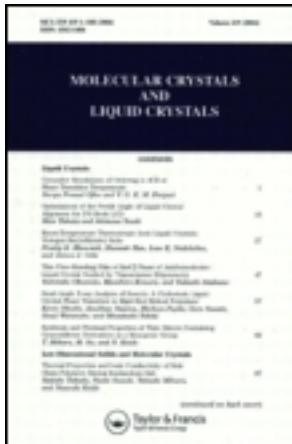


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V. A. Delev ^a & A. P. Krekhov ^{a b}

^a Institute of Molecule and Crystal Physics, Russian Academy of Sciences, 450025, Ufa, Russia

^b Physikalisches Institut, Universität Bayreuth, D-95440, Bayreuth, Germany

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Drifting Abnormal Rolls in Electroconvection of Hybrid Aligned Nematic

V.A. DELEV^a and A.P. KREKHOV^{ab}

^a*Institute of Molecule and Crystal Physics, Russian Academy of Sciences, 450025 Ufa, Russia and* ^b*Physikalisches Institut, Universität Bayreuth, D-95440 Bayreuth, Germany*

We report experimental and theoretical results on the conductive regime of electroconvection in hybrid aligned nematics. The drifting oblique/normal rolls below/above the Lifshitz frequency are observed at the onset of electroconvection under a.c. voltage. The experimental data on the threshold voltage, wavelength, oblique angle and drift period of the rolls as function of a.c. frequency are in good agreement with the results of linear stability analysis. The transition from drifting oblique rolls to abnormal rolls is found below the Lifshitz frequency with increasing applied voltage.

Keywords: electroconvection; hybrid aligned nematic; drifting and abnormal rolls

INTRODUCTION

Electroconvection (EC) in nematic liquid crystals (NLCs) has been studied extensively in experiment and theory for about 30 years. Depending on the alignment of the director \hat{n} that gives the preferred direction of molecular orientation, the EC system demonstrates a rich variety of pattern-forming instabilities (see, e.g., [1]). In particular, in planarly aligned nematics the rolls at onset are oriented either normally to the initial director orientation (normal rolls) above the Lifshitz frequency f_L (crossover from oblique to normal rolls at threshold) [2, 3] or obliquely to it (oblique rolls) below f_L [3, 4]. With increasing applied voltage one observes various secondary in-

stabilities, such as zig-zag and skewed-varicose patterns (see [1] for a review). Recently, a new secondary instability leading to abnormal rolls (ARs) that are characterized by a homogeneous twist deformation of the director field has been found in planarly aligned nematics [5]. In homeotropic system with an applied magnetic field one has the analogous situation, but here the homogeneous mode corresponds to a rotation of the in-plane director without (or with small) twist [6].

In comparison with the case of uniform director alignment (planar or homeotropic) only few works were devoted to EC in nematics with more complex director distribution, e.g., in hybrid aligned nematics (HAN) [7, 8]. Here below onset the director interpolates from the planar alignment at one confining plate to homeotropic orientation at the other one. For this geometry one may also expect to find a transition to ARs above threshold. In this paper we present the results of an experimental and theoretical study of the onset of electroconvection in hybrid aligned nematic in conductive regime under a.c. voltage. Below the Lifshitz frequency a secondary instability leading to drifting abnormal rolls was found for the first time.

EXPERIMENTAL

The nematic liquid crystal MBBA was sandwiched between two parallel glass plates with transparent electrodes. In order to achieve a uniform planar alignment, one electrode was rubbed in one direction. Homeotropic alignment at the other electrode was obtained spontaneously after cleaning of the electrode surface with alcohol. The electrodes were separated by mylar spacers with thickness $d = 40 \mu\text{m}$. The lateral size of the cell was $10 \text{ mm} \times 20 \text{ mm}$, so that the aspect ratios of the cell were 250 and 500. The temperature of the cell was kept at $T = 25 \pm 0.1^\circ\text{C}$. The a.c. voltage applied across the NLC layer was generated by the digital wave synthesizer card WSB-100

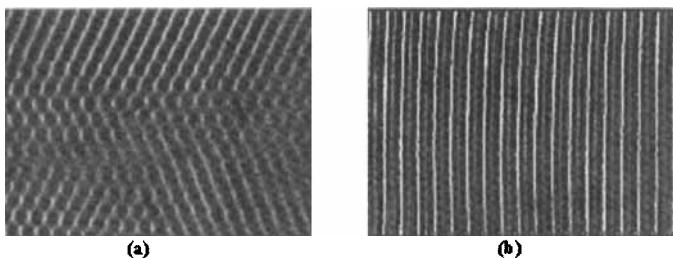


Figure 1: Typical images of drifting rolls at onset in a HAN cell: oblique rolls at $f = 10$ Hz, $U = 6.3$ V (a); normal rolls at $f = 30$ Hz, $U = 8.5$ V (b).

