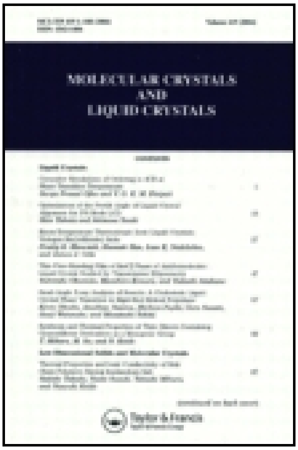

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Propagating Structures in a Nematic Liquid Crystal Subjected to Crossed Electric and Magnetic Fields

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Propagating Structures in a Nematic Liquid Crystal Subjected to Crossed Electric and Magnetic Fields

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The effect of a stabilizing magnetic field applied perpendicular to the electric field on the nematic liquid crystal MBBA undergoing electrohydrodynamic convection is studied on 60 micron thick samples. The resulting convective instability is found to propagate with a voltage dependent velocity that is well described by a power law with an exponent of ½. The pattern velocity at the onset of the instablity also decreases with increasing magnetic field. The wavelength of the instability similarly decreases with increasing electric and magnetic field strength.

Keywords: Travelling waves, bifurcation

The simplest liquid crystal phase (nematic) and most studied liquid crystal (MBBA) continues to provide unexpected discoveries that both delight us and challenge our understanding. In a previous paper[1] we have reported on propagating states and defect structures seen in electrohydrodynamic convection in the conduction regime of the nematic liquid crystal MBBA (*N*-(*p*-methoxybenzylidine)-*p*-butylanaline) subjected to a stabilizing magnetic field. Propagating states are also seen in thin samples and near the cut-off frequency in MBBA and other liquid crystals without a magnetic field.[2,3] The addition of the magnetic field introduces both qualitative and quantitative changes in the resulting patterns and their dynamics.

In this experiment, the liquid crystal is placed between two conductive glass electrodes with a separation of nominally 60 microns. The cell is about the size of a microscope slide with approximately a 2 cm^2 region filled with the sample. Experiments have been conducted using very old MBBA, as well as recently purchased MBBA, and no qualitative differences in pattern formation or behavior were noticed beyond a large reduction of the cut-off frequency to approximately 70 hz. The sample cell is housed in an insulated environment, but there is no active temperature control. The sample is placed in a magnetic field and white light, polarized along the magnetic field, is directed upward through the sample and detected with a microscope and a CCD camera (512 × 512 pixels) whose output is digitized into 256 grey levels. The A.C. driving voltage is a sine wave produced by a computer controlled function generator. The pattern is analyzed by periodically sampling the transmitted intensity at discrete points of the image and storing this data for later analysis.

The magnetic field increases the onset voltage of the instability to the order of 20 volts for a 8 Kgauss field. At these higher voltages, the domains are fully convective flow cells separated by what Igner and Freed[4,5] refer to as "Carr walls," which are splay-bend or twist walls caused by the convective flow. As the critical voltage is approached, the convective rolls begin to move parallel or anti-parallel to the magnetic field. As the driving voltage is increased further, the velocity increases and the interface between oppositely flowing regions acts as a nucleating site for disclination loops, which appear as dark loops 10 to 20 microns in diameter. The nucleation of such loops by shear flows has been previously studied.[6] These disclination loops are initially confined to the shear region, but begin to move outward as the voltage increases until a turbulent or chaotic state is achieved. Earlier results on this system[1,7] showed that organized fluid flow still coexists with the topological chaos.

In this paper the focus is on the onset of pattern formation and propagation. Figure 1 shows the velocity of propagation for a particular MBBA sample at 30 Hz. The velocity, near onset, is a linear function of the square of the reduced control parameter $\varepsilon = (V - V_c)/V_c$, giving an exponent of $\frac{1}{2}$. This bifurcation is subcritical as the velocity appears to jump discontinuously from zero to a finite value. A more detailed study of the transition to the propagating state confirms the discontinuous jump in velocity plus the fact that a propagating structure is seen as soon as a pattern is visible (Figure 2). The sample used to produce the data shown in Figure 2 is the same sample used for Figure 1 but aged, causing an increase in the cutoff frequency, and the excitation frequency has been raised to 300 Hz

