Topological defects in cholesteric liquid crystals

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The polarization microscopy method has been used to detect and study the domain defects in cholesteric liquid crystals (CLC), whose characteristic features are in agreement with those predicted theoretically for Dirac monopole structures. A model is proposed for the arrangement of CLC molecules in such formations.

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Various types of defects of the CLC structure have been classified theoretically and described. Among them, the monopoles, which are unique combinations of line and point defects, are of special interest for investigation, since the monopoles in CLC are analogous, in terms of their structure, to a Dirac monopole and also to a vortex with an end in the superfluid ^{3}He-A.[1] CLC is the most accessible medium for observing such formations: methods which use polarization microscopy and room temperature are usually adequate for the detection and identification of defects in CLC. Until now, however, the existence of Dirac monopole structures in either CLC or other media has not been verified experimentally in the literature, as far as we know.

Our purpose is to study experimentally the CLC textures by using the polariza-

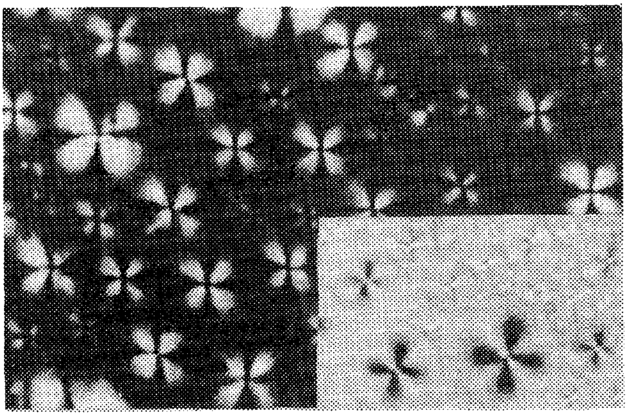

FIG. 1. Domain texture of a CLC sample with one free surface in the crossed-Nicol regime (lower right corner–obliquely crossed-Nicol regime). Magnification is 500.

tion-microscopy method and to determine whether the monopole-type defects exist in CLC.

The results of our study are shown in Figs. 1 and 2. Figure 1 shows a CLC texture that appears after the following operations have been performed: the CLC sample (cholesteryl chloride, Tecon-20, or a mixture of these materials) was placed in a flat quartz cell with a calibrated thickness (10–100 μm), whose faces were not treated in any special way. The sample was heated to the isotropic phase and then cooled; the resulting disordered pattern was changed into a planar texture by shifting the upper plate of the cell. In this case in the portion of the cell with one free surface a texture was formed with defect structures 5–30 μm in size (see Fig. 1), which exhibit no intrinsic selective coloration. A similar texture for the cholesteric mesophase had been observed earlier[2]; however, no explanations of its nature were given.

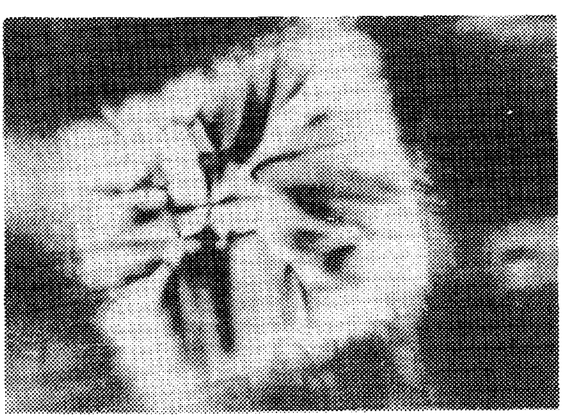

FIG. 2. Texture of a CLC sample with two free surfaces (crossed-Nicol regime). Sample is placed in a polymer-grid cell with dimensions $100 \times 100 \times 100$ μm.

We observed both single formations, which were surrounded by a planar texture, as well as whole groups of adjoining defects. The defects are outlined by boundary lines; this indicates the presence of a domain structure. Examination in the crossed-Nicol regime revealed for each domain four extinction arms that originate at the center and terminate at the boundary lines. The structure of the central region in crossed Nicols appears as a dark point $\lesssim 1\ \mu m$ in size, while in the parallel Nicols it appears as two points separated from each other by a distance of the same magnitude.

