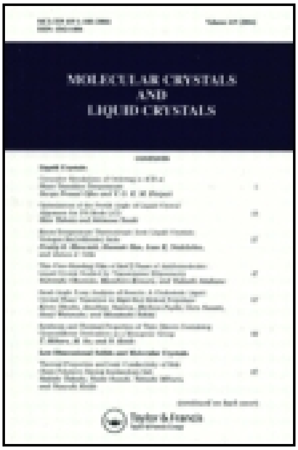

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Characteristics of Domains Appearing in Nematic Liquid Crystals Below the Threshold Voltage of Chevrons

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A new type of instability is studied, which was previously found to arise in nematic liquid crystals with negative dielectric anisotropy in the dielectric region, at a threshold voltage lower than the chevron threshold. The instability can be observed in the form of domains only between two polarizers. These domains may coexist with the chevrons, forming a complex optical pattern.

The dependence of the threshold voltage and of the domain period on various parameters is investigated. Striking similarities are found between this phenomenon and the electroconvective flow which reveals itself by the motion of dust particles. These similarities point towards the electroconvective nature of the observed domains, which hereafter will be referred to as electroconvective domains.

Some conclusions are drawn concerning the involved viscous torques.

1 INTRODUCTION

Dielectric type instabilities (chevrons) are known to appear in nematic liquid crystal with negative dielectric anisotropy ($\varepsilon_\perp > \varepsilon_\parallel$) at excitation frequencies larger than the charge relaxation frequency (of the order of tens to hundreds Hz). Their mechanism was explained by the Orsay Liquid Crystal Group,[1] by extending the theory of Carr[2] and Helfrich[3] to the AC regime.

The wave-vector of this type of instability was predicted to be much larger than the inverse thickness of the sample, which was proved experimentally to be true.

The instabilities of dielectric type arise just above a given threshold voltage as fine stripes of the same orientation as that of the Williams domains in the same cell. A slight increase in voltage brings about a distortion of the parallel strips, leading to the typical chevron pattern.

Dielectric instabilities may be observed with a single polarizer, parallel to the director at the entrance of the cell, or even in unpolarized light.

In the dielectric region, another type of instability was also detected.[4] It appears below the chevron threshold and reveals itself as a domain pattern visible only between two polarizers.

In the same dielectric region correlated motions of dust particles were observed,[5,6] being interpreted by the authors as due to electroconvective flows.

The Moscow group[5] reports on systematic studies of the threshold voltage of this electroconvective instability occurring in the dielectric region. The temperature dependence of the threshold voltage is also measured and attention is drawn to the continuity of the threshold at the transition temperature T_c from the nematic to the isotropic phase. Based on this continuity, the authors adopted for the observed electroconvective flow, the model elaborated by Felici[7] and Atten[8] for isotropic liquids, erroneously considering that the dielectric instability (the chevrons) is not due to the Carr–Helfrich–Orsay mechanism, but is a Felici-like instability.

By also observing the motion of dust particles, Ribotta and Durand[6] found that the electroconvective flow responsible for this motion exhibits a threshold voltage lying below that for the appearance of the chevrons. When the cell thickness is sufficiently large, the two thresholds are quite distinct over the entire frequency range and, as the temperature approaches T_c, they become better separated from each other. By increasing the temperature, the chevron threshold voltage increases and diverges near T_c, while the threshold voltage for the convective dust flow decreases continuously and presents no discontinuity at T_c.[5] Therefore, the French authors judiciously conclude that the chevrons and the electroconvective flow are instabilities of a different nature.

In the quoted papers the observations were made in planar cells.

It is shown in this paper that the instabilities appearing at voltages below the chevron threshold and which induce the motion of the dust particles are identical to those which can be observed as domains only between two polarizers.[4] The dependence on various parameters of the period of these domains as well as that of their threshold voltage was determined.

2 EXPERIMENTAL SET-UP

The measurements were performed in closed cells[6,8,10] and 15 μm thick, with both planar and twist geometry. The molecular alignment was obtained by rubbing the SnO_2 film deposited on the glass plates. The liquid crystal used was MBBA, Eastman Kodak No. 11246, with an electrical conductivity of about 10^{-9} ohm^{-1} cm^{-1}.

