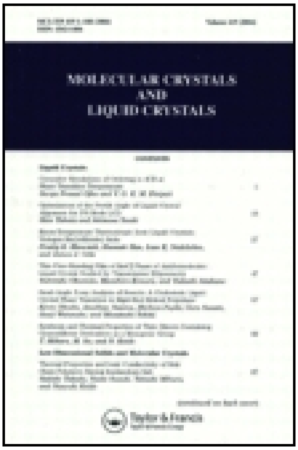

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Domains Due to Magnetic Fields in Bulk Samples of a Nematic Liquid Crystal

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DOMAINS DUE TO MAGNETIC FIELDS IN BULK SAMPLES OF A NEMATIC LIQUID CRYSTAL

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Abstract The production of domains during the application of a magnetic field on a bulk sample of nematic liquid crystal is shown. These domains are created during the process of realignment of the nematic directors and have many similar features to the domains created by electric fields (in the conduction regime). These domains are studied during realignment.

Material flow and molecular alignment due to electric fields (conduction regime) have recently been investigated[1,2] in bulk and thin samples of nematic liquid crystals. We have discovered that patterns similar to those produced by electric fields can be produced by magnetic fields.

A nematic mixture 5A (E. Merk) was used for the work reported here. The nematic range was -5°C to 75C$^\circ$ and all photographs were obtained at 18°C. The resistivity was approximately 10^9 ohm-cm and the dielectric anisotrophy $\varepsilon'_\parallel - \varepsilon'_\perp = -0.2$. The sample holder was constructed from two conductive coated glass electrodes with a 0.15 cm teflon spacer. The transparent electrodes, which were in a vertical position, were approximately 1.7 cm long and 1 cm deep.

The experimental setup for Figures 1 and 2 was similar to that reported earlier[1]. A laser beam was directed parallel to the electrodes and at an angle of approximately 20° with the free surface. Some of the light which entered through the surface was scattered upward by the liquid crystal. As this scattered light passed through the surface, defects or changes in alignment gave rise to a pattern that could be used to define domains (or flow cells).

Figures 1a and 1b show the patterns that were observed when a 50-volt (conduction regime) source was applied to the electrodes. These photographs are very similar to those discussed elsewhere[2] for another nematic mixture. They are presented here for comparison with the results using a magnetic field. The defects (or misaligned regions) which normally extend from one electrode to the other indicate the domain width. It was shown elsewhere[2] that the fluid velocity is a maximum at the defects and the direction of flow is opposite at adjacent defects.

Figures 1c - 1f show the patterns that were observed when a 1-kG magnetic field was applied perpendicular to the electrodes. The patterns are similar to those shown in Figures 1a and 1b. Earlier work[1] has shown that the flow cell width decreases with an increase in electric field intensity. Preliminary measurements with magnetic fields indicate that the cells get narrower for larger magnetic fields.

The photographs shown in Figure 2 indicate some material flow when a 1-kG magnetic field is applied perpendicular to the electrodes producing a 90° rotation of the nematic director. Unlike the application of an electric field (conduction regime), the flow ceases when the molecular alignment has undergone its maximum change. The defect (or misaligned region) shown in Figure 3a was created by rotating the director from a direction perpendicular to the electrodes to parallel to the electrodes with a 2-kG magnetic field. From results to be presented[3] elsewhere it appears that the nematic director on one side of the defect rotates 90° clockwise while the director on the other side of the defect rotates counterclockwise. The bending of the defect (Figure 2a) as shown in successive photographs (Figures 2b-2e) indicates the positions of maximum flow. From these observations it appears that the directors in adjacent cells (Figures 1c-1f) tend to rotate in opposite directions.

The domains which were photographed from a direction perpendicular to the electrodes are shown in Figure 3. The laser beam was directed vertically into the sample near the back electrode. The light that was scattered by the sample in a horizontal direction showed the domains in Figure 3. The domains in Figure 3a were created by a magnetic field whereas those in Figure 3b were created by a 40-Hz electric field. There are some variations in the patterns while they are being created, but after equilibrium was reached (Figure 3), it is difficult to distinquish between the domains created by a magnetic field and those created by an electric field. In some respects these domains look like the Williams domains[4] but many of the conditions investigators try to satisfy when observing Williams domains were not satisfied here. The sample was much thicker and the applied voltage was much higher than normally used to observe Williams domains. The nematic mixture 5A which was used for these results aligns with its

