrement $P_1/2$ for Θ=0, $\pi/2$ gives $\mu_4+\mu_7$ and $\mu_5+\mu_6+2\mu_8+\lambda_2^2/\lambda_1$ and hence, μ_7 and μ_8. s_4 measured for Θ=0, $\pi/2$ is enough to get thermoconductive constants $k_\perp$, k_a.

EXCITATION AND DETECTION OF EIGENMODES

In order to simplify calculation procedure used to evaluate constants from mode relaxation times and thus to increase the results accuracy it is natural to choose conditions simplifying expression (9). First of all, one should choose the excitation geometry such that $s_1 - s_5$ modes (set 1–5) and $s_6 - s_7$ modes (set 6,7) are excited independently. Table 1 shows that in general all modes of set (1 – 5) (or (6, 7)) having relaxation time s_i^{-1} greater than the pulse duration t_p will be necessarily excited, but different modes become dominating depending on the excitation manner. For optical eigenmodes detection by probing beam diffraction on the dielectric grating $\delta\varepsilon_{ij}$ arising due to δT, $\delta\rho$ and δn modulations, the actual contribution of each of these parameters to the diffraction efficiency is determined by the expression:

$$I_s/I_i = \varepsilon_a[k_s d/2n_s]^2\{(e_i e_s)[-(3S)^{-1}(\partial S/\partial T)\delta T + (\varepsilon_\perp - 1)(\varepsilon_a\rho)^{-1}\delta\rho] +$$

$$(e_i n)(e_s n)[(S)^{-1}(\partial S/\partial T)\delta T + \rho^{-1}\delta\rho] + [(e_i n)(e_s\delta n) + (e_i\delta n)(e_s n)]\}^2$$

where e_i, e_s, I_i, I_s – are the polarization vectors and intensities of probing and diffracted waves, S – order parameter, k_s and n_s – wave vector and refractive index of diffracted wave. This expression also serves as a natural criterion for comparing the excited eigenmode amplitudes.

For measuring s_6 and s_7 let us choose one of the exciting waves to be ordinary– e_1, and the other e_2– extraodinary with the wave vectors $\mathbf{k}_1$, $\mathbf{k}_2$ lying in the same plane with **n** (Fig. 2a). Thus the director is acted upon by a force $F_\perp = \varepsilon_a (ne_2)(E_1 E_2^* \exp(iqr) + conj.)/4\pi$ orthogonal to the plane (**n**,**q**). F_π and Q vanish due to $(e_1,n)=$

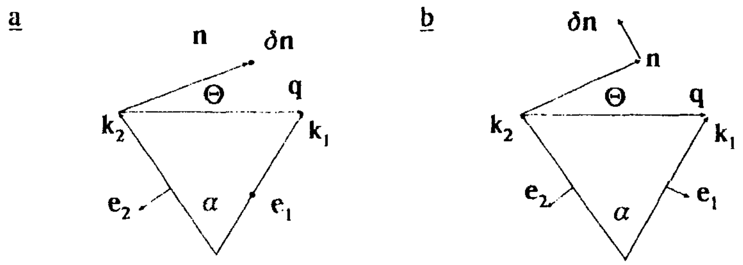

FIGURE 2. a) o – e exitation, b) e – e exitation.

$(e_1, e_2)=0$. Thus, the director declination in the direction orthogonal to (**n**,**q**) plane is the only contribution to the dielectric grating:

$$\delta n_\perp = F_\perp b_5 t_p (\lambda_1 b_5 + b_3^2 \rho)^{-1} [b_3^2 \rho \, (b_5 \lambda_1)^{-1} \exp(-s_6 t) + \exp(-s_7 t)] \, (e^{iqr} + conj.)$$

$$s_6 = (b_5 + b_3^2 / \lambda_1) q^2 \qquad (10)$$

It can be seen that by measuring the mode amplitude ratio in addition to s_6 it is possible to calculate both b_5 and $b_3^2\rho/\lambda_1 = \mu_2^2 \cos^2\Theta/\lambda_1 \, \rho$, and obtain another independent combination: μ_2 - μ_5 or μ_2^2/λ_1. One should decrease **q** to keep the relaxation time s_6^{-1} much larger than the order parameter relaxation time (10^{-8} s [11]). For o-e excitation the decrease of **q** is achieved if waves spread in the direction close to the director, but this also leads to decreasing of the excited grating efficiency. So, for homeotropical cell $F_\perp \approx \sin\gamma_e$, γ_e – is the incidence angle of e–wave. For instance, with $\gamma_e \approx 25^0$ and the angle between o and e waves 1.5°, $s_6^{-1} \approx 10^{-7}$ s, $(ne_2)=0.26$ (5CB). In general, two angles Θ are sufficient to get all independent viscosity combinations controlling the 6 and 7 mode dynamics. Any angle is suitable except $\pi/2$, when the mode 6 is not excited at all. $\Theta = 0$ is the most suitable angle,since it maximizes the fast mode amplitude. For probing e-o or o-e diffraction should be used.

