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Oscillations of the Fréedericksz critical field in a superthin nematic layer in the vicinity of the second order nematic–smectic A phase transition

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In the present paper the Fréedericksz transition in a superthin ($\sim 0.2 \mu\text{m}$), homeotropically aligned liquid crystal layer between two identical boundary surfaces (solid walls) in the vicinity of the second order nematic–smectic A phase transition is considered. It is shown that the interference between the boundary surface-induced smectic density waves results in oscillation of the Fréedericksz critical field as a function of nematic layer thickness, and the period of oscillation is equal to the molecular length l .

1. Introduction

It is known that interaction between boundary surfaces and both the mesogenic and non-mesogenic molecules results in the appearance of surface layers with properties different from those of the bulk phase of a liquid. For example, the liquid–solid substrate interface not only enhances the orientational ordering in nematics and imposes some orientational order on the isotropic phase of liquids having a nematic phase [1–6], but also induces orientational ordering in non-mesomorphic liquids [7]. Furthermore, both the nematic-free surface and the nematic–solid substrate interface have an effect on the positional molecular order in liquids that leads to the appearance of a layered smectic A structure [1, 8–12].

The thin layer of liquid or nematic between two identical boundary surfaces (solid walls or free surfaces in the case of a freely suspended film) is particularly interesting. When two such surfaces are sufficiently close together, then interference between the liquid surface layers takes place and results in the appearance of extra phenomena. These phenomena have been clearly revealed by Horn *et al.* [1], from measurements of the forces between two molecularly smooth surfaces of mica separated by the nematogen 4-*n*-pentyl-4'-cyanobiphenyl (5CB) in both the planar and homeotropic orientations. It has been found that there is a short-range force which oscillates, as a function of the nematic film thickness, between attraction and repulsion, and the period of oscillation is equal to the molecular length l and molecular diameter a for the homeotropic and planar orientations, respectively. The qualitative explanation of such a phenomenon was also given by Horn *et al.* [1]. They attributed the oscillations of the force between the two mica surfaces to the solid wall-induced smectic ordering of molecules in the liquid crystal layer. A simple theoretical description of the oscillations in the thermodynamic properties of thin nematic layers between two identical boundary surfaces has been offered in [13]. In a mean field approximation, it has been shown that the interference between the boundary surface-induced smectic density waves results in oscillations of the smectic order parameter which give rise to the

oscillations in the free energy of the liquid crystal layer and the disjoining pressure acting on the boundary surfaces.

It should be interesting to consider the effects of these oscillations on the electro(magneto)-optical phenomena in a very thin, but nevertheless macroscopic nematic layer between two identical boundary surfaces. The effect of the boundary surface-induced smectic ordering on the Fréedericksz transition in a this homeotropically aligned cell containing 4-*n*-octyl-4'-cyanobiphenyl (8CB) near the second order nematic–smectic A (N–S_A) transition has been studied by Rosenblatt [14]. He observed the anomalous increase in the Fréedericksz critical field and explained it in terms of smectic layering induced at the two boundary surfaces of the cell, so decreasing the effective thickness of the nematic region and thereby increasing the effective critical field. However, the thickness of Rosenblatt's cell, $L = 2.627 + 0.015 \mu\text{m}$ was much larger than the smectic correlation length ζ which is of the order of $0.1 \mu\text{m}$ for the temperature interval investigated [14]. Since the correlation length ζ is similar to the depth of the surface smectic ordering penetration into bulk liquid crystal, the interference between the boundary surface-induced smectic structures cannot occur in such a liquid crystal cell.

The purpose of the present paper is to investigate theoretically the influence of the interference of the boundary surface-induced smectic density waves on the Fréedericksz transition in a homeotropically aligned liquid crystal layer of a thickness L commensurable with the smectic correlation length ζ . The dependence of the Fréedericksz critical magnetic (electric) field on the nematic layer thickness and temperature is determined. It is shown that the value of the critical field must oscillate with the distance between two identical boundary surfaces and that the period of oscillation is equal to the molecular length l . The numerical estimations performed for octylcyanobiphenyl (8CB) allow us to conclude that in the vicinity of the second order N–S_A phase transition ($T - T_{\text{NS}_A} \sim 0.1 \text{ K}$), this phenomenon can be observed in a superthin, but nevertheless macroscopic ($\sim 0.2 \mu\text{m}$) liquid crystal cell.

