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Anchoring anisotropy of a nematic liquid crystal on a bistable SiO evaporated surface

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The angular dependence of the surface anchoring energy of the nematic liquid crystal 5CB on a bistable surface is measured using a twist-cell method. Anchoring bistability is obtained by a grazing SiO evaporation on glass. The data obtained are in good agreement with the simplest fourth order expansion in terms of the order parameter. The bistable anchoring is weak.

Among the different methods of orientation of nematic liquid crystals (NLC), the oblique evaporation of SiO is of great interest. This method gives usually a single direction of alignment, i.e. a 'monostable' anchoring [1]. Depending on the evaporation parameters, the angle ψ of evaporation compared to the normal of the plate and the total thickness h of the SiO layer, the NLC orientation is 'planar' (the NLC molecules are oriented in the plane of the substrate and along the perpendicular **I** to the direction of evaporation) or 'oblique' (the NLC molecules are oriented in the plane of evaporation and form an angle $\theta_0 \neq 0$ with the normal to the substrate). Varying h at fixed ψ, in a narrow range of h between planar and oblique anchorings, one can induce at the same physical point of the plate two easy directions of anchoring $\mathbf{n}'$ and $\mathbf{n}''$ for the NLC molecules, i.e. a 'bistable' anchoring [2]. The $\mathbf{n}'$ and $\mathbf{n}''$ directions form (see figure 1) the angles $\pm\,\phi$ with the direction **I** perpendicular to the direction of evaporation **e**, and the angle Θ_0 with the normal to the plate. These two directions $\mathbf{n}'$ and $\mathbf{n}''$ correspond to equal minima of the surface energy, separated by an energy barrier. This barrier depends on ϕ_0, as shown in [3]. The ϕ_0 dependence of the height of this barrier is important for academic and practical reasons. Recently, two independent methods of measuring the barrier have been used. The first one consists of switching the surface nematic orientation between $\mathbf{n}'$ and $\mathbf{n}''$ by using a variable amplitude horizontal electric field [4]. The other one involves the observation of the localized rotation of the surface director across a surface defect [3]. Up to now, no angular information has been obtained for the bistable anchoring energy. In this communication we report the experimental determination of the surface energy angular dependence for the bistable anchoring of a NLC on various bistable plates of different ϕ_0 orientations.

Let us discuss the bistable anchoring properties for fixed Θ_0 and ϕ_0. Under constraint, the orientation of the nematic director on a bistable substrate is defined by two angles Θ and ϕ i.e., the anchoring energy is a function of two variables $W(\Theta, \phi, \Theta_0, \phi_0)$. The values of Θ_0 and ϕ_0 are fixed by the evaporation parameters, but the values of Θ and ϕ depend on the torque applied on the plate. In [2] it was demonstrated that, when varying the evaporation parameters for zero applied torque, the easy surface

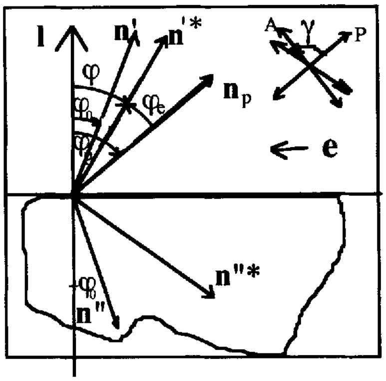

Figure 1. The nematic liquid crystal directors for two domains of the bistable plane. $\mathbf{n}'$ and $\mathbf{n}''$ are the easy directions on the bistable plate. $\mathbf{n}'^*$ and $\mathbf{n}''^*$ are the real orientations of the twisted nematic directors. $\mathbf{n}_p$ is the easy direction for the planar plate. **e** is the direction of evaporation. The surface twist distortion between $\mathbf{n}_p$ and $\mathbf{n}'^*$ is φ_e. $\mathbf{n}'^*$ forms the angle φ with the perpendicular **l** to **e**. γ is the angle between the analyser and polarizer in the extinction position for the upper domain. All angles are shown in projection on the substrate.