The measurements were carried out in a polarizing microscope, using two polaroids (polarizer and analyser); for both cell geometries the direction of the polarizer coincided with the molecular orientation at the entrance plate. A retardation plate was introduced in order to facilitate the observations by enhancing the contrasts.

The cell was placed in a thermostated chamber, made in the laboratory. The temperature in this chamber was measured by means of a thermocouple introduced in a similar cell, situated near the cell used for observations, the temperature being maintained constant within 0.1°C. A heat filter avoided heating of the cell by absorption of i.r. radiant energy.

A sine wave voltage was applied across the liquid crystal cell.

3 EXPERIMENTAL RESULTS

As previously noted,[4] the electroconvective domains, which are investigated in this paper, may be observed in the dielectric region, i.e. at frequencies f above the cut-off frequency f_c, at voltages below the chevron threshold, by using two crossed polarizers for planar cells and two parallel polarizers for twist cells.

At a given frequency, these domains appear above a threshold voltage U_{th}. The striations are oriented in the same direction as the Williams domains. So, if the director is aligned along the x-axis (in a planar cell), and the light propagates along the z-axis, the new domains are oriented along the y-axis. We must stress that, unlike Williams domains and chevrons, the electroconvective domains are *invisible in unpolarized light or with one polarizer only*.

For the previously mentioned orientation of the two polarizers and in the absence of the retardation plate the pattern consists of bright bands separated by narrow dark lines.

Inserting an appropriate retardation plate before the analyser, the bright bands become alternately red and blue.

As mentioned by Petrescu and Giurgea,[4] the successive bright bands may become differentiated also in the absence of the retardation plate. So, by a 10° to 20° rotation of the cell, the intervals between the dark lines become alternately darker and brighter. The same rotation, but in the opposite direction, converts the dark bands into bright ones and vice versa.

In Figure 1 electroconvective domains are shown, as obtained in the presence of the retardation plate in a planar cell at several volts above the threshold voltage. The successive domains appear in this figure with a various brightness due to the different sensitiveness of the photographic material to blue and red.

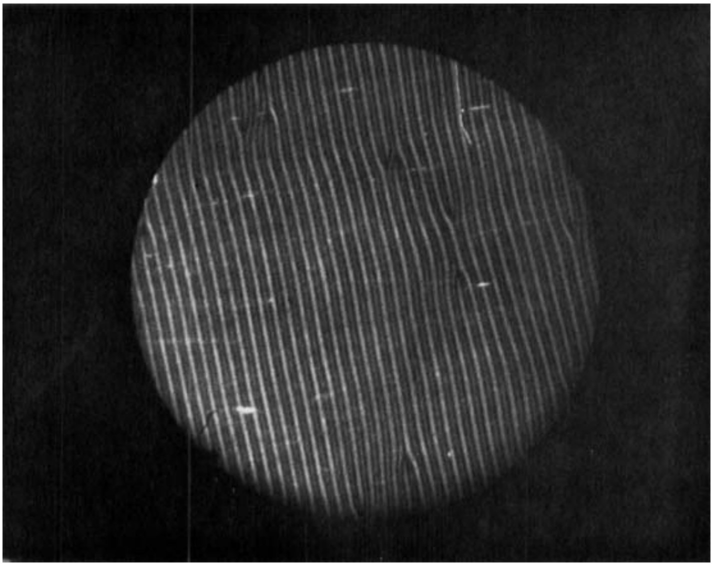

FIGURE 1 Electroconvective domain structure in a planar cell (in the presence of a retardation plate); $d = 10\,\mu m$; $U = 99\ V_{eff}$; $f = 10{,}000$ Hz; $T = 25.9°C$.

At a fixed frequency, no matter the cell geometry, there exists above the threshold value for the electroconvective domains another threshold at which these domains become crossed by chevrons, having different orientations in adjacent domains. In Figure 2 a pattern of this kind is shown. It was obtained, without a retardation plate, in a twist cell rotated by 15° from the position corresponding to the narrow line structure. In the photo-reproduction the chevrons in the bright bands are not visible, although they could be clearly detected by visual microscopic observation.

