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Comparison of Dynamic and Static Measurements of Surface Anchoring Energy in Nematic Liquid Crystals

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We measured the surface anchoring energy of a nematic liquid crystal by a dynamic light scattering experiment. A homogeneously aligned wedge-type cell with rubbed Nylon as the aligning layer and filled with the nematic 8CB was used. The spectrum of orientational fluctuations in confined liquid crystal depends not only on its bulk elasticity and viscosity but also on the surface anchoring energy. If the surface extrapolation length is small compared to the sample thickness the relaxation time of the fundamental mode is simply related to the inverse layer thickness. Fitting this relation to the measured relaxation times yields the azimuthal anchoring energy. The results are compared with the ones obtained by static measurements in a twisted cell. Here the surface anchoring energy is determined by the polarisation rotation of a light beam passing through a nematic slab. We show that the values of the surface anchoring energy obtained with both methods are in good agreement.

Keywords: surface anchoring; dynamic light scattering; nematic phase

INTRODUCTION

Understanding how a substrate influences liquid crystal orientation is crucial for development of new types of liquid crystal displays. The main

parameter that gives a quantitative description of the substrate effect on the liquid crystal director is the anchoring strength coefficient, often called the anchoring energy[1]. It tells us how much energy is needed to turn the orientation of the director at the surface away from the direction of the substrate's easy axes. In our case, we will discuss only the azimuthal anchoring energy, *i.e.* the energy needed to turn the director in the plane parallel to the boundary between the liquid crystal and the substrate.

The azimuthal anchoring energy has already been measured using different methods, which apply an azimuthal torque on the liquid crystal. The origin of the torque has been either electric[2,3], magnetic[4], or mechanical[5,6]. The actual twist angle of the liquid crystal director is compared to the angle between the substrate's easy axes to obtain the azimuthal anchoring energy. All these methods, however, use external torques acting on the liquid crystal, which deform the director's configuration.

To avoid the distortion of the liquid crystal, we performed the measurements with the dynamic light scattering experiment[7] on a homogeneously aligned sample, where no external torques were imposed. The results obtained by this method are compared to the standard, static anchoring energy measurement[8] and to the results obtained by the quasielastic light scattering in a hybrid film[9].

The paper is organized as follows. First, the orientational fluctuations in a confined nematic liquid crystal and their relation to the anchoring energy are discussed. Then, the dynamic light scattering experiment is described and the analysis of experimental data is presented. The next section includes the results of the static measurements. Both methods are compared in the conclusions.

ORIENTATIONAL FLUCTUATIONS IN CONFINED GEOMETRY

In general, the relaxation times of orientational fluctuations in a liquid crystal depend on the bulk elasticity and viscosity of the sample, the

surface effects being negligible. If, however, the sample is spatially limited in at least one direction, the confinement changes the spectrum of orientational fluctuations. The allowed wave vectors of the orientational fluctuations $\delta\phi$ can be derived using the wave equation [10]:

$$\gamma\delta\dot{\phi} = K\nabla^2\delta\phi \tag{1}$$

where γ is the effective viscosity and K the effective orientational elastic constant. The boundary conditions at $z = 0$ and at $z = d$, where d denotes the cell thickness, can be expressed as:

$$-K\frac{\partial\delta\phi}{\partial z}|_{z=0} + W\delta\phi|_{z=0} = 0 \quad K\frac{\partial\delta\phi}{\partial z}|_{z=d} + W\delta\phi|_{z=d} = 0 \tag{2}$$

with W standing for the azimuthal anchoring energy, which is equal on both $z = 0$ and $z = d$ boundaries. In planar geometry, the eigenmodes are sinusoidal standing waves and the set of the allowed wave vectors is discrete. The components q_z of the wave vectors perpendicular to the surface are determined by solving the secular equation[10,11]

$$q_z \tan\left(q_z\frac{d}{2}\right) = \frac{W}{K}. \tag{3}$$

The ratio of the elastic constant K and the anchoring strength W is the *extrapolation length* $\lambda = K/W$. In the case of infinite anchoring energy, and therefore zero extrapolation length, the wave vectors are determined by the thickness of the sample only

$$q_{zn} = \frac{(n+1)\pi}{d} \qquad n = 0, 1, 2, 3, \ldots \tag{4}$$

whereas in the case of strong but finite anchoring, Eq. 3 has to be expanded in terms of small deviations from q_{zn}. The expansion for the wave vectors component q_z of the fundamental mode ($n = 0$) yields

$$q_z \approx \frac{\pi}{d + 2\lambda}. \tag{5}$$

Taking into account that the relaxation times τ of orientational fluctuations with the wave number q are given by[12]

$$\tau = \frac{\gamma}{Kq^2}, \tag{6}$$

we obtain the relaxation time of the fundamental mode in one elastic constant approximation:

$$\tau^{-1} = \frac{K\pi^2}{\gamma}\frac{1}{d^2} - \frac{4K^2\pi^2}{\gamma W}\frac{1}{d^3}. \tag{7}$$

