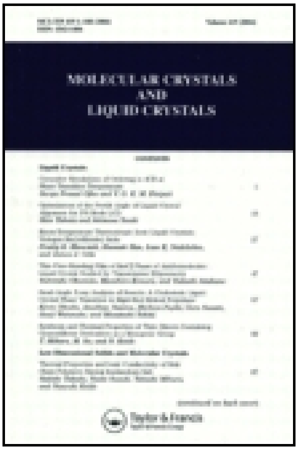

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Electro-Optic Dynamic Hysteretic Behavior of Weakly-Anchored Twisted Nematic Layers: Experimental Results

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ELECTRO-OPTIC DYNAMIC HYSTERETIC BEHAVIOR OF WEAKLY-ANCHORED TWISTED NEMATIC LAYERS : EXPERIMENTAL RESULTS

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The electro-optic dynamic hysteretic effect of weakly-anchored twisted nematic cells is reported. It depends on the relation between the relaxational time of the nematic director and the sweeping rate of the AC voltage up and down. A large dynamic hysteresis can be obtained at high threshold and applied voltages and a relatively fast sweeping rate of the excitating electric field. The liquid crystal parameters, the thickness of the cells and the value of the temperature might be important as well.

1. INTRODUCTION

In the last time one notes a considerable effort in search of bistability effects in the twisted nematics (TNs) due to their wide use in the display technique and their multiplex driving. Recently, more than 15-20 papers were published chiefly by scientists with Bell Laboratories. Our aim is to present a novel and interesting dynamic hysteretic effect (DHE). We have observed this effect after investigation of the conventional bistability in a cholesteric (Ch) layer with weak anchoring when the sweeping rate of the AC voltage up and down was sufficiently fast[1]. Further, our study was extended on a nematic (N) mixture with positive dielectric anisotropy, weak anchoring and reversely-pretilted surface bias angles. Again we observed a large DHE in a wide range of the sweeping rate of the excitating voltage[2]. Another type of DHE has been observed by Gerber in the rearrangement of fingerprint and scroll textures[3]. DHE of a TN under low frequency voltage (a triangular signal with a frequency of 0,5 Hz) was observed by Vlad[4]. However, at such a low frequency the electrode polarization[5], the nature of the electrodes and the possible influence of the flexoeffect, etc. are important.

2. COMPAUNDS AND SAMPLE PREPARATION

We have investigated a N mixture consisting of a 90 % wt. MBBA and a 10 % wt. 5CB with positive dielectric anisotropy measured to be between 1.5 and 2. The usual glass plates covered by a semitransparent conductive layer were initially strongly rubbed by a diamond paste[6] and were covered by a thick layer of common soap. The second rubbing with a cloth being in the same direction was able to predetermine the sign of the tilt angle (see Figures 1a, 1b and 1c). After the second rubbing a small quantity of the soap remains especially in the depth of the grooves (Figure 1d). In such a way of the glass plate treatment it is not possible to know the number of the soap layers and the orientation of the soap molecules. This is possible only by the use of the Blodjett-Lengmuir technique. However, this way of the soap treatment can determine reproducibly very well oriented N layers.

By an appropriate 90^0- twisting of one of the glass plates it is possible to obtain a weakly-anchored

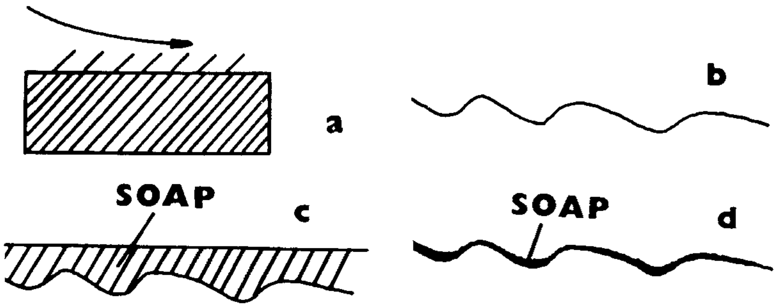

FIGURE 1 A way of the glass plate treatment: a) the rubbing direction can predetermine the sign of the surface LC tilt; b) the groove after the first rubbing; c) covering of the glass plates with a thick soap layer; d) the groove with a part of the soap after the second rubbing

MBBA-5CB N mixtures with a reverse pretilt of the LC molecules at the glass slides. The 5CB N molecules prefer to stay perpendicular to the glass plates used by us. Due to this reason the orientation of the LC molecules is tilted relative to the glass plate normal (see Figure 2c). The TN cells were prepared with the same glass plates and N mixture. In this case, however the rubbing of the two glass plates was in perpendicular directions (Figure 2a). For understanding the important role of the soap covering we have investigated TNLC layers without a soap treatment of the glass plates as well. This case is schematically shown in Figure 2b. The thickness of all the N layers under study was around 20 microns and all the studies were performed at room temperature.

