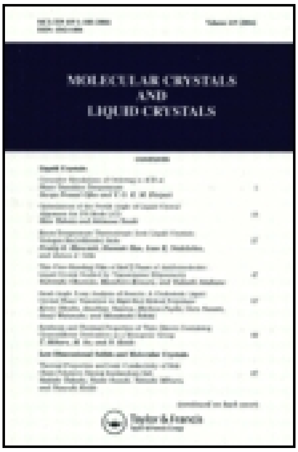

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Capacitive Transients during Freedericksz Transition in 7CB and 8CB

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The dynamic behaviour around the electrically driven Freedericksz transition in the nematic liquid crystals 7CB and 8CB has been studied experimentally by measuring the time dependence of capacitance of a thin layer of planarly oriented sample. The initial parts of both growth and decay of capacitance in both samples are found to be exponential in nature. Beyond the initial exponential part, we find that in 7CB, close to the N-I transition, the decay of capacitance is oscillatory. The rotational viscosity coefficient γ_1^* has been determined from the decay rates of capacitance.

Keywords: nematics, splay, capacitance, transients

INTRODUCTION

The transient patterns which are generated during the Freedericksz transition in a nematic liquid crystal has previously been studied both experimentally and theoretically.[1–4] The reorientation of the director in an applied field results in an elastic deformation of the sample. The director field is dynamically coupled to the velocity field and the rotation of the director induces a flow. The reorientation process takes place via formation of spatial structures and a periodic pattern evolves. The transient pattern has been studied optically using polarizing microscope along with a charge-coupled device camera by a number of authors.[3,4] In the present work we use a capacitance measurement method to study the behaviour of two nematics during the Freedericksz transition. The time dependence of the capacitance of a cell filled with a nematic was determined and the value of a rotational viscosity coefficient was determined from the data.

EXPERIMENTAL DETAILS

The nematic sample, which has a strong positive dielectric anisotropy, was sandwiched between two Indium-Tin-Oxide coated optically flat glass plates with a spacing of 30 microns. To ensure planar orientation, the glass plates had brushed polyamide coatings on the top of the ITO coatings. The orientation of the nematic within the cell was checked by using a Leitz polarising microscope and all over the cell it was indeed found to be planar. Further checking of the uniformity of the thickness of the cell was made by observing the cell in Sodium light and, as far as we could check, there was no visible deviation from uniformity.

The temperature was controlled to within ±0.1°C using a PID temperature controller and was measured using a Chromel-Alumel thermocouple and a HP 3458A DMM.

The capacitance measurements were carried out using a Hewlett-Packard impedance/gain-phase analyser HP 4194A and a LCR meter HP 4284A. The former instrument allowed the voltage across the cell to be varied from 10 mV to 1.0 V r.m.s. in discrete steps of 1 mV. This unique feature was exploited and for measurements in the neighbourhood of the Freedericksz transition, readings were taken at intervals of 2 mV. In all cases fairly sharp transitions were obtained and we could trust the recorded values of C vs V to extract the threshold voltage V_c. The permittivity $\varepsilon_\perp$ was obtained directly from $C_\perp$, the capacitance for $V < V_c$. The ratio $\gamma = \Delta\varepsilon/\varepsilon_\perp$ was obtained from a plot of $(C - C_\perp)/C_\perp$ vs. $1/V$ for $V \rightarrow 0$ as was first suggested by Meyerhofer.[6] The splay elastic constant K_{11} could thus be obtained directly from this value of V_c without going into a multiparameter least square fit.[5] For voltages exceeding 1 V the LCR meter was used for capacitance measurement and readings were taken for voltages up to 10 or 12 V. In all cases a spot frequency of 1 KHz was used.

In Table I we have furnished the values of V_c, $\Delta\varepsilon$ and K_{11} for 7CB at different temperatures. Also provided are the values of K_{11} as measured by Bradshaw *et al.*[5] and Madhusudana and Pratibha[7] for comparison. It is clear that our data[8] compares well with that obtained by the latter group.

