

INSTABILITIES IN ELECTRIC FIELDS OF A NEMATIC LIQUID CRYSTAL WITH LARGE NEGATIVE DIELECTRIC ANISOTROPY

W.H. DE JEU and J. VAN DER VEEN

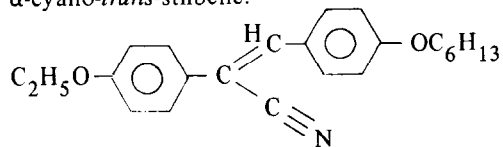
Philips Research Laboratories, Eindhoven, The Netherlands

Received 28 May 1973

A new nematic α -cyanostilbene with a dielectric anisotropy of about -5 is investigated in AC fields. On increasing the voltage in the conduction regime the instabilities disappear at a field threshold. In addition, chevrons can be observed over the whole frequency range.

Since the first observation by Williams [1] much work has been devoted to electric-hydrodynamic instabilities in nematic liquid crystals. The behaviour of a planar layer of a nematic with negative dielectric anisotropy ($\Delta\epsilon = \epsilon_{\parallel} - \epsilon_{\perp} < 0$) in AC fields now seems fairly well understood. Below a critical frequency ω_c proportional to the conductivity σ at a voltage threshold V_c cellular flow patterns are observed that correspond to the Williams domains [2-4] (conduction regime). On increasing the voltage the flow becomes more violent in which situation the nematic scatters light strongly [5]. Above ω_c parallel striations of much smaller period (chevrons) are observed at a field threshold [4, 6] (dielectric regime). These observations have been explained theoretically by Helfrich [7] and Dubois-Violette et al. [8]. However, all the experimental results have been obtained in nematics with rather small values of $\Delta\epsilon$ (typically -0.5). This letter reports for the first time on a nematic with a negative dielectric anisotropy that is an order of magnitude larger.

Larger negative dielectric anisotropies can in principle be obtained by introduction of a large dipole moment perpendicular to the long molecular axis. In this context we synthesized some α -cyanostilbenes [9]. These compounds are easily prepared by condensation of benzylicyanides with benzaldehydes. As an example we shall discuss *p*-ethoxy-*p'*-hexyloxy- α -cyano-*trans*-stilbene:



which is nematic from 54 to 80.5°C. The dielectric

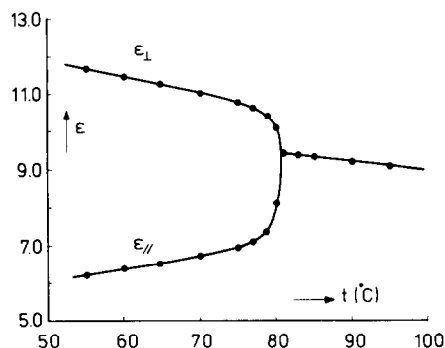


Fig. 1. Static dielectric constants of *p*-ethoxy-*p'*-hexyloxy- α -cyano-*trans*-stilbene.

permittivities were measured at 1592 Hz with a Wayne-Kerr B642 autobalance bridge. The dielectric cell consisted of two glass plates with vacuum deposited copper electrodes separated by 80 μm spacers. Alignment was assured by a magnetic field of about 13 kOe. As is shown in fig. 1 the dielectric anisotropy is indeed rather large.

The instabilities of a planar layer in electric fields were investigated at 55°C where $\Delta\epsilon = -5.5$ and $\sigma_{\parallel}/\sigma_{\perp} = 1.6$. The results are given in fig. 2. At low frequencies Williams domains appear at a voltage threshold while at higher voltage turbulence and dynamic scattering occur, as expected. However, when the voltage is further increased the turbulence diminishes, until finally the flow patterns (that are still of the order of the thickness) disappear completely. This effect is fully reversible. Experiments in a wedge-shaped sample indicate a field threshold. Identifying the top of the cone in fig. 2 with ω_c , we could again show that ω_c is proportional to σ . The threshold for the chevrons can be observed as usual but now extends

