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MEASUREMENTS OF PITCH OF A FERROELECTRIC LIQUID CRYSTAL AT HIGH PRESSURES

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Abstract We have carried out pitch measurements in the smectic C* phase of a commercially available room temperature ferroelectric liquid crystal, SCE12 (BDH), as a function of pressure. An optical diffraction technique has been employed for the purpose. The diffraction patterns were recorded using a video camera as a 2-d detector. The data is extracted using a frame analysis hardware-software combination. A detailed description of this method is presented. The results show that the application of pressure not only affects the absolute value of the pitch but influences its temperature dependence also. Measurements of spontaneous polarisation also show a similar feature. Possible correlation between the two results is discussed.

INTRODUCTION

The present study is in continuation of our efforts to characterise the behaviour of ferroelectric liquid crystals (FLCs) at high pressures. In previous papers[1–4], we reported the pressure dependence of the spontaneous polarisation P_s, unwinding field E_u and coercive field E_c in some FLCs. We present here the first detailed high pressure measurements of the pitch of a room temperature FLC. Using the standard Diamant Bridge technique, we have also measured P_s, E_c and E_u. Using the experimentally determined parameters, K_3, the coefficient of twist elastic energy associated with the unwinding process, has been calculated as a function of pressure.

EXPERIMENTAL

The material used is SCE12, a room temperature ferroelectric mixture (commercially available from BDH) showing the phase sequence:

Iso 119°C **Ch** 80.6 **A** 66.2 **C*** < -20 **I**

Pitch measurements have been carried out using an optical diffraction setup, a schematic diagram of which is shown in Figure 1.

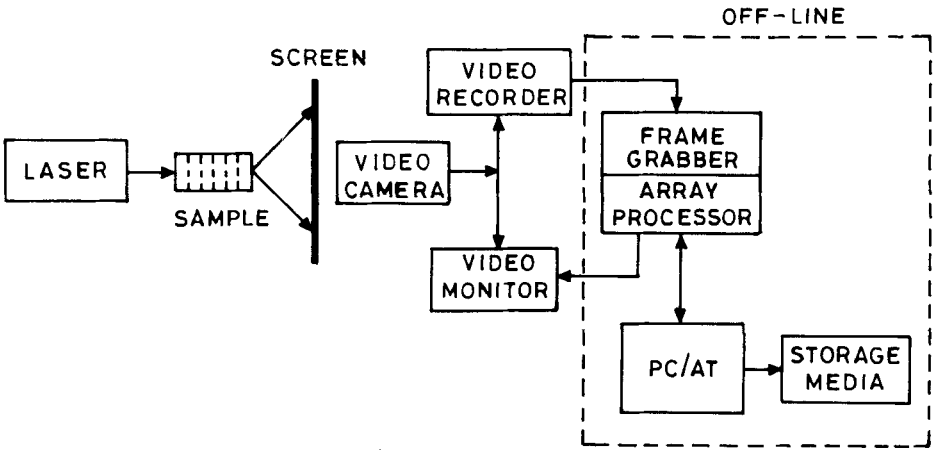


Figure 1: Schematic diagram of the optical diffraction setup

Details of the high pressure setup have been described elsewhere[5]. To recall the salient points, the sample is sandwiched between two optically flat sapphire cylinders (typical sample thickness 125μm) which are encapsulated in an elastomer tube (Fluran). The elastomer serves to contain the sample as well as transmit the pressure very effectively. A high flash point fluid (Plexol) is used to generate hydrostatic pressure on the sample. The output window has a 60° taper, permitting a wide diffraction cone to be observed. To obtain homogeneously aligned samples, the substrate surfaces are coated with a polyamide solution and unidirectionally rubbed. Since the material used has a very large cholesteric pitch (>100 μm) close to the Ch-A transition, very good quality alignment could be obtained by slowly

cooling the sample across the Ch-A transition. As the sample thickness is large, the bulk of the sample (except for a thin boundary layer on either side close to the glass surfaces) will adopt a helical structure and act like a phase grating. A He-Ne laser beam (λ=632.8 nm) was incident on the sample perpendicular to the helical axis. At low temperatures upto 3 orders of diffraction maxima could be seen, although with increasing temperature the intensity of the higher orders decreases substantially. The pitch p was calculated using the equation, $p = \lambda/sin\theta$, where $\theta = arctan(r/D)$, r being the distance between the main beam and the diffracted beam in the image plane and D is the distance between the sample and the screen.