Eq. 7 shows that by measuring τ as a function of the thickness d, the anchoring energy W can be obtained.

DYNAMIC LIGHT SCATTERING EXPERIMENT

In order to obtain the azimuthal anchoring energy from the dynamic light scattering experiment, the dependence of the fluctuations' relaxation times τ on the thickness of the sample d must be measured. The most appropriate way is by using a wedge-type cell. In our experiment the thickness of the cell was ranging from 0.6 μm to 3 μm. The cell was prepared with the glass plates, previously dipped in a 0.5% solution of Nylon in methanol. The Nylon on the plates was then rubbed with a velvet cloth under constant pressure. The cell was made with the easy axes of substrate parallel on both plates, causing homogeneous alignment of the liquid crystal. The liquid crystal used in the experiment was 4-n-octyl-4'-cyanobiphenyl (8CB) in the nematic phase.

The dynamic light scattering experiment was performed by the standard photon correlation set-up with a He-Ne laser operating at a wavelength of 632.8 nm. The normalized intensity autocorrelation function, defined as $g^{(2)}(t) = \langle I(t')I(t'+t)\rangle / (\langle I(t')\rangle \langle I(t'+t)\rangle)$, was measured using an ALV-5000 correlator at different sample thicknesses. During the experiment, the scattering angle was kept constant and was equal to 2° so that the scattering length is larger than the sample thickness. This enables us to observe only the fundamental mode of the fluctuations. Polarizations of the incoming and outgoing beams were orthogonal and only twist modes of the director fluctuations were detected.

A typical measured autocorrelation function $g^{(2)}(t)$ is shown in Fig. 1. It can be fitted by a single exponential function, since $g^{(2)}(t) - 1 \propto e^{t/\tau}$. The relaxation time τ obtained from the fit is 6.8 ms $\pm$ 0.25 ms for a

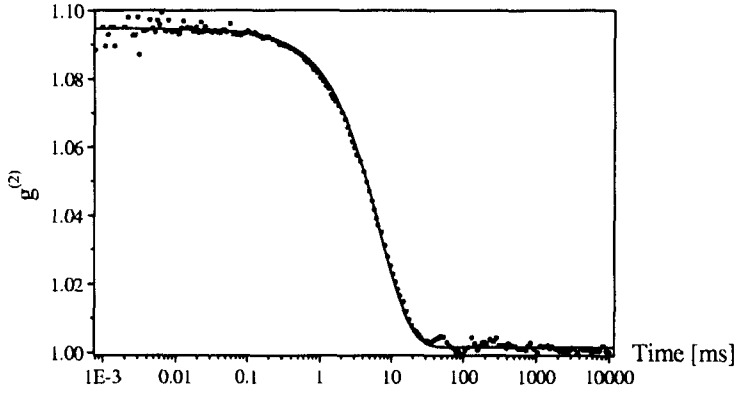

Figure 1: Autocorrelation function $g^{(2)}(t)$ measured with dynamic light scattering experiment at the 8CB sample thickness 2.3 μm at 37°C. The circles are experimental data, the solid line the exponential fit with the relaxation time 6.8 ms $\pm$ 0.25 ms.

sample thickness of 2.3 μm at 37°C. The autocorrelation functions were measured for different sample thicknesses at a fixed scattering vector. The corresponding inverse relaxation times of the fundamental fluctuations' modes are plotted as a function of the inverse sample thickness in Fig. 2. Their dependence on the thickness d is well described with a two-parameter fit of Eq. 7.

