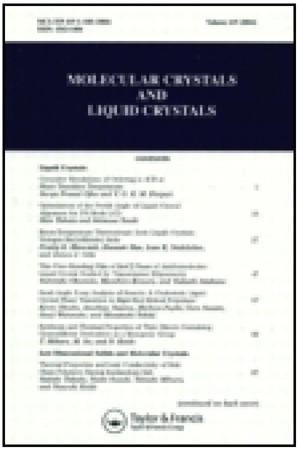

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Liquid Crystals on the Solid State Surface—The Determination of Anchoring Energy Under an Applied Magnetic Field

V. G. Podoprigora [a] , V. A. Gunyakov [a] , A. M. Parshin [a] , B. P. Khrustalev [a] & V. F. Shabanov [a]

[a] Institute of Physics, 660036, Krasnoyarsk, USSR

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Liquid Crystals on the Solid State Surface— The Determination of Anchoring Energy Under an Applied Magnetic Field

V. G. PODOPRIGORA, V. A. GUNYAKOV, A. M. PARSHIN, B. P. KHRUSTALEV and V. F. SHABANOV
Institute of Physics, 660036 Krasnoyarsk, USSR

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Thin nematic films behaviour under strong magnetic fields are investigated. The *S*-effect of homogeneous liquid crystals was used for experimental measurements. The relation between anchoring energy W and critical magnetic field parameters was obtained by the method of trial functions. It is shown that ideal Freedericksz transition threshold (H_{th}^{∞}, $W \rightarrow \infty$) and real threshold of finite anchoring energy may differ experimentally only for thin samples (1 μm) under strong magnetic field (about 100 kG). The value $W = 0.2$ erg/cm^2 has been found for the 5CB liquid crystal on quartz substrate of 20 nm roughness at room temperature.

Keywords: surfaces, anchoring energy

The interaction between liquid crystals (LC) and solid surface characterizes physical properties and behaviour of LC under external fields. This interaction has been characterized by anchoring energy of "LC-substrate" system. The investigation of this parameter is very important both for studying of interface peculiarities and for applied physics (threshold fields, operation rate, LC-cells contrast . . .). Using magnetic fields for determination of anchoring energy (W) make the advantage evident when compared with other methods because of an absence of secondary effects.[1] However, there are no experiments on measurement of energy W under magnetic field applied with LC parallel oriented to the substrate surface (*S*-effect). There are no experimental data on temperature dependence of Freedericksz transitions in magnetic fields for such LC-configuration either.

This paper is aimed to determine the anchoring energy using *S*-effect in thin nematic LC-films of 4-pentyl-4′-cyanobiphenyl (5CB) on quartz substrate under strong magnetic field applied.

It is well known that LC director is oriented along force lines under magnetic field (H) at some threshold value H_{th}. The last one depends on the anisotropy of LC diamagnetic susceptibility ($\Delta\chi$), elasticity constants, thickness of sample (d) and anchoring energy (W). The experimental setup for *S*-effect registration is shown in Figure 1. The strong magnetic field was applied in watercooling solenoid of bitter type with galet winding which permits the field of 120 kG in a bore of 0.036

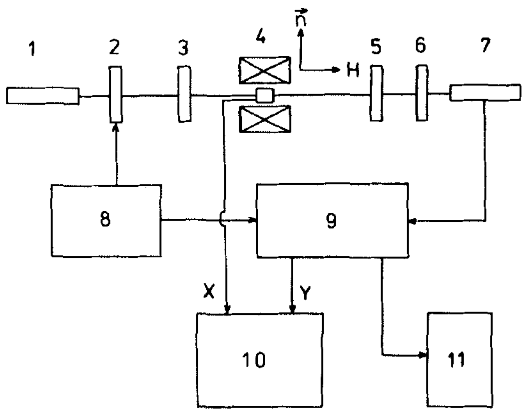

FIGURE 1 The experimental setup for determination of LC anchoring energy under magnetic field. 1, He-Ne laser; 2, modulator; 3 and 6, polaroids; 4, Hall analyzer; 5, λ/4 plate; 7, detector; 8, generator; 9, amplifier; 10, recorder and 11, oscillograph.

