for a single feedback loop system.

The theory has been worked out for a generalized feedback network concerned with an applied electric field from external plates.[1] However, this theory cannot be readily used in this case since the exciter plates are in good electrical contact with the plasma and so direct density perturbations as well as electric field perturbations must be included in the theory in order to describe these results. The main effects of the removal of the instability were that the density profile was "sharpened up" and that an inhomogeneity in the temperature profile was removed. The radial position of this temperature inhomogeneity corresponded to the maximum in the amplitude of the instability. When the instability was stabilized, it was seen that the density was higher at the center and fell off faster in the "wings" rather than when the instability was present. This is caused by the fact that the current in the arc column is stabilized at a constant value. The effect of this constraint is to make the total current density $J = e\int 2\pi n(r) V_{\parallel}(r) r dr = \mathrm{const}$, where $e$ is the electronic charge, $n(r)$ is the density, and $V_{\parallel}(r)$ the parallel electron velocity at a particular radius $r$ of the column. Assuming $V_{\parallel}(r)$ falls off in a monotonic manner, any decrease in the cross field diffusion constant $D_{\perp}$ would manifest itself by increasing the density at the center and decreasing it in the wings. This is observed experimentally when the instability is suppressed. Therefore it is inferred that suppression of this instability reduces the cross-field diffusion rate, but in the absence of a suitable theory to describe the dynamics of the arc column it is not possible to ascribe a value to the change in the diffusion constant.


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## QUASIELASTIC RAYLEIGH SCATTERING IN NEMATIC LIQUID CRYSTALS*


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Using a light-beat laser spectrometer, we observe the relaxation of the thermally excited fluctuations of anisotropy in the nematic phase of $p$-azoxyanisole. We identify the two low-frequency purely dissipative modes recently predicted. A first study of the angular dependence of the width of these modes allows a determination of three among the six viscosity coefficients introduced by Leslie.

In 1948 Chatelain[1] made the first investigation on the intensity of the light scattered by a nematic monocrystal; his most interesting result was the observation of a very strong depolarization in small-angle scattering. De Gennes[2] has recently explained these results in terms of low-amplitude thermally excited fluctuations of the nematic direction of molecular alignment (i.e., the "director"). A computation of the dynamical behavior of these fluctuations shows that they are dominated, for the light-scattering properties, by two purely dissipative low-frequency modes.[3] In this Letter we report on the first observation of these modes, by spectral analysis of the quasielastic scattered light from a nematic liquid monocrystal.

Let us recall the main results of the theoretical study[3]: $\vec{n}_0$ is the average nematic director, and $\delta\vec{n}(\vec{q})$ its fluctuations as a function of wave vector $\vec{q}$. $\delta\vec{n}$ can be decomposed into two uncoupled components: (a) $\delta\vec{n}_1$ in the $(\vec{q}, \vec{n}_0)$ plane, a combination of "bending" and "splay" deformations[4]; and (b) $\delta\vec{n}_2$ perpendicular to the $(\vec{q}, \vec{n}_0)$ plane, a combination of "bending" and "twist" deformations.[4] For the usual nematic materials, these modes are purely relaxational with Lorentzian spectral densities of half-width $u_{S1}$ and $u_{S2}$ (angular-frequency units). Assuming that piezoelectric effects[5] are negligible, the $\vec{q}$ dependence of $u_{s1,2}$ is expected to be of the form $Kq^2/\eta$, where $K$ and $\eta$ are angular averages of, respectively, the Frank elastic moduli[4] $K_{ii}$ ($i = 1, 2, 3$) and the six Leslie viscosity coefficients.[6] Assuming the knowledge of the $K_{ii}$, our experiment allows, in principle, the determination of the six viscosity coefficients.

Our experimental setup is the same as that of Chatelain,[1] except for the light source which is now a 50-mW He-Ne laser, and for the detector, a photomultiplier which detects the optical beats between the various spectral components of the scattered light. The resulting current fluctuations are Fourier analyzed by conventional spectrum analysis in the range 10 Hz to 500 kHz. The samples are para-azoxyanisole (PAA) monocrystals of variable thickness from 20 to 200 $\mu$, maintained at constant temperature ($125 \pm 1°$C).

