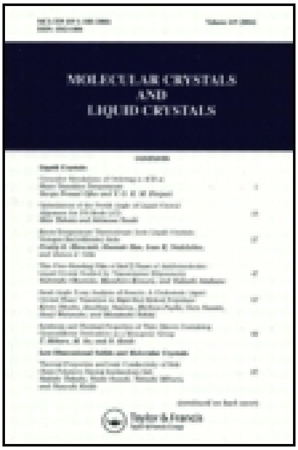

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Observation of a Bubble Texture At the Cholesteric To Homeotropic-Nematic Transition In a Confined Chiral Nematic Liquid Crystal

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OBSERVATION OF A BUBBLE TEXTURE AT THE CHOLESTERIC TO HOMEOTROPIC-NEMATIC TRANSITION IN A CONFINED CHIRAL NEMATIC LIQUID CRYSTAL

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A new texture is observed in a frustrated chiral nematic liquid crystal confined in a cell treated to induce homeotropic alignment. The texture is observed only in a narrow range of values of the confinement parameter close to the critical value for the change over between the homeotropic and the helical texture.

Keywords: chiral nematic; cholesteric; frustration; bubble domains; soliton

INTRODUCTION

Of all the intriguing problems in physics, frustration has attracted much attention from experimentalist as well as from theoreticians. A frustration occurs when a system is subjected to two or more interactions favouring incompatible ground sates. In the simplest case the system can adopt a stable configuration that satisfies none of the requirements of the interactions but minimises the overall energy of the system. Unstable configurations can occur in more complex situations. Liquid crystals provide a fertile ground for the investigation of frustrated situations. Blue phases and TGB phases are examples of naturally occurring frustrated phases. Frustration can also be created in liquid crystal by imposing boundary conditions that conflict with the bulk configuration of the material. A cholesteric liquid-crystal material will inevitably be frustrated when it is confined in a container with at least one dimension of the order or smaller that the bulk pitch of the material.

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The behaviour of confined chiral nematic has been investigated since the early days of liquid-crystal research [1,2]. Domains with the helical structure in a confined cholesteric forced into a homeotropic alignment have also been investigated [3–9]. Bubbles, loops and fingers can be produced in such specimens either by agitating the specimen with an electric field or by quenching it from the isotropic phase. These domains are metastable regions of helical texture in the otherwise stable homeotropically aligned chiral nematic. A review of the work done to date on these metastable domains is presented in the article by Oswald *et al.* [10].

A case that has not yet been fully investigated is the case of a homeotropically-aligned cholesteric where the value of the bulk pitch of the material is the critical value for the change of texture between the homeotropic alignment and the helical structure. In the present paper this critical region is investigated.

Abate *et al.* [11] in their work on the optical Friedericks transition in chiral nematics have reported instabilities at the transition from homeotropic to cholesteric. In their paper these authors have shown that, in the absence of the optical field, the homeotropic alignment becomes unstable if

$$\frac{k_2 d}{\pi k_3} q_0 > 1 \tag{1}$$

where $q_0 = (2\pi/p_0)$; p_0 is the bulk pitch of the material k_2 and k_3 are the twist and bend elastic constants and d is the cell thickness. For our discussion in this paper we introduce the parameter

$$\varsigma = \frac{k_2 d}{\pi k_3} q_0 = \frac{k_2}{k_3}\left(\frac{2d}{p_0}\right) \tag{2}$$

The changeover between the homeotropic and the helical textures is expected when

$$\varsigma = 1 \tag{3}$$

Our experimental observations show that under certain circumstances there are two critical values of ς close to $\varsigma = 1$. Between these two critical values the specimen adopts an intermediate texture where circular domains with a helical structure are formed in the otherwise homeotropically aligned material. These circular domains observed only between the two critical values of ς have little, if any thing, in common with the “bubble domains” previously reported in the literature [3–10]; hereafter the intermediate texture will be referred to as the “*bubble texture*”. The domains in the bubble texture could be regarded as a circular variant of the soliton walls predicted by Kamien and Sellinger [12] for the case of a cholesteric material in a uniform magnetic field.

2. EXPERIMENTAL

To investigate the critical region one needs to have a fine control over the value of the parameter ς. In the present work the parameter ς has been controlled by varying the temperature. It is not our aim in the present paper to discuss the origin of the temperature dependence of ς. We simply note that one might expect the ratio (k_2/k_3) to increase with temperature and, possibly, p_0 to decrease with temperature therefore one expects ς to increase with temperature. A transition from the homeotropic alignment to the helical texture will be observed provided that cell thickness is such that the temperature at which the critical value of ς is reached is lower than the temperature of the transition to the isotropic phase.

