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UNDULATION INSTABILITY IN COMPENSATED CHOLESTERICS

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ABSTRACT

Instability of the planar texture induced by temperature change was observed in a compensated cholesteric. The cause of the instability is the mechanical strain arising as a consequence of the pitch change. The threshold of the instability is calculated for thick samples.

АННОТАЦИЯ

Наблюдалась неустойчивость планарной текстуры в компенсированном холестерине, индуцированная изменением температуры. Причиной неустойчивости является механическая напряженность, возникающая вследствие изменения шага спирали. Порог неустойчивости расчитывается для толстых образцов.

KIVONAT

Hőmérsékletváltozással indukált instabilitást figyeltünk meg planáris texturáju kompenzált koleszterikusban. Az instabilitás kiváltó oka a spirálhossz változása miatt fellépő mechanikai feszültség. Vastag mintára kiszámoljuk az instabilitás küszöbét.

INTRODUCTION

Compensated cholesterics are usually mixtures of a right-handed and a left-handed cholesteric material but compensation may occur even if nematics are mixed with the right-handed cholesteryl-chloride (1). At the compensation temperature - which depends on the composition - the helical structure disappears, the pitch becomes infinite. Near to compensation this mixture has a large and strongly temperature dependent pitch, furthermore the handedness of the mixture below and above the compensation temperature is opposite.

The planar texture of cholesterics is often unstable when subjected to external influences. Instabilities may arise in the presence of electric or magnetic fields (2), (3), temperature gradient (4) or shear flow (5), (6). Mechanical strains may also influence the texture. Undulation instability - caused by dilation of the sample - may be observed not only in the smectic A phase (7), (8) but in cholesterics as well (9).

In this paper we report on the undulation instability in a planar oriented layer of a compensated cholesteric mixture. The mechanical strain leading to the instability was induced internally by reducing the pitch as a result of a temperature change. The possibility of such a phenomenon has been predicted (7) but as far as we know it has not been observed.

THE EQUILIBRIUM PLANAR TEXTURE

The strong anchoring planar boundary conditions mean that there always has to be an integral number of half-turns in a planar cholesteric layer. Since the sample thickness /L/ is usually not a multiple of the temperature dependent half-pitch /$P_o/2$/ the cholesteric helix must be in a compressed or dilated state. At a given thickness - pitch ratio /L/P_o/ the equilibrium number of half-turns in the layer /n_{eq}/ can be determined from the requirement that this deformation be minimal (8), which implies

$$\frac{2L}{P_o} - \frac{1}{2} \leq n_{eq} \leq \frac{2L}{P_o} + \frac{1}{2} \qquad /1a/$$

or

$$\frac{q_o L}{\pi} - \frac{1}{2} \leq n_{eq} \leq \frac{q_o L}{\pi} + \frac{1}{2} \qquad /1b/$$

where n_{eq} is an integral number and $q_o = 2\pi/P_o$ is the wave vector of the cholesteric helix.

However a real planar sample is rarely completely homogeneous, usually a planar texture with oily streaks is observed instead [10], i.e. domains separated by disclinations. The number of half-turns in these domains may differ from n_{eq}. Though this texture is not an equilibrium one it may remain for a long time since the relaxation to the equilibrium usually proceeds through the motion of the disclinations which motion is hindered by their interaction and by the pinning effect of surface defects.

The great advantage of compensated cholesterics is that near the compensation - where their pitch is large - the disclinations can move as easily as in nematics, so homogeneous planar samples can be prepared.

DESCRIPTION OF THE INSTABILITY

We prepared a 60 μm sandwich cell which was filled with the compensated mixture of 4-cyano-4'-n-octyl-biphenyl and cholesteryl-chloride in 1:1 weight proportion. The planar orientation was achieved by oblique evaporation of SiO onto the glass plates [11].

A special feature of the undulation instability induced by mechanical strains is that it can be observed for a limited time only. The life of the instability can be divided into three phases: growth, evolution and decay. All the photos /Figs.1-12/ were taken at the same place in chronological order to illustrate this process.

