

SOME ELECTROHYDRODYNAMIC DISTORTION PATTERNS IN A NEMATIC LIQUID CRYSTAL

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ABSTRACT

Distortion patterns in a homeotropically aligned nematic liquid crystal (*n-p*-methoxybenzylidene-*p*-butylaniline) under the action of electric fields have been studied employing a geometry in which the observation direction is along the optic axis of the undistorted specimen and the field direction perpendicular to it. Some interesting new features are described.

INTRODUCTION

WILLIAMS¹ was the first to observe that a thin sample of a nematic liquid crystal subjected to a DC electric field exhibits striations when the applied voltage exceeds a certain threshold value. Studies of these distortion patterns have since been extended to low frequency AC fields². The experimental set up generally consists of two transparent electrodes between which the specimen is sandwiched, and the observations are made along the direction of the electric field. In the case of a liquid crystal whose dielectric anisotropy is negative a homogeneously aligned specimen shows striations *perpendicular* to the initial orientation of the director. The pattern is now known to arise from a hydrodynamic cellular motion of the fluid; the motion has been explained in terms of the anisotropy of electrical conductivity of the liquid crystal, which is usually positive (the Carr-Helfrich model)^{2,3}. A small bend distortion in the medium produces a space charge in that region because of the conductivity anisotropy. The action of the applied electric field on the space-charge leads to the hydrodynamic cellular flow, which in turn increases the initial distortion until a stable pattern is obtained. At higher voltages, the pattern breaks up and the medium goes over to the dynamic scattering mode.

Recently Williams⁴ employed another geometry in which the direction of observation was transverse to the applied field. A homogeneously oriented specimen was sandwiched between two glass plates, one of which had deposited on it two parallel electrodes about 1 cm apart. A DC electric field gave rise to striations perpendicular to the initial direction of orientation of the molecules. More recently these observations have been extended by Richardson and Chang⁵ who used much smaller spacings between the electrodes. In the present study we have made observations transverse to the applied field on a *homeotropically* aligned specimen. Some new features have been noted which are described in this paper.

DC EXCITATION

A sample of *n-p*-methoxybenzylidene-*p*-butylaniline (MBBA) was homeotropically aligned between two glass plates, which were separated by two parallel copper electrodes $\sim 30 \mu\text{m}$ thick. The gap between the electrodes was $\sim 150 \mu\text{m}$ and the specimen was observed in a direction perpendicular to the glass plates through a polarizing microscope. The resistivity of the sample was $\sim 10^9 \text{ ohm cm}$.

In the absence of any applied field, the specimen in this configuration is dark between crossed nicols, the optic axis being parallel to the direction of observation. If a DC field is now applied no changes are observed at low voltages since the dielectric anisotropy of the medium is negative. At higher voltages ($\sim 12 \text{ V}$), the anisotropy of conductivity forces the medium to acquire some alignment along the field and there is no longer any extinction between crossed nicols set at 45° to the field direction. The alignment increases with increasing field and at $\sim 20 \text{ V}$ alternate bright and dark bands appear, and intense agitation can be seen. If the voltage is maintained at 35 V for some time, a regular, periodic though complex pattern is obtained. Figure 1*a* shows a photograph of the pattern taken between crossed nicols. As the voltage is raised to $\sim 40 \text{ V}$, dynamic scattering sets in and the regular pattern is lost.

AC EXCITATION

The pattern assumes simpler shapes under the action of low frequency AC fields. At 20 cps, the response for low voltages is similar to the DC case. At 24 V , a regular distortion sets in. Figures 1*b*, 1*c*, and 1*d* illustrate the patterns obtained at about 32 V for different settings of the nicols. In the setting corresponding to Fig. 1*c*, dark bands are seen to sweep across the domains from one wall to the other and back, the bands in adjacent domains moving in opposite directions. There are corresponding changes in the walls but these are better seen only when the nicols are set at 45° to the direction of the field. The width

of each domain, *i.e.*, the horizontal spacing in the pattern is approximately half the separation between the electrodes. Dust particles can be clearly seen to execute circular motion with a period of a few seconds. As the voltage is increased to ~ 40 V, there is intense motion in the medium which has now gone over to the dynamic scattering mode.

orientation near the electrodes becomes parallel to the field as evidenced by two bright patches between crossed nicols set at 45° . At higher voltages (~ 42 V), a wavy distortion begins to grow laterally from both sides of the field of view. On increasing the frequency further, the regular distortion becomes less and less conspicuous though some hydrodynamic motion persists upto ~ 800 cps