The defects vanished when the second plate of the cell was laid on the free sample surface. It was observed again on two free surfaces (Fig. 2). When the texture is viewed from the end of the cell, the domains are protrusions with a truncated vertex.[3]

We show that all the features of the defects observed experimentally can be explained if it is assumed that each domain is a monopole. We note that other possible assumptions about the domain structure—for example, a confocal or bubble structure or a polygonal texture—do not agree with all the experimental data presented above.

According to theoretical concepts,[1] a monopole in a CLC is a system of equidistant spherical concentric CLC layers, from whose center originates a force disclination $m = 2$, which is perpendicular to the layers, a $\chi(+2)$ line. The $\chi(+2)$ line, however, can decompose into two force disclinations $1-\chi(+1)$ lines. The sphere-like arrangement of the CLC layers is not changed in this case. Consequently, in the experiment the monopoles must have $\chi(+2)$ or $\chi(+1)$ lines and also, which is crucial, a domain structure.

The defects observed by us have clearly defined domains. An absence of selective coloration of the domains (in contrast to the planar texture surrounding them) is caused by the nonconservation factor of the effective pitch of the periodic helix in the direction of the light beam as it propagates through the system of concentric monopole layers (Fig. 3a). The annular boundary line around each defect is caused by the abrupt change in the direction of the vector **d**, which specifies the orientation of the molecules, as one goes from the surface layer of the monopole to the sur-

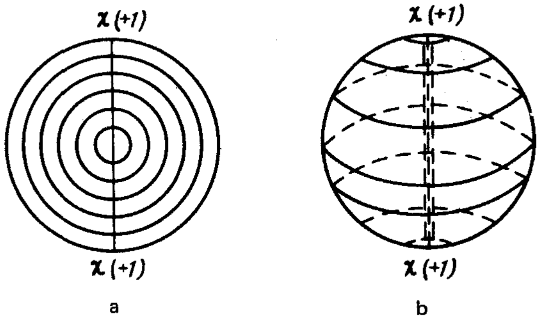

FIG. 3. (a) Arrangement of CLC layers and $\chi(+1)$ lines in the monopole for the care of the decomposition of the $\chi(+2)$ line into two $\chi(+1)$ lines; (b) arrangement of molecules on the outer surface of the monopole and at the center of the $\chi(+1)$ disclinations.

rounding structure.

The presence of four extinction branches indicates the formation of a force line 1 perpendicular to the CLC layers—a $\chi(+1)$ line (the sign of the defect force is positive).[4] This corresponds to the theoretically predicted splitting of the $\chi(+2)$ line, with length R and force 2, into two $\chi(+1)$ lines, each of which has a length R and force 1 (R is the monopole radius). Such splitting is energetically advantageous: the disclination formation energy is $f \sim m^2 l$, where l is the line length. The arrangement of disclinations along a vertical line can be explained if we consider the field **d** on the outer surface of the monopole. From the constraint of the minimum distortion energy near the monopole boundary and the planar texture surrounding it we can conclude that the field **d** is a series of parallel circles on the domain surface which are coplanar to the layers of the planar CLC texture. This also accounts for the vertical arrangement of the $\chi(+1)$ lines (Fig. 3b). The center of the $\chi(+1)$ line, according to Ref. 5, is nonsingular and consists of parallel-ordered molecules. Such ordering causes the $\chi(+1)$ lines to appear in the form of a dark, thick filament with a diameter of the order of the helix pitch.[6] As already indicated, a dark central point $\lesssim 1\ \mu m$ in size, which we attribute to the emergence of a disclination center on the monopole surface, has been observed. The two points in the central region, which are observed in the parallel-Nicol regime, are attributable to a change in the orientation of the vector **d** as we go from the disclination center to the spherical layers of the monopole.

The domains seen from the end of the cell as truncated protrusions are also consistent with the monopole concept: the protuberance is a part of the spherical surface of the monopole, and the truncation is attributable to the emergence of the center of the $\chi(+1)$ line at its vertex. The vanishing of the defects when the second confining surface is added occurs because the plane surface prevents a sphere-like arrangement of the CLC layers, which is necessary for monopole formation.

The data presented by us seem to indicate that the detected defects are monopoles in the CLC. Further studies are needed for a more detailed confirmation of this conclusion. It is important to investigate the behavior of such defects under the influence of various external conditions.

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