Growth

Our sample was thermostated near the compensation temperature for a considerable time until a large homogeneous domain /dark appearance in figures/ was obtained. The temperature was then slightly changed /by about 0.5 °C/ and the sample was again thermostated. The temperature change results in the change of the helical pitch consequently the number of half-turns ought to change as well. Since the texture cannot relax immediately the original equilibrium texture becomes a non-equilibrium one leading to the formation of large elastic strain.

Whenever the temperature change increased the pitch, i.e. the helix became compressed, no instability was observed, the texture could relax only very slowly through the motion of disclinations.

When the temperature change reduced the pitch, the helix became dilated and nucleation of the undulation instability was observed at the domain boundaries and at surface defects /Fig.1/. This then gradually extended over the whole region /Figs.2-4/. Meanwhile domains with a different number of half-turns /light appearance in figures/ remained unchanged.

This growth process took some minutes.

Evolution

When the instability had fully developed throughout the sample it showed a square-grid pattern which was only slightly distorted by defects /Fig.5/. Later this square-grid pattern became blurred and changed to a more complex polygonal spiral texture /Figs.6-8/.

This process took some ten minutes.

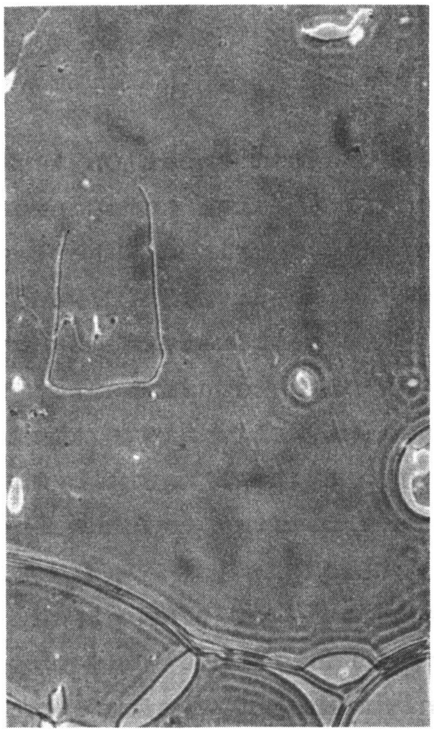

Fig.1.

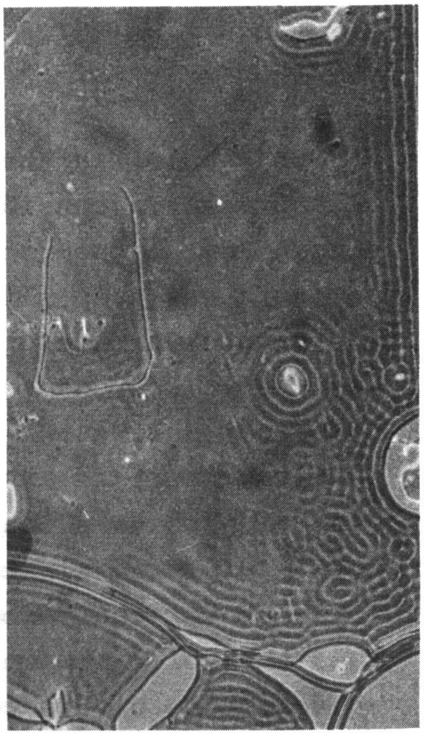

Fig.2.

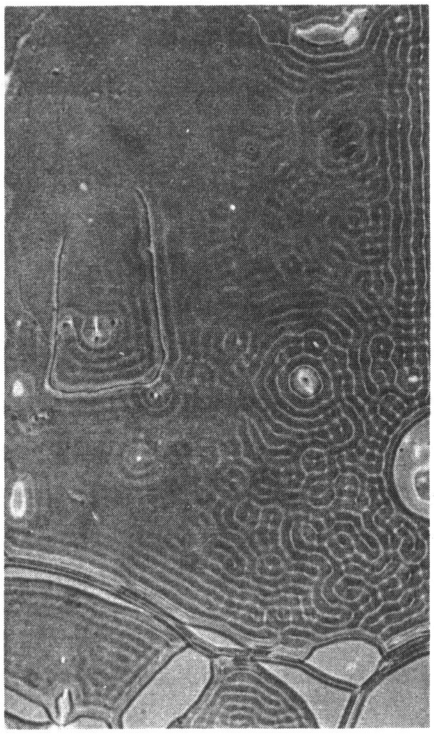

Fig.3.