If the voltage across the cell is raised continuously, from a given value on, the domain pattern becomes unstable; there appear frequent disclination loops, proceeding along the domains and leading finally to the deterioration of the pattern.

Figure 3 displays the dependence of the threshold voltage on the square root of the frequency at various temperatures. One can see that, for a given frequency, as in the case of the electroconvective motion,[5,6] the threshold value diminishes with increasing temperature.

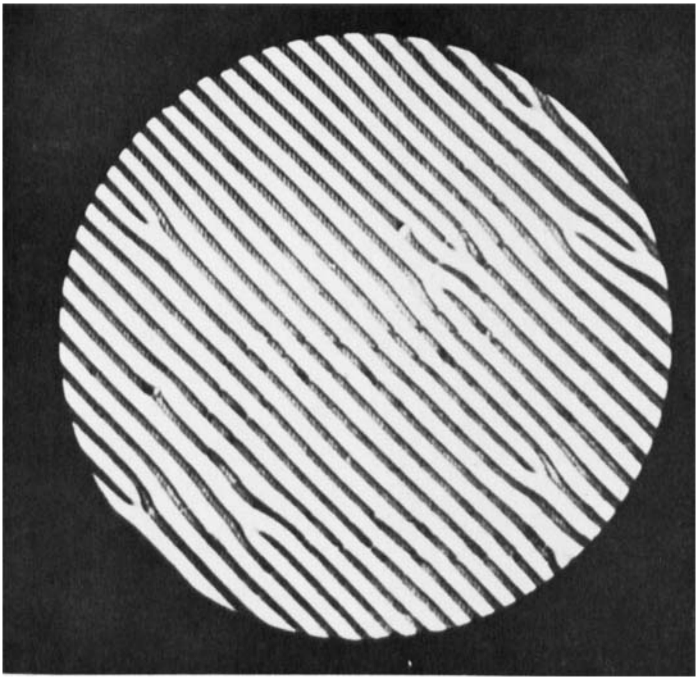

FIGURE 2 Domains crossed by chevrons in a twist cell (without a retardation plate); $d = 6$ μm; $U = 64\ V_{eff}$; $f = 3.250$ Hz; $T = 25°$C.

In Figure 4 the period λ† of the domain pattern is represented as a function of the applied voltage U, at constant temperature and with the frequency as a parameter.

The decrease of λ with increasing voltage at a given frequency is remarkably quick. It must also be noticed that the upper and lower limits of λ are the same for a given cell, whatever the frequency.

The results presented in Figures 5a and 5b were obtained through measurements at two different temperatures and various frequencies and show the dependence of the period λ on $(U - U_{th})$. One may see that the points corresponding to values measured at the same temperature, but at various frequencies, are situated (within the limits of experimental error) on a single straight line.

By plotting λ *vs.* $(U - U_{th})$ for different temperatures, one noticed a diminution of the slope with increasing temperature, as may be seen by com-

† λ is the distance between two corresponding points belonging to two successive bands of the same colour (in the presence of the retardation plate).