3. EXPERIMENTAL SET-UP

We have used the polish polarizing microscope NU-2, a photomultiplier, X-Y recorder endim 620.02, a spe-

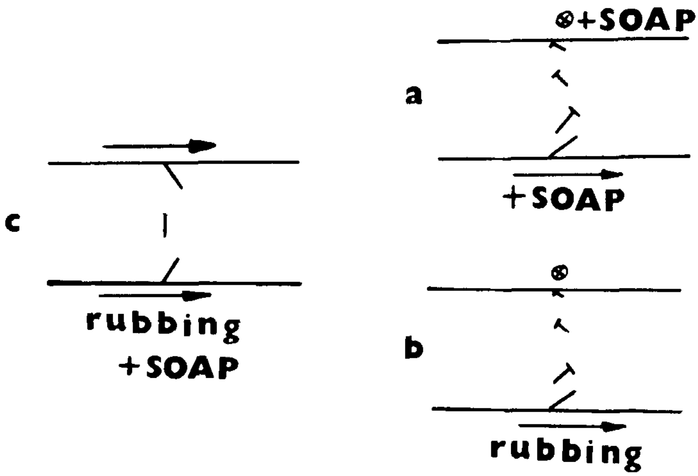

FIGURE 2 A schematic representation of the LC orientation of the three types of N cells under study: a) a weakly-anchored 15-20^0 twist cell; b) a slightly stronger anchored 90^0 twist cell; c) a splay-bend cell with a reverse pretilt and weak anchoring

cial constructed electronic device permitting the obtaining of a triangular signal with a positive alternation only and a different low frequency modulated by a high frequency voltage. We have worked chiefly in a conoscopic regime using a low aperture objective (x10, $\sin\theta_c/2 = 0{,}24$), a condenser and a special conoscopic ocular. Unfortunately, our technique did not permit the exact measurement of the LC tilt due to the special LC deformations and the absence of additional conoscopic technique. Consequently, our conclusions about the value of the LC deformations are only qualitative. The electro-optic transmission curves were obtained from the conoscopic patterns observed. The hysteresis curves were done at different sweeping rate of the AC voltage up and down. Their importance , in ouropinion, is due to the **observationof** a considerable hysteresis which is very interesting from a scientific point of view and might be useful for display applications.

4. EXPERIMENTAL RESULTS

A. Electro-Optical Behavior of Reversely-Pretilted Splay-Bend Nematic Layer with a Weak Θ-Polar Anchoring

Our aim was first to study the electro-optic behavior of this LC in order to compare its electro-optic transmission curves and conoscopic patterns to those obtained with the TN layers at the same conditions.

The conoscopic patterns were different depending on the position of the splay-bend plane relative to the position of the two nicols. When this plane coinceded with one of the two crossed nicols one appears the usual conoscopic cross. After the rotation of the sample by 45^0 we observed only the foci of the hyperbola shown in Figure 3a, **or** two hyperbolic bruches under voltage excitation (Figure 3b) . From the orientation of the hyperbolic brushes it is possible to conclude that the plane defined by the two optical axes also coincides with the splay-bend plane[8]. In effect, the splitting of the cross into two hyperbola is due to the special kind of the LC deformation.No bands of equal retardation (isochromates) were observed with our rather low numerical aperture of the objective used and the small sample thickness of the LC cells under study. Although there is a formula which permits the calculation of the mean tilt angle at the boundaries[8], our technique did not allow such measurements. However, it was possible to conclude that the maximal tilt of the LC at the

