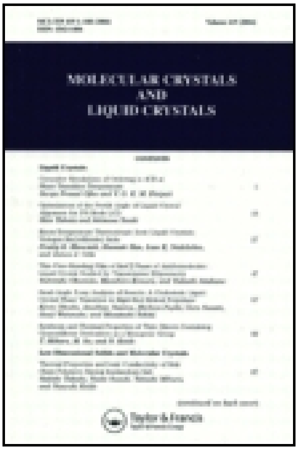

Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

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Version of record first published: 20 Apr 2011.

To cite this article: I. I. Gorina , N. L. Sizova & I. G. Chistyakov (1983): Marangoni Convection in Cholesteric Liquid Crystals of Low Thermal Sensitivity, Molecular Crystals and Liquid Crystals, 95:3-4, 271-278

To link to this article: http://dx.doi.org/10.1080/00268948308072467

Mol. Cryst. Liq. Cryst., 1983, Vol. 95, pp. 271–278
0026-8941/83/9504–0271/$18.50/0

Marangoni Convection in Cholesteric Liquid Crystals of Low Thermal Sensitivity

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(Received February 4, 1983)

The Marangoni convection in a layer of a nonthermosensitive cholesteric has been obtained. To induce the first stage of the convection (streaming the substance away from the "hot" area), a local heating of the layer is necessary which is from 3 to 4 times as much as that required for thermosensitive cholesterics. The CLC convection motion structures of "roll" type appeared when the layer was locally heated in a thermostat at temperatures close to the clearing point (T_{cl}) of the cholesteric. The results obtained are discussed in terms of thermal stability of the original cholesteric texture.

I. INTRODUCTION

In the previous paper,[1] we have described the Marangoni convection in a thermosensitive cholesteric liquid crystal mixture (CLC-I) locally heated from below. The heaters of linear geometry used were of several millimeters in length and from several micrometers to several tens of micrometers in width. Under such thermal conditions, in addition to a vertical temperature gradient (normal to the CLC layer) a horizontal temperature gradients (along the free surface of the layer) set in, which gave rise to convective motion of the substance from "hot" to "cold" areas. For the onset of the convection in a CLC-I layer, a temperature rise of 0.2 to 0.3°C was necessary in the region of local heating, relative to the unheated areas.

In the present paper we have investigated the Marangoni convection in a cholesteric mixture (CLC-II) which had a low sensitivity to temperature variations.

II. EXPERIMENT

The experimental procedure was the same as during the study of thermal convection in thermosensitive cholesterics.[1,2] The schematic of the local heating of a CLC layer is illustrated in Figure 1. The heaters A and B can be used separately or simultaneously, at will. The experiments were carried out without thermostatic control, at room temperature, or with thermostatic control at various temperatures including those close to T_{cl} of the CLC-II. The behavior of the CLC-II layers was studied using a microscope, in reflected (polarized or nonpolarized) or transmitted (polarized) light, and recorded at a black-white or color film.

The CLC-II mixture consisted of 26 percent (by weight) of cholesteryl chloride and 74 percent of cholesteryl oleate. At room temperature (~20°C) the CLC-II layer is orange-colored; with heating, the color changes to red one. At T_{cl} = 30.3°C, the CLC-II melts into isotropic (colorless) liquid.

III. EXPERIMENTAL RESULTS AND THEIR DISCUSSIONS

III.1. Local heating of a CLC-II layer at room temperature

In its initial state, the CLC-II layer was orange-colored and had an imperfect planar texture with separate, randomly distributed, small-sized shining spherulites which appeared as quarterfoils in transmitted polarized light. When the layer was locally heated with the help of the heater A (Figure 1), in the regions of local heating the planar texture became entirely reconstructed into a fine-spherulitic one; the use of the more powerful heater B caused the CLC-II to stream away from the heated area, the thickness of the layer decreasing in the heated area (dark region with clear boundaries

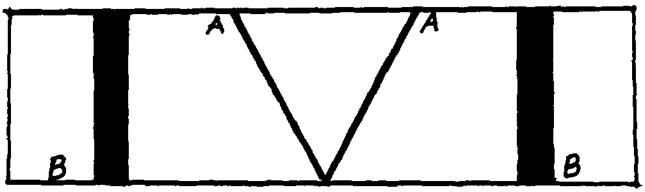


FIGURE 1 The scheme of the local heating from below of the horizontal CLC-II layer (plan). (A) regions of the local heating where a temperature increase of 0.2 to 1.0°C (in comparison with the environment) was assigned; (B) regions of local heating where the temperature increase was from 1.0 to 3.0°C.

in Figure 2) and increasing along the area boundaries (bright galo around the dark region). In regions of most intensive motion of the substance (in the center of the heated area), in thermostatically controlled samples a color shift to shorter wavelengths has been observed in the course of the flowing, the coloration of the flows being inhomogeneous. It could be seen in the microscope that small green areas appeared along the flow bands of, for the most part, red color. In peripheral areas, the flowing occurred without the color changing.

