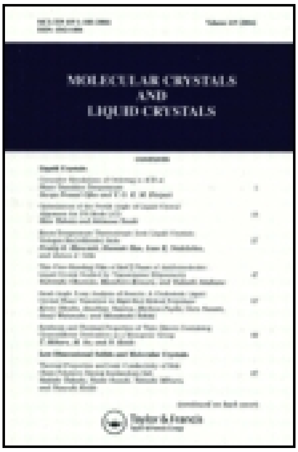

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

On The Optical Characterization of Convection Patterns in Homeotropically Aligned Nematics

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Version of record first published: 24 Sep 2006.

Mol. Cryst. Liq. Cryst. 1994, Vol. 251, pp. 181–189
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Printed in the United States of America

ON THE OPTICAL CHARACTERIZATION OF CONVECTION PATTERNS IN HOMEOTROPICALLY ALIGNED NEMATICS

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Abstract Two optical methods were applied to obtain information about the director configuration in electrically induced convective instabilities. The intensity of the transmitted light and the contrast of the patterns were measured. Normal, oblique and 'abnormal' rolls were studied and compared for initially planar and homeotropic samples.

A homeotropically aligned nematic liquid crystal cell has rotational symmetry, which will be broken spontaneously by the electrically induced bend Fréedericksz transition. The director field resulting from this transition might then become unstable with respect to electroconvection by means of the Carr-Helfrich mechanism [1]. The ensuing convection roll pattern might be normal or oblique with respect to the direction of the director, depending on the frequency of the driving ac-current. The main problem is that convection sets in upon an already distorted director configuration. The oblique roll regime is of special interest because it is expected to exhibit complex spatio-temporal behavior close to threshold [2]. There are only very few experimental investigations of electrohydrodynamic convection in homeotropically aligned nematics [3]. Several patterns in the high frequency dielectric regime are described in [4]. In a recent paper [5], we made an experimental attempt to determine the orientation of the rolls with respect to the director field in order to compare with theoretical predictions [2]. We studied the evolving patterns in a homeotropically aligned nematic by using two different optical methods, namely a refined analysis of intensity and contrast. Intensity measurement between crossed polarizers is a standard method to detect large director gradients e. g. in the vicinity of disclinations. Both methods deliver integral values and thus the interpretation of the results is not simple. A clarification of the meaning of the results obtained by those two measurement methods seems necessary. Thus in this paper we apply the methods to a flow pattern where the essential features of the director field are known, namely normal and oblique convection rolls in planarly aligned nematics [6]. These results are compared with those obtained in the homeotropic configuration.

The investigated nematic materials have negative dielectric anisotropy. Thus convection is invoked in *planar* alignment as first instability and as secondary instability, following the Fréedericksz transition, in the *homeotropic* case [2, 3]. We sandwich the nematic between two transparent glass electrodes with a distance of 15 to 25 μm. An ac-electrical voltage is applied in the z-direction perpendicular to the glass plates. For measuring intensity and contrast of the patterns in the sample we used a 512×512 square pixel 14 bit slow-scan CCD-camera. The exposure times depend on the amount of transmission that can be achieved in the cells, which are coated with different materials.

Let us start with the *planar* case. We choose the mixture Merck Phase 5 to study normal and oblique rolls in the planar geometry. Here a preferred direction $\mathbf{n}_0$ of the director is imposed by rubbing the polymer coating of the glasses. When applying an electrical field, convection sets in above the threshold voltage V_c as the first instability. At low driving frequencies convection starts with oblique rolls, which can be unambiguously identified, they become normal at higher frequencies and begin to travel close to the cutoff frequency [7]. Whether oblique rolls are present or normal rolls appear at low frequencies, depends on the material parameters of the nematic: One should mention MBBA is not suitable because it does not show oblique rolls.

