Step unwinding of a spiral in a cholesteric liquid crystal

S. V. Belyaev and L. M. Blinov
Scientific Research Institute of Organic Semiconductors and Dyes

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A nonmonotonic (step) dependence of the pitch of the cholesteric spiral on the magnitude of the field in a CLC layer, to the surfaces of which the director is attached, has been observed experimentally. Under these conditions for an abrupt turn-off of the relaxation of the unwound spiral is accompanied by the appearance of spatially modulated structures.

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When an electric field is applied perpendicularly to the spiral axis in a cholesteric liquid crystal (CLC) with a positive dielectric anisotropy ($\Delta\epsilon > 0$), an unwinding of the spiral is observed, i.e., an increase in its pitch.[1] In the simplest treatment for CLC layer thickness d considerably greater than the equilibrium pitch P_0 the pitch of the spiral P increases monotonically with an increase in the electric field[1-4] although, strictly speaking, in this case the unwinding of the spiral is accompanied by a movement of the Kano–Grandjean disclinations, which is caused by the nonmonotonic nature of the pitch variation in a field even for the free surface of the CLC layer.[5] However, no experimental study has been made of the character of the spiral unwinding in a CLC layer, to the surfaces of which the director is specially attached and consequently cannot rotate.

At the same time a qualitative treatment and calculations[6] show that if a planar

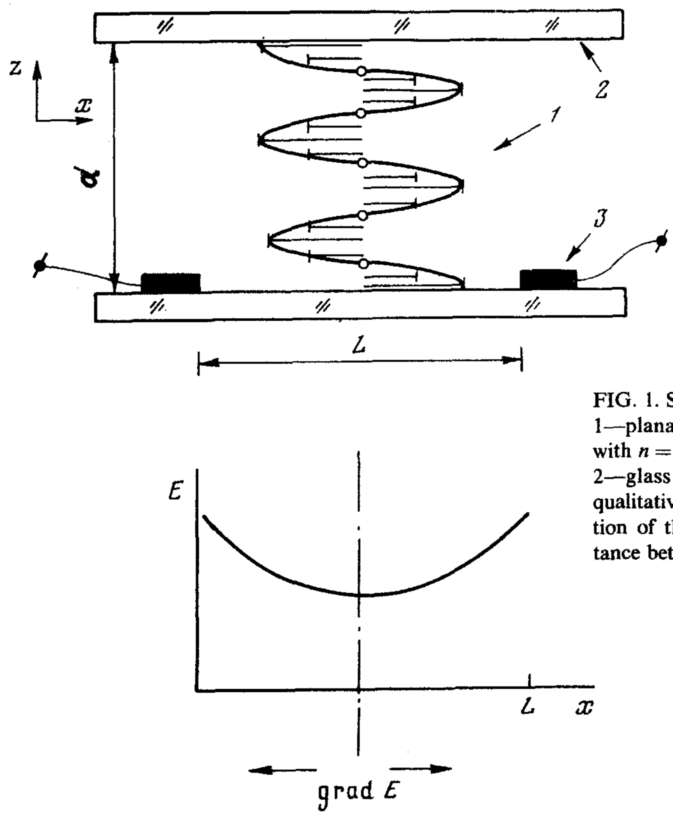

FIG. 1. Schematic of the experiment. Top: 1—planar CLC layer (Grandjean zones with $n = 5$ half turns of cholesteric spiral), 2—glass plates, 3—electrodes. Bottom: qualitative picture of the intensity distribution of the alternating field over the distance between the electrodes.

CLC layer, in which the axis of the cholesteric spiral is perpendicular to the plane of the layer, is enclosed between the two surfaces, orienting the molecules near the CLC surface parallel to some preferred direction at the surface, then the dependence of the spiral pitch on the field must have a step-like character since in this case the pitch can assume only discrete values. For parallel-directed orientations on the surfaces these values amount to $P = 2d/n$, where $n = 0,1,2,...$ and are determined by the necessity of a whole number of half-pitches.

This paper reports the first observation of this phenomenon and the characteristics of the relaxation of the unwound spiral under these conditions. An electric field that was nonuniform along the plane of the CLC layer was used to maximize the clarity of the experiment. With the application of such a field to a layer that is homogeneous throughout its thickness the step unwinding of the spiral is evident in the appearance of Kano–Grandjean disclinations, separating regions with different spiral pitch values and directed perpendicularly to the gradient of the field.