2.1. The Specimen Preparation

The chiral nematic material was prepared by doping a commercial room temperature multi-component nematic material (BLO32) with a small (0.5%–1% wc) percentage of chiral dopant (C15). Both materials were obtained from Merck Ltd (UK) and were used without any further purification. The cell was fabricated using glass plates treated with a solution of lecithin in chloroform (0.5% wc). The cell gap was achieved by placing gauged Mylar spacers on the opposite sides of the cell. The cell was filled by capillarity at room temperature. The filled cell was hermetically sealed using an inert epoxy (NOA65 from Norland). Several cells with cell gaps in the range of 20 to 50 μm were prepared by this method. All the specimens prepared are homeotropic at room temperature display the *bubble texture* and the helical structure at higher temperatures. As expected [11] we have observed that the temperature at which the textural change occurs decreases as the cell gap is increased. The temperatures at which the lower and upper critical values of ς are reached in the different cells are given in Table 1.

In the 50 μm thick cell the temperature range of the *bubble texture* is too narrow to measure. In thicker cells there is a direct change from the homeotropic to the helical structures.

TABLE 1 The Temperatures at which the Lower and Upper Critical Values of the Thickness are Reached in Different Cells

d (μm)	Tc_1 (°C)	Tc_2 (°C)
23	87.1	88.5
36	86.7	88.0
50	87.5	87.9

2.2. Observations

All the observations reported in this communication were made on the same specimen. The cell gap is 23 µm and the material contains 1% wc of chiral dopant. The observations were carried out using a polarised light microscope in conjunction with a heating stage and temperature controller (Linkam TMS 94) with a temperature resolution of 0.1°C.

The sequence of textures observed whilst cooling is different to that observed on heating. The textures observed on heating is

$$\text{hom eotropic} \xrightarrow{87.1} \text{bubble texture} \xrightarrow{88.7} \text{cholesteric} \xrightarrow{91.5} \text{Isotropic}$$

The temperatures are given in °C. It is emphasised that the texture changes are not driven by temperature but by the parameter ς. At low ς the texture is homeotropic; the twist is completely excluded from the specimen. Between the two critical values of ς (corresponding to 87.1°C and 88.7°C respectively) the twist is partially restored in the specimen; the twist is confined inside circular domains.

Above the upper critical value of ς, the helical structure extends to the entire specimen. The specimen in the bubble texture and in the helical texture is shown in Figures 1 and 2, respectively. The figures show the specimen viewed between crossed polarizers. In the *bubble texture* the size and the density of the bubble grow with increasing ς until the upper critical value of ς is reached. At that value, the homeotropically aligned regions between the bubbles switch to the helical structure show in Figure 2. The singularities observed in Figure 2 are the singularities that were at the centre of the bubbles. Notice that in the helical texture, Figure 2, there is no signature of the boundary of the bubble; this is in marked contrast to the metastable bubble domains reported in reference [10]. The boundary of these metastable bubble domains is stable irrespectively of the texture of the surrounding material. Figure 3 shows one of these loops with the surrounding material in the homeotropic and in the helical texture respectively. The boundaries of the loop are clearly visible in the helical texture. Notice the pair of singularities associated with the loop, one inside and one outside. We have consistently observed a pair of singularities associated with these bubbles and loops.

On cooling from the isotropic phase, circular bubbles of cholesteric appear in the isotropic phase. These bubbles grow, merge and evolve as the temperature is lowered. The walls of these bubbles become the boundaries of the metastable loops and fingers and bubbles previously reported in the literature. Below the lower critical value of ς regions of homeotropic alignment nucleate at the centre of the large islands of helical texture; the

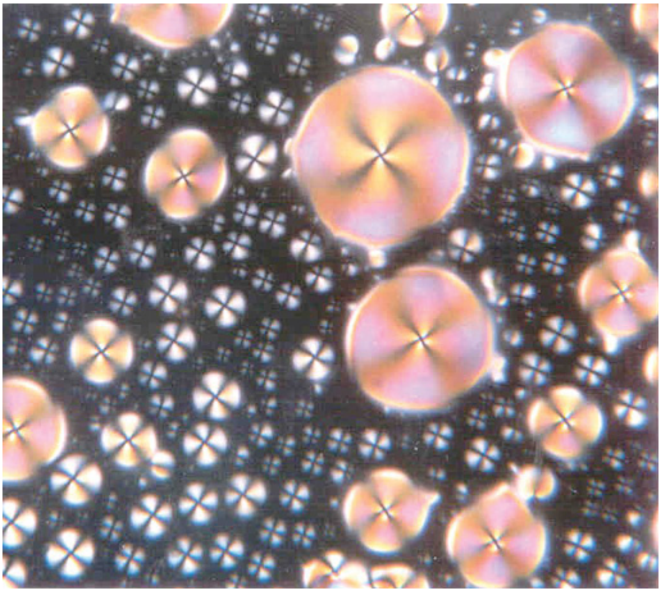

FIGURE 1 Bubble texture observed at values of the parameter ς between the two critical values. (See COLOR PLATE II)

homeotropic region grows inside the island and creates the loop at the boundary of the island. The bubble texture is not observed on cooling from the isotropic, the observed sequence is shown in Figure 4.

