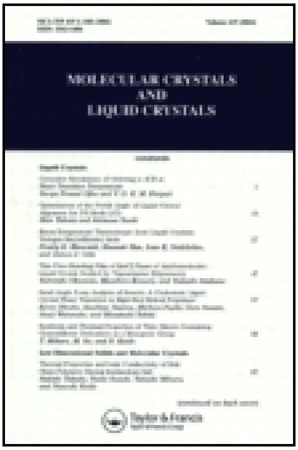

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PHYSICAL PROPERTIES OF TOPOLOGICAL DEFECTS IN HYBRID ALIGNED NEMATIC FILMS

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Abstract Topological defects in thin nematic films with different and degenerate orientation of the director on the upper and lower surfaces have been investigated. High strength defects with nonuniform deformations of the director in horisontal plane, strings connecting pairs of defects and different periodic structures have been described.

INTRODUCTION

Topological defects in the distributions of order parameter are extremely important subjects of research in various branches of physics. Some clarity has now been achieved in the classification of these defects for infinitely large volumes. On the other hand, the physical properties of defects located in bounded volumes have received little study. These properties are governed, in particular, by the nature of boundary conditions and the balance between the energetical parameters such as anchoring energy and elastic constants. Up to the present studies have been made for liquid crystal in capillaries and spherical drops.[1] Bounded geometry of capillaries and drops provides the stability of topological defects in a trivial manner. In this paper we report some results of the investigation of the defects in thin films of hybrid aligned nematic with degenerate boundary conditions (HAND films). It is shown that some properties of defects in this geometry are unexpected and such objects as high strength defects, strings and periodic domain structures can exist.

To provide the above mentioned b undary conditions, we deposited the nematic films on the surface of isotropic fluid (glycerine, for example), which imposed degenerate tangential orientation of the director $\vec{n}$ at the lower boundary of the film. The upper boundary was left free; since we were studing compounds MBBA, 5CB and ZhK-440, the orientation of $\vec{n}$ was nearly normal.

HIGH STRENGTH DEFECTS

HAND films with thickness h ($1\ \mu m \leq h \leq 20\ \mu m$) exhibit unusual textures which contain a rich array of singular points. It was founded by observations under polarizing microscope that these points correspond to defects with topological charges (strengthes) $m = 0, \pm 1, \pm 2, \pm 3$, etc. It is very important, that the distortions of the director are distributed nonuniformly in the film plane. Namely, inside one sector ($\Phi \leq \varphi \leq 2\pi$) the distribution is radial, as for m = 1 defect. The scarcity of the director revolutions up to $|m| > 1$ is filled up in the remaining narrow sector ($0 \leq \varphi \leq \Phi$). These configurations may be written approximately as

$$n_x = \cos\theta(z)\cos M\varphi,\ n_y = \cos\theta(z)\sin M\varphi,\ n_z = -\sin\theta(z), \quad (1)$$

where $M = 1$ for $\Phi \leq \varphi \leq 2\pi$ and $M = m' = 1 + 2\pi(m-1)/\Phi$ for $0 \leq \varphi \leq \Phi$, $\theta(z) = qz$, $q = (\theta_2 - \theta_1)/h$, θ_1 and θ_2 are the the angles between $\vec{n}$ and the normals to the lower and upper surfaces (axis z), respectively. Optical and elastic properties of these defects will be discussed elsewhere.[2] In this paper we illustrate the situation only for singularity with m = 2 (Fig.1). With this purpose let us compare the elastic energies of some possible director configurations in HAND films.

Elastic energy of m = 2 defect with trivial (uniformly deformed) structure (M = 2 in the whole azimuthal plane $0 \leq \varphi \leq 2\pi$) in one-constant approximation is

$$F_2 = \pi Kh(q^2R^2 + 4\ln(R/r_c))/2 + F_c \qquad (2)$$

(R is the radius of the film, r_c, F_c are the radius and energy of the defect core, respectively). F_2 is greater than the elastic energy F_o of the uniform state with M = m = 0 :

$$F_o = \pi Khq^2R^2/2. \qquad (3)$$

However, F_2 may be considerably reduced in the case of complex defect structure (1) with M = 1 inside sector ($\Phi \leq \varphi \leq 2\pi$) and with M = m'>2 inside sector ($0 \leqslant \varphi \leqslant \Phi$):

$$F_2' = \frac{\pi Kh}{2}\left[q^2R^2 + (3 + 2\pi/\Phi_o)\ln(R/r_c) - \right.$$
$$\left. - 2qR(1-\Phi_o/2\pi)\right] + F_c' . \qquad (4)$$

