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Some new types of electrohydrodynamic flow patterns in nematic liquid crystals

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Abstract. Electrohydrodynamic flow patterns in a homeotropically aligned nematic liquid crystal have been studied employing a geometry in which the observation direction is along the optic axis of the undistorted sample and the electric field direction perpendicular to it. A possible mechanism for the observed pattern, which is consistent with the Carr–Helfrich model, is discussed.

Interesting new observations are also described of dc and ac field induced distortions of nematic droplets suspended in the isotropic phase at the nematic–isotropic transition temperature.

Introduction

There have been a large number of studies of the Williams domains using the so-called 'sandwich' geometry. In this geometry, a nematic liquid crystal of negative dielectric anisotropy is homogeneously aligned between two transparent electrodes. If a dc or low frequency ac field is applied there appears, above a certain threshold voltage, a regular pattern of striations *perpendicular* to the undistorted director. The mechanism of this process is well established: 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 stable hydrodynamic flow pattern which at higher voltages gives way to turbulence[1,2].

Flow patterns in a homeotropically aligned sample

Recently, we[3], made some observations using a different geometry: the specimen was homeotropically aligned between two glass plates, and the electric field was applied perpendicular to the undistorted director between two copper or aluminium foils which served as spacers (figure 1a). Observations were made perpendicular to the glass plates (along the X-direction) and above a certain dc or low frequency voltage, regular patterns were found (figure 2). Similar observations have been independently reported by Chang[4].

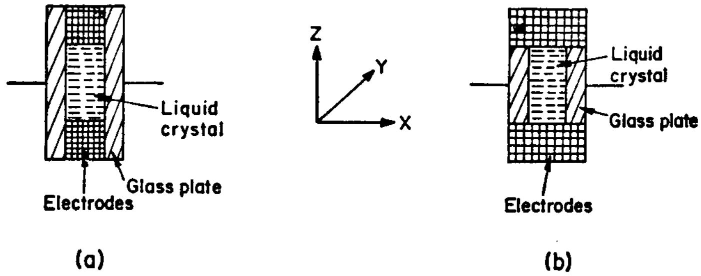


Figure 1 The geometry of the experimental set up for observing the electrohydrodynamic distortion patterns in a homeotropically aligned sample. The electric field is non-uniform in (a) and uniform in (b). Observations are made in the X-direction and the cross section of the sample is $\sim 170\,\mu \times 40\,\mu$.

The earliest observation in this geometry was in fact made by Freedericksz and Zolina[5]. However, at that time the exact explanation of the electrohydrodynamic phenomenon was not known.

The electric field in the above set up (figure 1a) is evidently non-uniform because of the fringing of the field at the edges of the electrodes. In order to eliminate any possible effects due to this, we repeated the experiment with a uniform field. The end faces of two non-magnetic steel blocks were polished and small glass pieces cut from microscope cover slips were placed in between, such that a narrow channel was available for containing the liquid crystal (figure 1b). As the thin edges of the cover slip ($\sim 170\,\mu$) could not be treated with lecithin to get a homeotropic alignment, the specimen was subjected to a strong magnetic field. Observations were made along the magnetic field by means of specially constructed microscope which could be slipped into the hole in the Zeeman pole piece of the electromagnet. The sample size was comparable to the one used in the earlier experiments, the X, Y and Z dimensions being approximately $40\,\mu$, 1 cm and $170\,\mu$ respectively. All the observations were made on n–p–methoxybenzylidene–p–butylaniline (MBBA). A dc or low frequency ac electric field was applied between the steel blocks. When the magnetic field was high, it was observed that the specimen did not exhibit the regular pattern that was observed with a non-uniform electric field. However, dust particles could be seen to move up and down in between the electrodes almost in a straight line, *i.e.*, there was a motion in the plane containing the direction of observation and the electric field direction (the XZ plane), in agreement with the Carr-Helfrich model. Moreover, a few vertical 'walls' could be seen in the field of view. They were rather similar to the walls seen in figure 2b and were clearly visible when the analyser (with no polariser) was vertical (Z–axis) but not so when the analyser was perpendicular to the electric field direction.

We can now think about a possible interpretation of the observed pattern. In the usual sandwich configuration, the distance between the

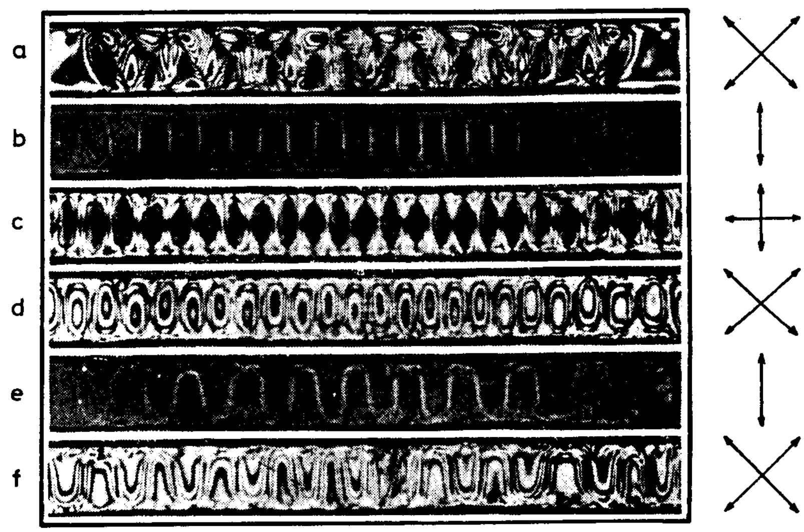


Figure 2 Electrohydrodynamic patterns in MBBA ; magnification x 120. The arrows on the right hand side indicate the settings of the nicols. (a) dc, 35V ; (b), (c) & (d) 20 cps, 32V ; (e) & (f) 100 cps, 45V.

