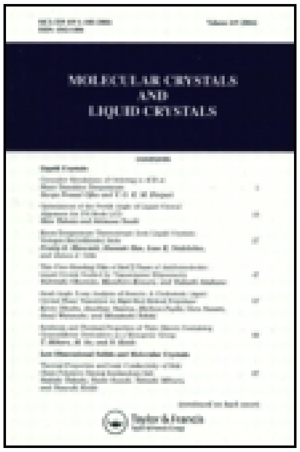

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Electrohydrodynamic Convection in Nematics Under Stochastic Excitation

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ELECTROHYDRODYNAMIC CONVECTION IN NEMATICS UNDER STOCHASTIC EXCITATION

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Abstract

We describe the influence of superimposed deterministic and stochastic electric fields on electrohydrodynamic convection in nematics. Multiplicative noise leads to complex spatio-temporally fluctuating patterns. We measure the thresholds for the onset of electroconvection, construct stability diagrams and compare the results to theoretical predictions.

INTRODUCTION

Since its discovery in 1963 [1] electrohydrodynamic convection (EHC) in nematic liquid crystals has been extensively investigated experimentally as well as theoretically [3]. EHC patterns in nematics are easily generated and observed in the laboratory. Their excitation with electric fields can be readily controlled, and because of their short characteristic times the patters are easily characterized by their optical texture in a polarizing microscope. Relevant LC material parameters can be determined in independent experiments. Because of these features, EHC has become a standard system in the investigation of dissipative pattern formation. A first theoretical explanation was given by Carr and Helfrich, and the theoretical analysis has developed from the early one-dimensional theory [2] to a three-dimensional description [4] and WEM [5].

Most experiments as well as theoretical work have been devoted to the analysis of EHC under deterministic excitation, which is comprehensively understood now. Noise excitation of EHC has gained rather few attraction [8, 6, 7], although the effects of stochastic fields on the formation of EHC instabilities promise many new features and insight in general mechanisms of pattern formation. In a theoretical study of superimposed deterministic and stochastic driving fields [6, 7] threshold voltages for the onset of EHC under noise influence have been calculated using different stability criteria. We test these predictions in the experiment.

EXPERIMENT

We use the standard experimental setup: Planar commercial cells (LINKAM) with transparent ITO electrodes and rubbed polyimide coating are filled with a nematic liquid crystal of negative dielectric anisotropy. The driving deterministic and stochastic electric fields are synthesized by means of a PC, mixed and amplified. Temperature control is provided by a hot stage. The sample is illuminated with white light and observed in transmission using a polarizing microscope. Video images are recorded with a CCD camera and digitized for further processing in the PC.

The substance used in the experiment was a four component mixture of disubstituted phenylbenzoates: $C_nH_{2n+1} - O - \emptyset - COO - \emptyset - O - C_mH_{2m+1}$ (nO-Om).

1O-O6: 22.0%	5O-O8: 30.3%
6O-O7: 13.3%	6 -O4: 34.4%.

It provides an large nematic range (70.5°C to below RT) and has been extensively characterized as a standard substance (e.g. [9]). In order to keep the number of unknown parameters in the comparison of theory and experiment small, we have determined most of the involved visco-elastic and electric material parameters in independent experiments. Data shown here were obtained in a 51.4μm cell at 50°C.

RESULTS

The threshold curve for pure deterministic square wave excitation is shown in Fig. 1. We concentrate here on the first instability only. The homogeneous ground state is instable with respect to oblique rolls at low frequencies, normal rolls at intermediate frequencies and travelling rolls near the cut-off frequency. Above the cut-off, dielectric rolls and chevron textures are observed. It turns out that the material parameters, in particular the conductivities, may vary remarkably from sample to sample. Correspondingly, the cut-off may differ by one order of magnitude for different cells.

Calculated threshold voltages were determined from 1D theory in the conduction regime.Measured threshold voltages, wave numbers and the Helfrich parameter (ζ^2=4) calculated from the material constants agree reasonably.