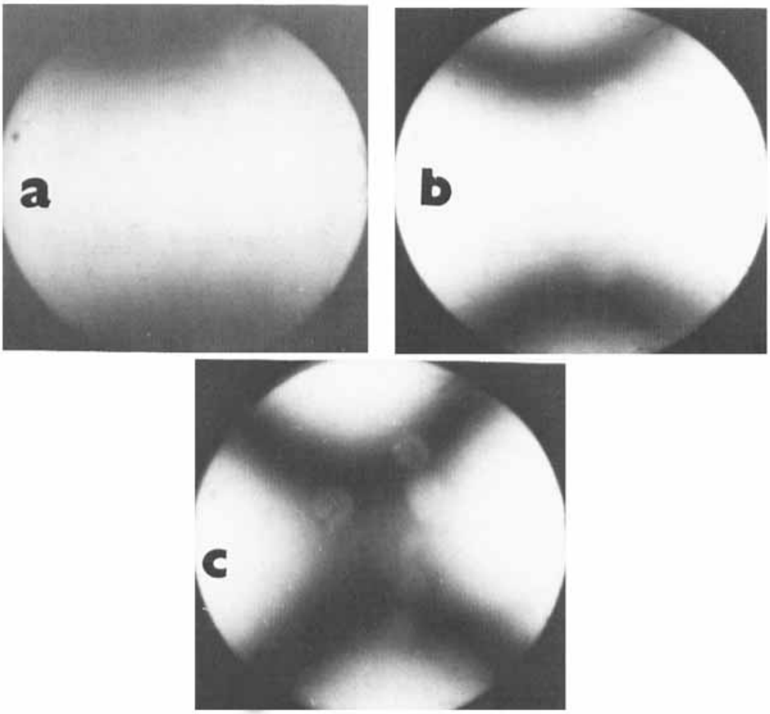

FIGURE 3 Conoscopic patterns of a splay-bend 90 % wt. MBBA and 10 % wt. 5CB N mixture under a voltage excitation (f = 5 kHz): a) U = 0 V; b) U =5 V; c) U = 25 V. The rubbing direction is along the bisectrix of the crossed nicols

boundaries was between 0 and 10-15^0 measured relative to the glass plate normal. Consequently, our experimental study of either the usual splay-bend or twist cells are predominantly for the surface rather than the bulk LC realignments and our study pointed out very interesting results. For instance, a number of authors have been dealt with the electro-optical behavior of usual splay-bend or twist cells with weak θ-polar anchoring [9-13]. Nehring et al[9] have found a second saturation voltage above which the surface forces have been overcomed , i.e, after this voltage the LC must be homeotropic. Our experimental results however, contradict to these theoretical results[9-13]. Although the LC in our case was with a very weak θ-polar anchoring due to the soap covering, a complete orientation of the LC molecules along the electric field was not possible even at a very high voltage being above 40 V (the threshold voltage was in the range of several volts). This experimental result can be seen from the conoscopic picture shown in Figure 3c. In our opinion this experimental finding is due to the action of the surface viscosity which had not been taken into account by these authors. On the other hand the role of the surface viscosity has been noticed in a number of papers[14-20]. The role of the surface viscosity in surface-induced low-frequency flexo electric oscillations has been pointed out by Derzhanski and by Derzhanski and Petrov[21, 22]. Another possible reason might be the influence of the second-order elasticity[23]. Finally, the very type of the serface energy. The electro-optic transient transmission curves obtained by the conoscopic patterns are illustrated in Figure 4 (this method has been used also by Van Dijk et al[24]). It is immediately seen the very slow relaxation of the LC being in the range of many seconds . In our opinion, the slow LC reaction is due to several causes: the existance of a large surface viscosity coefficient, the action of the rotational viscosity coefficient corrected by the back-flow effect γ_1^* and finally to the weak anchoring of the LC molecules. The electro-optic transmission curves obtained at different sweeping rates in a large scale between 0,1 V/sec and 2 V/sec pointed out a large dynamic hysteresis[2]. One example is shown

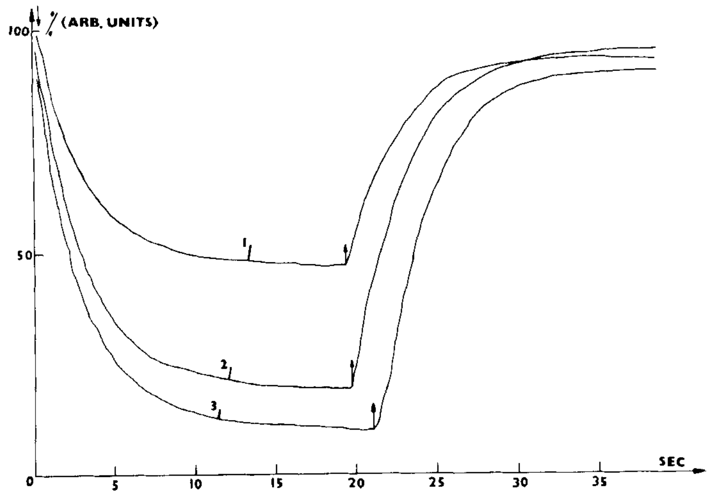

FIGURE 4 Electro-optic transient transmission curves of the splay-bend N mixture under study. The curves 1, 2 and 3 correspond to 2,5 V, 5 V and 10 V, respectively

in Figure 5. It is clear that this large hysteresis is due to the difference between the relaxational time of the N director and the value of the sweeping rate of the AC voltage up and down. We know that the rise time depends on both the surface and bulk viscosity coefficients, the thickness of the LC cell and the value of the dielectric anisotropy. It is very likely the relaxational time to depend on the strength of the surface coupling and on the value of the surface LC tilt.