To measure the transients, the HP 4194A had to be used in the programmed mode. There was a choice of three integration times 0.5 msec, 5 msec and 100 msec. A delay time, in multiples of 1 msec, could be introduced between the readings and this helped us to calibrate accurately the time intervals that elapsed between the successive readings. The programme worked in the following manner. For recording the growth of capacitance, the a.c. voltage across the sample cell was held fixed at 10 mV and a delay of 180 secs was introduced before the voltage was allowed to jump to a value exceeding the threshold voltage at that temperature. The HP 4194A captured the transient values of the capacitance, stored them in a

TABLE I

$T_{NI} - T$ (°C)	$\Delta\varepsilon$	V_c (volts)	K_{11} (10^{-7} dyn) Present work	Reference 7	Reference 5
2.5	7.85	—	—	3.6	—
5.0	9.00	0.720	4.1	4.7	5.5
7.5	9.90	0.765	5.2	5.5	6.4
10.0	10.45	0.820	6.0	6.2	7.2
12.5	10.90	0.831	6.8	6.7	7.9
15.0	11.25	0.856	7.4	7.2	8.5
17.5	11.60	0.877	8.0	7.6	9.1
20.0	11.80	0.897	8.5	8.0	9.7

table and displayed the capacitance-time graph on its CRT monitor. A logarithmic plot of the $C - t$ data was then dumped into a HP 7475A plotter which was connected to the impedance analyser over a HPIB bus. A similar procedure was adopted for recording the decay of capacitance when the voltage across the cell was removed. The voltage across the cell, in this case, was allowed to jump from a value exceeding the threshold voltage down to 200 mV, which was much smaller than the threshold voltage. We had to choose 200 mV as the lower limit of the voltage across the cell instead of, say 10 mV, to suppress the wild oscillations near the tail of the $C - t$ graph, whose initial part was an exponential decay. For the growth of capacitance in 7CB and 8CB the readings were taken at intervals of 315 msec and for decay of capacitance in 7CB it was 11 msec. Decay of capacitance in 8CB was found to be a relatively slower process and the data were recorded at intervals of 29 msec.

RESULT AND DISCUSSION

The initial part of the growth of capacitance against time was found to be exponential in 7CB and 8CB. The time constant, $\tau = 1/\alpha$ for the growth rate of C in both the samples has been plotted against temperature in Figure 1 for jumps in voltage from 0.01 V to 1.0 V.

In Figure 2 we have displayed the typical decay curves of capacitance that were obtained with 7CB and 8CB. The growth curves never exhibited any oscillation even when the shortest time constant of 0.5 msec was used. On the other hand, as has already been stated, the decay curves in 7CB and 8CB always exhibited oscillations, particularly near the tail, when the potential was allowed to jump down

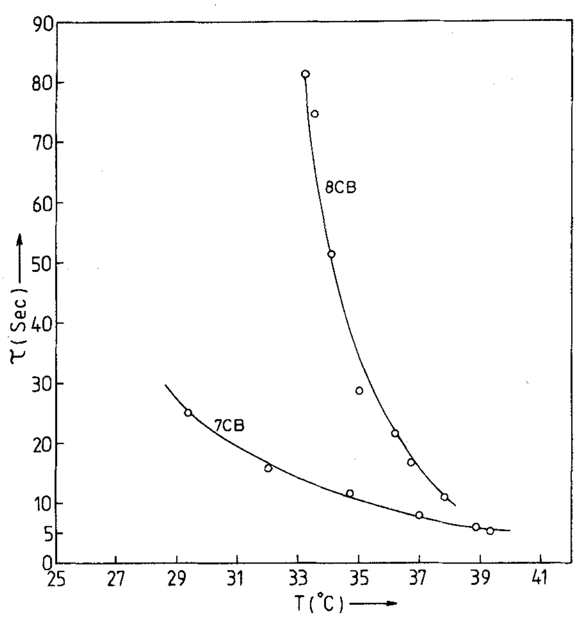

FIGURE 1 Time constant (τ) for the growth rate plotted against temperature in 7CB and 8CB.