2. The Fréedericksz critical field in a thin homeotropically aligned liquid crystal layer between two identical boundary surfaces

Let us consider the homeotropically aligned liquid crystal layer between two identical boundary surfaces (solid walls) in a transverse magnetic \mathbf{H} (electric \mathbf{E}) field. The temperature of the sample is assumed to be in the vicinity of the second order N–S_A phase transition. For simplicity, let us suppose that orientational order in the liquid crystal layer is ideal (the long axes of all molecules are oriented parallel to the director \mathbf{n} aligned along the z axis). This assumption is reasonable enough because the temperatures of experimentally observed second order N–S_A transitions are considerably lower than those of the isotropic–nematic (I–N) phase transitions [15].

Taking into account the boundary surface-induced smectic A ordering, the free energy of deformation for the liquid crystal layer in the transverse magnetic field \mathbf{H} can be written as [14]

$$F = \frac{1}{2} \int_0^L \left[K_3 \left(\frac{d\theta}{dz} \right)^2 - \chi_a H^2 \theta^2 + D(z) \theta^2 \right] dz, \quad (1)$$

where θ is the director tilt angle relative to the z axis, K_3 and χ_a are the spatially uniform bend elastic constant and volume-susceptibility anisotropy, respectively; the term $D(z)\theta^2$ is the extra energy required to tilt the director by an angle θ relative to the smectic layer normal, and L is the distance between the two identical boundary

surfaces. When the sample is in a transverse electric field \mathbf{E} , the term $\chi_a H^2 \theta^2$ in equation (1) must be replaced by $(\Delta\epsilon/4\pi) E^2 \theta^2$, where $\Delta\epsilon$ is the dielectric permittivity anisotropy. In the de Gennes model [16], $D(z) \sim \sigma^2(z)$, where $\sigma(z)$ is the boundary surface-induced smectic order parameter. It has been shown in [13] that $\sigma(z)$ in a thin homeotropically aligned nematic layer between two identical boundary surfaces is

$$\sigma(z) = \sigma_0 [\exp(-z/\zeta) + \exp((z-L)/\zeta)], \quad (2)$$

where

$$\sigma_0 = [nG_0/\alpha(T - T_{NSA})\zeta]R(L), \quad (3)$$

$$R(L) = [\cos\psi + \exp(-L/\zeta)\cos(2\pi L/l - \psi)] \\ \times [1 - \exp(-2L/\zeta)]^{-1}, \quad (4)$$

$$\psi = \tan^{-1} \left[\frac{\exp(-L/\zeta)\sin(2\pi L/l)}{1 + \exp(-L/\zeta)\cos(2\pi L/l)} \right], \quad (5)$$

where n is the number of molecules per unit volume, G_0 is the constant defining the strength of interaction between the mesogenic molecules and the boundary surface, and $\alpha = \text{constant}$. Then $D(z)$ can be written as

$$D(z) = D_0 R^2(L) [\exp(-2z/\zeta) + \exp(2(z-L)/\zeta) + 2\exp(-2L/\zeta)] \quad (6)$$

where in a mean field approximation $D_0 \sim [(T - T_{NSA}) \cdot \zeta]^{-2} \sim (T - T_{NSA})^{-1}$. When the nematic layer is sufficiently thick ($L \gg \zeta$), then $\exp(-L/\zeta) \rightarrow 0$, $R(L) \rightarrow 1$, and $D(z)$ moves to the expression used by Rosenblatt [14].