The experiments have demonstrated that the Marangoni convection could be obtained in cholesterics of low thermal sensitivity (CLC-II) as well as in mixtures of high thermal sensitivity (CLC-I). However, in CLC-II, in contrast to CLC-I, the Marangoni convection occurred only as streaming the substance away from the heated area, and required a higher local heating for the onset. As regards to the color changes observed in the course of flowing, they are, as will be shown later, caused by the deformation of the planar texture of CLC-II due to thermal flowing.

III.2. Local heating of a thermostatically controlled CLC-II layer at temperatures above T_{room}

When the heater A being used, in the regions of local heating a transformation occurred of the planar texture of CLC-II into a texture of the periodic net type which consisted of small spherulites (looking like quarterfoils when observed in transmitted polarized light) similar to the texture that had been obtained under the conditions of total heating of a cholesteric layer from below.[3] In CLC-II layers thermostatically controlled at tem-

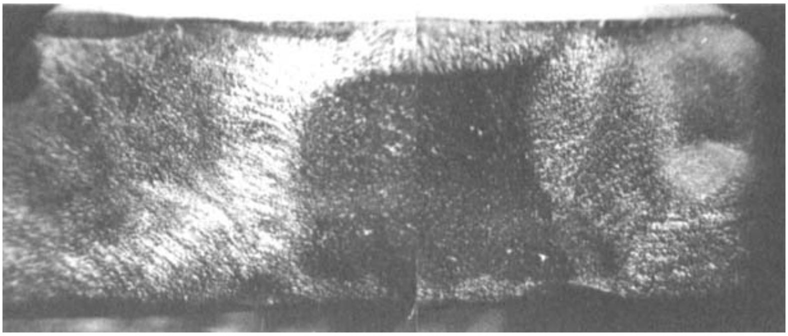


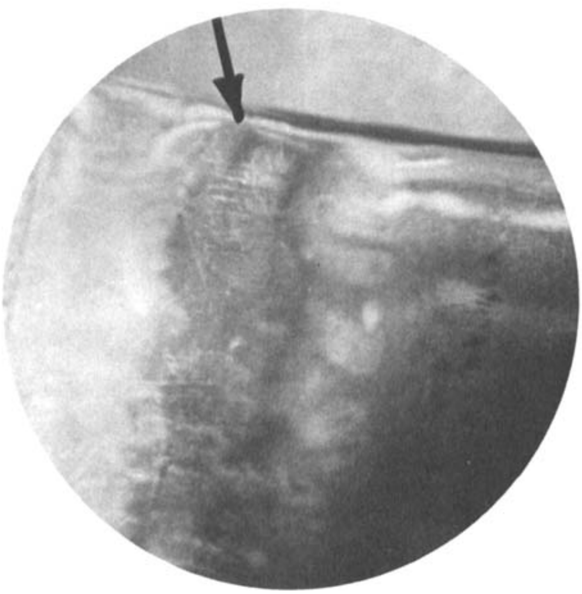
FIGURE 2 Flowing in the CLC-II layer (the Marangoni convection) in experiments at room temperature. Nonpolarized light.

peratures close to T_{cl} such as 29.3°C (1.0° below T_{cl}) or 29.8°C (0.5°C below T_{cl}), the CLC-II melted into isotropic liquid in the regions of local heating. This was indicated by a colorless band that appeared over the heated region and clearly visible against the red-colored background, and by the transition of the band into a milk-white one having a fine confocal texture after ceasing the local heating of the sample.

When the heater B was used which provided a greater local heating in comparison with the heater A, a picture of the Marangoni convection was obtained similar in structure to that observed in the thermally sensitive CLC-I.[1,2] At the beginning, a motion of the substance was observed, and streaming away from the locally heated region occurred (Figure 3, indicated by the arrow); afterwards, along the boundaries of the region, in the places of the layer thickening, the structures of convective motion appeared in the form of rotating "rolls" which were particularly well developed in the samples thermostatically controlled at temperatures close to T_{cl} of the CLC-II (Figure 3). The coloration of the CLC-II in the rotating rolls was inhomogeneous; green and greenish-blue areas occurred, mainly in the places where the rolls came in contact with one another (Figure 4).

