High transparency of nematic liquid crystal for *o*-waves (experimental)

N. B. Baranova, I. V. Gusev, B. Ya. Zel'dovich, and V. A. Krivoschekov
Leninist Communist Youth League Chelyabinsk Polytechnical Institute

(Submitted 13 June 1990)
Pis'ma Zh. Eksp. Teor. Fiz. **52**, No. 2, 745–747 (25 July 1990)

Thick cells (1–5 mm thick) with a nematic liquid crystal appear opaque because of inhomogeneities in the orientation in the volume. It has been found that an *o* wave can carry an image through such a crystal quite well if the orientation is uniform and rigidly fixed at the boundaries.

As light propagates through a nematic liquid crystal with smooth variations in the director, the light waves of both the *o* and *e* polarizations adiabatically follow the orientation of the optic axis. For the nematic liquid crystal 5CB, we have $n_e - n_o \approx 0.3$ and $\Delta K = K_e - K_o = 3\times 10^4\ \mathrm{cm}^{-1}$, so the condition for adiabatic tracking $|\Delta K| \gg |d\alpha/dz|$, holds with an ample margin even if the length scale of the variations is $L \sim |d\alpha/dz|^{-1} \sim 10^{-3}$ cm. The phase of the *e* wave varies in accordance with

$$\varphi_e(x, y, z) \approx \frac{\omega}{C}\int_0^z dz'[n_0 + (n_e - n_0)\sin^2\theta(x, y, z')],$$

where θ is the angle between the optic axis and the propagation direction $\mathbf{e}_z$. The wavefront of the *e* wave thus becomes greatly curved as a result of the variations in

$\theta(\mathbf{r})$, and the e wave is scattered through progressively larger angles as it propagates into the interior of the cell. In contrast, the phase of the o wave is not affected by the variations: In this case there is only an adiabatic variation of the polarization. Let us assume that the orientation is furthermore rigidly fixed at the cell walls. For example, we assume a planar orientation, the same at both surfaces. A plane wave of the o polarization then remains a plane wave as it passes through the cell. Its phase may change, possibly by π, if the adiabatic rotation results in a rotation angle which is 360° times a half-integer.

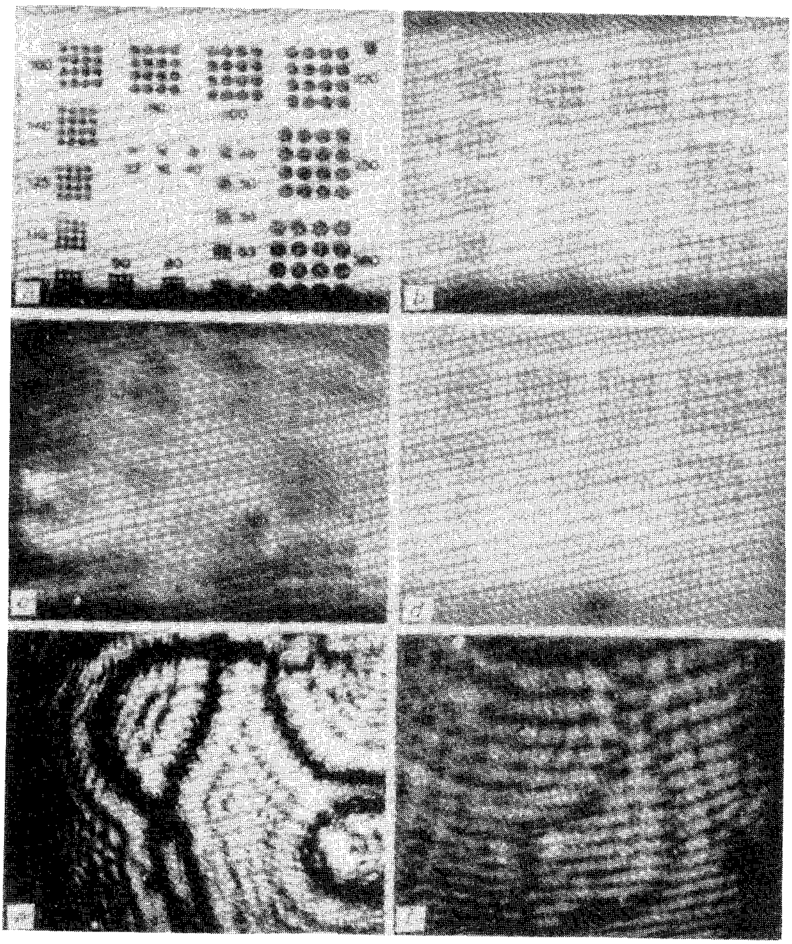

FIG. 1. *a*—Image of a test object in front of a cell with a liquid crystal; *b*—the same image, photographed in the *o* polarization transmitted through a cell 1 mm thick; *c*—the same image, photographed in the *e* polarization transmitted through a cell 1 mm thick; *d*—the same image, photographed in the *o* polarization transmitted through a cell 5 mm thick; *e*—projection onto a screen of a characteristic disclination which arose in a cell with a liquid crystal 1 mm thick; *f*—interference pattern produced by mixing a reference wave with the wave transmitted through a cell 1 mm thick.

Such a change in sign can occur as an o wave passes on different sides of a disclination.

The qualitative picture drawn above is taken from Ref. 1, where some quantitative theoretical estimates were made. In the present letter we are reporting the results of a special experiment carried out with cells having a planar orientation at the boundaries. The cell thicknesses were 0.4, 1.2, and 5 mm. The eye perceived the 5-mm cell as absolutely whitish and opaque, while the 1-mm cell scattered light extremely strongly and transmitted light weakly. When a polarizer was placed in front of and/or behind the cell, however, it was possible to draw the conclusion that essentially only the e wave was involved in the scattering.

When only the o wave or only the e wave was incident on the cell, the light leaving the cell was essentially 100% polarized, with the same orientation of the vector **E**.

Figure 1a shows a photograph of an image of a test object (a slide); Fig. 1b shows the same image when photographed in the o polarization transmitted through the 1-mm cell. Figure 1c shows the same, for the e polarization transmitted through the 1-mm cell, and Fig. 1d shows that for the o polarization transmitted through the 5-mm cell. The light transmitted through the 5-mm cell in the e polarization was scattered through angles $\sim\pi/2$, so no light at all struck the screen. This case is thus not shown in Fig. 1. Figure 1e shows a projection of the disclination onto the screen found during the exposure of the 1-mm cell to a spherical wave from a He–Ne laser.

The characteristic bands here—a fundamental black band and some bands running parallel to it on both sides— are a result of the diffraction of a plane wave $E(x) = \text{const}\ (x/|x|)$ (waves with a phase shift of π). To improve the reliability of the detection of the phase shift, we mixed a reference wave with the o wave transmitted through the cell (Fig. 1f). We see that the interference fringes are shifted half a wavelength upon the intersection of the projection of the disclination.

We hope that this effect will make it possible to develop several new devices to operate on the basis of a polarization discrimination of images.

We wish to thank V. N. Sadovskiĭ for furnishing the liquid crystal.

[1]N. B. Baranova and B. Ya. Zel'dovich, Pis'ma Zh. Eksp. Teor. Fiz. **32**, 636 (1980) [JETP Lett. **32**, 622 (1980)].

Translated by D. Parsons