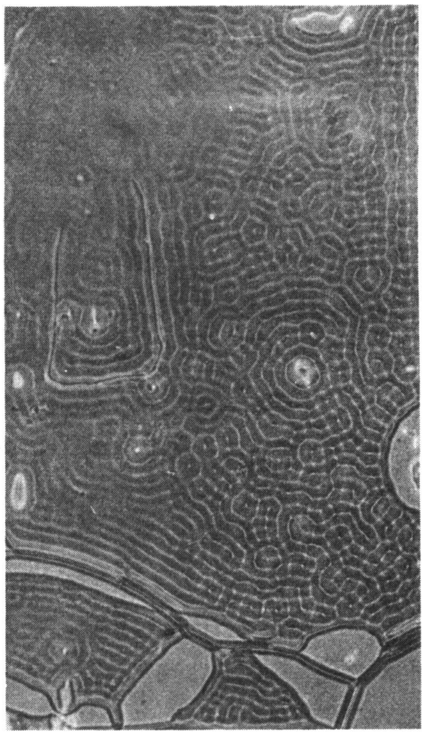

Fig.4.

Figures 1-4. Growth of the instability

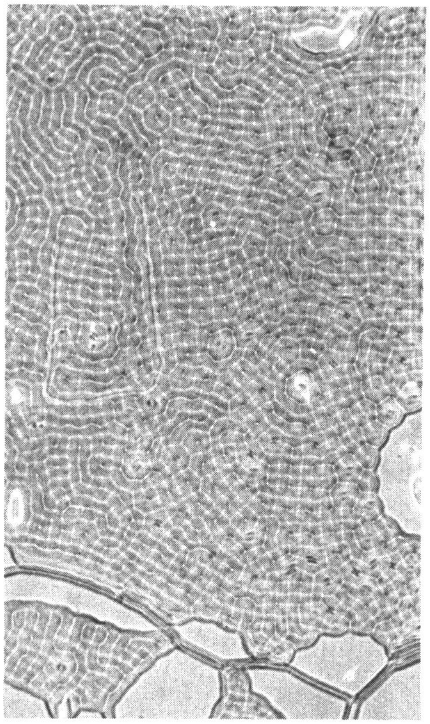

Fig.5.

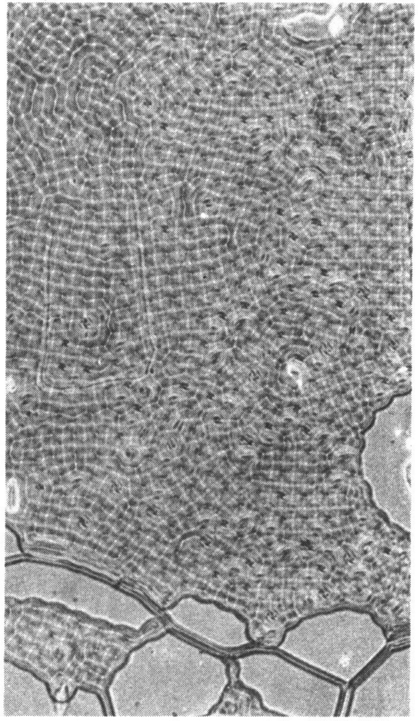

Fig.6.