Now let us determine the Fréedericksz critical field as a function of the layer thickness L and the temperature T . First of all, we should choose a suitable solution $\theta(z)$ which is symmetrical about the centre of the layer ($z = L/2$) and satisfies the boundary conditions

$$\theta(z=0) = \theta(z=L) = 0, \quad (7)$$

(here we neglect non-rigid anchoring effects). In addition, in the limiting case of a 'pure' nematic layer without any surface-induced smectic structures ($D(z) = 0$), this solution must become the well-known expression $\theta(z) = \theta_0 \sin(\pi z/L)$ describing the small deformation in a bend-configured nematic sample in the vicinity of the Fréedericksz transition [17]. The solution $\theta(z)$ satisfying all the aforementioned conditions can be represented in the form

$$\theta(z) = \theta_0 \left[\sin\left(\frac{\pi z}{L}\right) + \sum_{m=1}^{\infty} \alpha_m \sin\left[\frac{(2m+1)\pi z}{L}\right] \right], \quad (8)$$

where α_m are the coefficients to be found. Substituting the equation (8) into equation (1) we obtain the following expression for the deformation energy F :

$$F = \frac{\theta_0^2}{2} \left\{ \frac{1}{2} K_3 \frac{\pi^2}{L} \left(1 + \sum_{m=1}^{\infty} (2m+1)^2 \alpha_m^2 \right) - \frac{1}{2} \chi_a H^2 L \left(1 + \sum_{m=1}^{\infty} \alpha_m^2 \right) \right. \\ + D_0 R^2(L) \exp(-2L/\zeta) L \left(1 + \sum_{m=1}^{\infty} \alpha_m^2 \right) + (D_0 R^2(L) \zeta / 2) [1 - \exp(-2L/\zeta)] \\ \times \frac{\pi^2 (\zeta/L)^2}{1 + \pi^2 (\zeta/L)^2} + D_0 R^2(L) \zeta [1 - \exp(-2L/\zeta)] \sum_{m=1}^{\infty} \alpha_m a_m + (D_0 R^2(L) \zeta / 2) \\ \left. \times [1 - \exp(-2L/\zeta)] \sum_{m=1}^{\infty} \alpha_m^2 b_m + D_0 R^2(L) \zeta [1 - \exp(-2L/\zeta)] \sum_{m \neq n} \alpha_m \alpha_n C_{mn} \right\}, \quad (9)$$

where

$$a_m = \frac{1}{1 + \pi^2 m^2 (\zeta/L)^2} - \frac{1}{1 + \pi^2 (m+1)^2 (\zeta/L)^2}, \tag{10}$$

$$b_m = \frac{(2m+1)^2 \pi^2 (\zeta/L)^2}{1 + \pi^2 (2m+1)^2 (\zeta/L)^2}, \tag{11}$$

$$C_{mn} = \frac{1}{1 + \pi^2 (m-n)^2 (\zeta/L)^2} - \frac{1}{1 + \pi^2 (m+n+1)^2 (\zeta/L)^2}. \tag{12}$$

The Fréedericksz critical magnetic field H^* can be determined from the equation with $F=0$ which gives

$$H^{*2} = \frac{\pi^2 K_3}{L^2 \chi_a} \left[A_0(\zeta/L) + \sum_{m=1}^{\infty} B_m(\zeta/L) \alpha_m + \sum_{m=1}^{\infty} C_m(\zeta/L) \alpha_m^2 + \sum_{m \neq n} D_{mn}(\zeta/L) \alpha_m \alpha_n \right] / \left(1 + \sum_{m=1}^{\infty} \alpha_m^2 \right), \tag{13}$$

where

$$A_0(\zeta/L) = 1 + \frac{2\Lambda^2 R^2(L)(L/\zeta)^2}{\pi^2} \exp(-2L/\zeta) + \frac{\Lambda^2 R^2(L)(\zeta/L)[1 - \exp(-2L/\zeta)]}{[1 + \pi^2 (\zeta/L)^2]}, \tag{14}$$

$$B_m(\zeta/L) = \frac{2\Lambda^2 (L/\zeta) R^2(L)[1 - \exp(-2L/\zeta)]}{\pi^2} \times \left[\frac{1}{1 + \pi^2 m^2 (\zeta/L)^2} - \frac{1}{1 + \pi^2 (m+1)^2 (\zeta/L)^2} \right], \tag{15}$$

$$C_m(\zeta/L) = (2m+1)^2 + \frac{2\Lambda^2 R^2(L)(L/\zeta)}{\pi^2} \exp(-2L/\zeta) + \frac{\Lambda^2 R^2(L)(\zeta/L)(2m+1)^2 [1 - \exp(-2L/\zeta)]}{[1 + \pi^2 (2m+1)^2 (\zeta/L)^2]}, \tag{16}$$