Equilibrium value of Φ_o one obtains by minimizing F_2':

$$\Phi_o = (2\pi^2\ln(R/r_c)/qR)^{1/2}. \qquad (5)$$

An analysis of Eqs.(3)-(5) leads to the conclusion that for sufficiently large R/h defect states with complex structures are energetically preffered even than the uniform state of HAND film: $F_2' < F_o$. This result is a consequence of the principle of splay cancelling:[3] if the boundary conditions force a variation of $\vec{n}$ in one direction, than a variation of $\vec{n}$ in another direc-

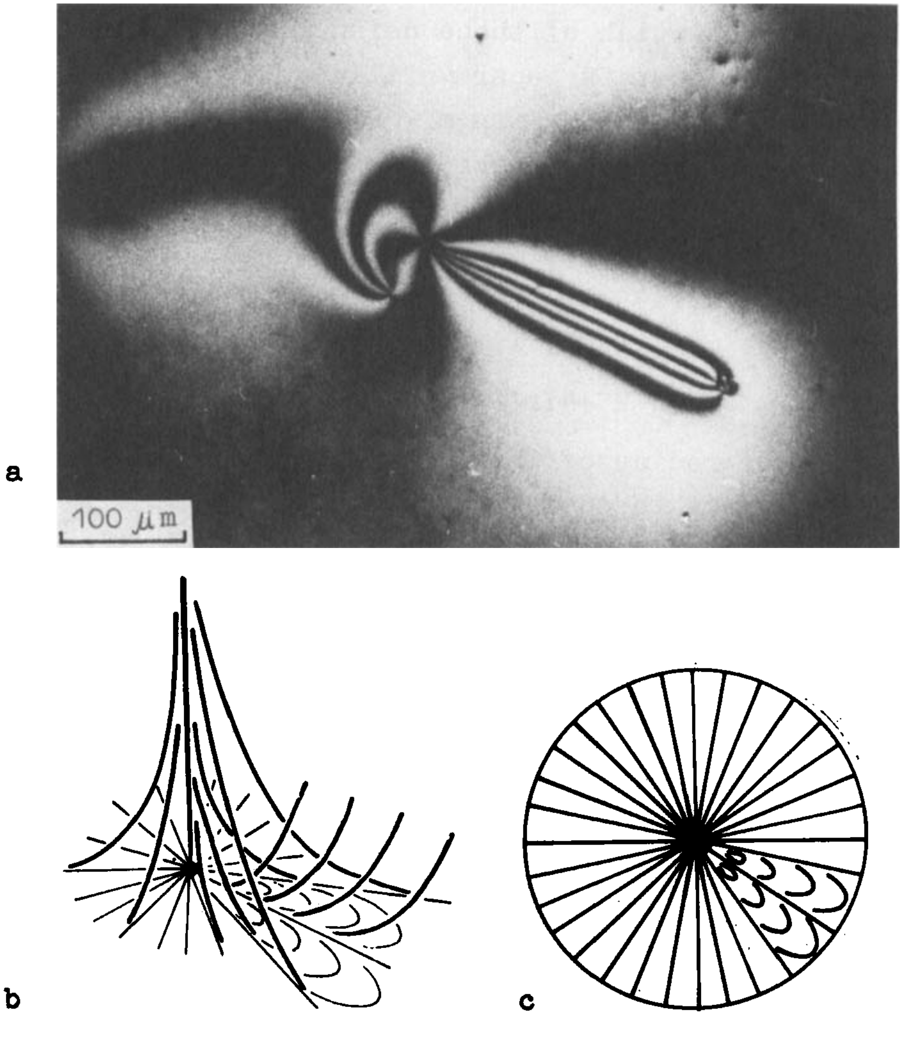

FIGURE 1 Defect with strength m = 2: a) texture of DHAN film of 5CB on glycerine; b) schematic representation of defect structure; c) projection of director field onto the horisontal plane.

tion can lead to a cancellation of splay contributions in elastic energy. This principle may be illustrated by rewritting $(\operatorname{div}\vec{n})^2$ as $(1/R_1+1/R_2)^2$, where R_1 and R_2 are the principal radii of curvature.[1] As a consequence, the elastic energy can be reduced when $R_1R_2 < 0$. This is exactly the situation of radial type distribution inside one sector of the complex structure of high strength defects, where $R_1R_2 < 0$ (Fig.1b). The presence of this sector saves the total energy of high strength defect.