A nematocholesteric mixture of azoxy compounds with cyanphenyl ether and cholesteryloleyl carbonate was used in the experiments ($\Delta\epsilon = +8$, $1\ \mu\text{m} < P_0 < 15\ \mu\text{m}$). A sandwich-cell (Fig. 1), consisting of two glass plates having a dielectric coating applied to the interior surface, was filled with the mixture. A rubbing of this coating with a cotton pad oriented the molecules of the CLC parallel to the surface of the

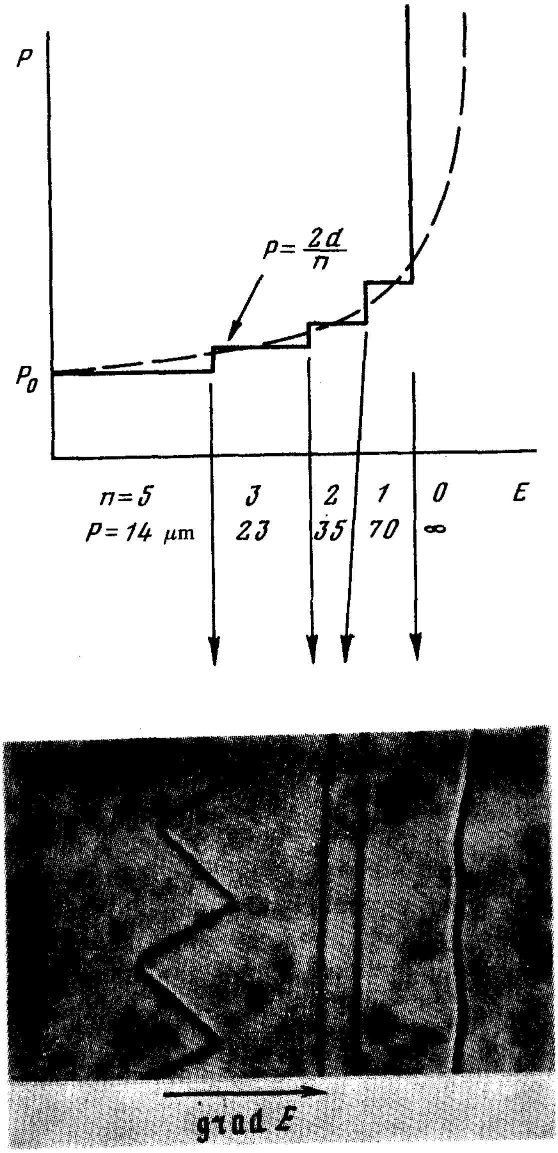

FIG. 2. Top: qualitative dependence of the cholesteric spiral pitch P on the electric field E. Dashed line represents case when there are no orienting surfaces.[1] Solid line represents situation in presence of orienting surfaces (n and P are the number of half-pitches and the pitch value of the spiral in the corresponding Grandjean zone). Bottom: appearance of Kano–Grandjean disclinations in 35-μm thick CLC layer in a nonuniform electric field. The direction of field increase is indicated by arrow. $P_0 = 14\ \mu$m.

plates. In this way we obtained a planar texture with the spiral axis perpendicular to the glass plates. The thickness of the CLC layer was determined by Teflon gaskets and was the same over the entire sample area. This was verified by the absence of equal-thickness fringes in the cell before it was filled with the mixture. The application of the electric field parallel to the CLC layer was accomplished by means of electrodes, sputtered onto one of the glass plates in the form of two parallel aluminum strips, separated by a distance $L = 300\ \mu$m. An alternating field with a frequency sufficiently high to avoid electrohydrodynamic effects was used in the experiments ($U = 300$ V, $f = 5$ kHz). In such a system the gradient of the field was directed basically from the