For acquiring and analysing the diffraction pattern we have adopted a method, which enabled fast acqusition of data with high spatial resolution. The diffraction pattern on the screen was captured by a high resolution video camera (Philips VK 4033) and was recorded on a video tape for storage and analysis. This enabled collection of data at close intervals of temperature. The off-line analysis part consisted of a 262K pixels/Frame and 8 bit data resolution Frame Grabber card with 0.5 MB on-board memory in conjuction with a Frame processor board (Data Translation DT 2851 and DT 2858) both of which were plugged into PC AT I/O slots. The cards accept the standard RS-170 PAL input and can be accessed and controlled through a high-level-language interface software. A user-written Fortran program converted the image files into ASCII format files which were later analysed using a peak finding program. A typical diffraction pattern recorded and its intensity profile along the equatorial direction are shown in Figure 2.

Spontaneous polarisation (P_s) measurements at high pressure were done using the standard Diamant bridge technique (see Figure 3). For this purpose the sapphire cylinders were replaced by steel cylinders which served as both substrates and electrodes. The cylinders were coated with polyamide to get the planar alignment in the C* phase. The thickness of the sample was defined by a 50 μm mylar spacer. The detailed description of this setup is given elsewhere[1].

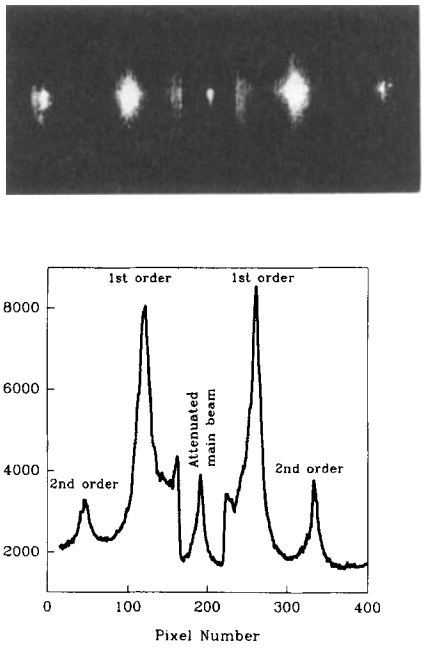
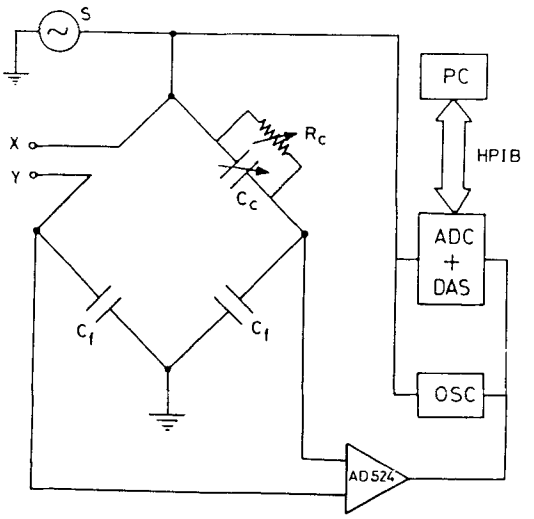


Figure 2: Typical diffraction pattern and its intensity profile



S: signal source,
X,Y= Samle leads
R_c, C_c: Compensating resistor and capacitor combination
C_f: Fixed value capacitor
OSC: Storage oscilloscope
ADC+DAS: Analog digital converter and the data acquisition system
AD524: Programmable gain instrumentation Op-amp