$$D_{mn}(\zeta/L) = \frac{\Lambda^2 (L/\zeta) R^2(L)[1 - \exp(-2L/\zeta)]}{\pi^2} \times \left[\frac{1}{1 + (m-n)^2 \pi^2 (\zeta/L)^2} - \frac{1}{1 + (m+n+1)^2 \pi^2 (\zeta/L)^2} \right] \tag{17}$$

where

$$\Lambda^2 = D_0 \zeta^2 / K_3.$$

In order to determine the critical electric field (E^{*2}) we must replace χ_a in equation (13) by $(\Delta c/4\pi)$. Minimization of equation (13), with respect to the unknown coefficients α_m , leads to the following:

$$\left[B_m(\zeta/L) + 2C_m(\zeta/L) \alpha_m + \sum_{n \neq m} D_{mn}(\zeta/L) \alpha_n \right] \left(1 + \sum_{n=1}^{\infty} \alpha_n^2 \right) - 2\alpha_m \left[A_0(\zeta/L) + \sum_{n=1}^{\infty} B_n(\zeta/L) \alpha_n + \sum_{m \neq n} D_{mn}(\zeta/L) \alpha_m \alpha_n + \sum_{n=1}^{\infty} C_n(\zeta/L) \alpha_n^2 \right] = 0, \tag{18}$$

which allows us to determine all these coefficients and consequently the Fréedericksz critical field.

Let us realize this procedure in the simplest way, restricting expression (8) to two first terms:

$$\theta(z) \approx \theta_0 \left[\sin\left(\frac{\pi z}{L}\right) + \alpha_1 \sin\left(\frac{3\pi z}{L}\right) \right]. \quad (19)$$

Then the Fréedericksz critical field is given by

$$H^{*2}(E^{*2}) = \frac{H_0^{*2}(E_0^{*2})[A_0 + B_1\alpha_1 + C_1\alpha_1^2]}{(1 + \alpha_1^2)}, \quad (20)$$

where

$$\alpha_1 = \frac{(C_1 - A_0) - [(C_1 - A_0)^2 + B_1^2]^{1/2}}{B_1}, \quad (21)$$

and

$$H_0^* = \frac{\pi}{L} \sqrt{\left(\frac{K_3}{\chi_a}\right)} \quad \text{and} \quad E_0^* = \frac{\pi}{L} \sqrt{\left(\frac{4\pi K_3}{\Delta\epsilon}\right)}$$

are the magnetic and electric critical fields, respectively, in the 'pure' bend-configured nematic sample without any boundary surface-induced smectic structures.

It should be useful to check the capability of equations (20) and (21) to describe the results of a Fréedericksz measurement performed by Rosenblatt [14]. As has been said above, the thickness L of Rosenblatt's liquid crystal cell was much larger than the smectic correlation length ζ . In this case $R(L) \rightarrow 1$ and the equations (14)–(17) can be considerably simplified:

$$\left. \begin{aligned} A_0 &\approx 1 + \Lambda^2(\zeta/L), \\ B_1 &\approx 6\Lambda^2(\zeta/L), \\ C_1 &\approx 9[1 + \Lambda^2(\zeta/L)], \end{aligned} \right\} \quad (22)$$

and

$$\alpha_1 \approx -\frac{3}{8}\Lambda^2(\zeta/L).$$

The main purpose of Rosenblatt's paper [14] was to determine the temperature dependence of a quantity Φ such that

$$\Phi = L_N H_N^* / L_W H_W^* - 1, \quad (23)$$

where H_W^* is the Fréedericksz critical magnetic field in a thick cell with $L_W = 76.2 + 0.3 \mu\text{m}$ and H_N^* is that in a thin cell with $L_N = 2.627 + 0.015 \mu\text{m}$. Taking into account that in the thick cell the critical field is similar to that in the 'pure' nematic sample, we can find that

$$\Phi = \{[A_0 + B_1\alpha_1 + C_1\alpha_1^2]/(1 + \alpha_1^2)\}^{1/2} - 1. \quad (24)$$