The stochastic experiments were performed as follows: A deterministic square wave was chosen with a frequency that leads to the formation of a specific pattern (oblique rolls, normal rolls, dielectric rolls). Then, noise of increasing amplitude was added. We use dichotomous Markovian noise, consisting of random jumps between values $\pm E_N$ with average jump rate τ_N, which is easy to synthesize and to treat theoretically.

It turns out that not only the threshold fields but also the character of the dissipative patterns changes with increasing noise amplitudes. In general, the patterns become instationary and fluctuating in time as well as in space. In particular, localized structures appear within the dielectric roll patterns.

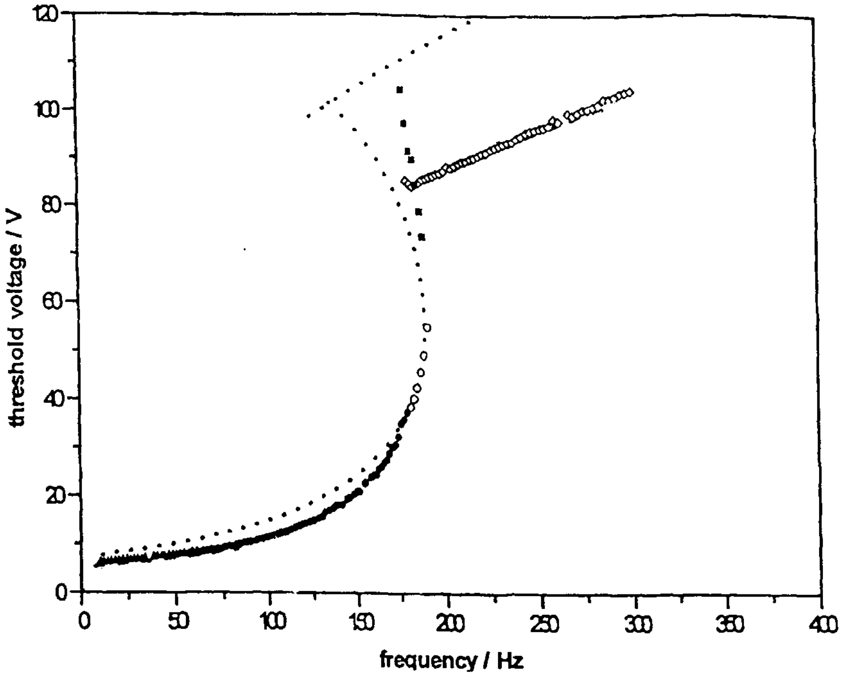

Fig. 1: Experimental thresholds for oblique rolls (▲), normal rolls (•), travelling rolls (○) and dielectric rolls (◇), compared to the calculated threshold curves with $\zeta^2=4$ (dotted line)

Figures 2,3 show typical images and threshold curves for superimposed deterministic and stochastic fields. The deterministic voltages have been chosen in the conductive (2) and dielectric (3) regimes, respectively. Note the characteristic changes in the optical textures with increasing noise. High frequency noise supports the formation of dielectric rolls but suppresses the onset of conductive patterns, as is seen from the behaviour of the threshold curves for not too high noise amplitudes.

At low noise strengths, sharp thresholds towards regular structures can still be defined. For stronger noise amplitudes, the threshold is no longer sharp as the first patterns are characterized by isolated domains varying in time. Within these domains, amplitudes and wave numbers fluctuate. The structures exhibit a characteristic sort of 'blinking' which resembles the recently discussed phenomenon of 'on-off intermittency' [10]. This phenomenon is described for systems randomly driven near a threshold of stability which is exactly the case in our experiments.

