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ON NEW TYPE OF ELECTROHYDRODYNAMICS INSTABILITY IN TILTED NEMATIC LAYERS

S. PIKIN (*), G. RYSCHENKOW and W. URBACH (**) 
Laboratoire de Physique des Solides 91405 Orsay, France 

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Résumé. — On prévoit et on observe une nouvelle instabilité dans les nématiques : les striations sont orientées perpendiculairement à celles que l’on observe dans le cas des domaines de Williams, et leur période spatiale dépend du voltage appliqué. Ce type d’instabilité est essentiellement dû à l’ancrage oblique imposé par les surfaces limitant l’échantillon.

Abstract. — We have predicted and observed in a nematic phase of a liquid crystal (MBBA) a new kind of instability formed of rolls perpendicular to the Williams domains. In contrast to the latter, the spatial period of this new instability is a function of the voltage. This instability is due to the fact that the director points out of the substrate plane.

A number of papers have been devoted to the theoretical evaluation of the threshold of electrohydrodynamic (E.H.D.) instabilities and to their experimental investigation [1-3] at low frequencies (\( \omega < 1/\tau \); \( \tau \) is the space charge relaxation time). Experiments are usually carried out on aligned samples with the director (\( n \)) in the \( XY \) plane (see Fig. 1), parallel to the plates, along \( X \) (planar condition). In this case, the two-dimensional theory [4-6] describes quantitatively the frequency dependence of the E.H.D. threshold. Goscianski and Léger [7] observed broken Williams domains (W.D.) in a certain temperature range for compounds having a positive torque coefficient \( \alpha_3 \). We also note that Pikin and Shtol’berg [5] have shown that, above a critical positive value of \( \alpha_3 \), the W.D. could not be observed. E.H.D. instability was also observed in homeotropic samples [8] and the corresponding experimental data confirmed the exact theoretical calculation. Chistyakov and Vistin [2] observed that under certain conditions (pure compound, sample thickness \( 1 < 12 \mu m \) and frequency \( \omega < 10 \) Hz), some domains were parallel to \( n \). The reason for this domain structure is not very clear. Guyon and Pierranski [9] also observed Williams domains becoming parallel to the flow with a sufficiently large Poiseuille flow parallel to the plates.

The classical roll structure (classical domains, C.D.), along the \( Y \) axis, has its periodicity along the \( X \) axis, thus parallel to the initial orientation. This letter describes a new E.H.D. instability in the case where \( n \) points out of the \( XY \) plane. We have observed domains parallel to the \( X \) axis and having a periodicity along \( Y \) (extraordinary domains, E.D.) in samples prepared as described in [10]. To avoid injection, a film of SiO is evaporated on the top of a thin Au film used as an electrode (both under normal incidence). A third film of SiO deposited at extreme oblique incidence is used as an orienting agent. The alignment is controlled by the homogeneity of the microscopic image in polarized light and the orientation angle of \( n \) in the plane measured by conoscopic observation. In the oblique cells, \( n \) is at an angle \( \theta = 30^\circ \) with the \( X \) axis and remains in the \( ZX \) plane [10] (tilted orientation).
(see Fig. 1). The cell thickness, $l$, is determined by optical measurements with an accuracy of 0.5 $\mu$m. In the presence of a large enough D.C. electric field, along $Z$ the perturbed state shows a small periodic distortion along $Y$ of the type $\varphi = \varphi_0 \cos (q_y, y)$. The azimuthal angle $\varphi$ is defined in figure 1. The elastic energy gives rise to a restoring torque. Because of the anisotropy of the conductivity ($\sigma_y > \sigma_z$), this distortion induces a periodic distribution of charge density along $Y$. This effect gives rise as in the classical Williams problem, to an electrostatic and hydrodynamic torque, which both tend to increase the distortion. The threshold D.C. electric field, derived from the set of nematohydrodynamic eq. (1), is given by (1) [11]:

$$E_0^2 = \frac{4 \pi K q_y^2}{\sin^2 \theta (a q_y^2 - b q_z^2)} \quad (1)$$

where $K$ is an elastic constant, $a$ and $b$ some dimensionless combinations of $\sigma_{yy}, \sigma_{zz}, \epsilon_{yy}, \epsilon_{zz}, \alpha_2$ and $\alpha_3$. (In MBBA, $a \sim 0.06 \ b \sim 4.4$.) $q_y$ and $q_z$ are the wave numbers along $Y$ and $Z$ and $E$ is calculated for $q_z^2 > q_y^2$.