B. Electro-Optical Behaviour of Weakly-Anchored Twisted Nematic Cells

We have investigated two types of TNs. The first type is shown in Figure 2a. The glass plates were treated in a way already described. The cells were prepared in

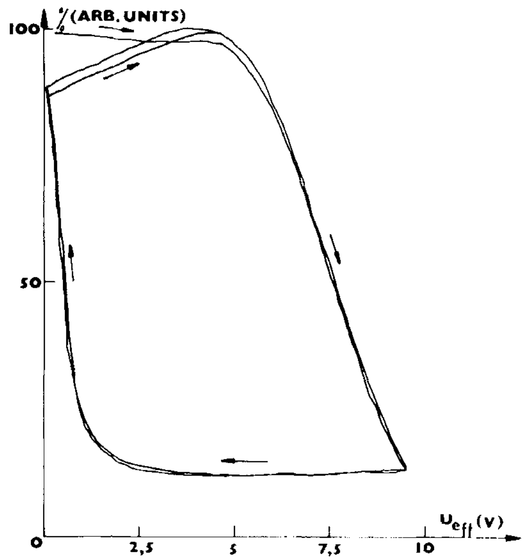

FIGURE 5 Electro-optic dynamic hysteretic curves of the splay-bend N mixture under study. The sweeping rate of the AC voltage up and down was 0,5 V/sec

such a way that the tilting of the molecules at the two glass plates was with a different sign. However, this tilting was accompanied by a certain twist of the molecules smaller than 90^0 due to the weak φ-azimuthal anchoring of the LC layer. The Θ-polar anchoring was also weak due to the soap treatment of the glass plates. Let us stress that the electro-optical transmission curves and the conoscopic patterns were very well reproducible. The second type of TN cell is shown in Figure 2b. The glass plates of this cell were only rubbed without the utilization of soap. Consequently, it is natural to assume that this type of TN cell is with a slightly larger surface anchoring. The conoscopic patterns of the weakly-anchored TN cell are shown in

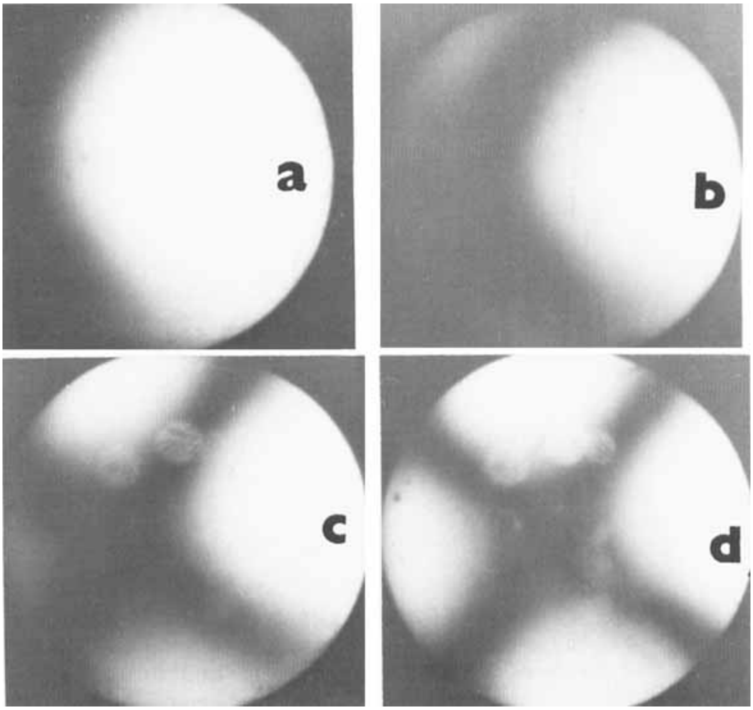

FIGURE 6 Electro-optic conoscopic patterns of a weakly-anchored $15-20^{0}$ twist MBBA-5CB mixture under AC (f = 5 kHz) voltage excitation: a) U = 0 V; b) U = 2 V; c) U = 5 V; d) U = 20 V