The temporal fluctuations can be analyzed in a time resolved measurement where we have used a fast 512 pixel line camera. It can be driven with time resolutions between 50μs and 4ms. Fig. 4a depicts the evolution of a spatial cross section of the transmission image normal to the roll pattern (horizontal axis) in time (vertical axis). The long term fluctuations are even more pronounced in the spatial Fourier transforms (Fig. 4b). The amplitudes of the ground mode and second harmonics

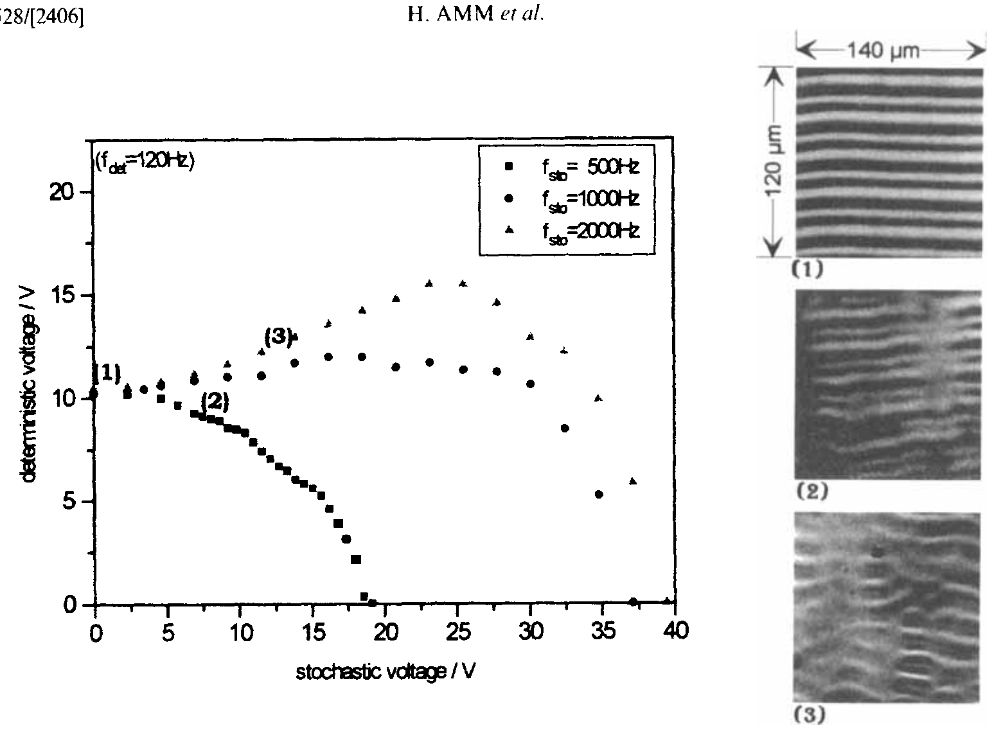

Fig.4: Threshold curve for the conductive regime under superimposed stochastic fields.