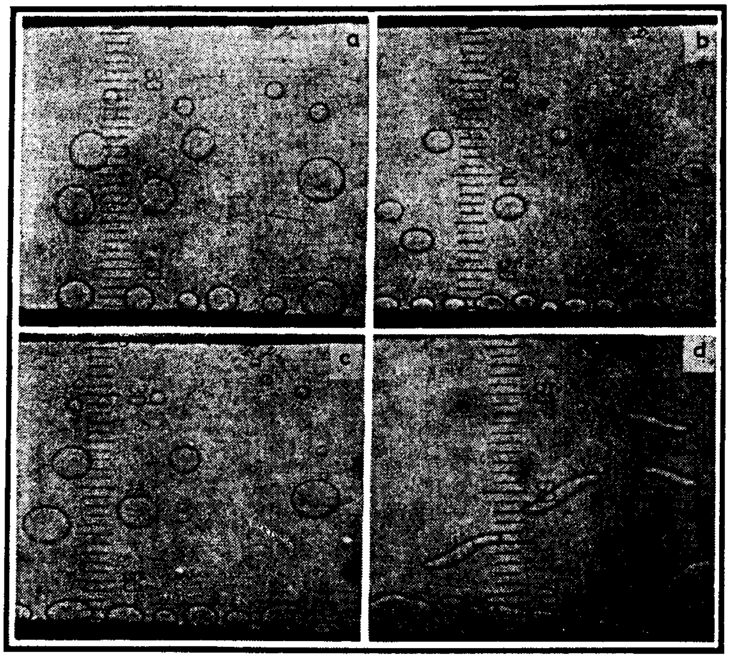
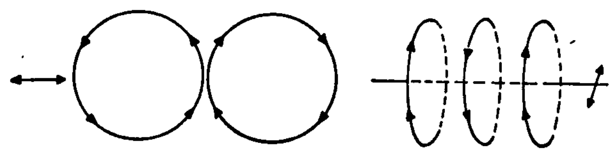


Figure 4 Electrohydrodynamic distortions of nematic droplets suspended in the isotropic phase at the transition temperature. (a) undistorted droplets under zero field ; (b) 200 cps, 100 V ; (c) 500 cps, 100 V and (d) 50 cps, 200 V.

electrodes is a small fraction of the length available perpendicular to the field (X direction) and it is well known that the repeat distance in the cellular flow pattern is determined by the distance between the electrodes. Therefore, several cells are formed with a periodicity along the X axis, the neighbouring striations corresponding to cellular motion of opposite sense so that the total angular momentum is zero. However, in the present configuration the distance between the electrodes is ~ 4–5 times the space available in the lateral (X) direction. Hence it is not possible to have more than one cell to be formed at any given value of the Y coordinate. Hence it is likely that, in order to conserve angular momentum, neighbouring regions of the liquid crystal along the Y–direction assume opposite senses of rotation. In other words, whereas in the usual sandwich geometry, neighbouring domains with opposite senses of the vortices meet as shown in figure 3 *a*, due to the physical restrictions imposed by the present configuration they meet as shown in figure 3 *b*. This can explain the patterns shown in figure 2 under various combinations of the polarizer and analyser orientations. Further, as was noted in our earlier



(a) (b)

Figure 3 The sense of vortex motion in adjacent domains (a) in the sandwich geometry and (b) in the proposed model for the geometry shown in figure 1.

publication[3], in the setting corresponding to figure 2c, dark bands could be seen to sweep across the domains from one wall to the other and back, the bands in adjacent domains moving in opposite directions. In the polariser and analyser setting of figure 2d, corresponding changes could be seen in the walls between the domains. We have undertaken further experiments to test this model.

Observations in homogeneously aligned samples

When the specimen prepared as described in the previous section is turned through 90°, about the Z–axis we get a homogeneously aligned sample, the magnetic field now acting parallel to the Y–direction (figure 1). Again the field induced electrohydrodynamic flow resulted in a set of domains when viewed along the X–axis. According to the Carr–Helfrich model the cellular motion is in a plane perpendicular to the direction of observation (*i.e.*, in the YZ plane) and the walls between the domains could be clelary seen at all settings of the analyser.

Electrohydrodynamic distortions of nematic droplets

Another interesting type of distortion was found during the studies described above. If the temperature of the sample is maintained at the nematic-isotropic transition point T_c, nematic droplets can be seen suspended in the field of view (figure 4a). If a dc or a low frequency ac electric field is applied between the electrodes, beyond a threshold voltage, the droplets get deformed and become elliptically-shaped with the major axis of the ellipse normal to the electric field direction (figure 4b, c). (The photographs of the droplets were taken with a flash light as there was considerable motion in the field of view.) The voltage necessary to deform the droplets increases with increasing frequency of the ac field and at very high frequencies, no deformation can be observed. As the voltage at the lower frequencies is increased, further deformation takes place and the droplets assume the form shown in figure 4d. Air bubbles or dust particles could be seen to have vortex motion inside the droplets, indicating an electrohydrodynamic origin of these deformations.

Acknowledgements

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DISCUSSION

Brown: Some years ago, we observed distortions of droplets similar to the ones shown here. We have mentioned this in a report to the Air Force.