(Quatech). The convection patterns were observed with polarising microscope and images were taken with a CCD-camera and digitized by frame-grabber DT3155 with resolution of 756×581 pixel and 256 gray scale levels. The cut-off frequency of the NLC sample was $f_c \sim 60$ Hz. The spatial periodicity of domain patterns was determined from the Fourier transform of images taken at threshold.

RESULTS AND DISCUSSION

At the onset of EC (U_c) drifting rolls oriented obliquely or perpendicularly (normal) to the x axis, depending on a.c. frequency f were observed (Fig.1).

Below the Lifshitz frequency f_L oblique rolls arise at first at the edges of the NLC cell so that the zig-rolls appear near one edge and zag-rolls near another one. Superposition of zig- and zag-rolls usually leads to the grid pattern formation in some places of NLC sample in the subcritical regime [Fig.1(a)]. This pattern is unstable and above onset oblique rolls become preferable.

Increasing the a.c. frequency a transition from oblique rolls to normal rolls was found at the Lifshitz frequency $f_L \simeq 19.8$ Hz. The

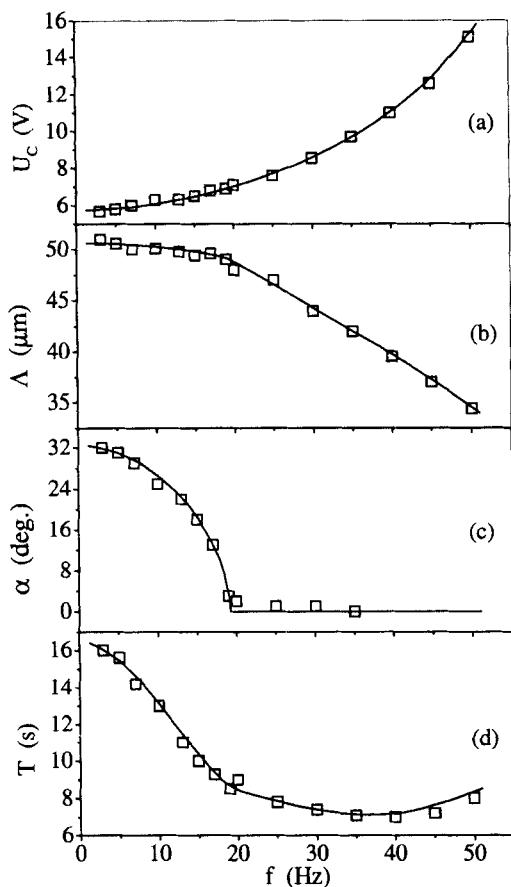


Figure 2: Threshold voltage U_c (a), roll period Λ (b), roll oblique angle α (c) and drift roll period T versus a.c. voltage frequency f .

drifting rolls were observed in all range of a.c. frequency and the drift direction is determined by the sign of the director gradient along the normal to the NLC layer in the initial hybrid state.

We have measured the threshold voltage U_c , roll period Λ , oblique angle α and drifting period T as function of the a.c. frequency f . These experimental data are in a good agreement with the results of linear stability analysis (Fig.2).

In our calculations we used the standard set of nematodynamic equations [4, 8]. Below onset of convection one has the director configuration distorted across the layer due to the opposite boundary conditions and no material flow is excited. The linear stability analysis of this state is based on a Galerkin method (see [8] for details). Material parameters of MBBA at 25 °C [8] were used with the only exceptions the values of conductivities $\sigma_{||}/\sigma_{\perp} = 1.71$ and $\sigma_{\perp} = 0.55 \cdot 10^{-8} (\Omega \cdot \text{m})^{-1}$ which were fitted from the experimental data on the threshold voltage U_c at low frequency of a.c. voltage and the cut-off frequency f_c , respectively.