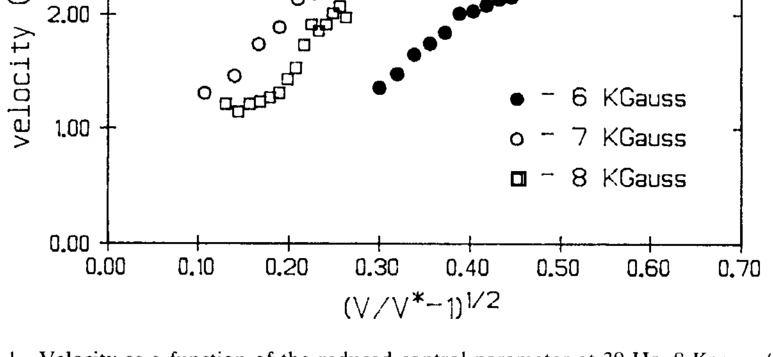

FIGURE 1 Velocity as a function of the reduced control parameter at 30 Hz. 8 Kgauss (circles), 7 Kgauss (squares), 6 Kgauss (triangles).

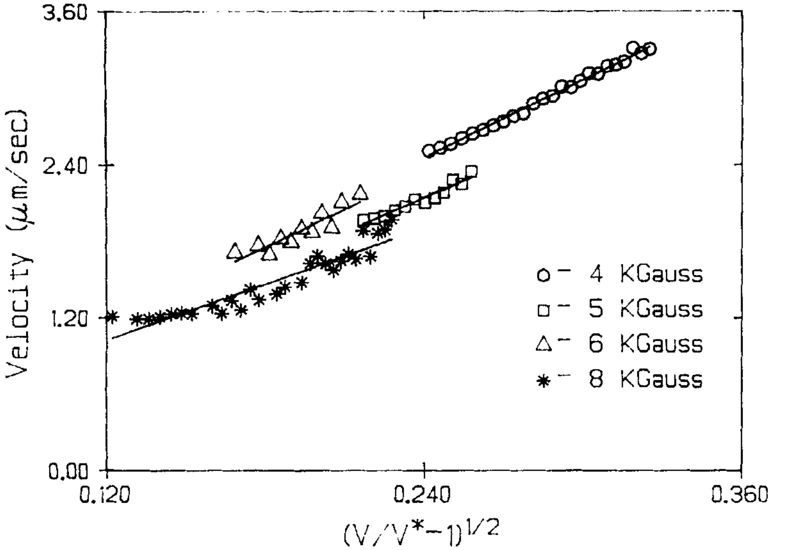

FIGURE 2 Velocity as a function of reduced control parameter at 300 Hz for an aged sample.

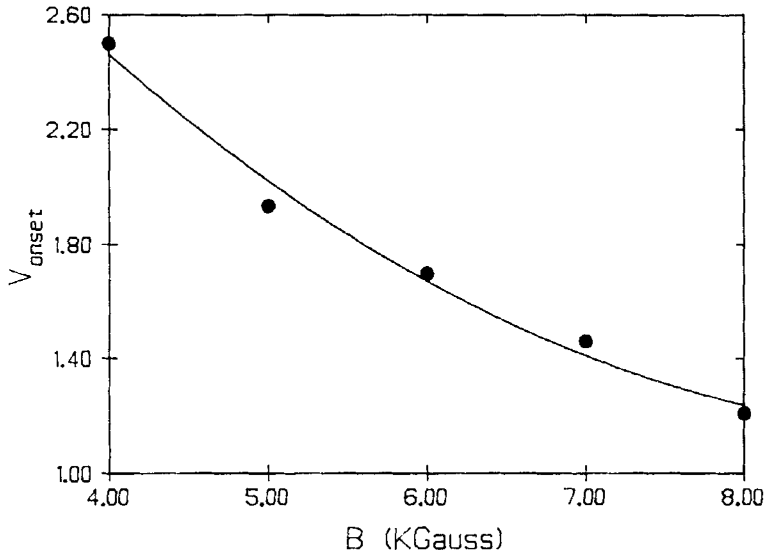

FIGURE 3 Velocity of pattern at onset of instability as a function of magnetic field strength.

because of equipment requirements. The voltage step has also been reduced by a factor of 5, providing higher voltage resolution.