If we assume that a finite azimuthal energy $W$ exists [1, 2], the solution $\varphi = A \sin (q_z z) + B \cos (q_z z)$ of the boundary problem with general conditions:

$$\left| K \frac{\partial \varphi}{\partial z} + W \varphi + \frac{C}{l} \frac{\partial \varphi}{\partial t} \right|_{z = \pm l/2} = 0$$

shows that

$$q_y^2 \sim W \left| lK \right|^{-1}$$

for

$$W < \frac{K}{l} \quad \text{and} \quad q_z^2 \sim l^{-2} \quad \text{for} \quad W > \frac{K}{l}.$$  

The threshold value $E_0$ is determined by minimizing $E^2(q_y^2)$ which leads to:

$$q_y = q_y^0 = \left( \frac{2b}{a} \right)^{1/2} q_z \quad (q_y^0 \gg q_z \quad \text{for} \quad b \gg a)$$

and

$$E_0 = \frac{4}{a \sin \theta} \left( \frac{\pi b W}{l} \right)^{1/2} \quad \text{for} \quad W < \frac{K}{l} \quad (2)$$

Thus, the threshold voltage $V_0 = E_0 l$ depends on the sample thickness ($V_0 \sim l^{1/2}$) and on

$$\theta (V_0 \rightarrow \infty \ \text{at} \ \theta \rightarrow 0).$$

The period of the $Y$-structure at the threshold follows the relation:

$$d_0 = \frac{\pi}{q_y^0} \approx \pi \left( \frac{a l K}{2 b W} \right)^{1/2}.$$  

Note that for $W > K/l$, the threshold voltage does not depend on sample thickness and $d_0 \sim l$ as in the C.D. case. In the first photograph the period of the Williams domains is of the order of the E.D. ones. In the case of A.C. electric fields, an examination of the boundary problem shows [11] that $q_y$ has the following qualitative dependence on $\omega$:

$$q_y^2 = q_y^0^2 \left( \frac{a}{2b} \right) \sim \left\{ \begin{array}{ll}
\frac{W}{IK} \left[ 1 + C^2 \frac{\omega^2}{W^2} \right] & \text{if} \ \omega < \frac{W}{C} = \omega_0 \\
C \frac{\omega}{IK} & \text{if} \ \omega > \omega_0.
\end{array} \right. \quad (3)$$

$C$ is the product of a viscosity and a characteristic molecular length ($C \sim 10^{-7}$ g s$^{-1}$). The threshold voltage is given by:

$$V_0 \sim \sqrt{\omega + \text{Const.}}, \quad \omega > \omega_0 \quad \text{and} \quad V_0 \sim \text{Const.} + \omega^2 \quad \omega < \omega_0 \quad (4)$$

When $\omega > 1/\tau$, the dielectric mechanism must be included but the qualitative dependence of $V_0$ on $\omega$ is the same as for $\omega < 1/\tau$.

The experimental threshold voltage $V_0$ is shown in figure 2. This curve shows two intervals of frequencies which correspond qualitatively to the two domains described by eq. (3) and (4).

