Negative-positive monopole transitions in cholesteric liquid crystals

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The nature of the changes in the monopole structures accompanying a transition out of a levorotary into a dextrorotary cholesteric is clarified experimentally for the first time. The concept of "+" and "−" monopoles in cholesterics is introduced. In the inversion region, textures are discovered with equatorial disclinations and surface and volume point defects. Analogies with textures of ^{3}He-A in a sphere are noted.

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The possibility of the formation of spherical concentric systems of cholesteric liquid crystal (CLC) layers with a defect line emerging from the center of each such system was established in Refs. 1 and 2 for the case $|q|R \sim 10$ ($|q| = 1/P$, where P is the pitch of the CLC helix, and R is the radius of the drop) as a result of investigations of spherical drops of CLC. In the continuum approximation ($|q|R \gg 1$), as shown theoretically in Ref. 3, such textures represent monopoles in CLS, the analog of the Dirac monopole. In addition, both structures with one $\chi(+2)$ and two $\chi(+1)$ lines were predicted. The experimental investigation described in Refs. 4 and 5, carried out for $|q|R \sim 100$, confirmed the results in Ref. 3.

A monopole in CLC is characterized by the presence of a point singularity in the field of the vector **n** normal to the cholesteric layers, out of which emerges the χ line.[3] Depending on the right or left-handedness of CLC helix (CLCR and CLCL, respectively), the vector **n** turns out to be parallel or antiparallel to the radius vectors of the spheres; in other words, it is possible to distinguish "+" and "-" monopoles. In this connection, it is interesting to investigate the nature of the possible transformations of "-" into "+" monopoles and vice versa, which was the subject of this work. Such a transformation can be realized for a mixture of two CLC with different signs of the helicity (sign of q), since it is well known that in such systems at a certain temperature a transition occurs from negative to positive values of q.[6] At the inversion point, $q = 0$ and the mixture is a nematic liquid crystal (NLC).

In this work, we used a mixture of cholestryl chloride and cholestryl myristate in a proportion 1.75:1.00 by weight with an inversion temperature of 41° C, above which the mixture is a CLCL ($q < 0$) and below which it is a CLCR ($q > 0$). The substance was dispersed in the form of spherical drops with radius $R \lesssim 50$ μm in isotropic liquids: pure glycerine in order to create tangential boundary conditions and glycerine with additions (up to 1%) of a lecithin solution in order to create normal boundary conditions.[7] The specimens were studied with the help of an NU-2*E* polarization microscope and the temperature was varied at a rate 0.2 °C/min.

The results of the investigations of freshly prepared mixtures for transitions of the isotropic liquid (IL)→CLCL→NLC→CLCR are shown in Figs. 1 and 2. We note that for the opposite transitions, the nature of the textural transformations does not change.

Tangential boundary conditions. In an IL-CLCL transition in drops, concentric spherical layers of CLC with χ lines form. Since the mixture at temperatures $t > 41\,°\mathrm{C}$ is levorotatory, the textures represent "-" monopoles. In addition, the probability for the formation of a $\chi(+2)$ line in a drop is greater than the probability for the formation of two $\chi(+1)$ lines by a factor of approximately 100. As the temperature decreases, the CLCL helix unwinds (Fig. 1a), while at the same time the positioning of the layers remains the same up to values $|q|R \sim 1$. In addition, only drops with $\chi(+2)$ lines are observed. The t dependence of q, measured by using the procedure in Ref. 2, is almost linear, consistent with the data in Ref. 6. The size of the cores of the $\chi(+2)$ lines increases with an increase in the pitch of the helix. For $|q|R \lesssim 1$, at the location where the χ lines reach the surface of the drop, the core degenerated into two singular points (Fig. 1b), which separated toward the poles of the drop (Fig. 1c); as a result, a so-called bipolar texture[2] with two diametrically opposite point surface singularities of strength +1 each were established. With further decrease in t and inversion of the sign of q, the singulari-

