Weak localization due to scattering of light in nonoriented liquid crystals

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The weak localization in a natural object has been demonstrated experimentally for the first time. This effect can be exploited to study the structural and time-dependent parameters of nonoriented nematic liquid crystals. The results of experimental studies of weak localization in nonoriented nematic crystals and in model-based systems used for calibration are presented.

The structural and spatial characteristics of nonoriented liquid crystals have heretofore been virtually ignored for several reasons. In the first place, the thermophysical methods, such as the measurement of heat capacity,[1] cannot be used because they are not sensitive to the degree of orientation of a sample. The standard optics methods in this case are inapplicable, since nonoriented nematic liquid crystals are highly dispersive media with an extinction coefficient on the order of 10^4 cm^{-1}. The specific features of a strong diffusion of light are stipulated by the $3D$ structure of the nematic liquid crystal and by the local anisotropy of the refractive index, which increases with distance from the phase transition point.

The study of weak localization,[2–5] from which new information on strongly dispersive media can in principle be obtained, has recently been a subject of considerable interest. Experimentally, weak localization can be described as one in which a sharp peak appears in the scattering indicatrix at an angle of exactly 180°. The physical mechanism responsible for the appearance of the peak or the weak localization as a result of multiple backward scattering is based on the reversibility of the photon transmission paths in the medium and on the appearance of mutually coherent components in the scattered field.[2–6]

We have used weak localization to study the structure of nonoriented nematic liquid crystals. The measurements were carried out using an experimental arrangement shown in Fig. 1.

A valid experimental study of weak localization involves an analysis and suppression of the interference effects associated with diffuse reflection and scattering from all optical elements of the apparatus and also carrying out of several other calibration experiments. In the control experiments we used a concentrated solution of a black watercolor to fill the scattering cell C with an absorption coefficient on the order of 10^4 -10^5 cm^{-1}. An empty square cell or one filled with a standard fluid could not be used as a test cell because of the strong diffuse reflection at its back window. In our apparatus the parasitic illumination at $\theta = 180°$ was no greater than 2%. The second light beam, reflected from a thick parallel-plane beam splitter BS (Fig. 1), was used for the

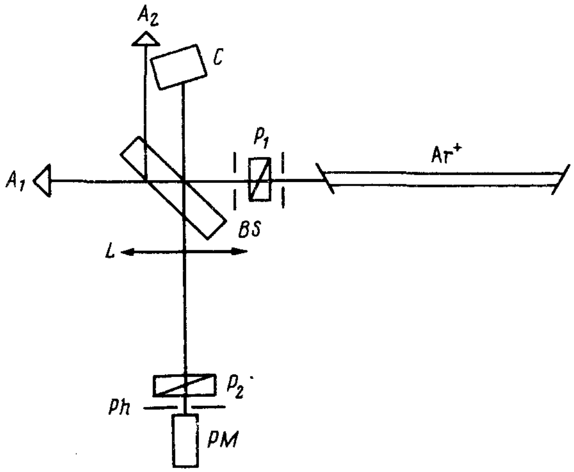

FIG. 1. C—Cell; BS—beam splitter; L—lens ($\phi = 50$ cm); P_1, P_2—polarizers; PM—photomultiplier; A_1, A_2—light-abosrbing cells; Ph—circular diaphragm ($\phi = 0.2$ mm).

fine adjustment of the entire apparatus. The intensity at angles $\theta \sim 180°$ was measured with approximately 2% error.

To check the reliability of the results which we have obtained, we carried out several measurements in polystyrene latex aqueous solutions with particle diameters 0.5, 1.02, and 2.55 μm. The results of measurements for particles with diameters to 1 μm agree with those obtained in Refs. 2 and 3 with respect to the relative intensity of the peak and with respect to its dependence on the scattering angle and polarization.