![Fig. 2. Typical threshold voltage, for classical domains C.D. and extraordinary domains E.D., versus frequency (sine wave). Sample thickness : 12 $\mu$m. $\Delta V = V_{CD} - V_{ED}$ versus frequency. The critical frequency $\omega_c$ ~ 90 Hz.](image)
\( \omega < \omega_0 \sim 100 \text{ Hz} \) (Photo 1), the C.D. and E.D. appear at the same voltage \( (V_0 \approx V'_0) \). However, in this range of frequencies the E.D., observed between crossed polaroids flicker with time. The unstable E.D. are separated by black walls (Photo 2) in which \( \mathbf{n} \) remains along its unperturbed orientation. The observ-

ed spatial period \( d_0 \) of this E.D. is much larger than \( l \). In a given E.D. domain, the direction of the Williams rolls (period \( \sim l \)) is tilted alternately with respect to the \( Y \) axis. If we assume that the W.D. remain perpendicular to \( \mathbf{n} \), the tilt angle of the rolls displays the average azimuthal deviation of \( \mathbf{n} \) in each extraordinary domain. The flickering effect, mentioned above, arises when \( d_0 \) is large \( (d_0 \gg l \) at low \( \omega_0 \), according to (3)). In this case, it is possible that the small value of the elastic energy \( F \sim q_s^2 \sim \omega \) is not large enough to limit the effect of the thermal fluctuations with

\[
q_s^2 \sim q_y^2 \left( \frac{E^2 - E_0^2}{E_0^2} \right).
\]

If \( \omega > \omega_0 \), the threshold voltage for E.D. is lower than for C.D. (Photo 3). At the threshold, the period \( d_0 \) of the E.D. decreases when \( \omega \) increases, in qualitative agreement with the result of eq. (3) (note that \( a \ll b \)). Furthermore the E.D. rolls are much more stable than in the low frequency range. At a fixed frequency, when the voltage increases above the threshold, the classical W.D. instability appears and is superimposed on the E.D. one. At higher voltages, the C.D. becomes unstable due to dynamic scattering (D.S.). The E.D. structure remains stable up to a larger voltage and then also disappears by a D.S. mechanism. We observe a decrease of the period of E.D. with increasing voltage. This qualitative observation also agrees with eq. (1). Here, the period of E.D. depends less on the thickness than it does in the C.D. (compare photos 1 and 2).

The threshold voltage of E.D. depends strongly on the experimental conditions and on the anisotropy of the electric conductivity and dielectric constant. In aged samples, the surface defects become wider and indicate a decrease in the anchoring energy \( W \) [12]. In such samples, we observed that, at high frequencies (300-500 Hz), the ranges of existence of the E.D. and C.D. were separated by a spectacular unstable structure in which appeared snake-like double disclinations (with core) moving along the \( Y \) axis (Photo 4). The number of these disclinations increases with the voltage. These lines do not disappear in the range of existence of the C.D. At higher voltages, these disclinations become turbulent and are broken when the D.S. appear. When we switch off the voltage, some of these disclinations remain present, and turn,
PHOTO 3. — At a higher frequency (250 Hz) the E.D. appear before the C.D. when we increase the voltage through a spreading of the core, into a surface defect, a wall where \( n \) is horizontal. The measurement of the wall thickness \( t \) leads to an estimate of \( W \) [13]:

\[
W \approx \frac{Kl}{T^2} \approx 10^{-4} \text{erg/cm}^2, \text{ for } t \approx 12 \mu \text{ and } l \approx 10 \mu.
\]

It is interesting to compare this value with that obtained from the estimate of the coefficient \( C \) and from the value of the limit frequency \( \omega_0 \):

\[
W \sim C\omega_0 \sim 10^{-5} \text{erg/cm}^2.
\]

Considering the uncertainty in the estimation of \( C \), the orders of magnitude are consistent.

In some instances we also observed E.D. in planar samples. The E.D. threshold is then larger than the C.D. one. In such cases the E.D. structure does not uniformly cover the sample surface. Above the Williams's threshold voltage, \( n \) is no longer in the planar configuration. If the voltage is large enough, an azimuthal deviation of \( n \) may occur in some regions, giving rise to the E.D. However this is a second order perturbation due essentially to a non-homogeneous angular orientation in C.D.

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References


Ryschenkow, G., Thèse de 3e cycle, Orsay (1975).