The texture of the flows has been shown to consist of finest-sized spherulites aligned into more or less regular rows and possessing a regular form (of quarterfoils in polarized light) in peripheral areas of flows, far from the center of the locally heated region (Figure 5). This texture transformation (accompanied by arranging the spherulites along the flows) occurred without the CLC color changing. In hotter areas of the flows, however, the spherulites were deformed (Figure 5, at the center); their domains became elongated in the direction normal to the flow (Figure 5, at right, near the center) and, arranging along the flow, they formed shining bands of confocals (Figure 5, at right) and bands with cross-striated structure (Figure 5, at the top). A similar texture was characteristic of the flow in the rotating rolls (Figure 6). The cross-striated bands lie along the turns of the rotating rolls. It is likely this structural rearrangement of the original planar texture of the CLC-II into polydomain confocal and striated bands which occurs in the course of the thermal convective flowing that accounts for the color changes in the flows of the nonthermosensitive CLC. The inhomogeneity of the flow coloration, for example, in rotating rolls (Figures 3 and 4), may be due to the difference in the depth of the rearrangement depending on the intensity of the thermoconvective motion.

In the literature, there is a description of color changes in nonthermosensitive CLC during flowing induced by shear stresses.[4] The color changes in nonthermosensitive CLC which are caused by flowing due to temperature gradients are described for the first time here in the paper. Our



FIGURES 3 and 4 Marangoni convection structures of the "rotating rolls" type.

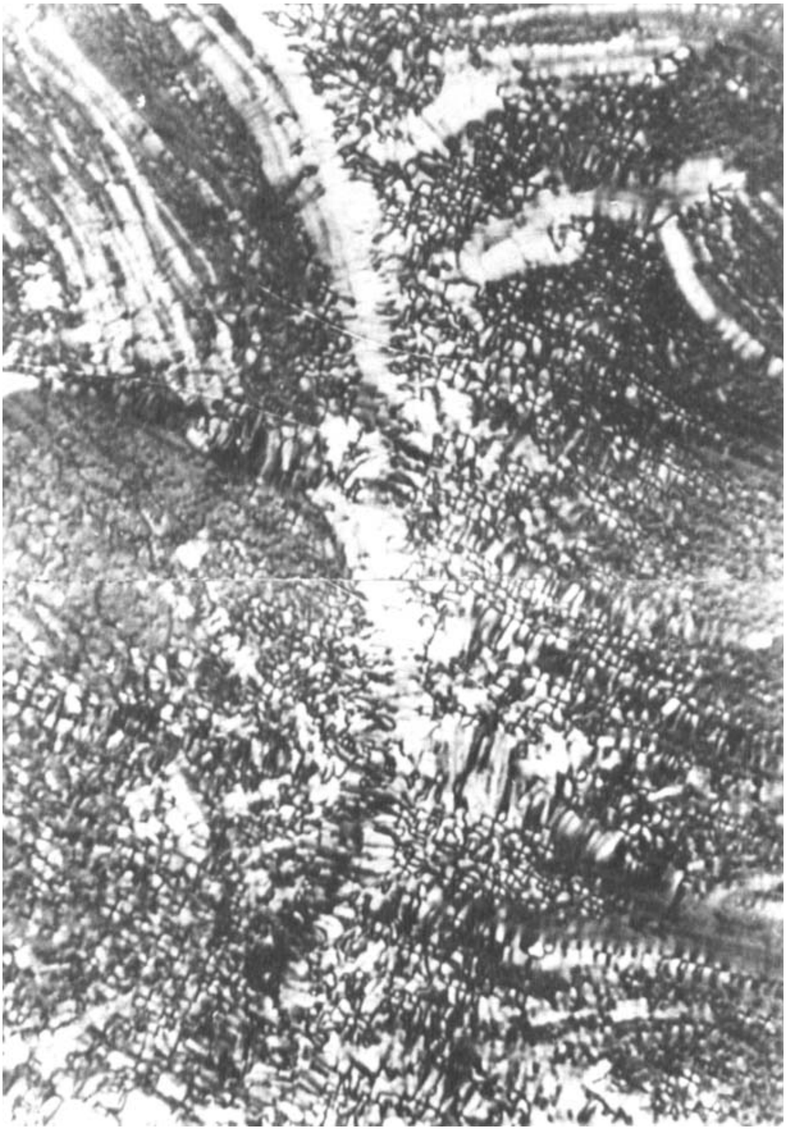


FIGURE 5 The fine structure of the flow in the CLC-II after the transformation of the planar texture into the confocal one.