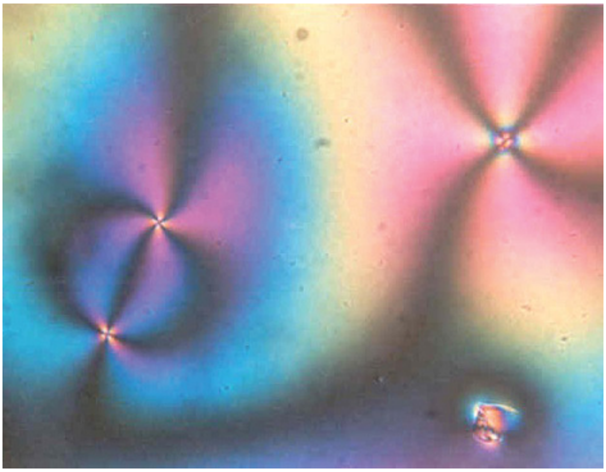

FIGURE 2 The specimen in the helical structure. (See COLOR PLATE III)

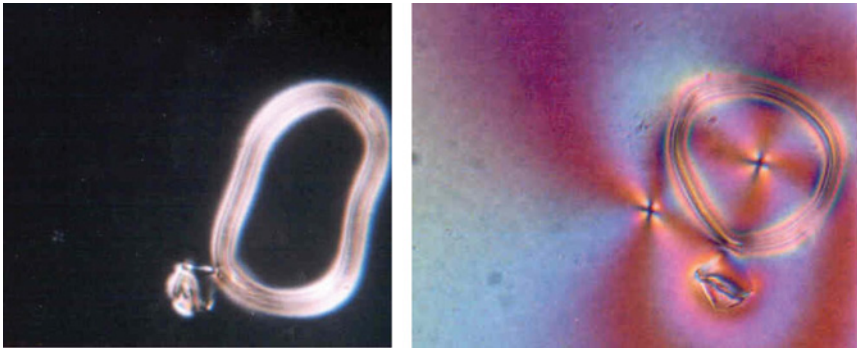

FIGURE 3 A metastable loop with the surrounding material in the homeotropic texture and with the surrounding material in the helical texture. (See COLOR PLATE IV)

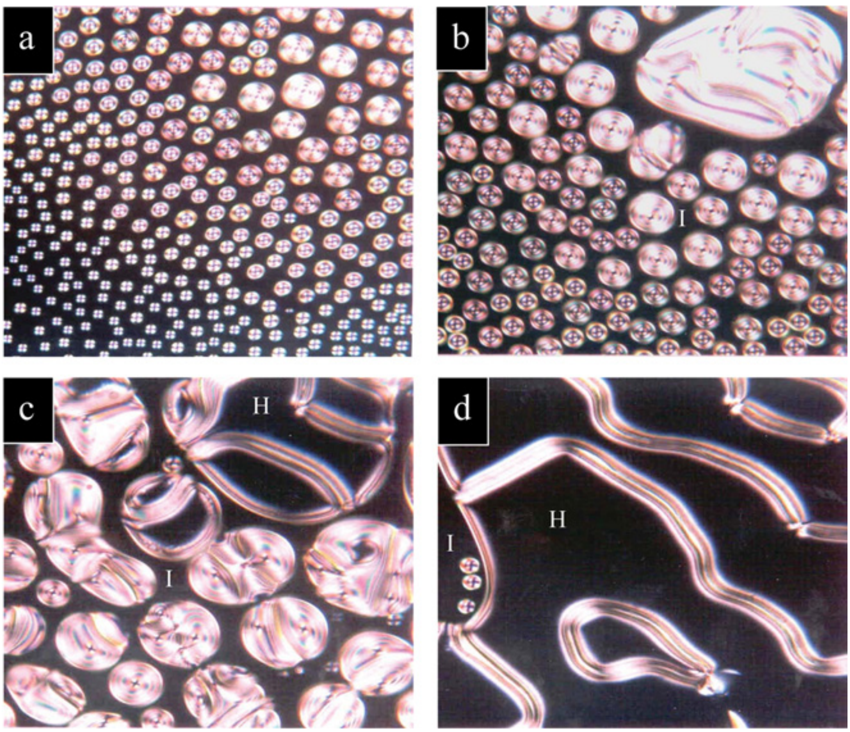

FIGURE 4 The sequence observed when cooling from the isotropic phase. **a.** T = 90.5°C, a bi-phasic region with cholesteric bubbles in the isotropic phase. **b.** T = 89.5°C, bubbles merge to form larger cholesteric domains; the background is isotropic (I). **c**. T = 88.5°C, homeotropically aligned regions (H) are formed inside the cholesteric island **d.** T = 86.5°C. The specimen is almost entirely homeotropic. (See COLOR PLATE V)

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