To obtain the data shown in Fig. 1 we placed the cell between a pair of crossed

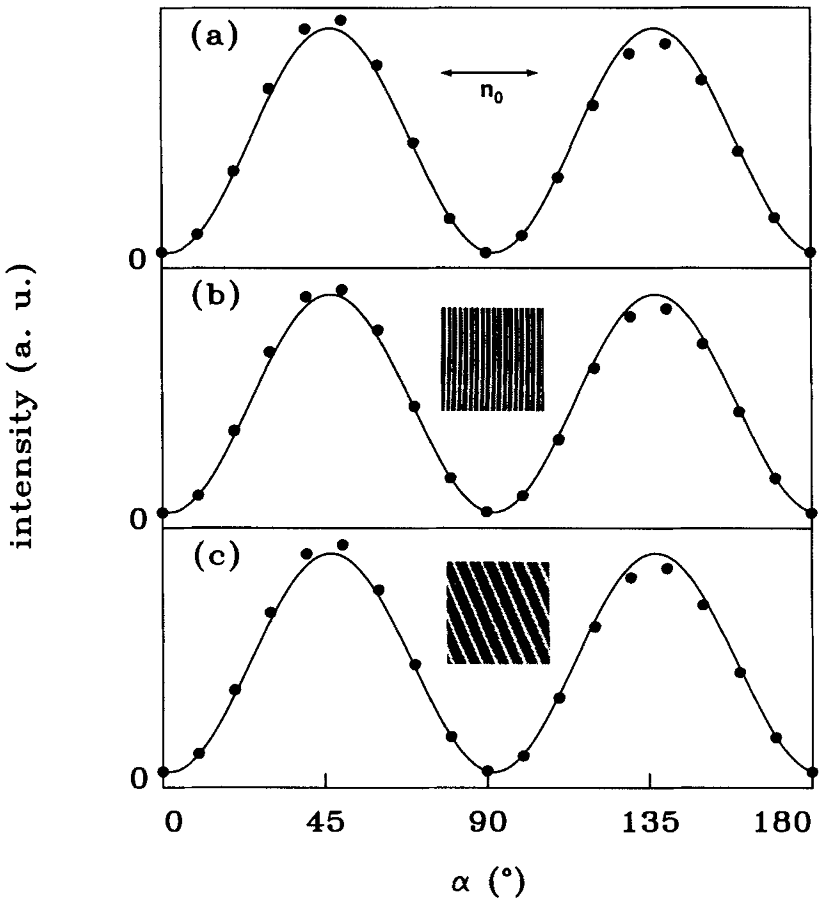

Figure 1: Angular dependence of the averaged intensity in planar alignment, the continuous lines represent a fit to $\cos(4\alpha)$, a) zero voltage, b) normal rolls, f=130 Hz, V=10.54 V, c) oblique rolls, f=20 Hz, V=5.53 V.

polarizers and measured the intensity of the transmitted light. Both the polarizer and the analyzer were rotated simultaneously and the intensity was measured as a function of the rotation angle α, which is the angle between the rubbing direction and the polarizer orientation. The minima of the observed curves at α=0, 90° and 180° indicate the mean orientation of the director and the direction perpendicular to it in the plane parallel to the glass plates. Figure 1a) shows the intensity variation as a function of α at zero voltage. The ideal curve of the angular dependence of the intensity should show total extinction at the minima. Introducing a quantity $M = 1 - \frac{I_{min}}{I_{max}}$ characterizing the intensity modulation, we can quantitatively describe the deviation from the ideal behavior (M=1). Our value of M =0.94 deviates only slightly from the ideal case, which might be caused by imperfections, which result in scattering and/or diffraction of the light or by an initial twist in the cell ($\mathbf{n}_0$ changes from one glass plate to the other). If there is an initial twist at all, it must be very small. Figure 1b) presents the intensity measurement in the regime of normal rolls at 130 Hz and in Figure 1c) we deal with oblique rolls at 20 Hz of about 65° with $\mathbf{n}_0$. The angular dependence of the intensity is the same for the nondeformed planar cell (Figure 1a)) and after the onset of convection (Figure 1b and c)).

One might have expected a difference between normal and oblique rolls because the latter induce a twist in the director field. This deformation alternates in neighboring rolls with respect to $\mathbf{n}_0$ in the $x-y$-plane [6]. The fact that this director configuration is not observable, indicates that this twist causes no resulting rotation of the light polarization because the rotation in the lower part of the cell is compensated by the effect in the upper part. The small difference between the maxima obtained at α=45° and 135° might be caused by geometric imperfections.

An alternative way to obtain information about the orientation of the director relative to the rolls is to measure the contrast. Here the light intensity is measured parallel to $\mathbf{n}_0$ across 7-9 rolls and spatially Fourier transformed. The contrast is then defined as the ratio between the amplitude of the first harmonic and the mean intensity. It is measured using only one polarizer as a function of the angle α between $\mathbf{n}_0$ and the polarizer. In the upper part of Fig. 2 the measurement of the contrast for normal rolls at 130 Hz is presented. The contrast is high, if the light is polarized

