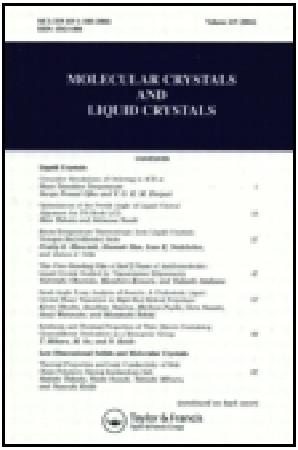


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# Electric Field Induced Transient Effects in a Nematic Liquid Crystal in the Presence of a Stabilizing Magnetic Field

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# Electric Field Induced Transient Effects in a Nematic Liquid Crystal in the Presence of a Stabilizing Magnetic Field

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A homeotropically aligned nematic liquid crystal with positive dielectric and diamagnetic anisotropies is subjected to a destabilizing *ac* electric field (**E**) in the bend geometry in the presence of a stabilizing magnetic field (**B**). When the applied voltage (V) is gradually increased at a given frequency, the distortion that results above a threshold ($V_{th}$) is spatially periodic with the wavevector depending on the electric frequency $f$. Sudden application of a voltage step, $V_s$, higher than $V_{th}$ causes a temporal evolution of the director field, which finally attains the homogeneously distorted *(HD)* state; the nature of temporal evolution depends on $V_s$. If $V_s$ is slightly higher than $V_{th}$, the transient deformation is periodic and the wavevector of periodicity depends on $f$. When $V_s$ is high enough, the transition to *HD* occurs *via* a turbulent state.

*Keywords:* transient phenomena; nematic; electric field; magnetic field; bend geometry; pattern formation

## INTRODUCTION

A variety of static distortions is observed when a homeotropically aligned sample of 5CB is studied in the 'crossed fields' configuration (action of a destabilizing **E** applied in the sample plane and a stabilizing **B** acting normal to the sample plane)[1, 2]. When **B** is strong enough, the static deformations that result above an electric threshold are spatially periodic with the wavevector of periodicity depending on $f$ [2]. It is known[3-5] that when a homogeneously aligned nematic sample is subjected to the action of a sufficiently strong **B** or **E** field applied normal to the initial director orientation (in the splay or twist Freedericksz geometry), the director field undergoes transient periodic reorientation before assuming the final, spatially aperiodic distortion state. The non-stochastic, linearized continuum theory explains many experimental observations connected with the effect of **B** as being caused by the coupling between orientation and flow [3,4,6]. The importance of thermal noise in determining the nature of pattern formation has also been indicated[7]. To explain the effect of **E**, it is necessary to take account of the non-linearity of perturbations as also the anisotropy of electrical conductivity [8]. Due to the unfavorable nature of the visco-elastic coupling, transient periodic structures are not observed in the bend geometry (initial homeotropic alignment with **B** applied in the sample plane) of calamitic nematogens. This work is a preliminary report on the observation of transient periodic reorientation in the bend geometry under the action of **E**. The very occurrence of pattern formation and the dependence of its temporal evolution on the different electric parameters show the importance of the coupling between **E** and the director field.

## EXPERIMENTAL SET-UP

The experimental set up (see Figure 1) is similar to the one previously used[2]. Cells having an approximate thickness of 400 microns are constructed using flat sheet electrodes which act as spacers. The electrode surfaces lie in the *yz* plane. The electrode separation varies from 3.4 to 4.1 mm for different cells. The surfaces of the glass plates are treated with a silane solution to obtain homeotropic alignment of the undistorted director field $\mathbf{n}_0$ (along $z$). The cell is filled with 5CB, checked for alignment and housed in a thermostat which maintains the temperature at 28.0 ± 0.1 °C. The thermostat is positioned between the poles of an electromagnet, which is controlled to maintain a steady **B** field of certain predetermined strength impressed along $z$ to stabilize the director. In the absence of director distortions, **E** should be in the sample plane (along $x$). The output from a function generator is amplified by a bipolar power supply before being fed to the electrodes. The function generator is controlled by the *IEEE* bus from a computer that runs *LabView 3.1* and is programmed to send a step voltage of certain amplitude and frequency. The cell is observed between crossed polarizers and the optical data collected with a fiberscope camera arrangement.