The first fitted parameter $K\pi^2/\gamma$ can be used as a check of our method, since both K and γ are known. The obtained value $K/\gamma = 1.04\,(1 \pm 0.03)$ 10^{-10} m^2/s is in excellent agreement with 1.1 $(1 \pm 0.10) \cdot 10^{-10}$ m^2/s, calculated from the known values of K and γ for 8CB[13,14]. The second fitted parameter in Eq. 7 gives information about the azimuthal anchoring energy W. The value obtained from this fit is $W = 2.6\,(1 \pm 0.15)\ 10^{-5}$ J/m^2. The extrapolation length λ is 100 nm $\pm$ 5 nm. The obtained value is in good agreement with the one reported previously[9] for 8CB in a hybrid film, 3.4 $(1 \pm 0.30)\ 10^{-5}$ J/m^2, with no Nylon specifications.

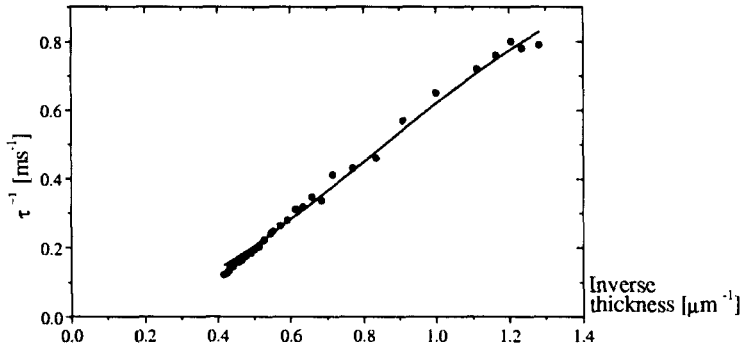

Figure 2: The fluctuations' relaxation rates as a function of inverse sample thickness. The solid line is a fit of Eq.7 to the experimental data (circles). The anchoring energy W can be determined from the fit.

STATIC MEASUREMENTS

The surface anchoring energy obtained from the dynamic light scattering experiment is compared to the result obtained by a standard, static method, where the polarisation of the light transmitted through a twisted nematic slab is observed. A twisted nematic cell illuminated with a linearly polarised light rotates the direction of the light polarisation. If the surface anchoring is strong, the twist angle of the molecules φ equals the angle ϕ between the easy axes of substrate and so does the change in polarisation direction of the transmitted light. However, if the anchoring is finite, the molecules form a twist angle smaller than the angle preferred by the substrate directions. The angle of polarisation rotation, which is the same as the actual twist of the molecules φ, is then related to ϕ by

$$\frac{(\phi - \varphi)d}{2\varphi} = \frac{K}{W}. \tag{8}$$

The anchoring strength W can thus be determined by measuring the rotation of polarization φ.

In our experiment, the liquid crystal 8CB was filled in a twisted cell with easy axes of rubbed Nylon forming an angle $\phi = 89.7°$. The Nylon-

coated glass plates were prepared exactly as in the first experiment, the concentration of the Nylon solution - and therefore the thickness of the Nylon layer - being slightly different (0.2%). The thickness of the cell was 3.1 μm in one case and 9.6 μm in the other, as determined with the spectrophotometer. The pitch of the liquid crystal was approximately four times the thickness of the cell, *i.e.* 12 μm and 38 μm, respectively. The pitch is thus much larger than the wavelength of the illuminating light and the Mauguin limit[11] is fulfilled.

The transmitted light through the sample was observed while rotating the polarizers. The angle φ was determined by the position of polarizers, at which there was no transmitted light and the extrapolation length was calculated using Eq. 8. The extrapolation lengths obtained from two cells with different thicknesses are identical, 142 nm $\pm$ 10 nm, and the anchoring energy W is 1.7 (1 $\pm$ 0.2) 10^{-5} J/m^2.

The value W obtained by this method is in a good agreement with the dynamic light scattering result. The difference which results partially from the different Nylon layer thicknesses used in the two experiments, is smaller than 30%. Larger concentration of Nylon gives stronger azimuthal anchoring at equal rubbing conditions.

CONCLUSIONS

We used the dynamic light scattering experiment in order to measure the azimuthal anchoring energy of a nematic liquid crystal on a homogeneously aligning substrate. Using this method the anchoring energy is measured through its effect on director dynamics. The obtained value for 8CB on rubbed Nylon, $W = 2.6\ (1 \pm 0.15)\ 10^{-5}$ J/m^2, is in good agreement with the value obtained by the standard, static measurement in a twisted cell.

We have shown that dynamic light scattering provides a reliable method for determination of the surface anchoring energy; its advantage is that the measurements are performed in a non-distorted configuration without any external torques acting on the liquid crystal.

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