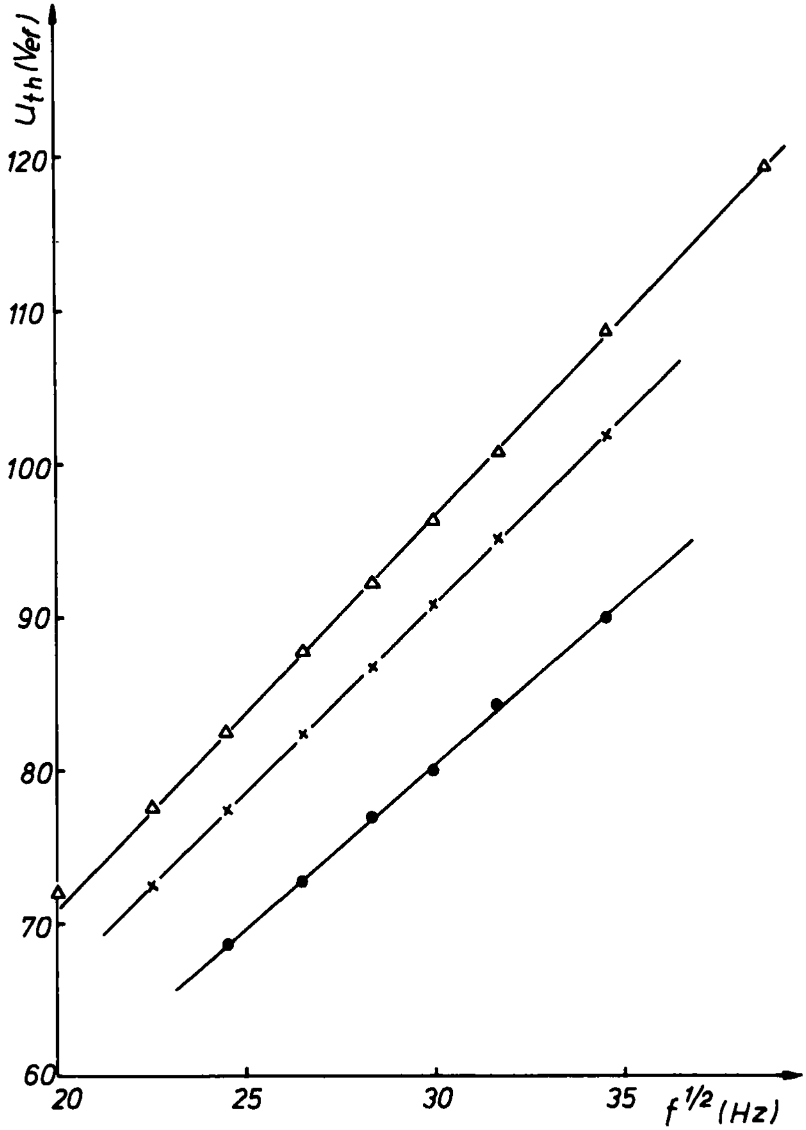

FIGURE 3 Threshold voltage of the domain structure as a function of the frequency square root, with the temperature as a parameter. Planar cell, $d = 10\ \mu$m · —27.6°C; × —24.9°C; △—22.8°C.

paring Figure 5a with Figure 5b. Therefore, the higher the temperature, the less is the period influenced by the applied voltage.

As results from the preceeding figures, the period of the electroconvective

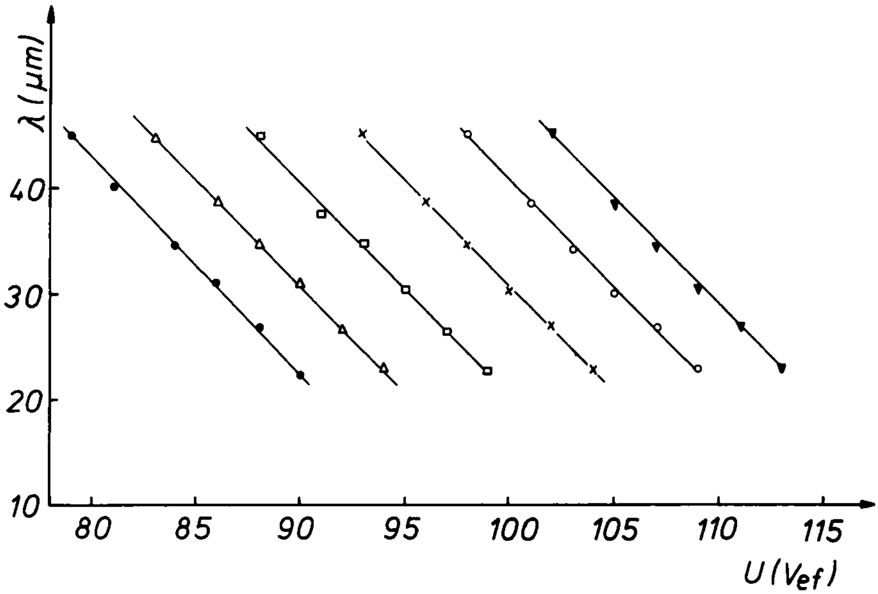

FIGURE 4 Period λ of the domains vs. the applied voltage U for various frequencies. Twist cell; $d = 15\ \mu m$; $T = 25.1°C$. •—500 Hz; △—600 Hz; □—700 Hz; ×—800 Hz; ○—900 Hz; ▼—1,000 Hz.

domains is comparable to the cell thickness, in contrast with the much smaller period of the chevron structure.