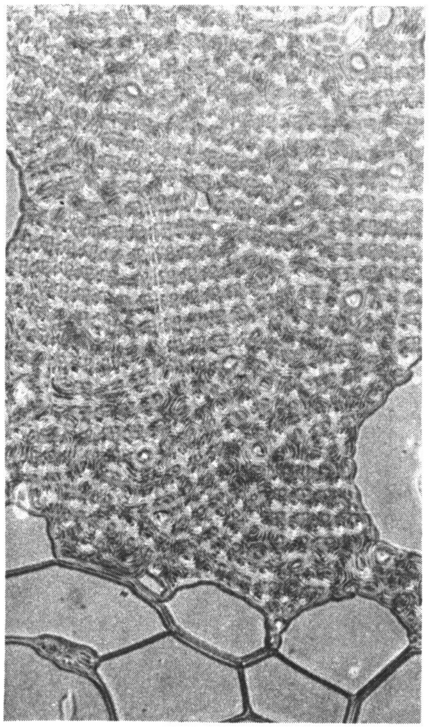

Fig.7.

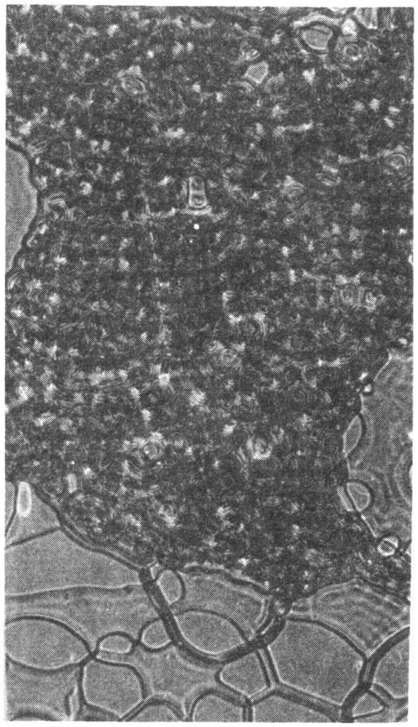

Fig.8.

Figures 5-8 Evolution of the instability

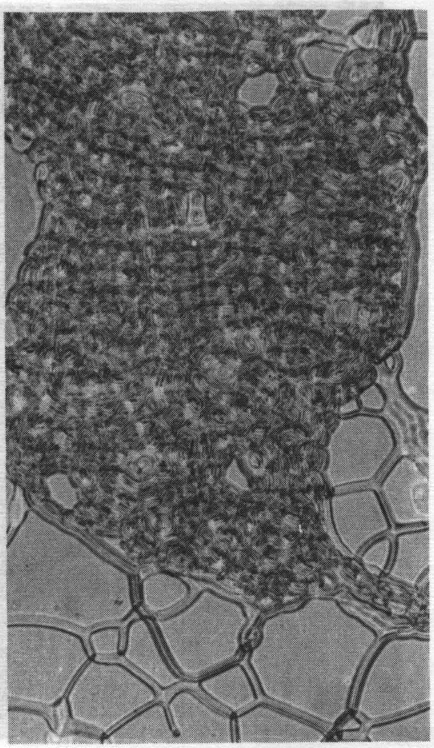

Fig. 9.

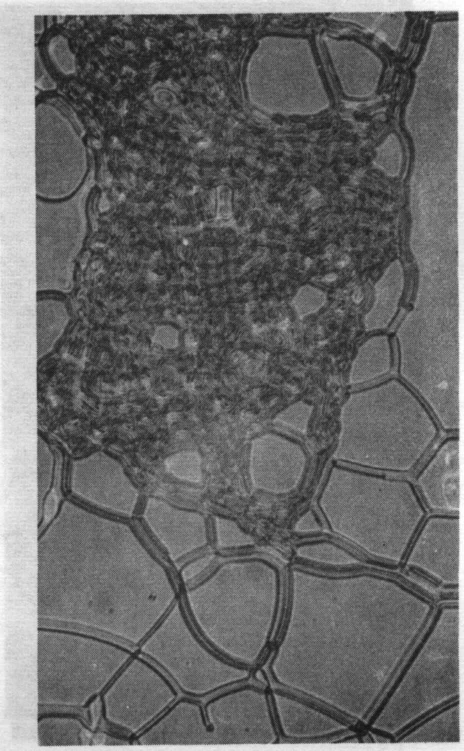

Fig.10.