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direction **n** rotates on a plane P oblique to the substrate. The angle Θ_0 changes from 0 for $\phi_0 = 0$ to $\sim 75°$ for $\phi_0 = \pi/2$. This suggests that the azimuthal anchoring (related to $\phi - \phi_0$) is weaker than the zenithal anchoring (related to $\theta - \theta_0$). We then assume that, under the action of an external twist, **n** will always rotate inside the plane P. Following [5], we write the anchoring energy as a function only of the azimuthal parameter ϕ as

$$W(\phi) = \frac{K}{2L}[\cos^2\phi - \cos^2\phi_0]^2. \tag{1}$$

In equation (1) ϕ is the angle between **n** and **l** inside the plane P; $K = 10^{-6}$ cgs units is an elastic constant and L is the anchoring extrapolation length [1]. In this approximation we can determine the energy minima $W(\pm\phi_0) = 0$ and two energy maxima

$$W_1 = \frac{K}{2L}\sin^4\phi_0 \quad \text{for} \quad \phi = 0,$$

and (2)

$$W_2 = \frac{K}{2L}\sin^4\phi_0 \quad \text{for} \quad \phi = \pi/2.$$

We have $W_1 < W_2$ if $\phi_0 < \pi/4$ and the opposite if $\phi_0 > \pi/4$. We shall test the form (1) of the bistable anchoring energy in the present experiment.

To measure the twist surface energy, one must use a system which allows production of a twist surface director deformation with variable amplitude. It is convenient to use a twisted nematic film, sandwiched between two plates, one of which is the bistable one to be characterized, and the second one is a standard planar mono-stable plate. For such a twisted texture we can write the surface torque from the bulk twist as

$$\Gamma_v = \frac{K}{d}(\phi_p - \phi), \tag{3}$$

where ϕ_p is the nematic director orientation on the planar plate and d is the cell thickness. We make the hypothesis of infinitely strong anchoring on the planar plate, so that the nematic director will rotate only on the bistable surface under study. The 'bulk' torque will be compensated by the surface torque calculated from equation (1) as

$$\Gamma_s = \frac{dW(\phi)}{d\phi} = -\frac{K}{L}[\cos^2\phi - \cos^2\phi_0]\sin 2\phi. \tag{4}$$

The equilibrium orientation ϕ of the nematic molecules gives the compensation of surface torques as

$$\frac{1}{d}(\phi_p - \phi) - \frac{1}{L}[\cos^2\phi - \cos^2\phi_0]\sin 2\phi = 0. \tag{5}$$

This equation can have one or an odd number of solutions for the unknown ϕ on the bistable substrate. In the simplest case, only one value of ϕ exists for given ϕ_p and ϕ_0. When we have three (or more) solutions, one is unstable but the others are stable and can give rise to first order surface anchoring transitions.

Experimentally, we measure the surface angle ϕ on the bistable plate and we calculate by (3) the bulk elastic torque $\Gamma_v(\phi)$ in the twisted cell. In this way, we obtained a point by point determination of $\Gamma_v(\phi)$ and we can check equation (4). This method is well known for monostable anchoring [6]. To measure the surface angle in the twisted cell we use a polarizing microscope. For infinite anchoring, one would observe at random two twisted domains connecting the plate orientations $\mathbf{n}'$, $\mathbf{n}_p$ or $\mathbf{n}''$, $\mathbf{n}_p$. As the bistable anchoring is finite, we observe two domains $\mathbf{n}'^*$, $\mathbf{n}_p$ or $\mathbf{n}''^*$, $\mathbf{n}_p$ (see figure 1). The twist angle is found by measuring the extinction direction of the analyser in the Magnuim regime [7], when illuminating the sample with light linearly polarized along the planar orientation $\mathbf{n}_p$. Practically, we measure the angle φ which is projection of ϕ on the plane of the substrate. We have obviously $\cos\phi = \cos\varphi\sin\theta$. Because the plane P is weakly tilted from the substrate, we can use φ instead of ϕ for the measurements.