The results of Rosenblatt's measurements of Φ are shown in figure 1. Let us consider the first experimental point in this figure, corresponding to the temperature $T = T_{NSA} + 0.8 \text{ K}$. The quantity Φ , at this temperature, is equal to 0.01, and according to

[14], the ratio ζ/L is equal to about 9×10^{-3} . Therefore the terms $B_1\alpha_1$, $C_1\alpha_1^2$, and α_1^2 in equation (24) can be neglected and Φ is given by

$$\Phi \approx \frac{1}{2}\Lambda^2 \cdot (\zeta/L), \quad (25)$$

and hence

$$[\Lambda^2 \cdot (\zeta/L)]_{T=T_{NSA}+0.8K} \approx 0.02.$$

Since in a mean field approximation, in the vicinity of the second order N-S_A transition $D_0 \sim (T - T_{NSA})^{-1}$, $\zeta \sim (T - T_{NSA})^{-1/2}$, and $K_3 \sim (T - T_{NSA})^{-1/2}$ [17], the value $\Lambda^2 \cdot (\zeta/L) \sim (T - T_{NSA})^{-2}$ and we can write

$$[\Lambda^2 \cdot (\zeta/L)]_T = 0.02 \times (0.8/(T - T_{NSA}))^2. \quad (26)$$

Substituting this relation in equations (22) and (24), we can calculate the quantity Φ at any temperature in the vicinity of the second order N-S_A phase transition for 8CB. The calculated temperature dependence of this value is also shown in figure 1. It is seen that equations (20) and (21) provide reasonable agreement with Rosenblatt's experimental results.

3. The oscillations of the Fréedericksz critical field with the distance between two identical boundary surfaces

Now let us consider the case of a superthin liquid crystal layer of thickness L commensurable with the smectic correlation length ζ . In this case, the value $R(L) \neq 1$ and oscillates with the distance L . According to [14], at the temperature $T = T_{NSA} + 0.1$ K, the correlation length ζ in 8CB is equal to about $0.1 \mu\text{m}$. Let us take the layer thickness L to be about $0.2 \mu\text{m}$ ($L/\zeta \approx 2$). Though such a liquid crystal layer is 'superthin', it can be considered as a macroscopic sample because L is much larger than the molecular length l ($L/l \approx 60-70$). The magnitude of Λ^2 for 8CB at the temperature $T = T_{NSA} + 0.1$ K can also be determined from Rosenblatt's experimental

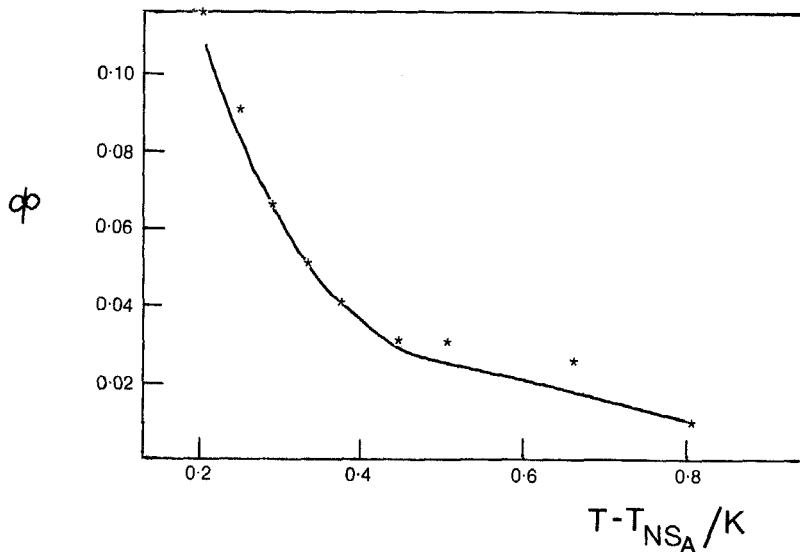


Figure 1. Temperature dependence of the quantity Φ . (*), experimental points [14].

results [14]. Remembering that $[\Lambda^2 \cdot (\zeta/L)]_{T=T_{NS_A}+0.8K} \approx 0.02$ and $\zeta/L \approx 9 \times 10^{-3}$ and taking into account that in a mean field approximation $\Lambda^2 \sim (T - T_{NS_A})^{-1.5}$ we find

$$(\Lambda^2)_{T=T_{NS_A}+0.1K} = (\Lambda^2)_{T=T_{NS_A}+0.8K} \times 8^{1.5} = 50.3$$