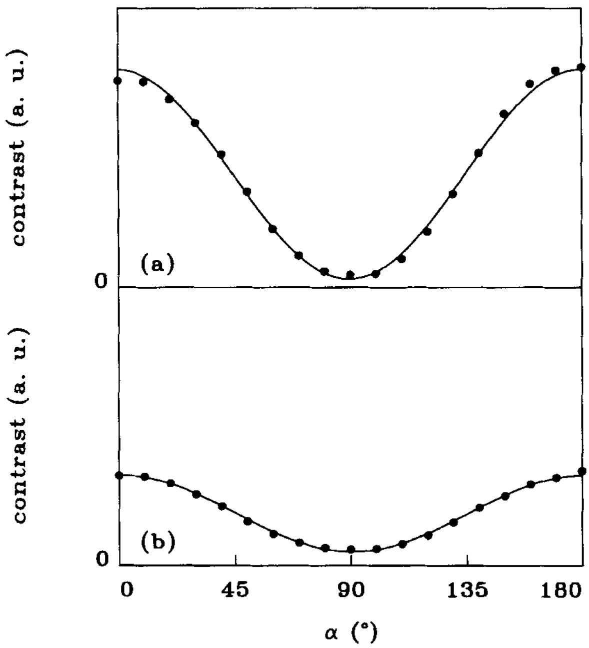

Figure 2: Optical contrast of the patterns as a function of α in planar alignment, the continuous lines represent a fit to $\cos(2\alpha)$, a) normal rolls, f=130 Hz, V=10.54 V, b) oblique rolls, f=20 Hz, V=5.53 V.

parallel to the director, and low if they are perpendicular. Zero contrast means the rolls are not visible at all.

Decreasing the frequency to 20 Hz the rolls become oblique. The location of the minima and maxima of the contrast (as seen in Fig. 2b)) does not change compared to normal rolls indicating that this method is also not sensitive to the alternating twist deformation caused by the oblique rolls.

In *homeotropically* aligned cells ideally no direction is preferred in the $x - y$ plane, the system is rotationally symmetric. The measurements presented here were carried out in a cell where the homeotropic alignment of the MBBA was achieved by coating the glass plates with chromium. Observing the intensity of the transmitted light with crossed polarizers at zero voltage, shows almost perfect extinction and no angular dependence. The first instability that takes place when applying an electrical voltage is the Fréedericksz transition. The direction of $\mathbf{n_0}$ has to be determined, in

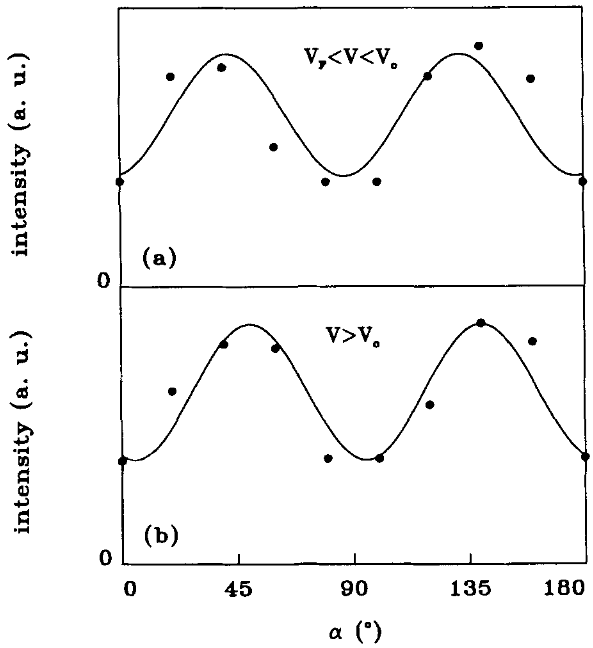

Figure 3: Angular dependence of the averaged intensity in homeotropic alignment, the continuous lines represent a fit to $\cos(4\alpha)$, at 1000 Hz, a) below the onset of convection, V =4.31 V, b) with convection, V =6.64 V.

order to decide whether rolls in the convection regime are normal or oblique with respect to $\mathbf{n}_0$. For that purpose we used crossed polarizers and measured the intensity of the transmitted light as described above. The result is shown in Fig. 3a) for a voltage above the Fréedericksz threshold V_F, but below the onset of convection V_c. The experimental error is larger here than that of the results presented in Fig. 1 due to the lack of an appropriate experimental setup at that time. The intensity is minimal for angles α=0, 90° and 180°, which we assume to determine now the mean orientation $\mathbf{n}_0$ of the director field in the plane parallel to the glass plates.

The directions of the extinction turn out to be reproducible in repeated experiments, which can be due either to a pretilt or to an anisotropic anchoring energy on the surfaces. We are aware of systematic investigations of this phenomenon [8].

