Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713926090

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To cite this Article Barbero, G. and Durand, G.(1987) 'On a Possible Mechanism for the Spontaneous Freedericksz Effect', Liquid Crystals, 2: 3, 401 — 403
To link to this Article: DOI: 10.1080/02678298708086685
URL: http://dx.doi.org/10.1080/02678298708086685

LIQUID CRYSTALS, 1987, VOL. 2, NO. 2, 401–403

On a possible mechanism for the spontaneous Freedericksz effect

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(*Received 5 February 1987; accepted 19 March 1987*)

Kaznacheev and Sonin have presented a model to explain the so-called spontaneous Freedericksz transition in nematic liquid crystals (1983, *Sov. Phys. solid St.*, **25**, 528; 1984, *Ibid.*, **26**, 486). A surface polarization, coupled with the negative anisotropy of the nematic, turns the two homeotropic anchoring plates into planar anchoring plates. We show that this model, correctly solved, cannot explain the observed critical thickness. The spontaneous Freedericksz transition is in fact the surface instability of a hybrid cell with weak planar anchoring.

Nematic liquid crystals can be oriented between two glass plates, with their mean axis (the director **n**) normal to the plates, that is in the homeotropic orientation. Chuvyrov *et al.* have observed [1–3] that thick samples undergo a spontaneous tilt transition, above a critical thickness $d = d_c$. This effect was related to the existence of surface electric polarization $\mathbf{P}_S$, already observed [4] in a different context. Following this idea, Kaznacheev and Sonin have developed a model [5, 6] to explain this so-called spontaneous Freedericksz transition. This model relates the observed spontaneous tilt of the director to the coupling of the electric field $\mathbf{E}_S$ created by $\mathbf{P}_S$, with the negative dielectric anisotropy of the material close to the plates. In this communication, we show that the model proposed in [5, 6] is incorrect, but can be reformulated correctly, if the assumed symmetry of the observed texture distortion is changed.

Let us recall the geometry of [5]; **z** is the normal to the plates, placed at $z = 0$ and $z = d$, while $(\mathbf{z}, \mathbf{n}) = \phi(z)$ is the tilt angle. The free energy density of a distorted texture is written, per unit area, as

$$F = (K/2)\int \dot{\phi}^2\, dz + (1/2)\{W_0 - (|\varepsilon_a|/4\pi)E_{0s}^2\varrho_0\}\sin^2\phi_0 + (1/2)\{W_d - (|\varepsilon_a|/4\pi)E_{ds}^2\varrho_d\}\sin^2\phi_d, \quad (1)$$

where $\dot{\phi} \equiv d\phi/dz$ and $K \simeq 10^{-6}$ dyn is the curvature elastic constant in the one constant approximation. W_0 and W_d are the surface energies of the plates plated at 0 and d, in the Rapini–Papoular form. ε_a is the (negative) dielectric anisotropy of the nematic material. $\mathbf{E}_{0s}$ and $\mathbf{E}_{ds}$ are the electric fields created by the surface polarization $\mathbf{P}_S$ in a localized region close to the plates, of thickness $\varrho_0, \varrho_d \ll d$. In [5], the two plates

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are assumed to be identical, with equal and negative surface energies,

$$\tilde{W}_0 = \tilde{W}_d = W - (|\varepsilon_a|/4\pi)E^2\varrho. \tag{2}$$

From this assumption of two plates with negative anchoring energy, we find, trivially, that the absolute lowest energy texture of the system is the planar one, ($\phi = \pi/2$, $\forall z \in [0, d]$), since there is no bulk curvature and the two surface energies are at their lowest values. Note then that, because there is no thickness dependence (for $d \gg \varrho$), there is no critical thickness either. The texture should always remain planar. The solution proposed in [5] was imposed to be antisymmetric, with $\phi = 0$ in the middle of the cell. This mathematical solution gives the minimum energy for the class of antisymmetric distortions. This energy minimum is obviously larger than the absolute minimum of the planar symmetric solution previously discussed. It cannot in any event represent a physical solution of this assumed symmetrical problem.

To understand the effect, we notice that the existence of a critical thickness d_c means that there is a critical surface torque density acting on one surface and transmitted through the bulk. This critical torque must be written as

$$K\dot{\phi} = K(\phi_d - \phi_0)/d_c.$$

With symmetrical solutions, ($\phi_d = \phi_0$); it is then impossible to transmit torques from one plate to the other. The experiment itself must therefore contain an asymmetry. This seems to be confirmed by the pictures of [2], which show that the instability is localized in ribbons. This geometry suggests that the anchoring on the plates is not uniform. For instance, the surface polarization $\mathbf{P}_S$ could be non-uniform. There would exist on the plates localized regions of spontaneous planar orientation ($\tilde{W}_P < 0$), embedded in regions of homeotropic spontaneous orientation ($\tilde{W}_H > 0$). This could lead locally to the existence, face to face, of hybrid anchoring, i.e. planar and homeotropic orientations, with the homeotropic energy $|\tilde{W}_H|$ larger than the planar one $|\tilde{W}_P|$, since the field created by $\mathbf{P}_S$ is probably weak, just able to compensate for W. As is well known, this situation leads to a surface instability [7–9]: above a critical thickness d_c, the weaker planar anchoring can build a finite tilt. Below d_c, the homeotropic anchoring imposes its orientation. At $d > d_c$, the surface torque balance [10, 11] leads to

$$|\tilde{W}_0/2|\sin 2\phi_0 = (K/d)\phi_0$$

in the hypothesis that $\tilde{W}_1 \gg |\tilde{W}_0|$. d_c measures the extrapolation length of the surface energy $d_c = K/|\tilde{W}_0|$. The experimental value for d_c of $\sim 33\,\mu$m [2] is one of the largest known for any nematic–solid interface; typical values are in the range 0·1–3 μm [12]. $\tilde{W}$ is then one of the weakest measured anchoring energies for a nematic liquid crystal. We can now understand why the calculation of [5] with the incorrect symmetry gave a useful result: the unexplained assumption of an antisymmetric solution, by fixing the tilt value $\phi = 0$ in the middle of the cell, was equivalent to assuming the existence of a strong homeotropic anchoring plate at this position, in front of a planar orienting plate. Apart from an obvious factor 2 on d_c, [5] discussed, without saying it, the surface instability of a hybrid cell with weak planar anchoring.

In conclusion, the spontaneous Freedericksz transition cannot be explained by the symmetric model of [5]. An antisymmetry must exist in the anchoring energies of the plates to explain the existence of a critical thickness. With this interpretation, the spontaneous Freedericksz transition is in fact a well-known transition observed in hybrid cells, where a strong homeotropic anchoring is opposed to a weak planar one.

The weak planar orientation could well result from the coupling of a surface electric field with the negative dielectric anisotropy of the material, or from any other reason. If this dielectric anisotropy coupling is correct, we predict that an equivalent transition should occur for a material with a positive dielectric anisotropy, starting from a planar orientation just compensated by the surface field effect.

This work was supported by CNET under contract number 86 8B-790 92 45.

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