The selection rules[2] for the scattered intensities allow us to observe either $\delta\vec{n}_1$ or $\delta\vec{n}_2$ by a convenient choice of geometry (Figs. 1 and 2): The incident laser beam, of wave vector $\vec{k}$, is normal to $\vec{n}_0$; the scattered-wave vector $\vec{k}' = \vec{k} + \vec{q}$ is in the $(\vec{k}, \vec{n}_0)$ plane; and $\varphi = (\vec{k}, \vec{k}')$ is the scattering angle in the liquid-crystal medium. The polarizations of incoming and scattered beams are purely ordinary or extraordinary (denoted, respectively, by a subscript o or e on $\vec{k}, \vec{k}'$). Mode 1 is observed with the $[\vec{k}_e, \vec{k}_e']$ configuration, and mode 2, with the $[\vec{k}_e, \vec{k}_o']$ or $[\vec{k}_o, \vec{k}_e']$ configuration.

We have studied the spectral density of the scattered light for variable $\varphi$ in these three geometries. One of the difficulties of this experiment is caused by the large amount of stray (unshifted) laser light in forward scattering, already observed by Chatelain.[1] The resulting superposition of the so-called "heterodyne" and "homodyne" signals implies a delicate analysis of the experimental spectra. We select here two simple cases where one signal dominates: (a) a "heterodyne" regime for the $[\vec{k}_e, \vec{k}_e']$ configuration at small angles ($0 < \varphi < 4°$), where the low-intensity wave scattered by the fluctuation $\delta\vec{n}_1$ beats with the intense unshifted light; (b) a "homodyne" regime, for the $[\vec{k}_e, \vec{k}_o']$ and $[\vec{k}_o, \vec{k}_e']$ configurations, at sufficiently large angles, where the depolarized component of the stray light is negligible compared with the strong intensity of the wave scattered by $\delta\vec{n}_2$. In these two cases, we observe pure unshifted Lorentzian spectra, and we derive the corresponding widths $u_{s1}$ and $u_{s2}$; $\varphi$ is determined from Chatelain's refractive-index data.[7]

In Fig. 1, we have plotted the angular dependence of the experimental half-width $u_{s1}/2\pi$ of the first mode. One finds that $u_{s1}$ tends parabolically to zero with $\varphi$, which is to be expected be-

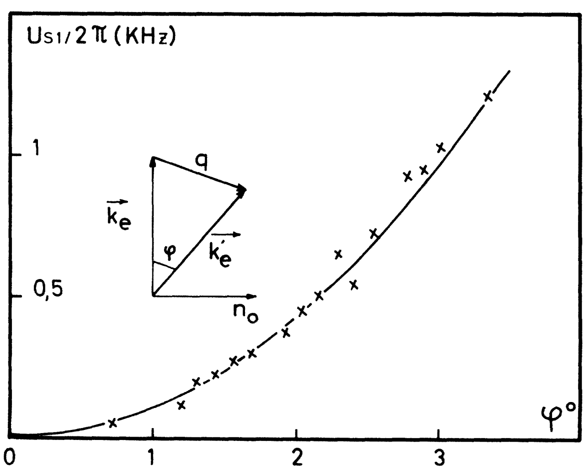


FIG. 1. Angular dependence of the half-width of the Lorentzian spectral density for mode 1 of the thermal director fluctuations in PAA at 125°C. Crosses denote experimental values. The curve results from a least-squares fit with the theoretical expression of Ref. 1.