Plotting the onset velocity as a function of field strength shows that the velocity depends quadratically on the field (Figure 3). The best fit second order polynomial shows a minimum, but not a zero, at about 11 Kgauss. Investigation into this region is planned. At the other extreme of zero magnetic field, the fit predicts an onset velocity in excess of 5 microns per second. Observations on this sample show transitions to topological turbulence at velocities of this order. Additionally, the value of ε at onset appears to grow with decreasing magnetic field. These two points may explain why propagating patterns are not readily observed in thick samples well below the cut off frequency.

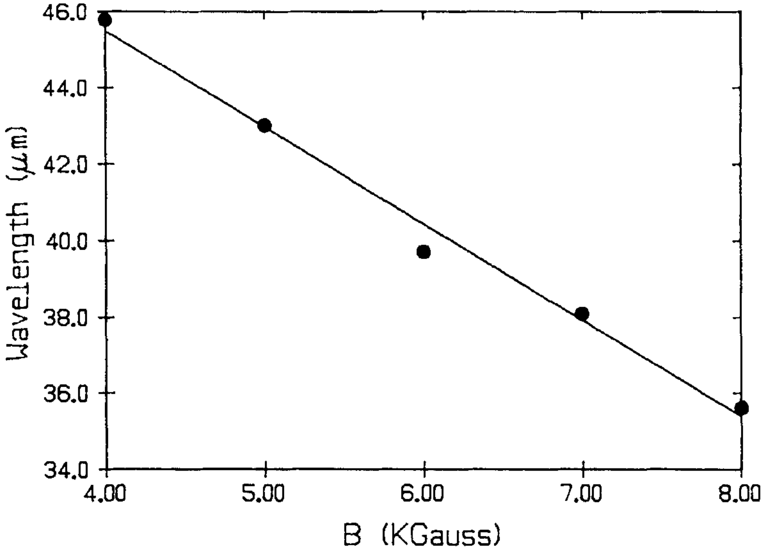

FIGURE 4 Wavelength of instability at onset as a function of magnetic field strength.

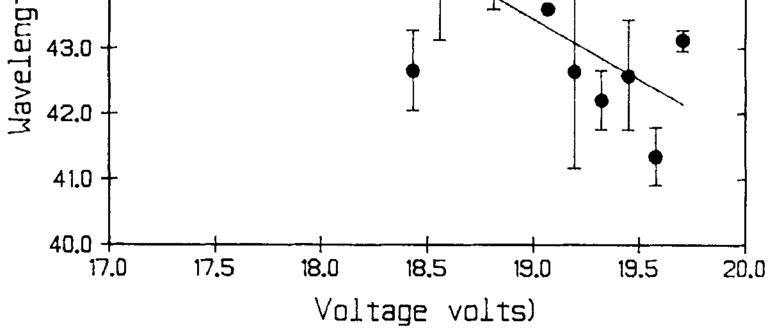

FIGURE 5 Wavelength as a function of voltage (30 Hz. excitation, 8 Kgauss field). Error bars represent width of the peak of the Fourier transform of the spatial modulation of the instability.

The wavelength of the instability is found to depend on the magnetic field and on the driving voltage. Figure 4 shows the wavelength at onset for the four magnetic fields used in this study while Figure 5 shows the change in wavelength as a function of voltage at a particular magnetic field. The wavelength dependence at onset is well fit by a straight line with a slope of −2.5 microns/Kgauss and an intercept of 55.6 microns, which is near the nominal thickness of the sample, 60 microns. Figure 5 shows a decreasing wavelength with voltage that is also well fit by a straight line with a slope of −1.5 microns/volt. The change in wavelength over the restricted voltage range studied is sufficiently small that an average value is used to calculate the velocities in Figure 1 and the onset wavelength is used in the calculation of the velocity of Figure 2.

In conclusion, a robust system for studying the transition to travelling wave states is explored. A great deal of exploration of its phase space needs to be completed before this state can be understood. Nevertheless, a few trends are clear. Near the onset of pattern formation the instability propagates with a velocity that depends on the square root of the voltage. The velocity discontinuity decrease as the magnetic field increases, reminiscent of the approach to a critical point with the velocity playing the role of an order parameter. The wavelength of the instability decreases slowly with increasing voltage and magnetic field.

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