

ELECTROHYDRODYNAMIC INSTABILITIES IN NEMATIC LIQUID CRYSTALS

W. H. De JEU, C. J. GERRITSMAN and A. M. Van BOXTEL
*Philips Research Laboratories, N. V. Philips' Gloeilampenfabrieken
Eindhoven, the Netherlands*

Received 18 February 1971

Contrary to earlier reports nematic liquid crystals with a positive dielectric anisotropy can form domains on application of an electric field. Results are reported for N-p-ethoxybenzylidene-p-amino-benzonitrile (PEBAB).

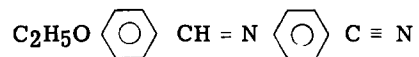
On increasing the voltage over a thin (10-100 μm) layer of a nematic liquid crystal sandwiched between planar electrodes, we see usually the following sequence of events. Above a threshold V_C of about 5 volt a stationary domain-like pattern is observed [1]. When the voltage is further increased this laminar flow pattern gradually changes into a regime of turbulent flow in which the liquid crystal strongly scatters light [2]. Although this effect is normally seen both in dc and in ac excitation there are some important differences between the two cases: (a) The dc effect exists only when the electrodes inject charge carriers into the fluid [2], while the ac threshold is unaffected by whether the electrodes are separated from the nematic by thin insulating sheets or not [3]. (b) The dc effect is also found above the nematic-isotropic transition temperature [4], while the ac effect disappears at this point [3].

Two theoretical models are available to explain these observations. In the Felici model space charge due to unipolar injection leads to cellular hydrodynamic flow [5]. In principle this model is valid for all liquid dielectrics but it is, of course, restricted to the dc case. As the experimental thresholds in normal dielectrics are of the same order of magnitude as in nematics [6], the dc behaviour of a liquid crystal above and below the transition point can be understood in this way.

In the Carr-Helfrich model [7, 8] the space charge which leads to cellular flow is due to the anisotropy in the conductivity and in the dielectric constant. Recently this model has been extended successfully to the ac case [9, 10]. Consequently, one would expect that these aniso-

tropies also interfere in the dc case.

On the basis of the Carr-Helfrich model the conclusion was arrived at that in the dc case domains can only be formed when $\epsilon_{\perp} > \epsilon_{\parallel}$ [11]. The observation [2] that no dynamic scattering is found in some nematic liquid crystals with $\epsilon_{\perp} < \epsilon_{\parallel}$ like PEBAB



seemed to support this statement experimentally.

However, we have found that above a dc threshold of 2 to 3 volt domains are formed in

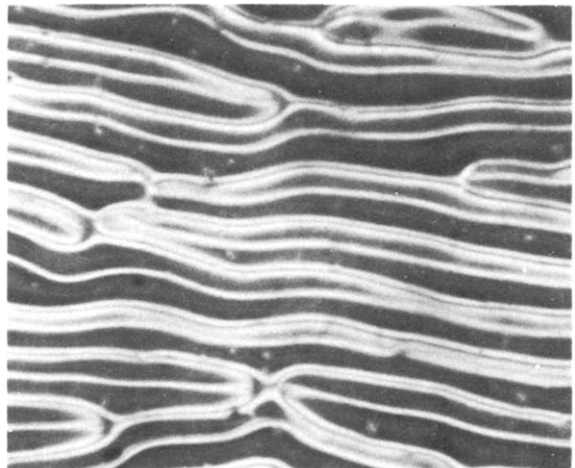


Fig. 1. Domains in a 50 μm layer of PEBAB, orientated by the Chatelain rubbing technique ($\rho \approx 10^7 \Omega \text{cm}$). Crossed nicols; magnification 80x; applied coltage 4 volt dc.

PEBAB. A typical domain pattern is shown in fig. 1. The same threshold was found in samples of 12, 30 and 50 μm thickness. When the voltage is further increased the long domains are divided up into smaller domains parallel to the short axis, while at about 20 volt a state of turbulence is reached. Above the threshold the molecules are orientated parallel to the electric field. The scattering of incident light is confined to a very small region around the specular reflected light. Hence the deviations from the parallel orientation during the turbulent flow are clearly very small. The same behaviour is found in the compound with both para substituents interchanged.