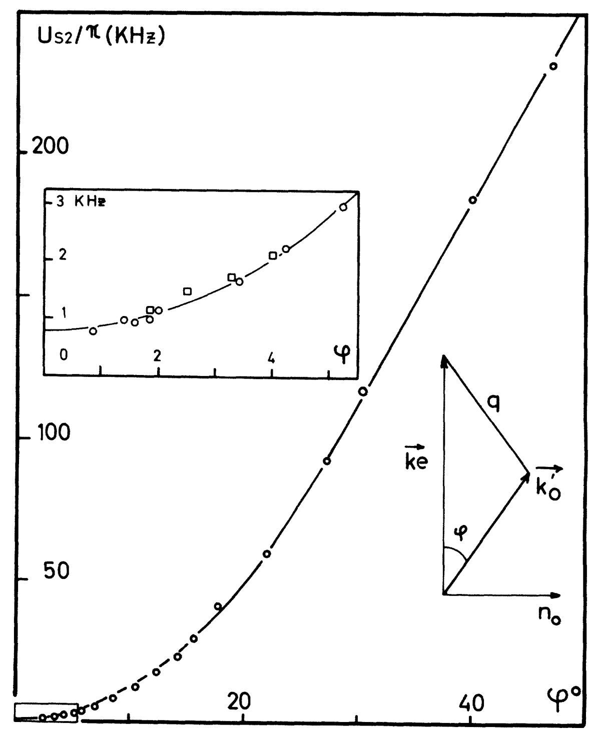


FIG. 2. Angular dependence of the width of the Lorentzian spectral density for mode 2 in PAA at 125°C. Open circles denote experimental values in the $[\vec{k}_e, \vec{k}_o']$ configurations; open squares, in the $[\vec{k}_o, \vec{k}_e']$ case. The curve results from a least-squares fit with the theoretical expression of Ref. 1.

cause in the $[\vec{k}_e, \vec{k}_e']$ configuration, $\vec{q}$ vanishes with $\varphi$, remaining parallel to $\vec{n}_0$. $\delta\vec{n}_1$ is thus a pure bending mode.

Figure 2 represents the $\varphi$ dependence of the second-mode width $u_{S2}/\pi$ in the $[\vec{k}_e, \vec{k}_o']$ case. $u_{S2}$ tends to a finite nonzero value for vanishing $\varphi$; this results from the forward-momentum mismatch $k_e - k_o$ caused by the strong birefringence of the nematic material. $\delta\vec{n}_2$ is then a pure twist mode. For larger $\varphi$ values the "bending" gives a noticeable contribution. In the $[\vec{k}_o, \vec{k}_e']$ configuration the observed $u_{S2}$ merges with that for $[\vec{k}_e, \vec{k}_o']$, for small angles, as long as the $\varphi$ dependence $k_e'$ is negligible; as expected, we observe indeed the same mode.

To try to fit our data with the computation of Ref. 1, we have taken for the PAA elastic moduli the best values from Zwetkoff,[8] i.e., in cgs units, at 125°, $K_{11} = 4.5\times 10^{-7}$, $K_{22} = 2.9\times 10^{-7}$, and $K_{33} = 9.5\times 10^{-7}$. For $u_{S2}$ $(\varphi)$, since the domain of $\vec{q}$ investigated is large enough to observe both twist and bending deformations, we can make a complete fit between our data (Fig. 2) and the $u_{S2}$ analytical form [Eq. (IV 26b) of Ref. 1]. A least-squares adjustment leads, in cgs units, to $\gamma_1 = 9.1\times 10^{-2}$, $\alpha_v' = \alpha_v/\alpha_2(\gamma_2-\gamma_1) = 13$, and $\alpha_4' = \alpha_4/\alpha_2(\gamma_2-\gamma_1) = 1.9$. The bending viscosity $\eta_B = \gamma_1 - 1/\alpha_v'$ is found to be $\eta_B = 1.4\times 10^{-2}$, distinctly smaller than the equivalent twist viscosity $\gamma_1$. The standard deviation between the calculated curve and the experimental values of $u_{S2}$ is equal to 2.5%. Taking into account the experimental uncertainties of $u_{S2}$ (noise, limited angular resolution, finite width of the beam, etc.) of the order of ±6%, we estimate the following limits for the three constants: $8.9\times 10^{-2} < \gamma_1 < 9.3\times 10^{-2}$, $12 < \alpha_v' < 14$, and $1.4 < \alpha_4' < 2.4$. This estimation does not include the uncertainty on the $K_{ii}$. For the first mode, in the "bending" regime, $u_{S1}$ depends only on $\eta_B$ [Eq. (IV 26a) of Ref. 1]. The curvature of $u_{S1}(\varphi)$, through a least-squares adjustment, gives the independent value $\eta_B = 1.4 \times 10^{-2}$ cgs units, in good agreement with the previous determination. The analysis of the first-mode width, in large-angle scattering, should lead to the determination of the last three viscosity constants. A full account of this analysis, with the temperature dependence of the Leslie coefficients, will be published in a forthcoming paper.

To conclude, our observation shows the existence and the dissipative character of the thermally excited fluctuations of the director in a nematic liquid crystal. The angular dependence of the effect is in reasonable agreement with a recent theoretical computation.

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