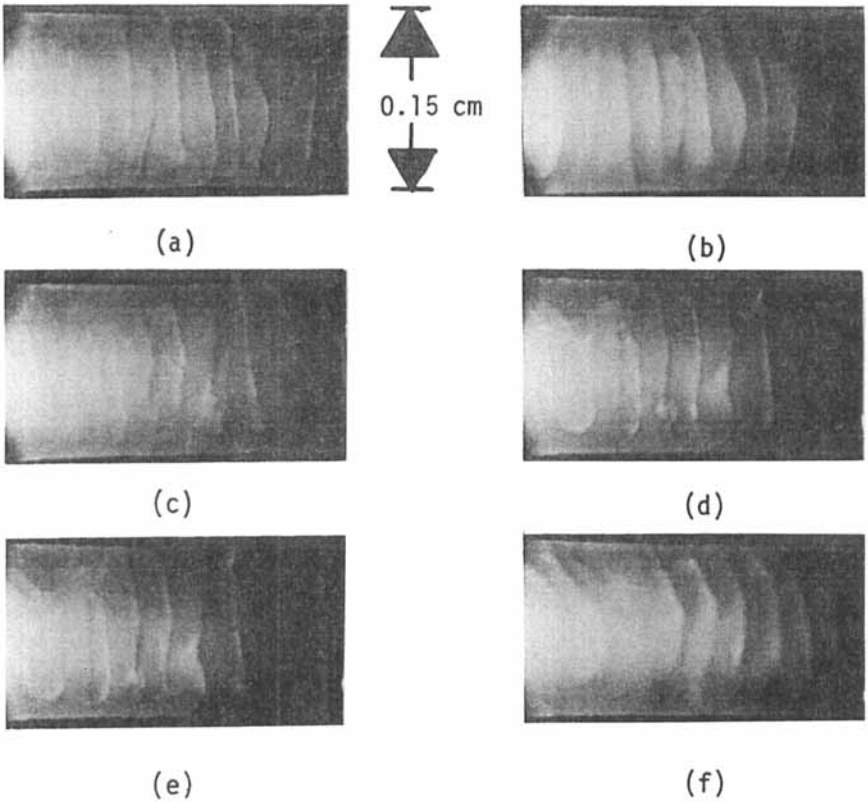


FIGURE 1. Flow patterns (or domains) due to electric and magnetic fields at the air to NCL interface. Electrode separation = 0.15 cm (a) Forty sec after applying a 50-volt (40Hz) source. The nematic director was aligned parallel to the electrodes before applying the field. (b) Two min after turning off the 50-volt source which had been on for 40 sec. (c) Twenty sec after applying a 1-kG magnetic field perpendicular to the electrodes. The director was aligned parallel to the electrodes before applying the field. (d) Forty sec after applying the 1-kG field. (e) Sixty sec after applying the 1-kG field. (f) Two min after turning off the 1-kG field which had been on for 60 sec. The electric field was zero for photographs c,d,e, and f.

