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Odd–even effects in the threshold and saturation behaviour of long pitch cholesteric systems

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The cholesteric–nematic phase change under tilted surface alignment has been investigated in long pitch systems. An alternation of the saturation voltage with increasing ratio between cell thickness and helical pitch and an alternation in the relaxation behaviour have been observed. The internal structure of tilted cholesteric systems is useful to discuss these results.

The field-induced cholesteric–nematic phase change in liquid crystals has been studied for many years. This phenomenon is well investigated at planar (surface tilt angle $\phi_s = 0^\circ$) and homeotropic ($\phi_s = 90^\circ$) surface alignment of the liquid crystal [1]. The electro-optical behaviour of such systems depends strongly on the ratio d/P_0 , where d is the thickness of the layer and P_0 is the natural pitch. However, at arbitrary ϕ_s the details of the phase change are not sufficiently clear. Some measurements have shown the dependence of the threshold voltage, U_{th} , on d/P_0 , the sequence of appearing textures, and the occurrence of scattering free states on relaxation. Moreover, two different threshold voltages, which correspond to different surface conditions, could be observed [2]. Here we report on an odd–even effect of the saturation voltage, U_s . The odd–even behaviour on relaxation from the homeotropic state has also been studied.

We performed our measurements on wedge-shaped cells with different surface tilt angles ($\phi_s = 0^\circ$ – 30°). The preparation of the liquid crystal cell has been described previously [3]. We used the nematic mixture E5 (BDH Chemicals Ltd.) and added small amounts of S811 (Merck) to induce a helical structure. In order to obtain weak anchoring conditions lecithin (0.1 wt %) was also added. The surface orientation was chosen in such a manner as to form parallel cells in which the directors at both surfaces are arranged parallel to each other and symmetrical cells in which the surface directors are symmetrical with respect to the mid-plane. In these cells the total twist angle, α , is $N\pi$. Electro-optical transmission characteristics of the cells between crossed polarizers have been recorded up to 15 V at 500 Hz and a sweep rate of 0.05 V s^{-1} . With tilted surface alignment the threshold voltage, U_{th} , is used in the sense of an apparent threshold [3, 4], and the saturation voltage U_s is defined in the same manner.

With $\phi_s = 0^\circ$ the voltage U_s increases in a linear way with increasing d/P_0 [5]. This corresponds to the behaviour of short pitch cholesteric systems [6], where the voltage for unwinding the helix is

$$U_{cn} = \pi^2 \left(\frac{k_{22}}{\epsilon_0 \Delta \epsilon} \right)^{1/2} \frac{d}{P_0}, \quad (1)$$

with the only difference being a shift to higher voltages

$$U_s = \pi^2 \left(\frac{k_{22}}{\epsilon_0 \Delta \epsilon} \right)^{1/2} \frac{d}{P_0} + A. \quad (2)$$

With weak anchoring U_s is smaller than with strong anchoring.

At $\phi_s > 0^\circ$ we observed an odd-even alternation of U_s in the parallel cells, as shown in figure 1. U_{th} and U_s have been measured only in the centre of the regions of constant twist (from $N = 1$ to $N = 8$), where the induced pitch is equal to P_0 . Therefore, the connecting lines between the measured points do not have to correspond to the true values between them. At odd N ($d/P_0 = 1/2, 3/2, \dots$) the saturation voltage is higher than in the following even twist region. If there are both even N and weak anchoring, then we observe the smallest U_s , and the shift parameter A is zero. Therefore, the helical system behaves as a short pitch system which is characterized by equation (1). The influence of boundary forces on the unwinding of helical systems becomes negligible. In this sense, the shift parameter A is a measure of the action of the surface conditions. The alternation of U_s is probably connected with the internal structure of long pitch cholesteric cells caused by the surface conditions (cf. figure 2). For reasons of symmetry in the regions with odd N the tilt angle of the molecules in the mid-plane of the cell has to be $\phi = 0^\circ$, whereas for even N a continuously tilted structure is possible [3]. The different structures caused by surface conditions have been denoted by the terms: matching surface condition (at even N) and mismatching surface condition (at odd N) [2]. Under the mismatching condition the transition to the homeotropic nematic state is obviously hindered.