STRINGS

In thin DHAN films ($h \sim 10\,\mu m$) neighbouring singularities of opposite signs are connected by strings, in which the nonuniform distribution of $\vec{n}$ between defects is stretched out, Figs.1a,2. String is seen as 4 parallel brushes in polarized light due to the fact that n undergoes a rotation through 2π within the string width D. Approximately,

$$n_x = \cos qz \cos py,\quad n_y = \cos qz \sin py,\quad n_z = -\sin qz, \qquad (6)$$

where $p = 2\pi/D$. As time elapses, defects close on each other along the string. The closing velocity V does not depend on the distance L between defects.[4] The dynamics of the string is ruled by the law of the interaction of two point singularities. Elastic energy F_{st} of string with distribution (6) is

$$F_{st} = \pi^2 KL(D^2 + 8h^2)/8Dh. \qquad (7)$$

It follows from Eq.(7) that the force of interaction of point defects in HAND film does not depend on the separating distance. It is this circumstance that explains the experimental data V = const. Really, from the equation of motion

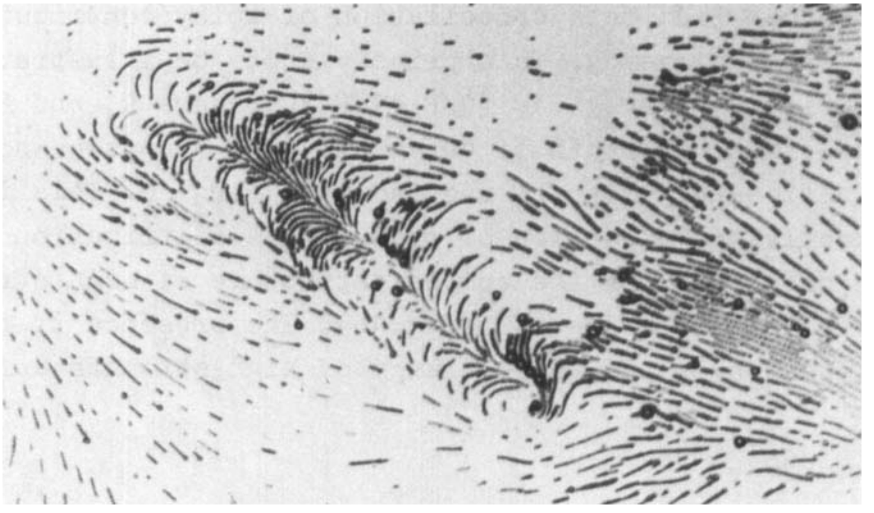

FIGURE 2 Decorated sample of HAND film with string connecting defect m = 1 and antidefect m = -1. The chains run along lines of the director on tangentially anchored lower surface of HAND film.

$$dF_{st}/dL = \gamma DV, \qquad (8)$$

where γ is effective orientational viscisity, one can find the defect closing velocity

$$V = \pi^2 K(D^2 + 8h^2)/8\gamma D^2 h, \qquad (9)$$

which does not depend on L.

We wish to stress the importance of the three-dimensional nature of the deformations of $\vec{n}$ in thin HAND films for the appearance of strings. In thick films ($h > 50\,\mu m$) strings were not observed; furthermore, strings were not observed in samples of any thickness if the boundary conditions were the same. The explanation apparently lies in the two-dimensional nature of the director field in these samples.