In order to reveal the direction of the mean drift velocity, small tracer particles (2–4 μm in diameter) were immersed in the nematic. The observations show that the particles move on closed trajectories within EC rolls in the plane perpendicular to the roll axis and also drift together with rolls. We found that the direction of the particle motion is not parallel to the wavevector for the oblique roll regime. In particular, for the applied voltage $U = 6.3$ V at $f = 10$ Hz the direction of the mean drift velocity has an angle $\sim 20^\circ$ with respect to the wavevector. This is also in agreement with the theoretical calculations.

With increasing voltage above the threshold U_c the angle of obliqueness decreases continuously and vanishes at some critical value of the control parameter $\epsilon_{AR} = (U_{AR}^2 - U_c^2)/U_c^2$. The dependence of the roll angle α on the control parameter ϵ for a.c. frequency $f = 10$ Hz

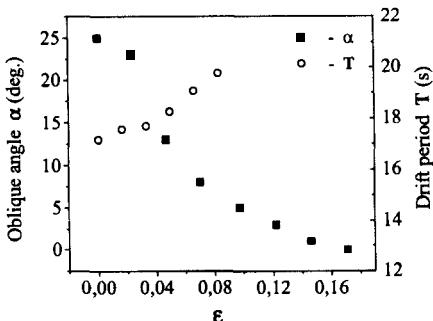


Figure 3: The dependence of the roll angle α and drift period T on the control parameter ϵ for a.c. frequency $f = 10$ Hz.

is presented in Fig.3. The drift period T of oblique rolls increases slightly with applied voltage (Fig.3). Further increasing of the applied voltage leads to the appearance of defects and weak turbulence is developed.

The polarised-optical analysis shows that at ϵ_{AR} the director is twisted away from the plane of initial orientation ($x - z$ plane). In the case of hybrid cell, when the incident light enters into the lower electrode with planar director alignment, polarisation of the transmitted light is parallel to the director projection onto the $x - y$ plane (\mathbf{c} director) in the bulk of the NLC. Therefore it is quite easy to determine the effective twist angle of the director ϕ by rotation of the analyser by an angle that corresponds to maximum contrast of the intensity profiles along the line perpendicular to the rolls. We found that the twist angle ϕ practically does not change beyond ϵ_{AR} . For example, at $f = 10$ Hz and $\epsilon > \epsilon_{AR} = 0.17$ one has $\phi \simeq \pm 45^\circ$.

Thus, there is a symmetry breaking of the in-plane director, i.e., one has a kind of transition to *drifting abnormal rolls*. The system is divided into areas consisting of drifting rolls with two symmetry-

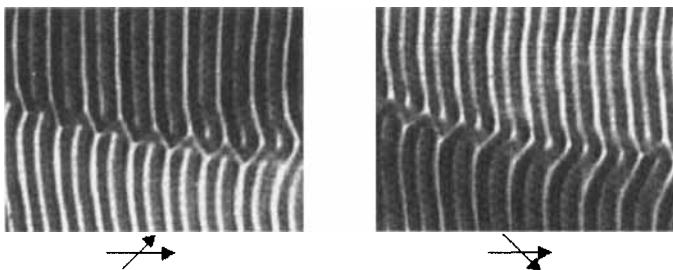


Figure 4: Snapshots of abnormal rolls taken for two positions of analyser with polariser along x axis (arrows) demonstrated two symmetry-degenerated \hat{c} director orientations ($\pm\phi$).

degenerate \hat{c} -director orientations ($\pm\phi$), which are separated from each other by moving domain walls (Fig.4).

CONCLUSION

We have shown that the results of linear stability analysis and the experimental data on the threshold characteristics of EC in the hybrid aligned nematic under a.c. voltage are in a good quantitative agreement.

In contrast to the case of planarly aligning nematics, the primary bifurcation is non-stationary and drifting rolls are observed at the onset. The drift direction is determined by the sign of the director gradient along the normal to the NLC layer in the initial hybrid state. A particularly interesting feature is that the direction of the mean drift velocity below the Lifshitz frequency does not coincide with wavevector.

The transition from drifting oblique rolls to drifting abnormal rolls was found below Lifshitz frequency with increasing applied voltage. The study of the dynamics of domain walls separating abnormal rolls with two degenerate \hat{c} -director orientations is in progress.

Acknowledgments

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