Figures 6 a-d. They were taken at such a position of the sample that the rubbing direction of one of the glass plates coincided with one of the nicol. If the rubbing direction coincides with the other nicol we shall obtain the symmetric conoscopic patterns relative to the glass plate normal. Every other position of the sample led to the observation of complicated conoscopic pictures[25]. There is one detail which is not evident from the conoscopic patterns. The moving of the cross in the left (or in the right) after the decreasing of the voltage is accompanied by a certain deplacement of the two hyperbola. This shows that the sign of the LC tilt at the two glass plates is different. On the other hand, from the conoscopic measurements it is known that the position of the cross can approximately determine the value of the tilt of the LC relative to the glass plate normal[26]. From the conoscopic patterns we can conclude that the Θ-tilt of the LC molecules is about 15-20^{0}, when the voltage is not applied. It is much more difficult to determine the value of the twist angle. According to our electro-optic observations made in a transmitted light it is also around 15-20^{0}. An interesting result obtained from the conoscopic patterns is that the movement of the position of the cross shown in Figure 6c was achieved by a very low AC voltage (5 V, 5 kHz), whereas the final homeotropic orientation was obtained at 20 V, 5 kHz.

The conoscopic patterns of 90^{0} twist cells being prepared without utilization of soap are shown in Figures 7, a-d. Although one notes a similarity between the conoscopic patterns from Figures 6 and 7, there are some differences. For instance, the first conoscopic figure appears at about 5 V, 5 kHz in the form of a nearly stright black line shown in Figure 7a which under the further increase of the voltage bends and then appears the decentered cross. The other conoscopic patterns resemble to those illustrated in Figure 6, b-d. However, they are obtained at a slightly higher voltage due to the slightly higher surface anchoring of the molecules. The transient electro-optic transmission curves for the two types of the LC twist cells are shown in Figure 8 and one can see the slightly higher voltage needed for the reorientation of the LC molecules of the twisted cells prepared wothout utilization of soap. The electro optic curves directly obtained from the conoscopic patterns at different sweeping rates of the high-frequency (5 kHz) voltage up and down are shown in Figures 9a-9e. The corresponding sweeping rate of the AC voltage was 0,5 V/sec, 0,25 V/sec, 0,1 V/sec, 0,05 V/sec and 0,017 V/sec, respectively.

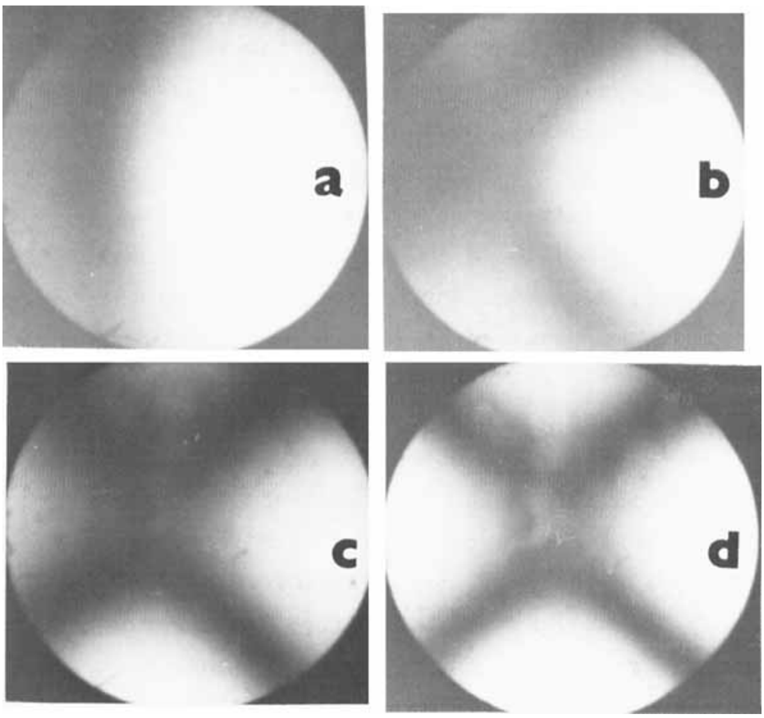

FIGURE 7 Conoscopic patterns of a slightly-stronger anchored 90^0 twist MBBA-5CB mixture under AC (f = 5 kHz) voltage excitation: a) U = 3 V; b) U = 6 V ; c) U = 15 V and d) U = 25 V