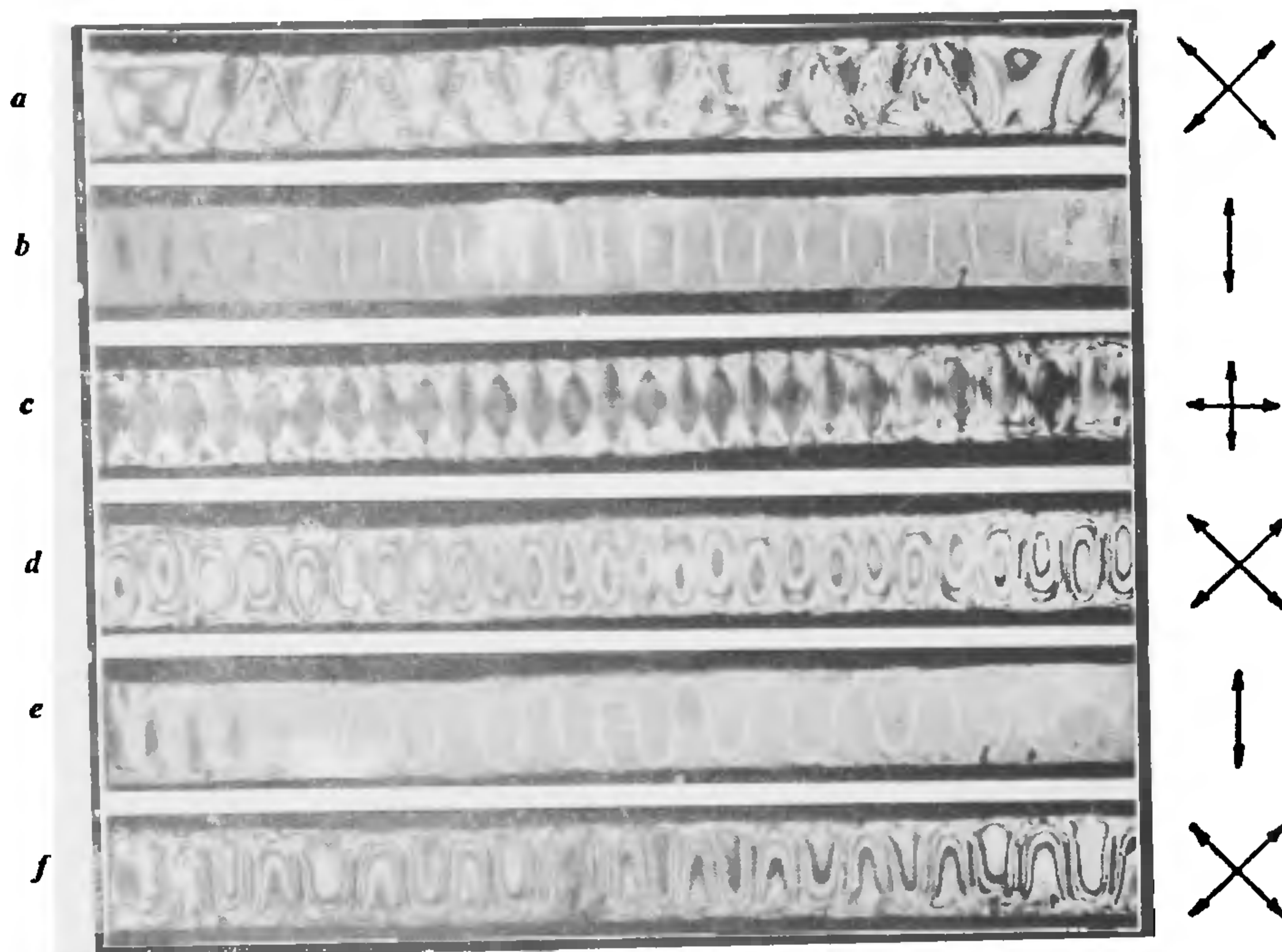


FIG. 1. Electrohydrodynamic patterns in MBBA. Photographs taken in monochromatic light (λ 5893 Å); magnification $\times 75$. In all cases, the applied electric field is vertical and the director of the undistorted specimen is parallel to the direction of observation. The arrows on the right hand side indicate the settings of the nicols. (a) DC, 35 V; (b), (c) and (d) 20 cps, 32 V; (e) and (f) 100 cps, 45 V. (The horizontal lines in the centre of each photograph are the graduations in the microscope eye-piece.)