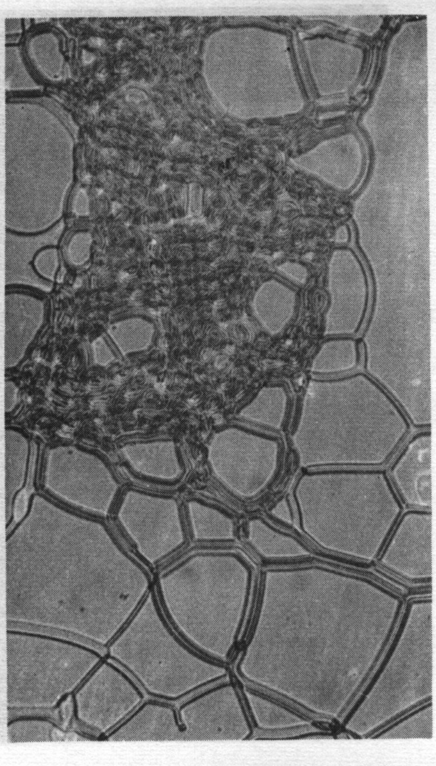

Fig.11.

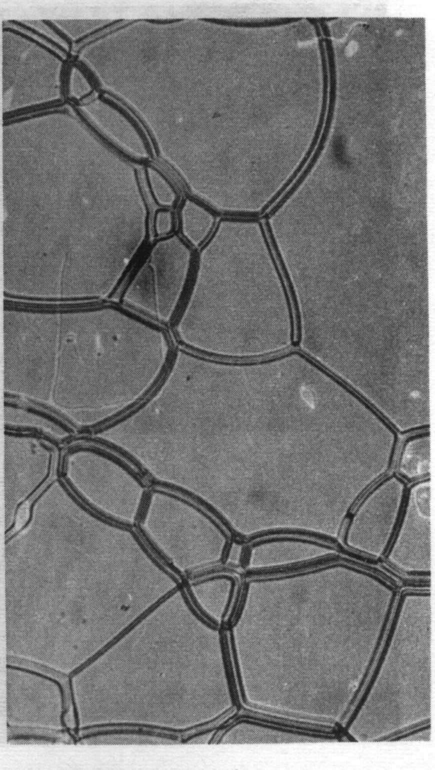

Fig.12.

Figures 9-12 Decay of the instability

Decay

As time passed the size of the unstable domain gradually decreased because of the motion of the bordering disclinations; furthermore inside the instability new disclinations and stable domains /light appearance in figures/ appeared. /Figs.9-11/. Finally the instability disappeared completely leaving behind a net of disclinations surrounding the stable domains, i.e. the usual planar texture with oily streaks reappeared /Fig.12/.

This decay process took about an hour.

After some hours the majority of the disclinations disappeared resulting in a homogeneous planar texture, similar to the original one but with a different number of half-turns.

We would mention that the same temperature change that led to an instability in a homogeneous planar sample could not induce an instability when the sample contained many disclinations and small domains, i.e. when the sample had not been thermostated for long enough for the disclinations to move out of the sample. It shows that the presence of disclinations may lessen the elastic strain coming from changes of the pitch. If this strain is below a certain threshold, no instability occurs; the only way that texture relaxation can take place is the motion of disclinations just as in the case of a compressed helix.

ESTIMATION OF THRESHOLD

As can be seen from the figures the appearance of the undulation instability is very similar to that induced by electric fields. Furthermore it is known that the mechanical strain corresponding to the requirements of the planar boundary conditions influences the threshold of the field induced instability [12]-[15], namely dilation of the helix reduces the threshold.

It suggests that for quantitative estimation of the threshold of the undulation instability one can use the technique developed for the description of the field induced instabilities. Taking into account the effect of the constrained pitch /P=2L/n, where n is the number of half-turns /the following formula was obtained from the continuum theory for the threshold voltage [14], [15].

$$V_{th} = V_o \sqrt{|n| \left(1 - |n| \sqrt{\frac{2K_2}{3K_3}} \; \frac{P - P_o}{P_o} \right)} \qquad /2/$$

In this formalism the undulation instability refers to the case when the threshold voltage becomes zero, viz. the instability occurs spontaneously without an external field.