Furthermore we want to point out that the Carr-Helfrich model does not exclude domains for PEBAB. This theory states that for an electric field perpendicular to the molecular axis domains are in principle possible when the quantity ξ is positive [8]:

$$\xi = (\epsilon_{\parallel} - \epsilon_{\perp}) \frac{\sigma_{\perp}}{\sigma_{\parallel}} + \frac{\kappa_1}{\eta_1} \epsilon_{\parallel} \left(\frac{\epsilon_{\perp}}{\epsilon_{\parallel}} - \frac{\sigma_{\perp}}{\sigma_{\parallel}} \right). \quad (1)$$

Only when the first term is much smaller than the second one this reduces to

$$\epsilon_{\perp}/\epsilon_{\parallel} - \sigma_{\perp}/\sigma_{\parallel} > 0 \quad (2)$$

where κ_1/η_1 is taken to be positive. For a small value of the anisotropy in the conductivity eq. (2) is about equivalent to $\epsilon_{\perp} > \epsilon_{\parallel}$. The threshold field E now can be calculated from

$$-\xi E^2 / 4\pi + q^2 K_{33} = 0. \quad (3)$$

Usually q is taken inversely proportional to the thickness and then a threshold voltage is predicted independent of the thickness. For para-azoxyanisole (PAA) Helfrich calculates a threshold of 5.3 volt [8] which compares very well with the experimental results. For PEBAB $\epsilon_{\parallel} = 21$ and $\epsilon_{\perp} = 7$ [12]. Taking the PAA values for the other quantities we calculate that ξ is again positive while the threshold is lowered to 1.6 volt, in reasonable agreement with the experimental value.

The sign of ξ is determined by a delicate balance of two terms that both can have either sign. Therefore one would expect that nematic compounds that do not show domains can also be found. Moreover, a positive ξ is in the Carr-Helfrich theory a necessary but not a sufficient condition for domain formation. A positive ξ can lead either to domains or to a new static situation of alignment in another direction than originally. In this respect further studies are being carried out in this laboratory on some nematic azo- and azoxy-compounds.

The authors wish to express their gratitude to Dr. J. Van der Veen for preparing the sample and to Drs. H. Koelmans, W. J. A. Goossens and A. K. Niessen for valuable discussions.

References

- [1a] V. Fréederickz and V. Zolina, *Trans. Faraday Soc.* 29 (1933) 919.
- [1b] R. Williams, *J. Chem. Phys.* 39 (1965) 384.
- [1c] G. Durand, M. Veyssié, F. Rondelez and L. Léger, *Compt. Rend.* B270 (1970) 97.
- [1d] P. A. Penz, *Phys. Rev. Letters* 24 (1970) 1405.
- [2] G. H. Heilmeyer, L. A. Zanoni and L. A. Barton, *Proc. IEEE*, 56 (1968) 1162.
- [3] F. Rondelez, thesis, Université de Paris, Orsay (1970).
- [4] H. Koelmans and A. M. van Bortel, *Phys. Letters* 32A (1970) 32.
- [5] N. Felici, *Rev. Gen. Elec.* 78 (1969) 717.
- [6] J. C. Filippini, J. C. Lacroix and R. Tobazeon, *Compt. Rend.* B271 (1970) 73.
- [7] E. F. Carr, in *Ordered fluids and liquid crystals* (Am. Chem. Soc. Public., 1967), p. 76.
- [8] W. Helfrich, *J. Chem. Phys.* 51 (1969) 4092.
- [9] E. Dubois-Violette, P. G. de Gennes and O. Parodi, *J. Phys.*, to be published.
- [10] Orsay Liquid Crystal Group, *Phys. Rev. Letters* 25 (1970) 1642.
- [11] P. G. de Gennes, *Comm. Sol. State.*, *Phys.* 3 (1970) 35.
- [12] G. H. Heilmeyer, L. A. Zanoni and J. E. Goldmacher in *Liquid crystals and ordered fluids* (Am. Chem. Soc. Public. 1970) p. 215.

* * * * *