Figure 3: Diamant Bridge setup

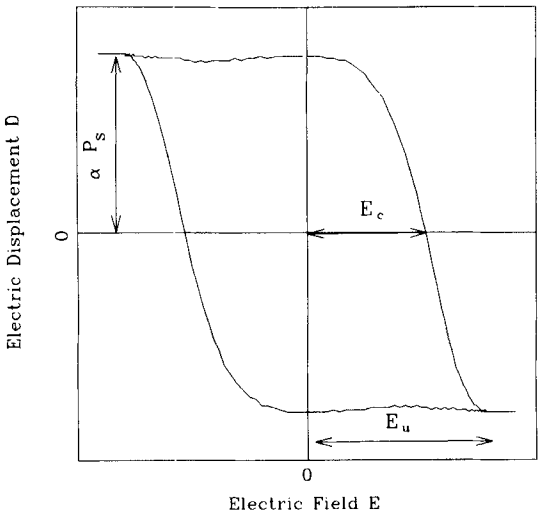


Figure 4: Definition of spontaneous Polarisation (P_s), coercive field (E_c) and unwinding field (E_u)

A schematic diagram of a hysteresis loop is shown in Figure 4. The spontaneous polarisation (P_s) is proportional to the height of the loop, while the coercive field, E_c is given by the width of the loop on the D=0 axis, and the unwinding field E_u is the field required to achieve saturation polarisation.

RESULTS

Figure 5 shows the pressure–temperature (P-T) phase diagram. The slopes of the Ch-A and A-C* lines are almost identical (dT/dP=13.9°C/kbar and 13.7°C/kbar respectively) indicating that the range of the A phase is hardly influenced by the application of pressure.

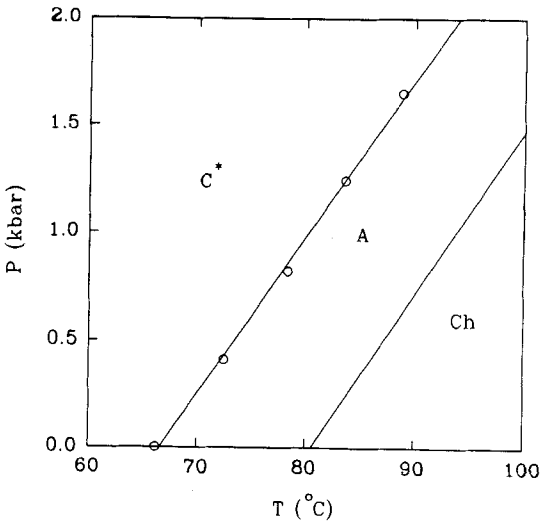


Figure 5: Pressure-temperature phase diagram. The solid lines are obtained by the optical transmission method and the circles are from pitch and polarisation measurements. The values determined from the pitch and polarisation agree within experimental limits.

Pitch measurements in the C* phase have been carried out at four different pressures, 0.42 kbar, 0.84 kbar, 1.2 kbar and 1.65 kbar in addition to room pressure (1 bar). Figure 6 shows the thermal variation of pitch at these pressures. Although the behaviour of pitch near the transition seems to be the same at all pressures, the thermal dependence away from T_c is altered by the application of pressure. In other words, the slope dp/dT is observed to be smaller at higher pressures. This feature becomes clear when pitch is plotted as a function of reduced temperature $\Delta T = T_c - T$, where T_c is the A-C* transition temperature (see Figure 7). Figure 8 gives the pitch values at different ΔT, as function of pressure, the straight lines representing the least squares fit to the data. The slope increases with increasing ΔT. Interestingly the three lines when extrapolated meet at a point at about 2.5 kbar. Thus at this pressure the pitch is independent of ΔT.