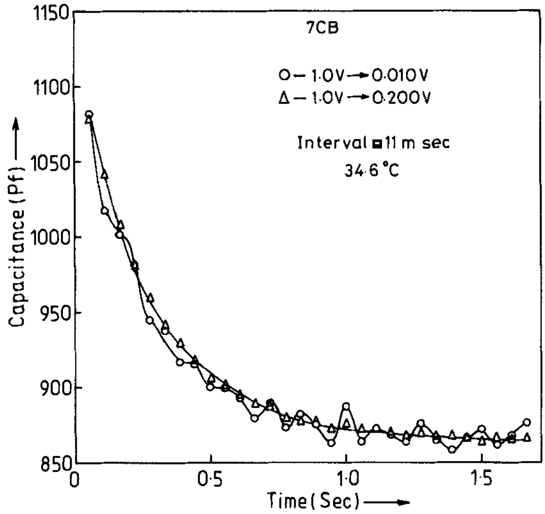

FIGURE 2 Capacitance vs time graph in 7CB at 34.6°C as the voltage across the cell is allowed to jump from 1.0 to 0.01 V and from 1.0 to 0.20 V.

to 0.01 V. Raising the lower limit of the voltage across the cell was found to have an increasingly smoothing effect on the $C - t$ oscillations. The decay of capacitance vs. time in 7CB at 34.6°C for transitions resulting from jumps 1.0 V → 0.01 V and 1.0 V → 0.20 V has been shown in Figure 2 for comparison. However, close to the nematic-isotropic transition, we have observed an increase in the $C - t$ oscillation in 7CB, which could not be suppressed even by the 0.20 V signal (Figure 3). For comparison the growth curve of capacitance at this temperature is also given. No such oscillation was however apparent in 8CB.

During the reorientation of the director field in a nematic a hydrodynamic flow is induced since the director is dynamically coupled to the velocity field. This is the so called *backflow* effect, first demonstrated by Pieranski *et al.*[2] who studied the static and dynamic behaviour of a nematic liquid crystal in a magnetic field induced Freedericksz transition process. More recently Buka *et al.*[3] and Winkler *et al.*[4] have studied the dynamic behaviour in an electric field induced splay Freedericksz transition in 5CB. According to these authors, when the reorientation takes place in a nematic on the application of an electric field, spatially periodic structures are formed. These patterns exist for a short while before the director field in most of the sample aligns normal to the plates. When the electric field is removed the director field relaxes to the original planar configuration without the formation of the transient periodic patterns. Winkler *et al.*[4] have reported the decay of susceptance after turning off the electric field in 5CB and there is no evidence of any oscillation in the value of the susceptance as has been observed by us (in capacitance). One possible reason perhaps is that the authors have carried out the susceptance measurement in 5CB at a temperature (22.1°C) well below the nematic-isotropic transition temperature.

Referring back to the result obtained by Pieranski *et al.*[2] when the magnetic field was suddenly turned off in case of splay Freedericksz transition, we find that

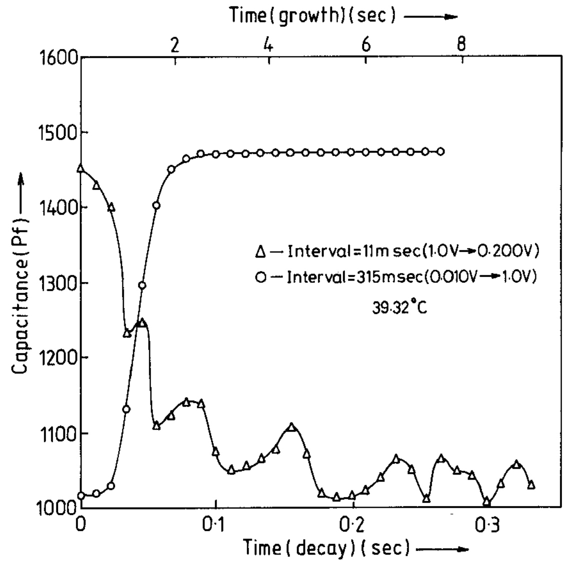

FIGURE 3 Growth and oscillatory decay of capacitance in 7CB at 39.32°C.

nowhere did the authors report any oscillatory behaviour (in time) of the director relaxation. Close to the Freedericksz threshold, in this geometry, the backflow effect can be regarded to be of negligible importance which is however not the case if fields much greater than the threshold field are used.