m.[2] The pulsations of H-field generated in the solenoide do not exceed 10^{-3}. The information about a sample state was registrated by polarized optical part of setup. It allows to measure the intensity of light passing through LC-sample from He-Ne laser (1) ($\lambda = 0.633$ μm). For the actual signal amplitude being comparably small for such thin nematic films the modulation method with synchronous detection was used here. For this zond laser irradiation modulated over amplitude was transmitted through the sample, phase plate λ/4 (5), analizator (6) and fell on photodetector (7). Signal from the photodiod being proportional to optical transmission of the cell was increased by selective amplifier; then it was controlled by oscillograph and passed to the enter of sinchronic detector (9). A sound generator feeding in the modulator (2) supplied the detector with supporting tension. Having been detected the signal was directed to y-entry of the coordinated recorder (10). The tension from Hall analizator placed in the bore of solenoid was directed to the x-entry. A gauge up to 150 kG on the basis of heteroepytaxial structures of indium antimonide being linear over the field was used here. Using of both phase plate and analyzer in the compensation scheme of initial phase delay ($H = 0$) for samples being planar oriented permitted to determine the threshold fields directly from the shock of optical transmission of a cell. Moreover the accuracy of H_{th} measurement is not less than 0.2 kG. The LC-sample temperature was controlled with copper-constant thermopaire. The temperature stabilization was ±0.2°C.

Planar orientation of 5CB in the parallel quartz plates was achieved by the processing of internal cell surfaces by a) alcohol solution of adypine acid; b) unidirectional polish with small-dispersed diamond pastes AP1; c) unidirectional polish with submicropowder ASM-0.5/0.[3] The cells were filled with LC heated up to isotropic phase temperature along the direction of polishing. Nematic thickness was regulated by teflon and polyethylenephtal film washers. To obtain accurate measurements of nematic film thickness the interference of laser beam reflected from nonfilled cell was used.[4] With the cell being filled the thickness of LC layer was controlled also by measuring the ellipticity angle using the refractive indexes

$n_{\parallel}$, $n_{\perp}$ known for the given crystal. The quality of LC orientation was controlled with polarized optical microscope having cross polaroids.

The anchoring energy value W was found from formula

$$W = \frac{H_{th}}{H_{th}^{\infty}} \frac{\pi K_{11}}{d} tg\left(\frac{H_{th}}{H_{th}^{\infty}} \frac{\pi}{2}\right) \tag{1}$$

where H_{th} and H_{th}^{∞} are the threshold magnetic fields corresponding to finite and infinite strong ($W \to \infty$) anchoring LC-substrate surface:

$$H_{th}^{\infty} = \left(\frac{\pi}{d}\right)\left(\frac{K_{11}}{\Delta\chi}\right)^{1/2} \tag{2}$$

K_{11} is the splay elastic constant. The formula (1) was deduced by two methods: the first was known as Euler-Lagrange equation which minimized LC free energy under certain boundary conditions.[6] The surface-like free energy term K_{13} div ($\bar{n}$ div $\bar{n}$) was ignored in this paper. That is why the second order constant K_{13} which described the distortion of the LC director n near boundary surface was disregarded in Equation (1).

The cell of 1.5–19.2 μm thickness was investigated under room temperature. The dependence of 5CB threshold fields on thickness of different cells is shown in Figure 2. Solid line corresponds to the values of H_{th} calculated from Equation (2). The elastic constants K_{11} and the anisotropy of magnetic susceptibility $\Delta\chi$ was taken from Reference 7. One can see that the determination of anchoring energy over