An increase in the frequency of the applied field results in an increase in the threshold voltage at which the distortion sets in. Figures 1 e and 1 f illustrate the wavy pattern obtained at 100 cps and 45 V. It is seen that the spatial periodicity of the distortion has increased compared to the lower frequency case.

At still higher frequencies (~ 250 cps) the homeotropic alignment improves when the voltage is less than about 25 V, but at about 30 V the

at high fields. Beyond this frequency there is only a small, irregular motion near the electrodes at very high voltages (~ 500 V).

As the separation between the electrodes is increased to 1–2 mm the regular distortions especially under low frequency AC fields are confined to the neighbourhood of the electrodes at low voltages and grow to join up at higher voltages. A similar effect has also been observed by Williams⁴ for the configuration employed by him.

Detailed measurements of related optical and electrical characteristics are under way and will be published in due course.

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2. Dubois-Violette, E., de Gennes, P. G. and Parodi, O., *J. Phys.*, 1971, 32, 305.
3. Helfrich, W., *J. Chem. Phys.*, 1969, 51, 2755.
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5. Richardson, J. M. and Chang, R., *Proceedings of the Fourth International Liquid Crystal Conference*, Kent, Ohio, August 1972.

RELATIVISTIC INVARIANCE AND DISCRETE SYMMETRIES*

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I HOPE to outline to you in this lecture briefly and rather imperfectly the method whereby geometric transformations like rotations and space time translations are implemented as invariance transformations in quantum mechanics. There are good reasons for such a study. The existence of such symmetries implies that of all possible theories, a certain subset sharing specific features is singled out as acceptable. This is an enormous simplification and in fact leads to definite predictions. Actually the significance of geometric symmetries is deeper. Thus, the Hamiltonian which governs the time evolution and hence the dynamics of the theory, corresponds on exponentiation to time translation. Thus, geometry in fact determines dynamics. It may be noted in this context that the conservation of angular or linear momentum is a consequence of geometrical invariance principles which decide the commutation relations of such operators with the Hamiltonian.

This is a conference on unsolved problems. The field which is surveyed now contains perhaps the unsolved problems in relativistic quantum mechanics. Let us briefly review a few of these.

1. Previous remarks suggest that the "correct" realization of geometric symmetries will lead in a direct way to the "correct" theory. This task has certainly not been carried out.

2. The analysis of continuous geometric transformations leads to certain relatively definite rules on how they are to be implemented. However, for discrete symmetries like parity P or time reversal T , the situation is more diffuse. In particular, that P is unitary and T anti-unitary is not a consequence of general principles alone, but requires the extra assumption that there are no negative energy states. There are further ambiguities regarding T and PT .

It is known that T^2 can be $+1$ or -1 . However, in all the theories we deal with in practice, the choice $T^2 = (-1)^{2j}$ for a particle of spin j is made. Whether this hypothesis is binding on us is not clear to me.

3. Experimentally, we know that P and T are not exact invariance properties, that is to say, that they cannot be implemented in the usual theories with the proper commutation relations with the Hamiltonian. Whether the preceding remarks have a bearing on this matter is not clear. If in fact what is observed is the impossibility of implementation of these geometric transformations, the nature of geometry itself may be different from the present concepts.

4. There are a whole group of symmetries like isospin and unitary spin transformations which do not seem to originate in an intimate way from geometry. There have been many attempts to bring these too into the geometric fold, but the successes have been limited. In fact, there are negative theorems (like McGlinn's, Sudarshan and co-workers', O'Raiheartaigh's, etc.) which indicate serious difficulties for such a program within the present framework.

5. Finally we may ask whether relativistic quantum theory should really be formulated so as to be generally covariant. The success in this task has been limited. It is often claimed that gravitation is too weak to be relevant in particle physics. This claim is ambiguous. Let us consider an example from another context to illustrate the ambiguity. At very low energies, we expect relativistic effects to be unimportant and nonrelativistic considerations to suffice. Consider now the CPT theorem which essentially says that CPT is always implementable as a symmetry transformation in a certain class of quantum field theories. Such a theorem cannot be proved using nonrelativistic dynamics although its effects persist at low energies. Conceivably similar effects could occur with general relativity.

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