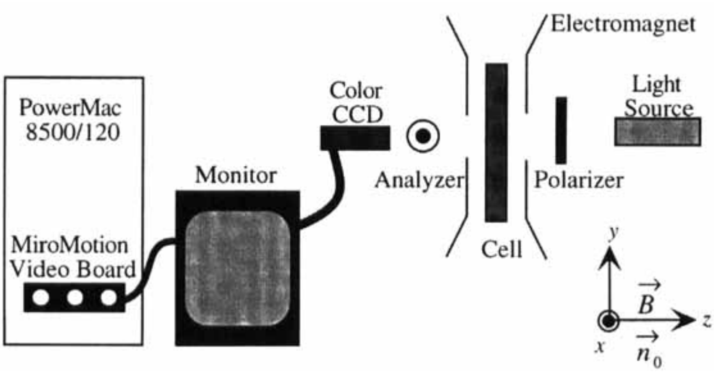


FIGURE 1 Experimental set-up for capture of video data

The fiberscope is positioned through one of the magnetic poles and the video data from the cell is sent to a digitizing *Miro Board* (model *DC* 20). The software *Adobe Premiere* enables a 'stop motion' video capture and allows a capture rate of 30 frames per second or less; this permits the digital images to be collected over the requisite period of time.

The earlier experimental observations on static deformations[2] induced by a gradually incremented voltage yielded the following results: (i) When $f$ is high ($900 < f < 1500$ Hz), only $X$ stripes (periodicity parallel to $x$) appear above a threshold. (ii) In the middle range ($300 < f < 900$ Hz), the $X$ stripes appear and change into $X+Y$ stripes when the voltage is increased; (iii) When $f$ is low ($30 < f < 300$ Hz), only $Y$ stripes (periodicity along $y$) are seen. At any $f$, a sufficiently high voltage ensures that the sample becomes stripe-free with a *HD* of the director field.

The experimental procedure is as follows. Initially, **B** is applied at a fixed strength, say B = 1000 Gauss. At a given $f$, the voltage threshold ($V_{th}$) for the static periodic distortion ($X$, $X+Y$ or $Y$) is determined[2]. Starting with an aligned sample, a step voltage $V_S > V_{th}$ is now impressed on the cell and the data for the transient deformation collected. This process is carried out for different $V_S$ measured as ratios of $V_{th}$. By changing $f$ to different values ($f$ = 100, 300, 600, 900 and 1500 HZ) and repeating the experiments, the data for the given B are obtained. B is now changed successively to 1200, 1500, 2000, 2400 and 3000 G for the next sets of observations. The main results are summarized below.

## RESULTS

When $V_S$ is just above $V_{th}$, stripes are not seen. Stripes appear only when $V_S$ is sufficiently higher then $V_{th}$. Figure 2 shows the time evolution of the patterns for the $f$ = 100 Hz, B = 1000 G. Typically, the orientation of the stripes that dominates the transient pattern at a given $f$ is the same as that of the static pattern. For example, at $f$ = 100 Hz transient $Y$ stripes are observed; at $f$ = 1500 Hz one sees $X$ stripes when the pattern evolves. For a given pair of $f$ and B, there exists a critical step size, $V_C$, with the following property. When $V_S < V_C$, the final deformation is 'quasi-static' and periodic (see Figure 2).

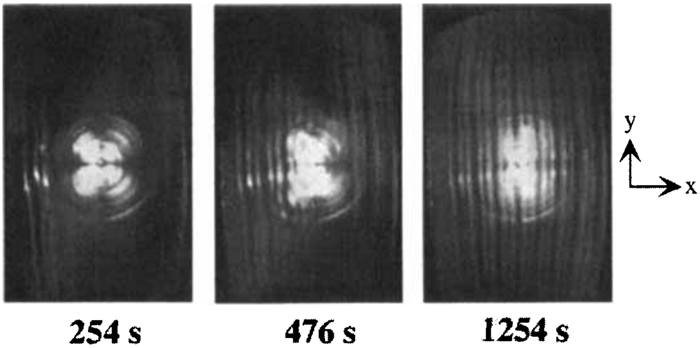


FIGURE 2 The time evolution of transient periodic patterns with $f$=100 Hz, B=1000 G, $V_s$=1.16 $V_{th}$.

If the voltage is increased even slightly, the static stripes disappear leaving the sample with the final *HD* state. The stripes of the transient and final states generally get localized near the electrodes if $V_S$ is low. When $V_S$ approaches $V_C$, the stripes tend to fill the entire sample. When $V_S > V_C$, the final state is *HD* but the transient state is turbulent (see Figure 3).