The liquid crystal cell is made of two parallel glass plates separated by a steel wire or mylar spacers of calibrated thickness. As a lower plate, we use an oblique SiO evaporated float glass plate with $\Psi = 60°$. The total SiO thickness is $h = 77$ Å. We obtain a monostable planar orientation $\mathbf{n}_p = \mathbf{l}$ of the nematic director. The anchoring strength, measured by an independent technique, gives an extrapolation length $L \sim 0{\cdot}1\ \mu$m, short compared to the one later measured for the bistable plate, i.e. the planar anchoring can be considered as strong compared to the bistable anchoring. The bistable anchoring plate is used as the top surface. Using the following controlled conditions of evaporation: $\Psi_1 = \Psi_2 = \Psi_3 = 75°$, $h_1 = 85$ Å; $h_2 = 90$ Å and $h_3 = 95$ Å, we obtain three different substrates with angles $\phi_0 = 26°$, 45° and 68°. The cell is filled with the nematic liquid crystal 5CB (4-pentyl-4′-cyanobiphenyl) which is nematic at room temperature $T = 20$°C [8].

To measure the angular dependence of the surface torque on the bistable surfaces, two independent methods are used. In the first one the cell has a fixed thickness $d = 3{\cdot}5\ \mu$m. The twisted texture is obtained by mechanically rotating the upper bistable plate through a varying angle φ_p. Figure 1 illustrates how the angles are calculated. By rotating the analyser through an angle γ, one can obtain the extinction for each bistable domain and calculate $|\varphi_e|$ as

$$|\varphi_e| = |\gamma| - \pi/2$$

and the angle $|\varphi|$ between $\mathbf{n}'^*$ and $\mathbf{l}$ as

$$|\varphi| = |\varphi_p| - |\varphi_e|.$$

The bulk torque from (3) is

$$\Gamma_v(\varphi_e) = \frac{K}{d}\varphi_e. \qquad (6)$$

By repeating this procedure for different φ_p we can plot $\Gamma_s(\phi)$.

The second method uses a wedge cell of fixed twist angle, but variable thickness d which allows creation of a variable bulk torque $\Gamma_v(\varphi_e, d)$. We have used two angles φ_p for these wedge cells. In the first case $\mathbf{n}_p$ coincides with the direction of evaporation ($\varphi_p = \pi/2$) and in the second, it is perpendicular to it ($\varphi_p = 0$). The bulk torque and the surface torque are functions of d. By performing the $\varphi(d)$ measurements, we can also obtain the $\Gamma_s(\phi) = -\Gamma_v(\phi)$ dependence from equation (3). There is a critical thickness d_c below which twist is not longer observed, on a black zone. $d_c = L/(2\sin^2\theta_0)$ for $\varphi_p = 0$ and $d_c = L/(2\cos^2\theta_0)$ for $\varphi_p = \pi/2$. This method is faster than the first, but is less accurate, since one observes different points on the plate i.e., a possible dispersion of the anchoring. It is also inapplicable for small d (i.e. for large surface torques) because we are no longer in the Mauguin regime. In our measurements, we have used method 2 down to $d \sim 2$ µm. For lower d we apply method 1.

We present in figures 2 (*a*)–(*c*) the experimental Γ_s data for our three samples with various evaporation parameters. The points are obtained from both methods, but give rise to the same curve. We can see that the surface torque $\Gamma_s \rightarrow 0$ when $\phi \rightarrow \phi_0$, as expected. We observe a maximum in the volume torque $|\Gamma_{v\,\max}|$ which is a function of ϕ_0. $|\Gamma_{v\,\max}|$ is larger if it separates two widely spaced energy minima as expected for W_1 and W_2. The solid lines represent the best fit of the experimental points with formula (4). The dashed lines represent the surface energy as function of ϕ, calculated from equation (1). One can see good agreement between the experimental data and the theoretical description. The fit gives the corresponding values of the anchoring extrapolation lengths: $L = 0{\cdot}72$ µm, 0·53 µm and 0·70 µm for $\varphi_0 = 26°$, 45° and 68°. These values are interesting to compare with the ones obtained from direct microscopic observations of the black zone for small d values by method 2. In this zone, the angle φ is $\varphi = \varphi_p = 0$ or $\pi/2$. Using the expression (3) and the measured maximal thickness of cell in the 'black' zone, we find $L = 0{\cdot}75$ µm, 0·50 µm and 0·76 µm for $\varphi_0 = 26°$, 45° and 68°, very comparable with those from the general fit. These values correspond to $W \sim 10^{-2} - 10^{-3}\,\mathrm{erg\,cm^{-2}}$, and compare also with the mono-stable anchoring energy values measured when approaching the bistable region in the Ψ, h diagram [5].