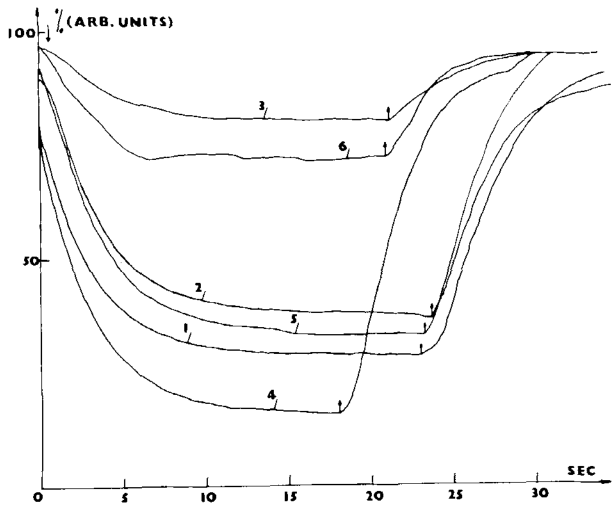

FIGURE 8 Electro-optic transient transmission curves of the two types of twist cells under study. The applied AC voltage was with a frequency of 5 kHz. The curves 1, 2 and 3 correspond to U = 5, 2 and 1 V, respectively and were obtained for the 90^0 twist cell; the curves 4, 5 and 6 correspond to U = 2, 1 and 0,5 V, respectively and were obtained for the $15-20^0$ twist cell

The lower hysteretic curves correspond to the soap-treated weakly-anchored twist cell and the upper curves correspond to the 90^0 twist cell with rubbed glass plates only. It is evident that a large hysteresis can be obtained at a relatively fast scanning of the LC layer and when the threshold voltage and the voltage being applied are sufficiently high.

5. DISCUSSION

The curves from the Figure 9e unambiguosly show that the DHE must disappear at a very small sweeping rate • of the AC voltage. This nonconventional hysteresis is