Substituting this value and the ratio $L/\zeta = 2$ into equations (14)–(16) and (20)–(21), we can calculate the dependence of the Fréedericksz critical field in a superthin liquid crystal layer when the layer thickness L changes from Kl to $(K+1)l$ where K is an integer. This oscillatory dependence is shown in figure 2. The critical field has a maximum value H_{\max}^* (E_{\max}^*) at a distance L equal to an integral number of molecular lengths l ($L = Kl$, $L = (K+1)l$) and it has a minimum value at $L = (K+0.5)l$. Thus the most important characteristic of macroscopic magneto(electro)-optical phenomena oscillates with a period equal to the microscopic molecular length l .

A qualitative explanation of the results obtained can be presented as follows. When the distance between the boundary surfaces is equal to an integral number of smectic layer thicknesses ($L = Kl$, $(K+1)l$, ...), then the interference between the boundary surface-induced smectic density waves is constructive and the smectic ordering is enhanced. This enhancement of the boundary surface-induced smectic ordering gives rise to a growth in the Fréedericksz critical field. In the opposite case, ($L = (K+0.5)l$), the interference between the boundary surface-induced smectic density waves is destructive and the smectic ordering grows weak and results in a decrease in the critical field.

Finally, let us estimate numerically the magnitudes of the magnetic and electric Fréedericksz critical fields for the bend configured sample of 8CB with thickness $L = 0.2 \mu\text{m}$ at the temperature $T = T_{NS_A} + 0.1 \text{K}$. In 8CB, in the vicinity of the second order N-S_A transition, the magnitude of the bend elastic constant K_3 is of the order of $\sim 10^{-6} \text{dn}$ [18]. Substituting this and a typical value of $\chi_a = 10^{-7} \text{CGSE}$ [15] into the expression for H_0^* , we obtain $H_0^* \approx 5 \times 10^5 \text{G}$, and according to figure 2, $H_{\max}^* \approx 1.6 \times 10^6 \text{G}$ and $H_{\min}^* \approx 1.3 \times 10^6 \text{G}$. Evidently such magnetic fields are not available now.

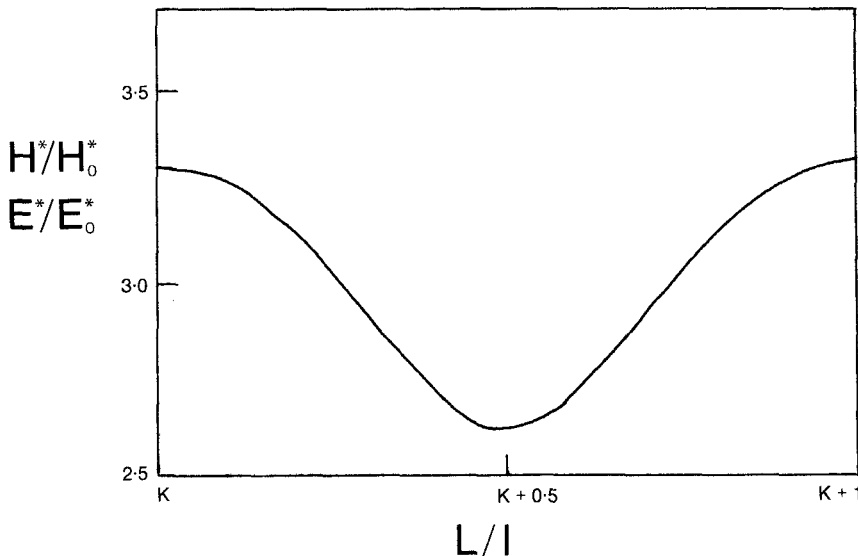


Figure 2. Oscillatory dependence of the Fréedericksz critical field for 8CB on the distance between the two identical boundary surfaces. $T = T_{NS_A} + 0.1 \text{K}$, $L = 0.2 \mu\text{m}$ ($L/\zeta \approx 2$).