$$V_{th} = 0 \Longrightarrow 1 - |n| \sqrt{\frac{2K_2}{3K_3}} \; \frac{P - P_o}{P_o} = 0 \qquad /3]$$

From Eq.3 one can get the instability condition

$$\frac{P - P_o}{P_o} = \sqrt{\frac{3K_3}{2K_2}} \; \frac{1}{|n|} \qquad /4/$$

for the pitch. This yields that the undulation instability will occur if

$$\left| \frac{2L}{P_o} \right| \geq |n| + \sqrt{\frac{3K_3}{2K_2}} \qquad /5a/$$

or

$$\left| \frac{q_o L}{\pi} \right| \geq |n| + \sqrt{\frac{3K_3}{2K_2}} \qquad /5b/$$

Equations 5 give the threshold pitch as a function of the number of half-turns in the sample.

Let us now investigate our experimental conditions. As described in the previous section the sample was first thermostated at a temperature /T_o/ until a homogeneous planar texture was obtained. Hereby the number of half-turns was fixed according to Eq.1, i.e.

$$\left|\frac{Lq_o(T_o)}{\pi} - n\right| \leq \frac{1}{2} \qquad /6/$$

After this the sample was again thermostated but at a temperature T_1. The instability can arise if the condition in Eq.5 is fulfilled, i.e.

$$\left|\frac{Lq_o(T_1)}{\pi}\right| \geq n + \sqrt{\frac{3K_3}{2K_2}} \qquad /7/$$

Comparing Eq.6 and Eq.7 one can calculate the change in the wave vector / $\Delta q_o = q_o(T_1) - q_o(T_o)$/ which is necessary for inducing an instability. It follows immediately that Δq_o is independent of the number of half-turns /n/ but depends strongly on how much the helix was distorted in the equilibrium state /at T_o/. The lowest threshold obtainable is when the constrained helix was originally a maximally dilated one:

$$\Delta q_o = \begin{cases} + \left(\sqrt{\frac{3K_3}{2K_2}} - \frac{1}{2} \right) & \text{if } q_o(T_o) > 0 \\ - \left(\sqrt{\frac{3K_3}{2K_2}} - \frac{1}{2} \right) & \text{if } q_o(T_o) < 0 \end{cases} \qquad /8/$$

The highest threshold obtainable is when the constrained helix was originally a maximally compressed one:

$$\Delta q_o = \begin{cases} +\left(\sqrt{\frac{3K_3}{2K_2}} + \frac{1}{2}\right) & \text{if } q_o(T_o) > 0 \\ -\left(\sqrt{\frac{3K_3}{2K_2}} + \frac{1}{2}\right) & \text{if } q_o(T_o) < 0 \end{cases} \qquad /9/$$

Equations 5 and Eqs.7-9 show that the threshold depends on the ratio of the elastic moduli. It follows from Eq.8 that if $K_2 > 6K_3$ were fulfilled for a material the dilation from the boundary conditions in the equilibrium state /Eq.1 and Eq.6/ would induce an instability by itself, consequently a stable planar texture could not exist at some temperature ranges. However this is not a real case since for the known compounds K_3 is always greater than K_2.

We would emphasize that as Eq.2 was derived in the approximation of L/P_o being large our expressions for the threshold in Eqs.5 and Eqs.7-9 are valid only in this limit, i.e. for thick samples when $|n| >> 1$.

Unfortunately disclination-free thick planar cholesteric samples are very hard to get and in the presence of disclinations the undulation instability cannot be observed. Thin homogeneous planar samples can easily be prepared using compensated cholesteric mixtures, as in our case, but Eqs.5 and Eqs. 7-9 no longer hold for thin samples. Moreover analytical solutions cannot be obtained when L/P_o is small. This means that the above threshold formulae can only be informative in nature.

SUMMARY

We observed undulation instability of the planar texture of a compensated cholesteric that was induced by the internal mechanical strain owing to the pitch change. The onset of this instability speeds the texture relaxation by enabling the development of new disclinations.

We calculated the threshold of this instability for thick samples but it gives only a coarse estimation for the experimentally available thin samples.

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