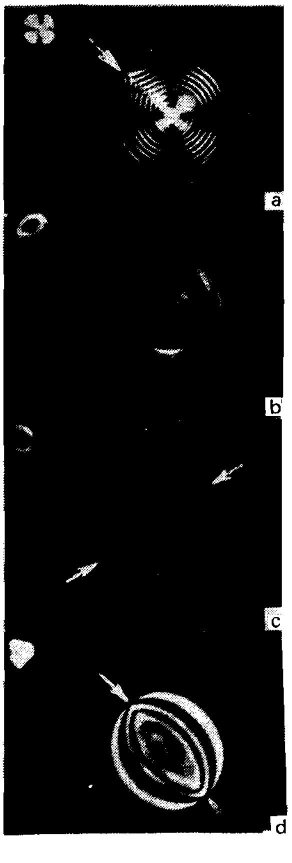

FIG. 1. CLC drop with $R = 35\ \mu\mathrm{m}$ in glycerine. The nichols are crossed. a) Monopole structure with $\chi(+2)$ line, $P = 6.5\ \mu\mathrm{m}$; b, c, d) show the degeneration of the $\chi(+2)$ line into two singular points and their divergence toward the poles of the drop ($P \approx 40, 60 > 100\ \mu\mathrm{m}$, respectively). The defects are indicated with arrows.

ties converge and, at the point where they are localized, $\chi(+2)$ disclinations of "+" monopoles with a dextrorotary helix emerge.

Thus, for CLC drops with tangential boundary conditions, transitions of "+" into "-" monopoles (and vice versa) are caused by mutual transformations of $\chi(+2)$ disclinations and surface point singularities with intensity +1. We note that the convergence of two points of a bipolar texture is reminiscent of a transition to the boojum type texture[8] with a single surface singularity with intensity +2, but only for the case $|q|R < 1$, since for $|q|R \gg 1$, as pointed out in Ref. 5, the formation of a boojum is related to considerable energy losses due to the existence of the condition for equidistant separation of CLC layers.[3]

Normal boundary conditions. For high values $|q|R > 10$, the textures in the drops represent "-" monopoles; i.e., in this case, the conditions on the surface do not change the packing of the layers. However, they are manifested for $|q|R < 5$: the appearance of an additional defect, an equatorial disclination, is observed (Figs. 2a and 2b). Such a defect was predicted theoretically[9] and observed experimentally[2] for drops of a nematic liquid crystal in a strong magnetic field. The results of this study indicate that the presence of an external magnetic field is not a necessary condition for the formation of a sur-

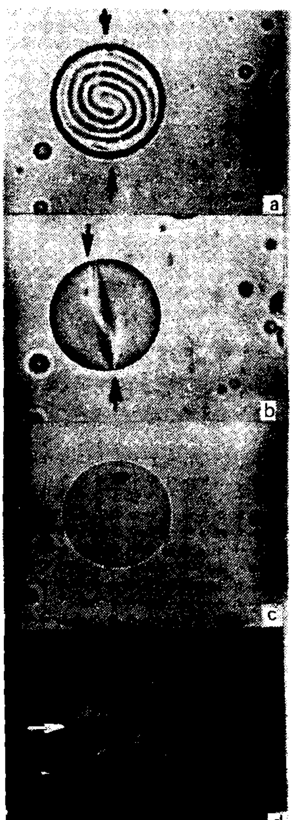

FIG. 2. The CLC drop with $R = 38$ μm in glycerine but with the additions of lecithin. The nichols are missing. a) Equatorial disclination, $P = 16$ μm; b) equatorial disclination, $P = 80$ μm; c) point surface singularity, $P \geqslant 80$ μm; d) same, in crossed nichols. The defects are indicated with arrows.

face disclination. In the region $|q|R < 1$, a disclination can relax into a point surface defect (Fig. 2c). Investigation of this texture in crossed nicols (Fig. 2d) confirms that the configuration of the director **d** for it is analogous to the distribution of the vector **l** of the orbital angular momentum for superfluid ^{3}He-A in the boojum texture.[8,10,11] The contraction of the disclination into a point defect is analogous to the relaxation of the texture of ^{3}He-A in a sphere with equatorial semidisgyration to the texture of a boojum[10,11] and results from the energy conditions: the energy of linear defects, in contrast to point defects, contains logarithmically divergent terms $\sim R \ln R$.

Textures with equatorial disclinations and surface point defects were not the only possible ones: Their transitions into radial structures (studied in detail in Ref. 2) and the reverse transitions out of the radial textures into textures with surface point defects were observed.

A further decrease in temperature results in the formation of "+" monopoles. In addition, if these monopoles are preceded by textures with a surface point singularity, $\chi(+2)$ lines will emerge at the location of this point.

Thus, the transition "+" to "-" monopoles in CLC (and vice versa) under normal boundary conditions is characterized by the formation of additional surface defects, equatorial disclinations, and a point singularity analogous to the singularity of the **l** vector in the boojum structure for ^{3}He-A, as well as the formation of a point defect in the drop.

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