Figure 6 shows the dependence of λ_{th}—the period at the threshold—on cell thickness at constant temperature. It is worth mentioning that, for identical cell thicknesses, the period in cells with twist geometry has smaller values that in planar cells.

4 DISCUSSIONS AND CONCLUSIONS

4.1 Similarities of behaviour between the domain structure studied in this paper and the electroconvective flow[5,6]

a) Both the domain structure and the convective flow, Ref. 6, appear at threshold voltages lying below the chevron threshold.

b) The threshold voltage of the domain structure increases linearly with the square root of the frequency of the applied electric field, as indicated by Eq. (3), Ref. 5 and displayed in Figure 2, Ref. 6, for the threshold voltage of the electroconvective flow.

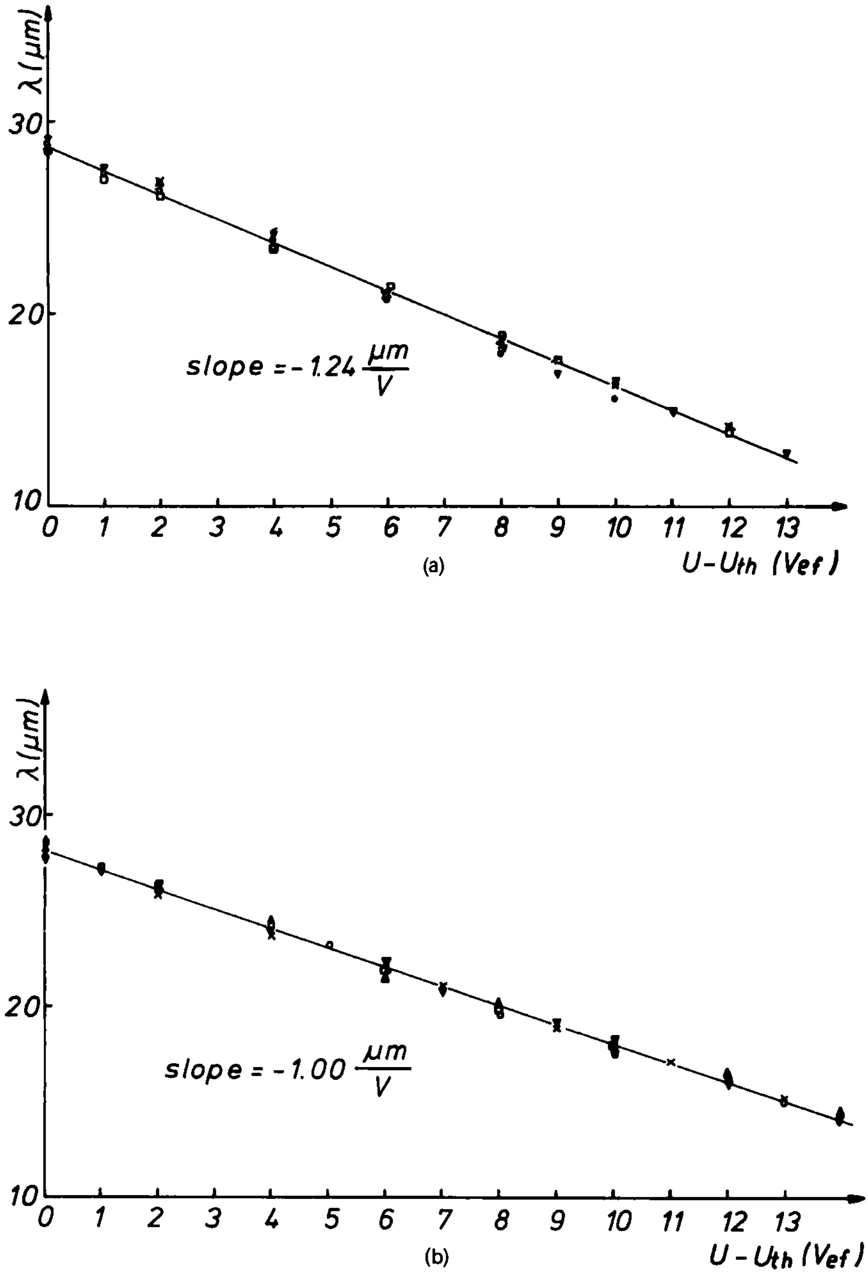

FIGURE 5 Period λ *vs.* $(U - U_{th})$, at constant temperatures; *a* and *b* planar cell; $d = 8$ μm. a) $T = 21.5$°C; ○—400 Hz; ·—500 Hz; ×—700 Hz; /—900 Hz; □—1,000 Hz; ▼—1,700 Hz. b) $T = 27.6$°C; ·—900 Hz; □—1,000 Hz; ×—1,400 Hz; ▲—1,600 Hz; ▼—1,800 Hz; ○—2,200 Hz.