In this context it is worthwhile to refer to the work of Gerritsma *et al.*[9] who observed an oscillatory after effect in the light transmission through a twisted nematic layer when the driving electric field is switched off. This phenomenon, the so-called *bounce* effect, was subsequently explained by van Doorn[10] who attributed it to the fluid motion. Ericksen-Leslie equations were invoked and were numerically solved to explain the phenomenon of bounce not only for the twist geometry but also for planar orientation.[10,11] It is possible that similar effects are responsible for the oscillatory decay of capacitance we have observed close to the nematic-isotropic transition. Changing the frequency of the applied signal from 1 kHz to up to 100 kHz produced no noticeable change in the behaviour of the director relaxation.

A plot of $\alpha(=1/\tau)$ against the driving factor $\varepsilon = (V^2/V_c^2 - 1)$ has been made in Figure 4 for 7CB only. We were able to explore accurately the region slightly above V_c, as was permitted by our experimental setup. It is interesting to note that the α vs. ε graph in 7CB is of universal nature. We have plotted data for 29.68°C, 34.1°C and 38.5°C for jumps in voltage from 0.01 V to voltages exceeding V_c at those temperatures. Also plotted in the same graph are the data for six other temperatures for jumps in voltage from 0.01 V to 1.0 V (which well exceeds the value of V_c at these temperatures). The values of α, within the limits of their experimental errors, fall on the same curve. The upward bend from linearity is perhaps connected with the backflow effect as discussed by Pieranski *et al.*[2]

From the study of the director relaxation rates after the removal of the electric

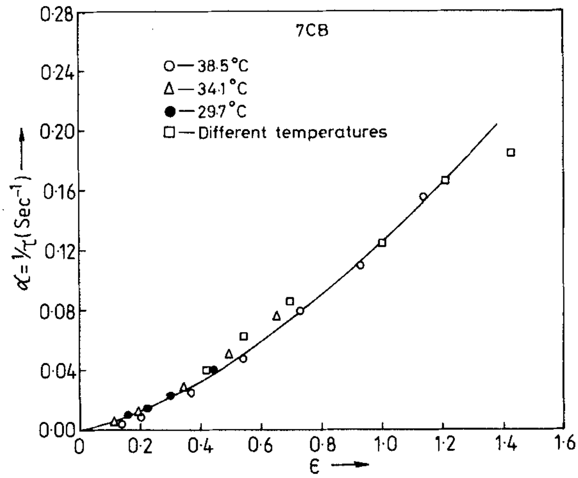

FIGURE 4 Reciprocal of the time constant (α) for growth plotted against the driving parameter ε in 7CB. ○, △, ● correspond to three temperatures where the voltage is allowed to jump from 0.01 V to different voltages exceeding V_c. □ corresponds to jump in voltage from 0.01 to 1.0 V for six temperatures: 29.35°, 32.0°, 34.7°, 36.94°, 38.82° and 39.32°C.

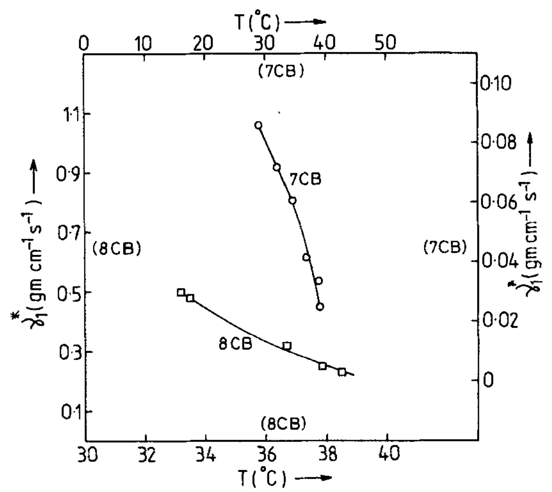

FIGURE 5 The rotational viscosity coefficient (γ_1^*) plotted against temperature in 7CB and 8CB.

field, we were able to extract the value of the rotational viscosity coefficient γ_1 or more precisely the effective rotational viscosity coefficient γ_1^*. As has been pointed out by Pieranski *et al.*[2] the director relaxation induces a flow, which effectively helps to reduce the viscosity coefficient. According to these authors, $\gamma_1^* = k_{11}\pi^2\tau/d^2$, where K_{11} was determined in the static part of the experiment as has already been described. The values of γ_1^* for 7CB and 8CB are plotted against temperature in Figure 5. We estimate that these results are accurate to within ±5%. The viscosity coefficient of 8CB in the nematic phase is about 10 times greater than that in 7CB.

Acknowledgment

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