Let us choose two extraordinary exciting waves so that $\mathbf{k}_1$, $\mathbf{k}_2$, **n** are coplanar (Fig. 2b). Thus, the 6,7 modes can not be excited and the director is acted upon by a force $F_\pi = -\varepsilon_a [(e_1 n)(e_2 m) + (e_2 n)(e_1 m)] (E_1 E_2^* \exp(iqr) + conj.)/4\pi$ lying in the (n,q) plane (m $\perp$ n in the (n,q) plane, $|m| = 1$) In this case, δn makes the main contribution to $\delta\epsilon$ modulation:

$$\delta n = F_\pi b_4 t_p (\lambda_1 b_4 + b_2^2 \rho)^{-1} [b_2^2 \rho (b_4 \lambda_1)^{-1} \exp(-s_3 t) + \exp(-s_5 t)] (e^{iqr} + \text{conj.})$$

$$s_3 = (b_4 + b_2^2 \rho / \lambda_1) q^2 \quad (11)$$

In this geometry the flow arising due to **n** rotation causes temperature and density changes which also contribute to $\delta\epsilon_{ij}$ modulation. Estimations show that maximum contribution is connected with temperature modulation in the fast mode s_3, but it is also $\gamma(1-\gamma)\ (s_3/\Omega)^2\ (\partial S/\partial T)/S/a_p \approx 10^{-3} \div 10^{-1}$ times smaller than that of δn. (for PAA $\gamma(1-\gamma)(\partial S/\partial T)/S/a_p \approx 8$, T=399 K° and ≈ 270 for T= 408 K°). Measuring s_3 for one angle $\Theta \neq 0, \pi/2$ one can calculate $(\lambda_2^2/\lambda_1 - \mu_1)$. If absorption is small additional measuring of the mode amplitudes ratio for the same Θ gives b_4 and $b_2^2\rho/\lambda_1 = (\lambda_2^2\cos^4\Theta/\lambda_1 - (\lambda_2^2/\lambda_1 + \lambda_2)\cos^2\Theta + (\lambda_2 + \mu_2^2/\lambda_1))/\rho$, and hence, the fifth independent combination: $\mu_1\cos^2\Theta - \lambda_2$, or $\lambda_2 - \lambda_2^2\cos^2\Theta/\lambda_1$. Absorption causes additional $\delta\epsilon$ modulation due to heating. $\delta T = Q\exp(-s_4 t)/\rho C_p \gamma$ of the thermal mode makes the maximal contribution and δn amplitude increases by $\delta n_Q = Qa_p(\rho b_2 P_2 \exp(-s_3 t)/s_3\lambda_1 + A\exp(-s_4 t) - As_5\gamma\exp(-s_5 t)/s_4)/\rho C_p \gamma$. For measuring only relaxation times this effect improves the experimental conditions by increasing the grating amplitude. However, in this case the formula (11) does not describe the mode amplitude ratio correctly. The heating influence is minimum near $\Theta = 0, \pi/2$, because P_2, A~ sin2Θ. When$((e_s n)(e_i n) - (e_s e_i)/3) \neq 0$, the absence of contribution relaxing with s_4^{-1} in the diffracted signal can serve as a reliable criterion for the formula (11) to be used. As a whole $\delta n_Q < \delta n$ when the absorption coefficient $g < \rho C_p \epsilon_a ((e_1 n)(e_2 m) + (e_2 n)(e_1 m))/2c\lambda_1 a_p (n_1 n_2)^{1/2}$. Conditions both maximizing the grating diffraction efficiency and keeping s_3^{-1} greater than the order parameter relaxation time are achieved for the angle between exciting waves $\approx 0.5°$ when the angle between the director and the wave spreading direction in the cell is $\approx 45°$. One should use e-e diffraction when probing.

According to (9), the director deviation is proportional to the pulse energy. Since $E_1 E_2^* \sim 2\pi W/c\, t_p$, where W [j/cm^2] is the exciting light energy density, $\delta n \approx \epsilon_a W/2\lambda_1 cn \approx 1.5 \cdot 10^{-3} W$ for PAA and about $10^{-4}W$ for 5CB. For PAA the diffraction efficiency of the grating is $I_s/I_1 \approx (0.03W)^2$ if d=100μ.

The viscosity $\mu_{7,8}$ of compressible LC can be determined by measuring the damping decrement of sound excited owing to light absorption. Two ordinary waves are most suitable in this case since there is no field directly acting on the director. According to[12] $\delta T = Qt_p((\gamma - 1)\cos(\Omega t)\exp(-0.5P_1 t) + \exp(-s_4 t))(\exp(iqr) + \text{conj.})/$

ρC_p makes the main contribution to $\delta\epsilon$. To excite sound effectively sufficiently short pulses are required: $t_p < (V_s q)^{-1}$. But it is better to use a mode locked laser and select the angle between two beams such that the pulse interval coincides with the sound oscillation period. A more serious problem in this experiment is connected with spatial finiteness of light beams and cell leading to additional damping due to the sound running out of the probing area.This demands the restrictions: a/V_s, $d/RV_s >> \rho/\mu q^2$, R – is the coefficient of sound reflection from the boundary. More precise calculations allowing for boundary conditions weaken these restrictions. The diffraction efficiency expected for the cell width 100μ is $I_s/I_p = (0.29\ gW)^2$ (for PAA,T=399K°, g [sm^{-1}]). o-o or e-e diffraction is used for probing. Simultaneously $k_\perp$ and k_a can be found by measuring s_4^{-1}. The latter lowers the requirements to $t_p < s_4^{-1}$. Such method has been used[12] to measure thermoconductivity constants.