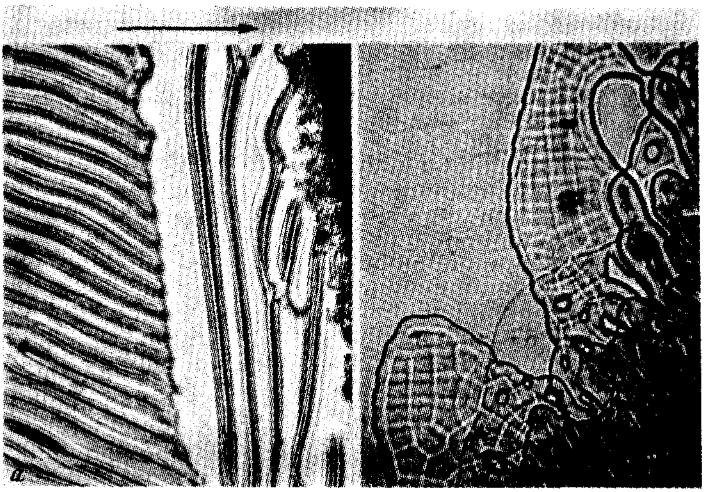

FIG. 3. Spiral relaxation pattern in different regions for sudden removal of the field: $a - n = 0$ (at right) and $n = 1$ (at left); $d = 21$ μm, $P_0 = 14$ μm. Rubbing direction is shown by arrow. $b - n > 10$; $d = 50$ μm, $P_0 = 4.5$ μm.

midpoint between the electrodes toward the electrodes, i.e., along the field. The field direction and the orientation of the molecules near the surface were chosen to be parallel. Microscopic examinations and photographic studies were made in polarized light.

With no voltage on the electrodes the sample was a uniform planar structure with a cholesteric spiral pitch that was the same throughout the entire sample and equal to the equilibrium pitch P_0 or only slightly different from it. With the application of a field to the sample the pitch of the cholesteric spiral tended to increase. The pitch value in the absence of orienting boundary surfaces would be determined by the magnitude of the local field (see dashed curve in Fig. 2). The discreteness of the pitch under our conditions leads, in a nonuniform field (Fig. 2), to the appearance of Kano–Grandjean disclinations (lines where the pitch changes by a jump), separating regions with a constant pitch, which are the analogs of the Grandjean zones in wedge-shaped cells.[1] In the photograph, Fig. 2, the number of spiral half-pitches in the layer thickness changes by one as one passes through the first-order Kano–Grandjean straight disclinations lines. The zigzag-shaped line—a second-order Kano–Grangjean disclination—separates regions in which the number of half-pitches differs by two. The zigzag pattern of such lines appearing in the field wedge-shaped cells is caused by the specific distribution of the director near then and was investigated in Ref. 7. The number of half-pitches n in each region and the pitch values P, indicated in Fig. 2, were calculated, starting from the values of the layer thickness and the equilibrium pitch P_0.

Previous literature contains no data about Grandjean disclinations in a planar structure, where the gradient of the external field plays the role of the Kano wedge. It is interesting to note that these disclinations are a convenient method for visualizing field inhomogeneities.

As the voltage on the electrodes is smoothly reduced, the disclinations disappear, moving in the direction of the field gradient. When the voltage is removed suddenly, the movement of the disclinations is accompanied by a relaxation of the unwound spiral to the original number of half-pitches via a stage involving the formation of a striated or grid structure (Fig. 3). The direction of the bands that appear is perpendicular to the director in the middle of the layer. Thus, during the relaxation of a region with $n = 0$, where the spiral is completely unwound and where the director at the middle of the layer thickness is parallel to the rubbing direction, the direction of the deformation that appears is perpendicular to the rubbing direction (Fig. 3a, left). Conversely, in the region with $n = 1$, where the director at the middle of the layer is perpendicular to the rubbing direction, the direction of the bands is parallel to this direction. In regions with larger "n" the relaxation passes through a stage involving the formation of a grid structure (Fig. 3b). Let us make mention of the similarity of the deformation pattern during the relaxation of the cholesteric spiral under the conditions described above to the stationary patterns in the presence of electrohydrodynamic and field instabilities in a planar CLC structure.[8] The stationary domains of the pattern are usually the result of the competition of the elastic and field (or hydrodynamic) moments, acting on the director.[9] Here, however, is the first realization of the case when a spatially modulated structure occurs due to the action of only the elastic moment, true for the conditions of director relaxation from a state preset by the external field.

Thus, a nonmonotonic (step) dependence of the pitch of the cholesteric spiral on the magnitude of the unwinding field in a CLC layer, at the surfaces of which the director is fixed, has been observed for the first time.

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