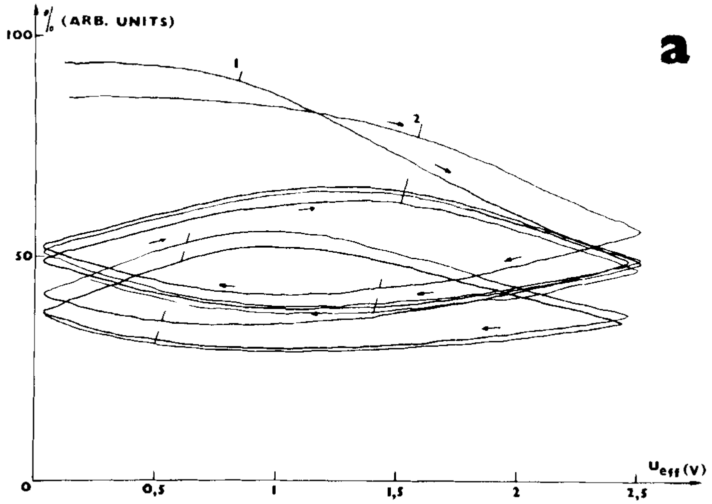

FIGURE 9a

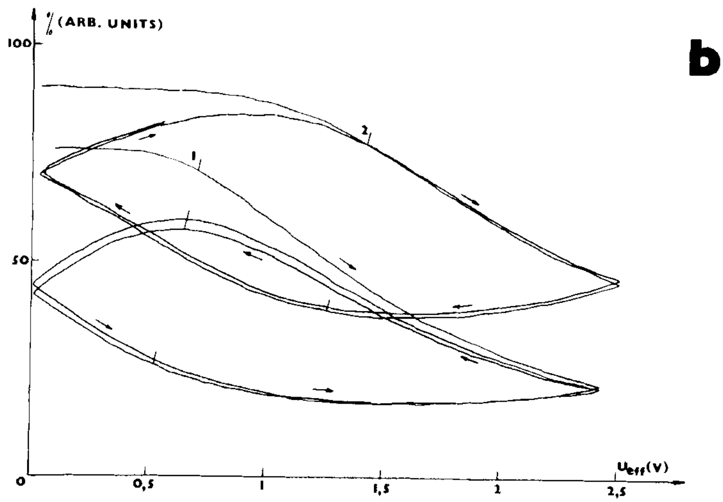

FIGURE 9b

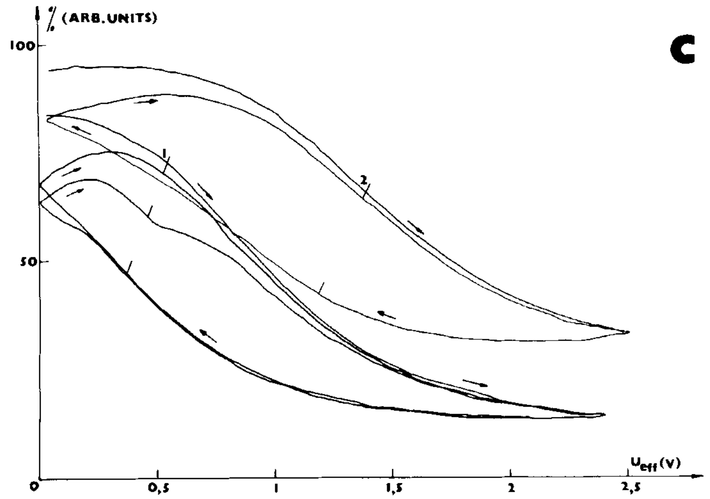

FIGURE 9c

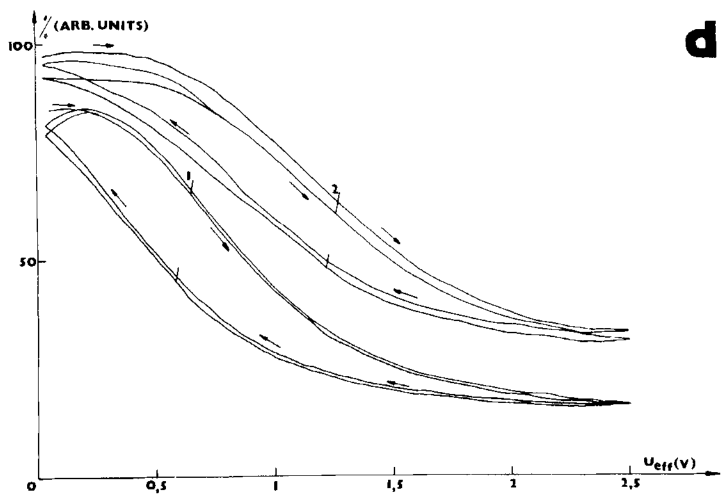

FIGURE 9d

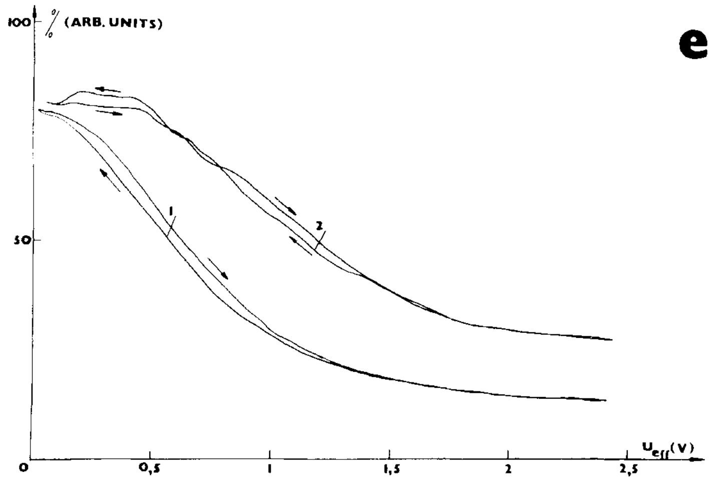

FIGURE 9 Electro-optic dynamic hysteretic curves for the MBBA-5CB mixture under study. The curves 1 correspond to the 15-20^0 twist cells with weak anchoring; the curves 2 correspond to the 90^0 twist cells with a slightly larger anchoring
a) the sweeping rate of the AC voltage up and down was 0,5 V/sec; b) 0,25 V/sec; c) 0,1 V/sec, d) 0,05 V/sec and e) 0,017 V/sec

only due to the difference between the relaxational time of the N under study and the sweeping rate of the applied AC voltage. We know that the conventional twist cells with strong planar anchoring relax with a rise time in presence of the voltage which is in the range between 30 ms and 100 ms[27]. From the results of Gerber[28], Van Doorn[29] and Gerber and Schadt[30] it is easy to understand that the sclution for the dynamic behavior of the usual twist cells is very combersome and it would be more difficult for the TNs under study. We like, however, to use the formula, obtained by Jakeman and Raynes[31] for the rise time of the N director in one conventional twist cell:

$$\tau_{rise} = \frac{\eta d^2}{K \pi^2} \left((V/V_c) - 1 \right)$$

where $K = (K_{11} + (1/4)K_{33} - (1/2)K_{22})$

which is valid at least for small LC deformations . In our opinion, the formula points out that the DHE for such TN cells should disappear when during this rise time the voltage is almost constant. Inversely, when the voltage changes even slightly the DHE must exist.For our case under study only the exact solution would give the correct answer. The results obtained by Baur et al [32, 33] can give a qualitative answer for our results, obtained with the splay-bend N cell. According to their results, the rise time of the N director in presence of the voltage is in the range of seconds. In addition, we like to point out the analogy between the results obtained by Brochard[34] and Brochard et al[35] about the behavior of a homeotropic N layer in a rotating magnetic field with our experimental results. It is clear thata synchronous and asynchronous rotation of the N director also exists depending on the scanning rate of the AC voltage. For a large sweeping rate of the voltage the LC molecules cannot follow the changes in the voltage and there is a retardation which causes the dynamic hysteresis observed. In the synchronous regime the director rotates with the nearly linear velocity of the voltage. The exact theoretical calculation of the problem under consideration or of one more simpler case will shows in analogy with the Brochard's results whether the N director have to follow the variation of the AC voltage with a constant retardation, which in the asynchronous regime must be no longer constant in time and the LC molecules could not follow the too rapid variation in the AC voltage amplitude. Finally, we wish to discuss the posible θ, φ orientations of the TN cells under study. There are only several papers devoted to this problem[36-38]. However, the LC orientation of weakly-anchored θ, φ twist N layers with a serface reverse pretilt angle θ_0 has not been investigated either theoretically or experimentally. From the general theory of the N which are twisted developed by Leslie, it is known the importance of the sign of $K_{33} - 2K_{22}$. It is known from the literature that for the MBBA $K_{33} \sim 2K_{22}$ at least at room temperature[39, 40]. The elastic constants of the 5CB have also been measured[41]. It is seen that at room temperature K_{33} of 5CB is nearly equal to that of MBBA, while K_{22} is much lower. Consequently, it is clear that for the MBBA-5CB mixture under study $K_{33} - 2K_{22} > 0$. This important result was confirmed by observation of twist walls illustrated in Figure 10a

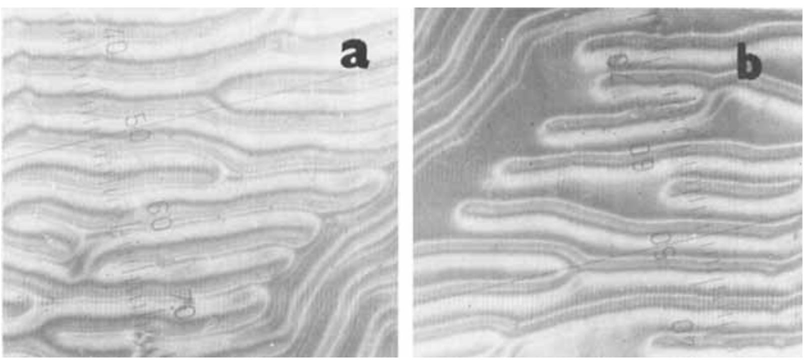

FIGURE 10 Twist walls in a 90 % wt. MBBA and 10 % wt. 5CB N mixture with a thichness of 10 microns at room temperature: a) in the voltageless state; b) under AC (f = 5 kHz) voltage of 1 V

which clearly implies that $2K_{22} < K_{11} + K_{33}$ [42-44]. Furthermore, the very low voltage being sufficiently to remove the twist walls which is shown in Figure 10b clearly pointed out that the adjacent walls are separated by non-singular disclinations of strengths $s = +1$ [45, 46]. According to the theoretical calculations of Fraser[37] and Scheffer[38] the $K_{33} > 2K_{22}$ case is more complicated when there is a tilting at the glass plates. However, we need from the exact theoretical solution of our problem which should be compared to that already obtained by Scheffer[38]. It seems that the maximal angle in the midplane θ_m is larger than the surface tilt θ_0, whereas the characteristic angle θ_c determined from the relation:

$$\sin^2\theta_c = \frac{K_{33} - 2K_{22}}{2(K_{33} - K_{22})}$$

for the our case is close to zero. Consequently $\theta_0 > \theta_c$ even for the case of high voltages applied across the cells. So in our opinion, it is more likely the following solution $0 < \theta_c < \theta_0 \leqslant \theta_m \leqslant 90^0$.

6. CONCLUSION

We have experimentally investigated the electro-optic behavior of θ, φ weakly-anchored twisted N layers of two kinds. At the first kind of these cells we treated the glass plates with soap after rubbing and at the second kind, the glass plates were only rubbed. We obtained a number of conoscopic patterns and electro-optic transmission curves for different sweeping rates of the AC voltage up and down. The variation in the amplitude of the voltage was linear in a time. We observed a large dynamic hysteresis which is very interesting from a scientific point of view and might be applied in the dysplay technique. This dynamic hysteresis depends on both the surface and bulk viscosity coefficients, the nematic characteristic constants, the sample thickness , the value of the threshold voltage and the value of the applied voltage as well as on the sweeping rate of the voltage. It is very likely that the temperature also shall be an important parameter for the type of the hysteretic curves.

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