CONCLUSION.

We have considered the unbounded LC excited by plane waves. This is correct for $q^2 >> (p/d)^2$, a^{-2}. We have not taken into account uniform (on q^{-1} scale) reorientation and heating in LC. Relaxation times of such perturbations are $\max[(qd/\pi)^2, (qa)^2] \approx 10^2$ times greater than for gratings. Thus, they can be interpreted as systematic errors in determining initial director orientation and temperature. Uniform force is $2\Sigma_i(ne_i)(e_i - n(ne_i))I_i$ for e-e excitation and $(ne_2)(e_2 - n(ne_2))I_2$ for o–e excitation (2 – is extraordinary wave). In both cases director rotates in the (n,q) plane resulting in $\delta\Theta \sim \delta n \sim 10^{-3} \div 10^{-4}$. Uniform heating leads to the measurement temperature increasing by $\delta T \sim gW/\rho C_p$ (for $g = 10^{-2}\ sm^{-1}$, $W \approx 5\ j/sm^2$, $C_p \approx 2j/gK°$, $\delta T \approx 0.03$ K°). In our case the well known intensive light scattering in LC connected with thermal fluctuations whose dynamics is controlled by slow modes is a noise. Radiation power scattered to a solid angle $\delta\omega$ is $P_{sp} = P_0 d k_B T k^4 \epsilon_a^2\ \delta\omega / K_{ii}/(4\pi q^2)$ [13], where k_B – Boltzmann constant. Considering the solid angle for useful signal $\delta\omega = (\lambda D/a)^2$ (D – is a sum of ratios of probing and exciting beam divergences to the diffraction divergences, their cross sections being equal). The ratio of the useful signal power on the detector to the thermal noise power is

$$P/P_{sp} = \epsilon_a^2 K_{ii} d q^2 (ne_2)^4 W^2 a^2 (n_s \lambda_1 c D)^{-2} (k_B T)^{-1} \approx (10/D)^2$$

where $(ne_2) = 0.26$, $W = 5j$, $a = 2.5 \cdot 10^{-3}$m, $d = 100\mu$, $q = 2.4 \cdot 10^5 m^{-1}$. If $P/P_{sp} \approx 1$ the mixed variant can be used: active exitation of fast modes and analysis of thermal fluctuations of slow modes.

The advantages of this method are connected with the use of the same approach and techniques for measuring the whole set of viscosity, thermoconductivity and elasticity constants. In comparison with other methods, which are sometimes not capable of measuring the needed number of independent combinations of viscosity constants, in this case, some of them can be determined twice or more from independent measurements without additional experiments. The abundant information can be used to ascertain the results or to check some of the main theoretical postulates of NLC hydrodynamics, such as Onsager reciprocal relation (Parodi relations) and so on. Refractive indices at exciting radiation frequency are needed when processing experimental data, but these parameters can be found by using the same equipment [14].

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REFERENCES

1. H. Hsiung, L. P. Sci and Y. R. Shen, Phys.Rev. A, 30, 1953 (1984)
2. N. C. Khoo and R. Normandin, Optics Letters, 9, 285 (1984)
3. A. A. Kovalev, G. L.Nekrasov, V. A. Pilipovich, et al., Pis'ma Zh. Tech. Fis., 5, 159 (1979)
4. S. Chandrasekar, Liquid Crystals (Cambridge University Press, Cambridge, (1977), Chap. 3
5. V.G. Chigrinov and M. F. Grebenkin, Kristallografiya, 20, 1240, (1973)
6. V.V.Belyaev and M. F. Grebenkin, Kristallografiya, 29, 815, (1984)
7. W. Urbach, H. Hervet and F. Rondeler, Mol. Cryst. Liq. Crist., 46, 209 (1978)
8. B. Ya. Zeldovich, N. V. Tabiryan, Uspekhi Fis Nauk, 147, 633 (1985)
9. V. B. Nemtsov, Molecula - Statistical theory of nonequilibrium processes in liquid crystals.,Thesis of Dr. Phys. Math. .Minsk, Byelorussian Technological Institute, 1986.
10. L. D. Landau, E. M. Lifshits, Theory of elasticity, Moscow, Nauka, 1978, (in Russian)
11. Orsay groupe, J. of Chamical Physics, 51, 816 (1969)
12. V. N. Sadovsky, N. A. Usova, Akusticheskii Zh., 33, 551 (1987)
13. P. De Gennes, The Physics of Liquid Crystals, (Oxford, University Press, 1974)
14. I. Haller, H. A. Huggins and M. J. Freiser, Mol. Cryst. Liq. Cryst., 16, 53 (1972)