To conclude, we have studied the orientation of the 5CB nematic liquid crystal on a bistable glass substrate under the direct twisting action of an elastic bulk torque. The anchoring bistability is obtained by a controlled grazing

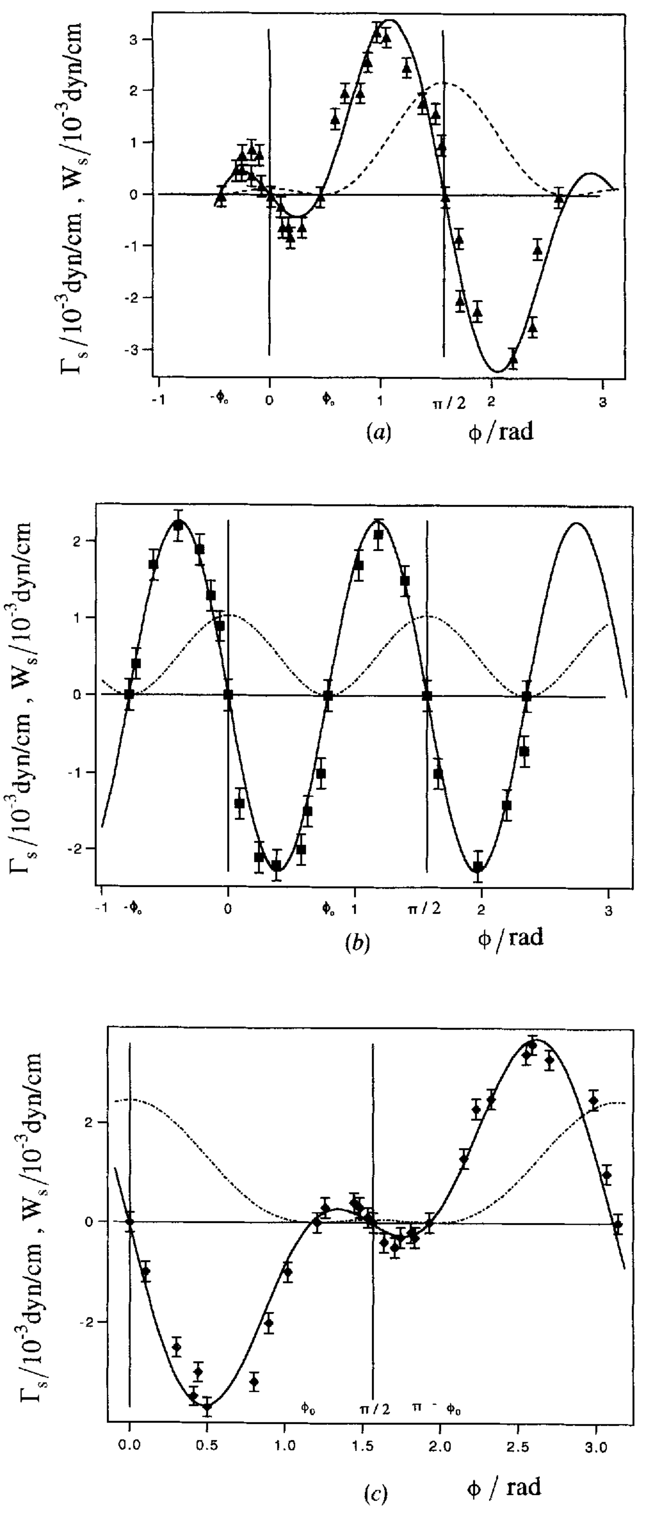

Figure 2. Torque $\Gamma_s(\phi)$ for three different cells with $\varphi_0 = 26°$ (see figure 2 (*a*)), 45° (see figure 2 (*b*)) and 68° (see figure 2 (*c*)). The solid lines represent the $\Gamma_s(\phi)$ fit with equation (4). The dashed lines represent the surface energy calculated from equation (1).

evaporation of SiO. The measured surface torques and energies compare well with the simple angular anchoring-model of [3] and [5], i.e. the simplest fourth order development in powers of the order parameter. The twist anchoring energy can be considered as 'weak', with an extrapolation length in the μm range.

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