experiments represent a direct confirmation of the Leslie's theoretical predictions on the possibility of a thermomechanical interaction in cholesterics.[5]

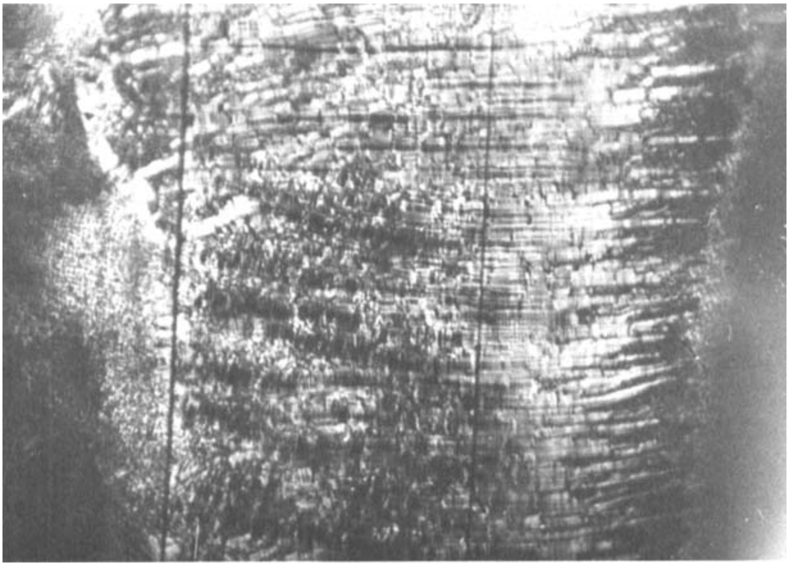


FIGURE 6 The fine structure of the turns of the rotating rolls.

Resuming the experimental results on the CLC-II and comparing them with those previously obtained for the thermosensitive CLC-I,[1,2] the following should be noted.

For the onset of the Marangoni convection in CLC-II with its low thermosensitivity, a higher local heating (with the help of the heater B) is necessary which provides a temperature rise in the region of local heating 3 to 4 times as much as that required for the thermosensitive CLC-I. In the CLC-I, the convection was induced with the help of both A and B heaters, in either case the convective motion structures taking the most developed form—of rotating rolls. In CLC-II the roll-type convective motion structures occurred only during local heating of the layers thermostatically controlled at temperatures close to T_{cl}. The difference between the two cholesterics may be due to the different stability of the original texture of the cholesteric layer with respect to the temperature gradient, which is confirmed by the following experiment.

As we had already said, in the initial state, without being locally heated, the texture of the CLC-I layer was confocal, and that of the CLC-II layer was planar at room temperature or deformed planar (of the periodic net type) in specimens thermostatically controlled at higher temperatures, close to T_{cl}. We have investigated in a microscope the behavior of the textures in the case of heating the whole layer from below. The thermosensitive compositions of the CLC-I type which had the temperature ranges of selective reflection 1.0, 1.2, 1.5, or 2.0°C in width underwent sharp texture rearrangements after already a slight temperature increase (of the order of several tenths of centigrade), the texture being "improved": confocals — enlarged confocal domains — defective planar. The rearrangement was accompanied by an essential narrowing of the peaks of λ_{max} (the maximum wavelength of the selective reflection) and by their shift into the violet range of the light spectrum. At the stage of the violet planar texture formation, a weak flowing of the substance developed accompanied with the formation of shining bands reminded the banded textures in the experiments on local heating (Figure 5). The initial planar texture of the nonthermosensitive CLC-II is extremely stable against the temperature action. The disturbance of the planar texture was gradual. At first, small spherulites appeared distributed randomly throughout the planar (imperfect planar texture); on further heating, at temperatures close to T_{cl} of the CLC-II (when the temperature increase reached about 10°C), a deformed planar texture developed which was called "the periodic net".[3] This texture was also characterized by relatively high thermal stability and remained unchanged up to T_{cl} of the CLC-II (30.3°C). The maximum wavelength of the selective reflection of the CLC-II was shifted slightly to longer wavelengths (by about 20 nm). The width of the λ_{max} peak was not practically altered.

At present, the investigations are in progress on the threshold values of the temperature gradient that causes the Marangoni convection depending on the cholesteric layer texture.

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