It is interesting to note that scatterers whose indicatrix is extended in the forward direction retain a strong effect whose existence in them is not obvious beforehand. In

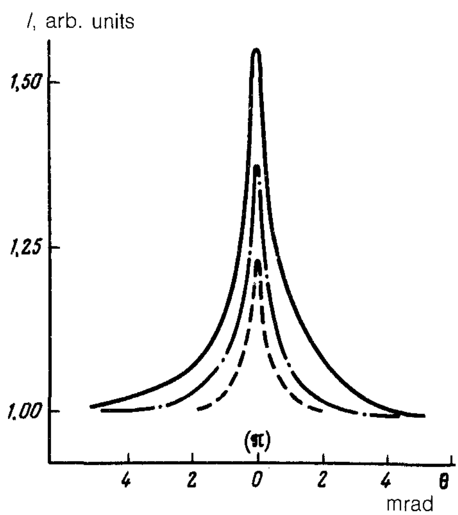

FIG. 2. Angular dependence of the scattering intensity in the region $\theta \sim 180°$ for a latex solution ($\phi = 2.55$ μm). Solid curve—Volume concentration of the latex, $c \approx 15\%$; dot-dashed curve—$c \approx 5\%$; dashed curve—$c \approx 1.5\%$.

our experiments a weak localization in a latex with a particle diameter 2.55 μm was detected consistently in the range of concentrations from 15% to 0.5%. The results of measurements are shown in Fig. 2. In the case of a fixed measurement time on the order of 5 s, the dispersion of the measured intensity near the peak center is markedly greater than that of a latex with smaller particle size, reaching a level of 10–15%. As a result, we could estimate the time scales of the fluctuation in the distribution of the intensity of weak localization. In particular, the variance of the peak fluctuations correlates well with the estimate of the time required for changing the speckle structure of the scattered field, $\tau = \lambda^2/D = 2.5$ s, where λ^2 is the wavelength of light, and D is the self-diffusion coefficient of latex particles.

We have studied two liquid crystals, BMOAB and a mixture of MBBA + EBBA, as a function of temperature near the point at which the samples undergo a transition to the liquid phase. These studies were carried out on the basis of a method which was verified in the control experiments described above.

The backscattering peak was clearly seen in the polarized component of each sample. A slight increase in the relative intensity was detected with distance from the transition point, in qualitative agreement with the behavior of the optical anisotropy $n_0 - n_e$. As can be seen from Fig. 3, the relative peak height in BMOAB exceeds the corresponding peak height in the mixture of MBBA + EBBA, which is attributable to the difference in the quantities $n_0 - n_e$.

Since a rigorous theory of weak localization has been developed only for particles with a circular scattering indicatrix,[6] experimental results on liquid crystals cannot be analyzed quantitatively. A comparison of the characteristics of weak localization in nonoriented nematic liquid crystals with similar data on latexes showed, however, that

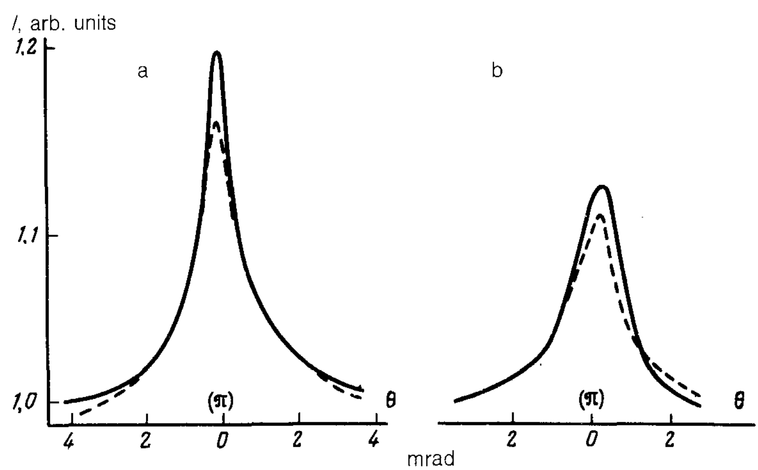

FIG. 3. Angular dependence of the scattering intensity in the region $\theta \sim 180°$ for nonoriented nematic liquid crystals. a—BMOAB, $T_c = 72°$C—solid curve, $T^0 = 41°$C; dashed curve—$T^0 = 58°$C; b—a mixture of MBBA + EBBA, $T_c = 57.7°$C—solid curve, 43.5°C, dashed curve, 56.5°C.

their characteristic size in the region of preferred orientation is on the order of several microns and that they can be distinguished in particular samples. Since no noticeable variance in the intensity of the backscattering peak was detected in the samples, we could not set a lower limit on the time scale for the change in the $3D$ structure.

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