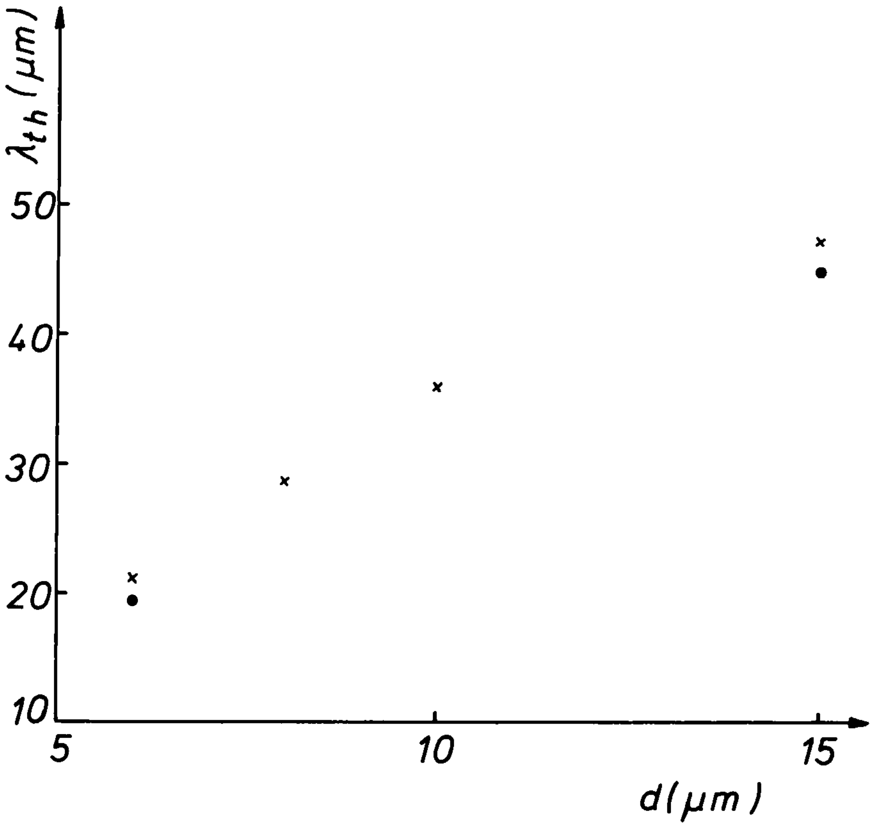

FIGURE 6 Period λ_{th} (at threshold voltage), for various cell thicknesses d. $T = 23°C$; × —planar geometry; · —twist geometry.

c) For a given cell and a fixed frequency the threshold voltage of the domain structure diminishes with increasing temperature. The electroconvective flow exhibits a similar behaviour.[6]

d) At constant frequency and temperature, the threshold voltage of the domain structure increases with increasing cell thickness; a similar behaviour is mentioned for the convective flow, too.[6]

e) The period λ of the domain structure, comparable to the cell thickness, is much larger than the chevron period. Similarly, the convective flow, revealed by the motion of dust particles, proceeds over distances of the order of the cell thickness, i.e. over a distance much larger than the distance between the dielectric stripes.[6]