However, 8CB is a strongly polar liquid crystal with $\Delta\epsilon \approx 10$ [19] and this gives quite achievable magnitudes of critical electric fields, namely $E_0^* \approx 5.3 \times 10^4 \text{ V cm}^{-1}$, $E_{\text{max}}^* \approx 1.74 \times 10^5 \text{ V cm}^{-1}$, and $E_{\text{min}}^* \approx 1.38 \times 10^5 \text{ V cm}^{-1}$. These estimations allow us to hope for the possibility of experimental observation of the phenomenon under consideration in an electric field.

In conclusion, let us discuss briefly some moot points in the above considerations. First, the equation (1) for the free energy of deformation in the liquid crystal layer in the transverse magnetic field is obtained in the framework of a continuum model which neglects the structural details of molecular size. Is this model appropriate for the consideration of a superthin sample of thickness $L \sim 0.2 \mu\text{m}$? As stated above, though the liquid crystal layer under consideration is superthin, its thickness L is much larger than the molecular length l ($L/l \approx 60-70$) and it can be considered as macroscopic. Therefore the continuum model should be appropriate for the description of the deformations in such samples [20]. Secondly, in the determination of the value $\Lambda^2 \cdot (\zeta/L)$, we use the temperature dependences of the elastic constant K_3 and the correlation length ζ in the framework of a mean field approximation. However, the experimental data often do not correspond to this very simple theory [18]. We must note that the mean field approximation used here is the simplest approach to the phenomenon under consideration and its utilization would only give a result that is qualitatively right.

References

- [1] HORN, R. G., ISRAELACHVILI, J. N., and PEREZ, E., 1981, *J. Phys. Paris*, **42**, 39.
- [2] MIYANO, K., 1979, *Phys. Rev. Lett.*, **43**, 51.
- [3] MIYANO, K., 1979, *J. chem. Phys.*, **71**, 4108.
- [4] MADA, H., and KOBAYASHI, S., 1979, *Appl. Phys. Lett.*, **35**, 4.
- [5] MADA, H., and KOBAYASHI, S., 1981, *Molec. Crystals liq. Crystals*, **66**, 57.
- [6] VAN SPRANG, H. A., 1983, *J. Phys., Paris*, **44**, 421.
- [7] DERIAGIN, B. V., POPOVSKI, Iu. M., and ALTOIZ, B. A., 1982, *Dokl. Akad. Nauk SSSR*, **262**, 853.
- [8] ROSENBLATT, C., and AMER, N. B., 1980, *Appl. Phys. Lett.*, **36**, 432.
- [9] NINHAM, B., 1981, *Pure appl. Chem.*, **53**, 2135.
- [10] ALS-NIELSEN, J., CHRISTENSEN, F., and PERSHAN, P. S., 1982, *Phys. Rev. Lett.*, **48**, 1107.
- [11] PERSHAN, P. S., and ALS-NIELSEN, J., 1984, *Phys. Rev. Lett.*, **52**, 759.
- [12] PERSHAN, P. S., BRASLAU, A., and WEISS, A., 1987, *Phys. Rev. A*, **35**, 4800.
- [13] MIRANTSEV, L. V., 1992, *Liq. Crystals*, **11**, 421.
- [14] ROSENBLATT, C., 1984, *Phys. Rev. Lett.*, **53**, 791.
- [15] DE JEU, W. H., 1980, *Physical Properties of Liquid Crystalline Materials* (Gordon & Breach).
- [16] LUBENSKY, T. C., 1983, *J. Chim. phys.*, **80**, 31.
- [17] CHANDRASEKHAR, S., 1977, *The Physics of Liquid Crystals* (Clarendon Press).
- [18] LITSTER, D., ALS-NIELSEN, J., BIRGENEAU, R. J., DANA, S. S., DAVIDOV, D., GACIA-GOLDING, F., KAPLAN, M., SAFINYA, C. R., and SCHAEZING, R., 1979, *J. Phys., Paris*, **40**, C3-339.
- [19] THOEN, J., and MENU, G., 1983, *Molec. Crystals liq. Crystals*, **97**, 163.
- [20] DE GENNES, P. G., 1974, *The Physics of Liquid Crystals* (Clarendon Press).