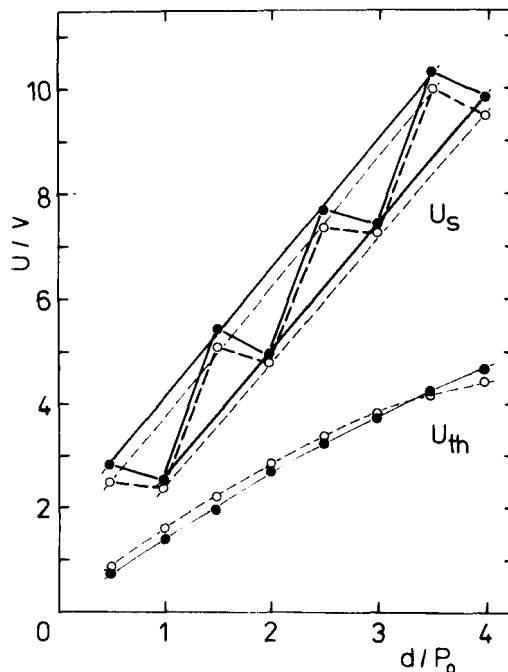


Figure 1. Threshold voltage, U_{th} , and saturation voltage, U_s , versus the ratio d/P_0 ($P_0 = 4.25 \mu\text{m}$) in a parallel cell. The surface tilt angle is 8° . The liquid crystal mixtures are (●) E5 + 2.14 wt % S811 and (○) E5 + 2.14 wt % S811 + 0.1 wt % lecithin.

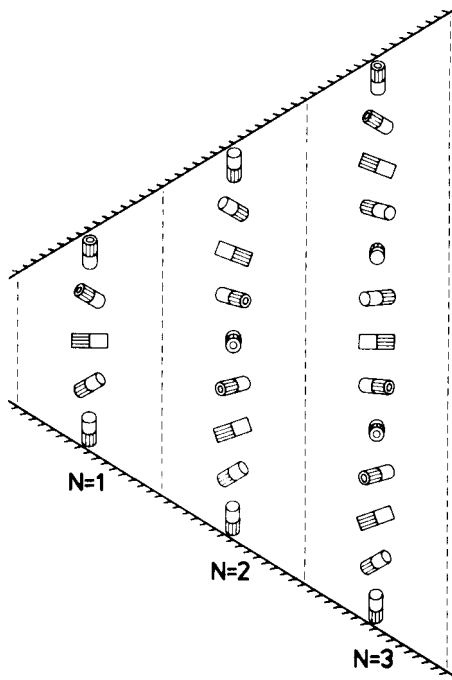


Figure 2. Internal structure of the regions of constant twist in a parallel cholesteric cell with surface tilt angle. N is the number of the region.

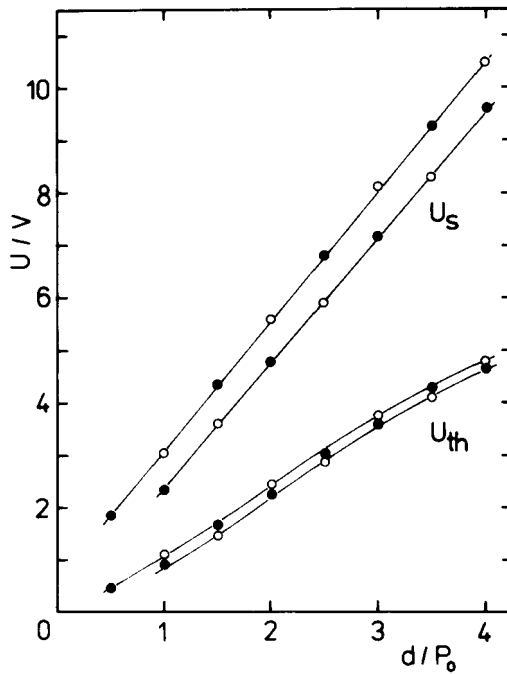


Figure 3. Threshold voltage, U_{th} , and saturation voltage, U_s , versus the ratio d/P_0 ($P_0 = 4.25 \mu\text{m}$) in (●) parallel and (○) symmetrical cells. The surface tilt angle is 27° . The liquid crystal mixture is E5 + 2.14 wt % S811.

In symmetrical cells the matching and mismatching surface conditions are interchanged with respect to even and odd N . The high and low values of U_s are also interchanged, as shown in figure 3. Moreover, the measured values for parallel and symmetrical cells are situated on common straight lines. Therefore, the only reason for the odd-even alternation of U_s , of a special configuration of surface orientation, is the change between matching and mismatching surface conditions. The known alternation of U_{th} [2] is also depicted in figure 3; here the difference between the two curves is in the order of 0.2 V.

Finally, we have studied the relaxation from the homeotropic state. The observed odd-even behaviour of symmetrical cells [2] could also be found in parallel cells. Only with matching conditions does the homeotropic state transform directly into the initial one after removal of the field. With mismatching conditions the relaxation goes through a transient state which differs from the initial one by $N = \pm 1$. This is also valid in cells which have a total twist angle α of $(N + 1/2)\pi$ [7].

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