PERIODIC STRUCTURES

Being able to form the periodic spatial structures either due to specific intermolecular interactions (cholesterics, smectics, blue phases) or under the action of external directive forces (for example, electromagnetic field) is one of the most important properties of liquid crystals. We have experimentally discovered the periodic structures in the translationally symmetric nematic phase with no external field.[5] The observations under polarizing microscope revealed one- and two-dimensional periodic structures in very thin ($h \leqslant 1\,\mu m$) HAND films. One-dimensional structures were observed and theoretically described in Ref.5. It was shown that the uniform state of HAND film for which the director has been assumed to be deformed only in vertical plane, can be unstable with respect to the deformations in horisontal plane. The main reason for the formation of one-dimensional stripe domains is the smallness of the twist elastic constant.

Two-dimensional structures are too complicated for a description. There are two types of two-dimensional structures: (1) nonsingular one, which can be smoothly transformed into one-dimensional stripe structure and (2) singular one, consisting of lattices of $m = +1$ and $m = -1$ defects, Fig.3. Physical nature of these structures may be caused by both the balance of elastic moduli and the splay cancelling principle.

a

b

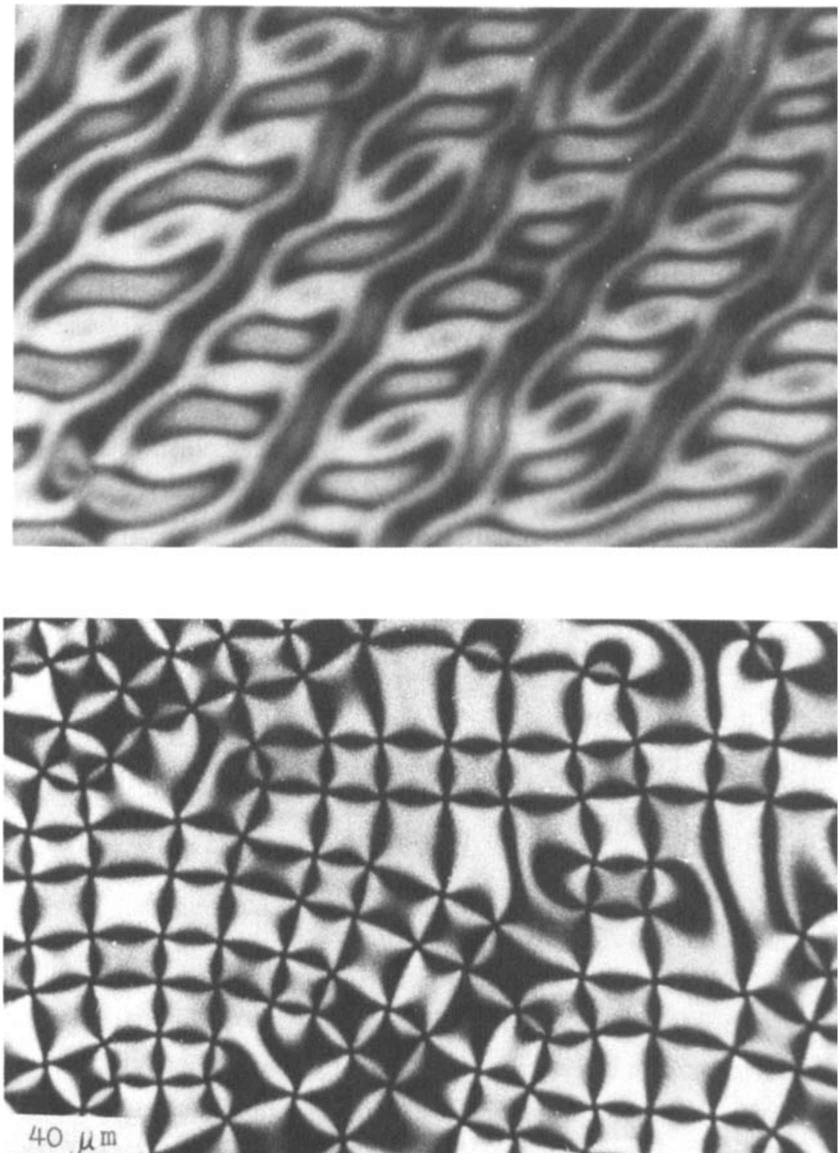

FIGURE 3 Two-dimensional periodic structures in HAND film (5CB on glycerine) with nonsingular (a) and singular (b) distributions of the director.

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