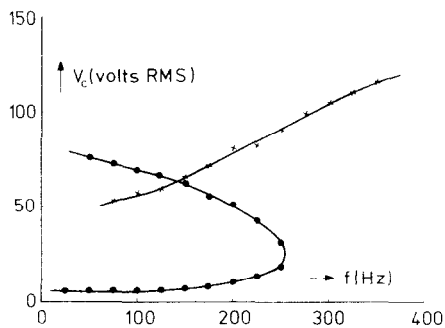


Fig. 2. Threshold for domains (●) and chevrons (x) in AC fields of a 15 μm planar layer of *p*-ethoxy-*p'*-hexyloxy- α -cyano-*trans*-stilbene; $\sigma \approx 10^{-8} \Omega^{-1} \text{cm}^{-1}$.

to far below ω_c . Due to the diminished turbulence threshold curves can also be given at the left of the crossing point (see fig. 2). Clearly the two types of instability behave rather independently. Summarizing we conclude that all the well-known features of a planar nematic layer with $\Delta\epsilon < 0$ are present while in addition: (a) there is a second threshold leading to a closed region of instability for the conduction regime; (b) chevrons can be observed over the whole frequency range; consequently ω_c is not a frequency limiting the dielectric regime.

Qualitatively the existence of an upper threshold limiting the conduction regime can be understood as follows. Assuming a small perturbation the total torque on the director is given by:

$$\Gamma_{\text{tot}} = \Gamma_{\text{elast}} + \Gamma_{\text{diel}} - \Gamma_{\text{visc}} \quad (1)$$

The stabilizing part of the dielectric torque due to the external field is equal to $\Delta\epsilon E^2$. On increasing the voltage this torque increases strongly. On the other hand the destabilizing part of the dielectric torque and the viscous torque depend on the space charge induced by the anisotropic conductivity [7]. Above the first threshold the molecules reorientate, and at an angle θ for which $\text{tg}^2\theta = \sigma_{\parallel}/\sigma_{\perp}$ the anisotropy in the conductivity is effectively zero. Finally, this may again lead to a stabilizing Γ_{tot} at high electric fields. A more quantitative understanding can be obtained from the frequency dependent theory for electrohydrodynamic instabilities [8, 10] and will be given elsewhere.

In our case stabilization occurs at a field of about 10^5 V/cm . In a nematic like MBBA with a much smaller value of $\Delta\epsilon$, the same effect can then be expected at about 10^6 V/cm . This cannot easily be observed because of the unpractical high fields. Nevertheless such a behaviour has been reported in a very small frequency region below ω_c with square wave excitation instead of a sine wave [11]. In that case the higher harmonics above ω_c in the square wave contribute only to the stabilizing part of the dielectric torque.

Apart from the physical interest the large negative values of $\Delta\epsilon$ reported here are of great practical importance. It could lead to the choice of an optimum $\Delta\epsilon$ of nematic mixtures for dynamic scattering [5] displays. Furthermore the double valued conduction regime can be in principle be used in combination with the memory effect in cholesteric nematic mixtures [12]. Choosing a suitable frequency for the writing cycle erasing can simply be accomplished by increasing the voltage, and no second frequency is necessary.

The authors thank Dr. W.J.A. Goossens for valuable discussions.

References

- [1] R. Williams, J. Chem. Phys. 39 (1963) 384.
- [2] G. Durand et al., Compt. Rend. Ac. Sc. (Paris). B270 (1970) 97.
- [3] P.A. Penz, Phys. Rev. Lett. 24 (1970) 1405.
- [4] Orsay Liquid Crystal Group, Mol. Cryst. Liq. Cryst. 12 (1971) 251.
- [5] G.H. Heilmeyer, L. Zanoni and L. Barton, Proc. IEEE, 56 (1968) 1162.
- [6] G.H. Heilmeyer and W. Helfrich, Appl. Phys. Lett. 16 (1970) 155.
- [7] W. Helfrich, J. Chem. Phys. 51 (1969) 4092.
- [8] E. Dubois-Violette, P.G. De Gennes and O. Parodi, J. Phys. (Paris), 32 (1971) 305.
- [9] J. Van der Veen and Th.C.J.M. Hegge, to be published.
- [10] E. Dubois-Violette, J. Phys. (Paris), 33 (1972) 95.
- [11] Orsay Liquid Crystal Group, Phys. Lett. 39A (1972) 181.
- [12] G. Heilmeyer and J. Goldmacher, Proc. IEEE, 57 (1969) 34.