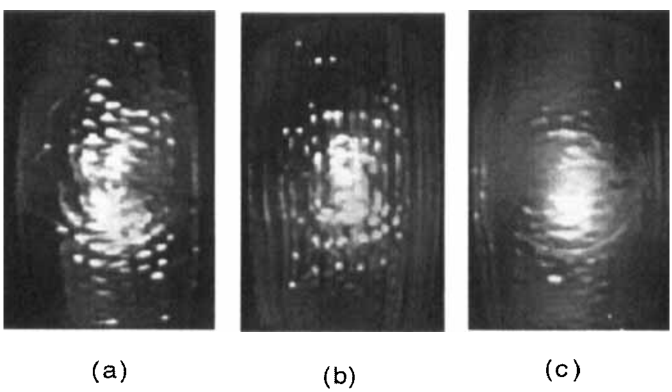


FIGURE 3 Intermediate turbulent stages for: (a) B=1200 G, $f$=600 Hz, $V_S$=1.39 $V_{th}$; (b) B=1000G, $f$=100 Hz, $V_S$=1.31 $V_{th}$; (c) same as (b) but with $V_S$=1.46 $V_{th}$.

In this case, there exists no discernible periodicity in the transient pattern whose appearance is similar to that of dynamic scattering [2]. An additional feature is observed with strong **B** (B > 2000G). The application of $V_S > V_C$ initially causes turbulence. With passage of time, the turbulence gives way to a striped, transient pattern which covers almost the entire sample; in due course the stripes also dissolve away leaving the sample stripe-free (see Figure 4).

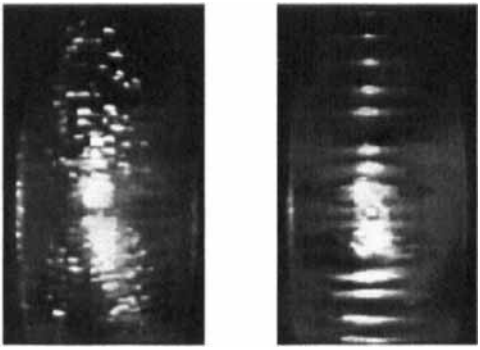

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FIGURE 4 Transient patterns and the periodic intermediary state for B=3000 G, $f$= 1500 Hz and $V_S$= 1.54 $V_{th}$.



The intensity of transmitted light is measured along $x$ at different time instants after $V_S$ is applied. A typical set of plots is shown in Figure 5. The initial rapid growth of the periodicity wavevector is discernible by comparing the few initial plots. The wavevector changes very little as the final, equilibrium state is approached. It is found, however, that the separation between adjacent stripes, generally increase with time.

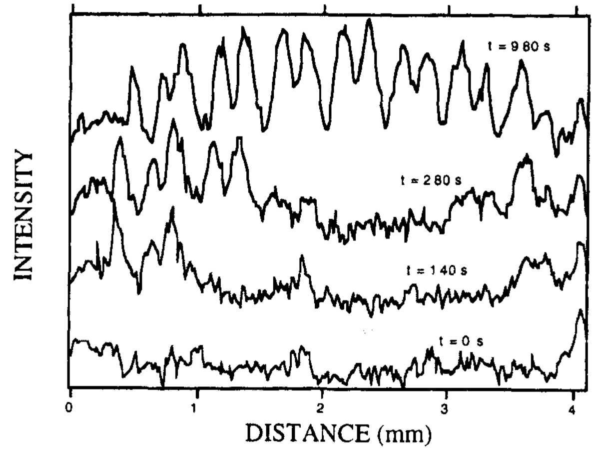


FIGURE 5 Intensity variation along $x$ axis at different time instants after impressing the voltage step; parameters are as in Figure 2.



The main observations of this work are the following. The initial homeotropic alignment is stabilized by **B**. Under the action of a sufficiently strong destabilizing electric field applied in the sample plane, the director field undergoes transient reorientation before assuming the equilibrium, aperiodic state. The nature of the transient reorientation is determined by B, $f$ and $V_S$. The transient may be spatially periodic with a time dependent wavevector or turbulent. In general, increase of B requires a higher $V_S$ to produce a periodic transient. In the lower range of $V_S$ (at a given B and $f$), the stripes appear broader and stripes are not seen at all if $V_S$ is closer to $V_{th}$. The parameters of interest are the wavevector, its temporal evolution and the time of transition from the initial homeotropic orientation to the final state. The next step will be to seek some form of dependence of these parameters on the control variables such as $f$, B, the inclination of **B** away from $z$, $V_S$, the sample thickness and the electrode separation.

Complete results will be communicated in future. An attempt will also be made to develop a mathematical model to explain these observations.

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