4.2 Other remarks

a) It must again be emphasized that the domain structure is visible only between two polarizers and that a rotation of the cell by 10° to 20° brings about the modification of the domain pattern mentioned in Chapter 3.

b) In the present domain structure all bright bands (whatever their colour in the presence of the retardation plate) are observable for the same focalization of the microscope, unlike the two sets of focals corresponding to the Williams domains.

c) When a chevron pattern is superposed over the domain structure (Figure 2), the orientation of the chevrons differs in adjacent domains, i.e. in red and blue bands, respectively, when the observation is made with the retardation plate. Therefore, the period of the chevron orientation coincides with the period of the electroconvective domain structure.

It is likely that this structure induces the well known orientation of the chevrons.

d) Dust particles, accidentally present in the cell, are crossing the domains *very slowly*. A particle starting from a blue (red) band seems to draw this band after it until its arrival at the next blue (red) band, when the first band jumps back to its initial position.

e) By raising the voltage, elongated disclination loops may appear in the field of view of the microscope (Figure 7). These loops proceed *rapidly* along the lines separating two adjacent bright bands. The disclination loops advance in opposite directions if the red band is situated on one or on the other side of their advancing line. In Figure 7 one can see loops moving in the same direction; these loops arrange themselves at distances equal to the period of the domain structure.

4.3 Conclusions

The fact that the domains are not visible without an analyser (4.2a) and that there are no focals situated in different planes (4.2b) indicates that the instability responsible for the domains does not create z-components of the director, but new components in the xoy plane (along the y-axis in planar geometry).

The inversion of the brightness (colour) of adjacent bands for a cell rotation in opposite directions (4.2a) indicates that in neighbouring bands, the director (located in the xoy plane) makes equal angles, but of opposite sign with its direction in the absence of the electrical field.

We believe that this last observation is to be correlated with the different orientations of the chevrons in adjacent bands of the domain structure (4.2c).

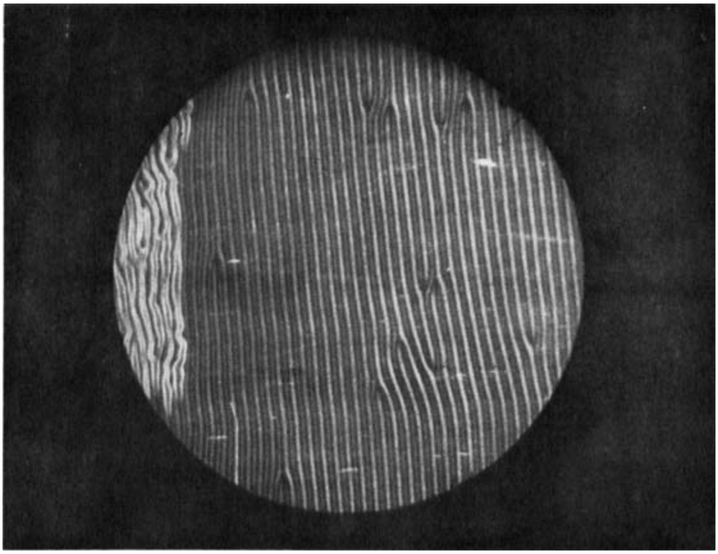

FIGURE 7 Disclination loops proceeding along the dark lines of the electroconvective domains at distances equal to the period of the domain structure (in the presence of the retardation plate). The exposure being long (about 2s), the disclination loops have proceeded a long distance in the field of view.

The facts discussed under 4.1 point to the electroconvective nature of the phenomenon which induces the appearance of the domain structure. That is why we used the term electroconvective domains.

As vortices with the axis along y (in a planar cell) would induce disorientations of the director in the xoz plane, we are determined to suppose that the viscous torque involved in this electroconvective motion must possess other components than the y-component. The observations summarized in 4.2 seem to support this supposition.

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We would also like to mention that Figure 2 was taken from the documents left over by the late Academician Paul Peterscu.

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