The fact that the intensity modulation M=0.55 is much lower here than in the planar case might be caused by a much larger overall twist, which results from

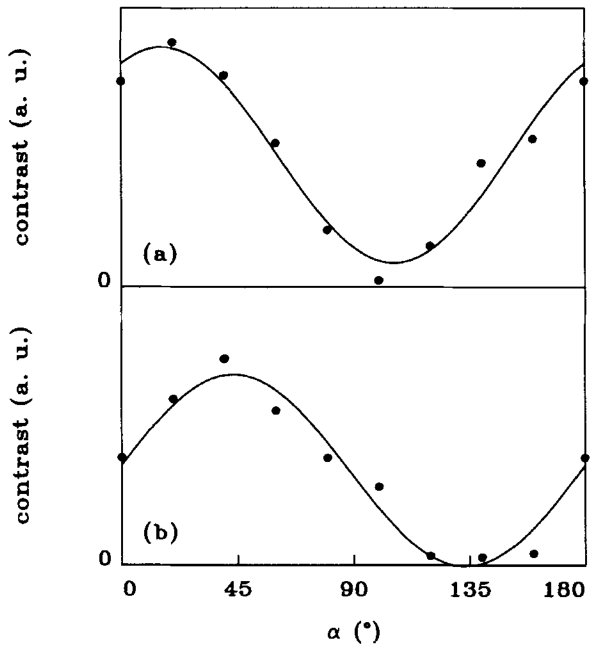

Figure 4: Optical contrast of the patterns as a function of α in homeotropic alignment, the continuous lines represent a fit to $\cos(2\alpha - \varphi)$, a) f=30 Hz, V=5.76 V, b) f=1000 Hz, V=6.64 V.

the uncorrelated preferred directions on the two glass plates. There is no reason to suppose larger scattering than in the planar sample. Consequently we conclude that the director configuration has a very complicated z−dependence in the Fréedericksz distorted state, involving bend-splay type deformation near the boundaries and a large twist in between.

When increasing the voltage above V_c, we find fairly extended patches of parallel rolls perpendicular to $\mathbf{n}_0$. Only taking into account this information, one would identify them as normal rolls. Their orientation changes on a large spatial scale in the sample. We choose for our measurements relatively big homogeneously oriented areas. The intensity variation is not influenced by the convective instability, as indicated in Fig. 3b) and is independent of frequency.

The contrast measurements on the other side show a frequency dependence. First we concentrate on the measurement at a driving frequency of 30 Hz and 5.76 V.

The curve in Fig. 4a) is very similar to the results of normal rolls in the planar case (as seen in Fig. 2a)), however, the contrast shows a small shift φ of about 10°, which can definitely not be explained by the experimental error.

A real puzzle appears at driving frequencies higher than 120 Hz. Though the rolls stay perpendicular to the $\mathbf{n}_0$ direction, determined in the Fréedericksz distorted state, the angular dependence of the contrast is shifted by $\varphi \approx 45°$ as shown in Fig. 4b), indicating a symmetry breaking with respect to the roll direction. Comparison with Fig. 2 leads us to the assumption that we neither deal with normal rolls nor oblique rolls. We called these rolls *abnormal* rolls.

In conclusion, we applied intensity and contrast measurements to convection patterns, which delivered the information that the twist deformation of the director in the oblique roll regime in planar samples does not cause a resulting rotation of the light polarization. On the contrary in the homeotropic case, however, we detected a phase shift up to 45° in the contrast, which has not been reported before and is probably due to the complex director configuration already existing before convection sets in. We cannot give a detailed analysis of the abnormal rolls, but the comparison presented here makes it very likely that it is influenced by an overall twist within the cell. Both further measurements quantifying this conjecture and a theory taking into account such an effect is in progress in order to come to a convincing conclusion about the nature of this pattern.

The work was financially supported by Deutsche Forschungsgemeinschaft through Graduiertenkolleg Nichtlineare Spektroskopie und Dynamik and SFB 213, Bayreuth and by the Hungarian Academy of Sciences (OTKA 2976).

References

[1] W. Helfrich, J. Chem. Phys. 51, 4092 (1969).

[2] A. Hertrich, W. Decker, W. Pesch, and L. Kramer, J. Phys. France II, 2, 1915 (1992).

[3] L. M. Blinov, Electro-optical and Magneto-optical Properties of Liquid Crystals (Wiley, New York, 1983).

[4] S. Kai, Y. Adachi and S. Nasuno, preprint.

[5] H. Richter, A. Buka, and I. Rehberg, to appear in Proceedings of the NATO Advanced Research Workshop on Spatio-Temporal Patterns in Nonequilibrium Complex Systems, 1994.

[6] E. Bodenschatz, W. Zimmermann and L. Kramer, J. Phys. France, 49, 1875 (1988).

[7] I. Rehberg, B. L. Winkler, M. de la Torre Juarez, S. Rasenat, and W. Schöpf, in Festkr̈perprobleme/Adv. in Solid State Physics, ed. by U. Rössler (Vieweg, Braunschweig, 1989), 35.

[8] I. Jánossy and A. Jákli, see this volume.