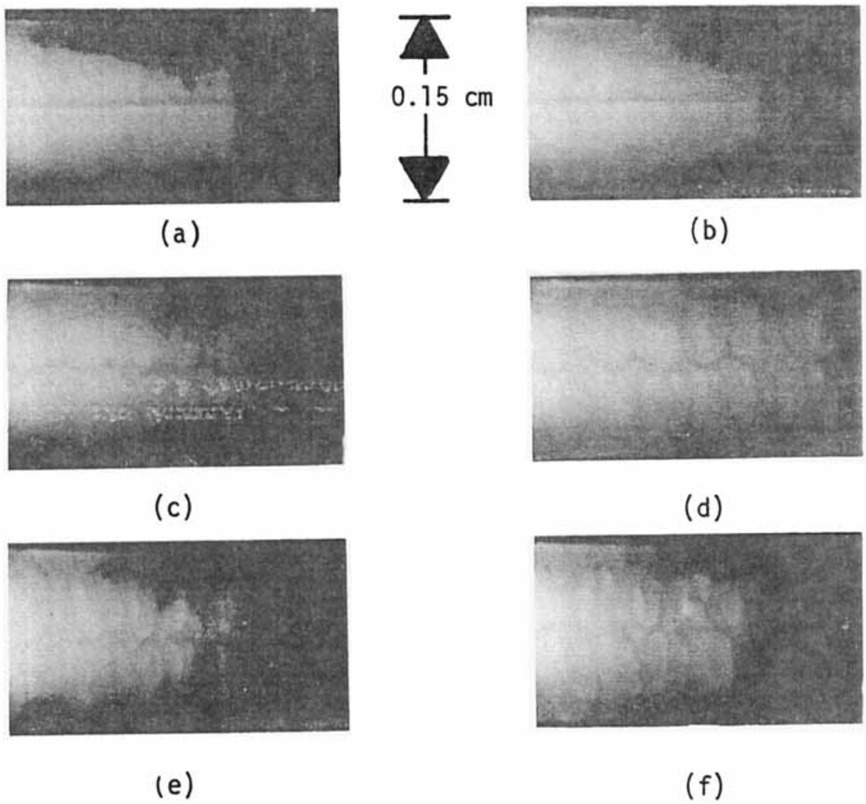
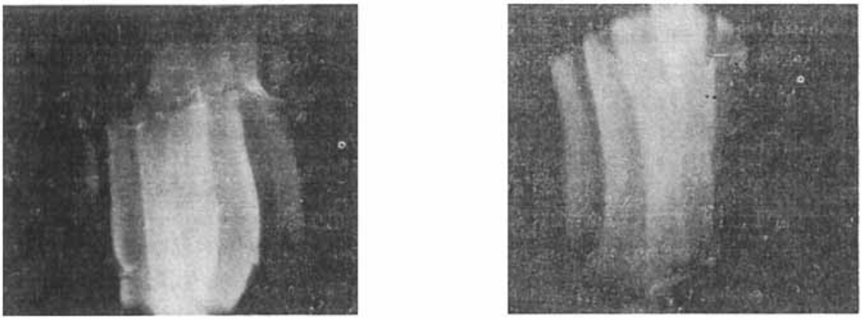


FIGURE 2. Material flow due to a magnetic field at the air to NCL interface. Electrode separation = 0.15 cm. (a) A Defect (or misaligned region) parallel to the electrodes which was created by applying a 2-kG magnetic field parallel to the electrodes for 25 sec. The director was aligned perpendicular to the electrodes before applying the 2-kG field. (b) Five sec after applying a 1-kG magnetic field perpendicular to the electrodes. Photograph (b) followed (a) after turning off the 2-kG field and rotating the sample. (c) Ten sec after applying the 1-kG field. (d) Fifteen sec after applying the field. (e) Twenty-five sec after applying the field. (f) Forty-five sec after applying the field. Electric fields were not employed here.



(a) (b)

FIGURE 3. Vertical domains due to electric and magnetic fields which were observed in a direction perpendecular to the electrodes. Electrode separation = 0.15 cm. (a) Approximately two minutes after turning off a 1-kG magnetic field which had been applied perpendicular to the electrodes for 1 min. The procedure was the same as that followed for Figure 1a except for a 90^o rotation of the microscope (b) Ten minutes after a 50-volt (40 Hz) source had been turned off which had been on 40 sec. The procedure was the same as that followed for Figure 1b except for a 90^o rotation of the microscope and a longer waiting period.

director perpendicular to a wall rather than parallel. The average angle of rotation of the director is very small when observing Williams domains, but the average angle of rotation is quite large for the results shown in Figure 3. Conductivity measurements indicated that after a 1-kG magnetic field had been applied for 20 sec, the average angle of rotation of the director was greater than 45 degrees.

When a polaroid sheet was placed before the microscope (figure 3) there was not much variation as the film was rotated. The patterns appeared slightly clearer when the direction of polarization was perpendicular to the initial alignment of the director. However, if a 1-kG magnetic field is maintained parallel (horizontal) to the electrodes while an electric field (> 70 volts) was applied perpendicular to the electrodes, the patterns were clearer when the direction of polarization was parallel to the initial alignment of the director. This observation is consistant with those of Williams domains, and suggests that if the electric and magnetic fields are applied simultaneously the director tends to rotate in the plane formed by the fields. If only one field is used the angle that the director makes with the horizontal plane is probably a function of position.

Defects similar to those shown in Figure 2a can be created with a 4000 Hz electric field (dielectric regime). This implies that rotations of the director, whether they are associated with torques due to dielectric, conductivity or magnetic permeability anisotropies, have much in common. Although the emphasis here is on molecular alignment and material flow, the results which are presented suggest some interesting problems involving the creation of defects.

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