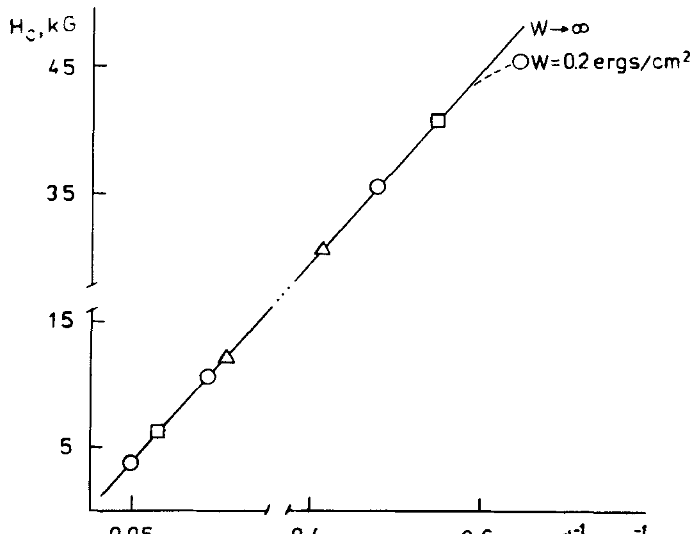

FIGURE 2 The dependence of 5CB threshold fields on thickness of substrates of different types.

magnetic threshold fields appeared not to be effective for thick planar LC-layers, as the difference between H_{th} and H_{th}^{∞} is comparable with the precision of the very threshold fields in this case. Reliable resolution of H_{th} and H_{th}^{∞} was obtained within the range of nematic layer thickness of 1 μm as well as at anchoring between LC and substrates processed by submicropowder. Substrate surface roughness parameters were measured with laser interferometer-profilograph and reflectometer. These investigations show that initial planar LC orientation was set by the parallel microfurrows having the depth of 0.02 μm and step of 3 μm. Deviation of real experimental threshold H_{th} from theoretical value H_{th}^{∞} allowed to calculate the anchoring energy W using Equation (1). This value turned out to be 2.10^{-4} J/m^2 at 23.5°C. The temperature dependence of threshold field is shown in Figure 3. Freedericksz transition for the cell of thickness 1.54 μm and having finite anchoring energy was also measured (Figure 3). Dotted lines illustrate the behaviour of the threshold fields calculated from Equation (1) for different values of W (Figure 3). In isotropic phase of 5CB no changes of optical signal were observed, so the temperature interval of changes was limited by the temperature of phase transition NLC-isotropic liquid T_{NI}. The experimental dependence of the threshold field of a nematic planary oriented on the temperature (Figure 3) coincided qualitatively with analytical one presented in Reference 4.

Energy W measured in magnetic field had its characteristic features. Its value was more than the ones $W = 1.7 \cdot 10^{-5}$ J/m^{-2} obtained in Reference 5 for homeotropic orientation of 5CB, that confirmed more rigid anchoring between the substrate and planar layer of LC. On the other hand the coefficient value W found

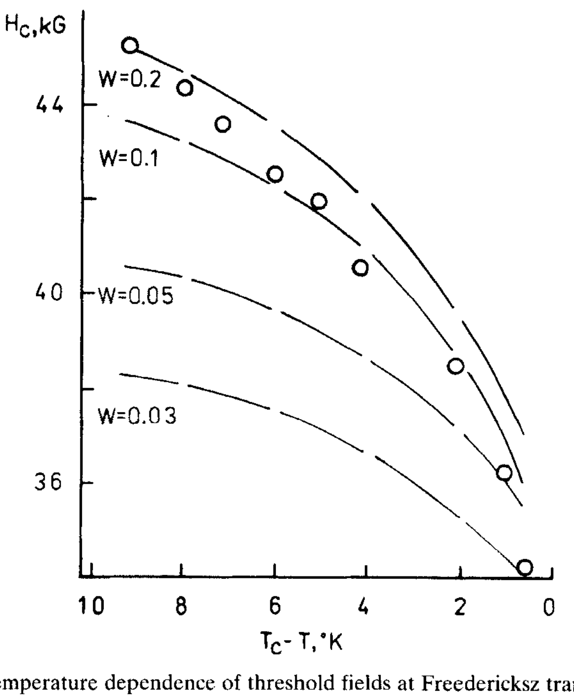

FIGURE 3 The temperature dependence of threshold fields at Freedericksz transition for the cell of thickness $d = 1.54$ μm.

is below the effective anchoring energy $W^* = (7-12) \cdot 10^{-4}\ J/\mathrm{m}^2$ obtained in Reference 8 using the method of complete director reorientation in strong electric field, that seems to be due to the absence of effects of surface electric polarization distorting the critical field value. These distortions were especially strong in LC thin layers on crystal layers where the method of W measurement in strong magnetic field was more preferable.

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