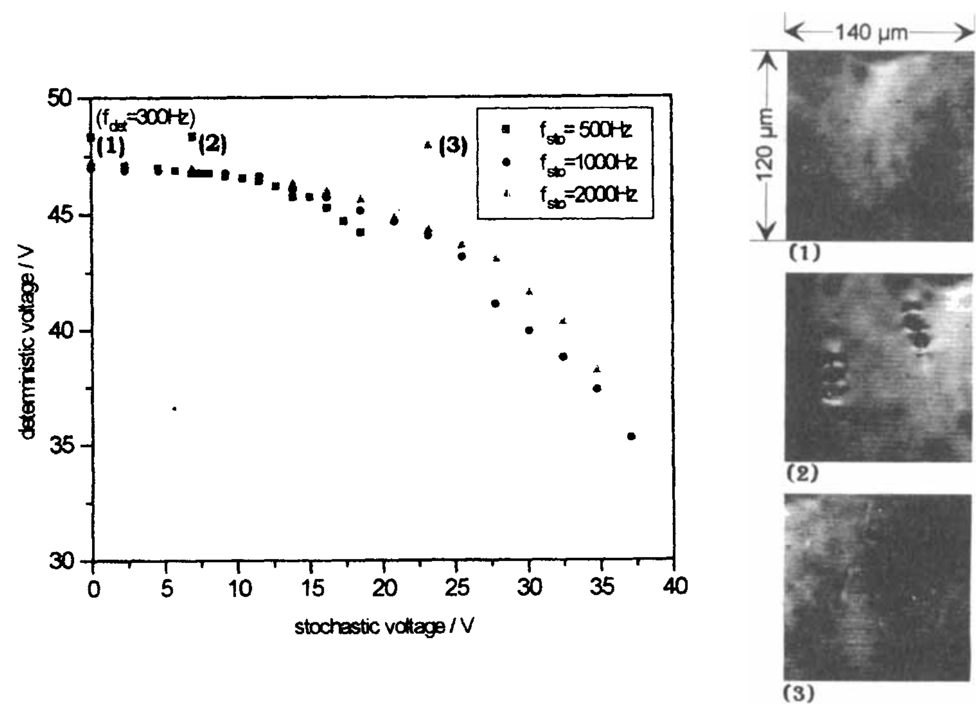

Fig.5: Threshold curve for the dielectric regime under superimposed stochastic fields.

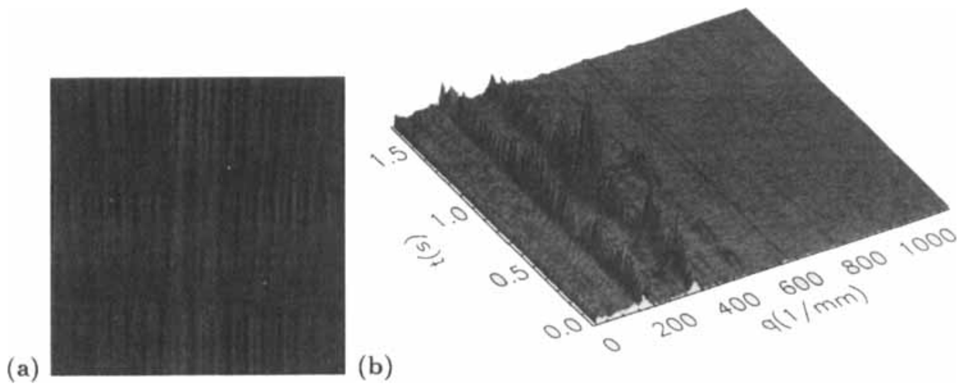

Fig. 4: (a) Time evolution (vertical, 1.68s) of a cross section (horizontal, 300μm) of the transmission image normal to the rolls at $f_{det} = 240Hz$, $U_{det} = 27V$, $f_{sto} = 1000Hz$, $U_{sto} = 9V$.
(b) Time evolution of the spatial Fourier transforms of Fig. 4a.

both fluctuate nearly synchronously in time. The image of the texture is maintained while its amplitude undergoes fluctuations with characteristic times of 0.1 .. 1s. This timescale is characteristic for viscoelastic director fluctuations, while the autocorrelation times of the noise sequences is shorter by nearly two orders of magnitude.

DISCUSSION AND SUMMARY

We have investigated a nematic mixture which produces all types of EHC patterns, which is chemically stable and has been extensively characterized in its electric and visco-elastic properties. The threshold curves for pure deterministic excitation have been determined. In the conductive regime, they agree very well with the calculated curves when the known material parameters are used. With superimposed noise, we observe complex spatial and temporal fluctuations of the textures. The correlation times of these fluctuations are in the range of 0.1 to 1s, that is much slower than the noise autocorrelation time. A similar observation has been reported in MBBA by Kai and Brand. Moreover, localized patters appear and the patterns show also large scale spatial fluctuations. One has to keep in mind that the ideal dichotomous Markovian noise process (DMP) contains large fractions of low frequency noise in its frequency spectrum, which is a Lorentzian with maximum at 0.

We shortly discuss one further aspect. The structures at stronger noise amplitudes are apparently not characterized by a single wave number. This could be a consequence of the fact that for high electric fields characteristic times of the system and of the noise are not well separated. Thus mode selection is no longer perfect, a band of wave numbers becomes relevant. Previous theory [7] considers only the stochastic stability with respect to patterns with a single wave number, which is in this regime not sufficient for a quantitative description of our experiment.

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