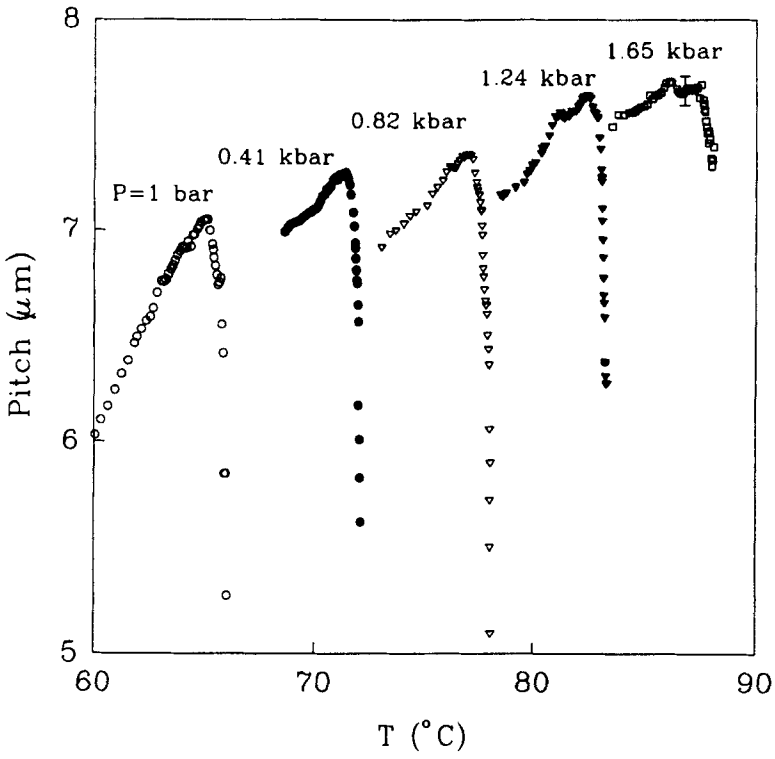


Figure 6: Thermal variation of pitch at different pressures

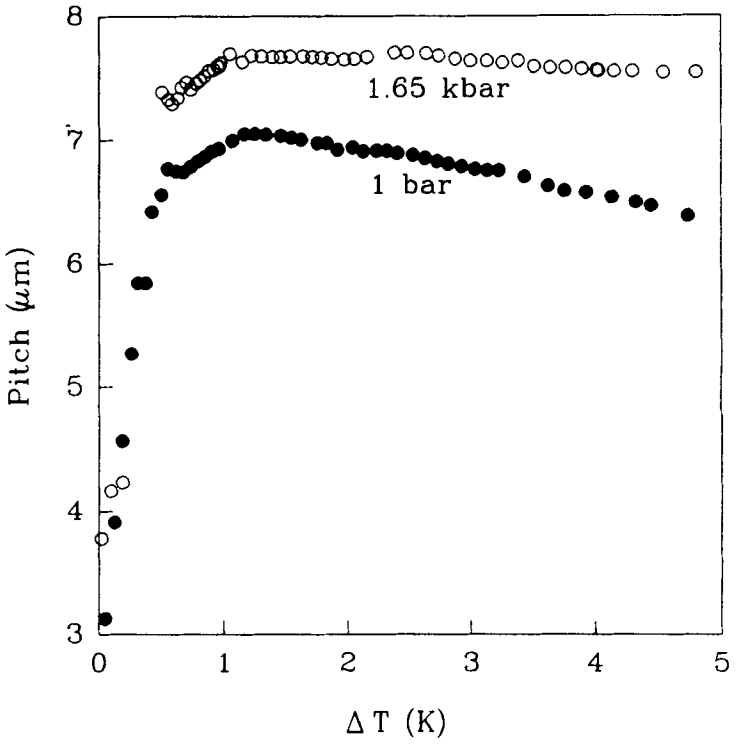


Figure 7: Variation of pitch vs reduced temperature at 1 bar and 1.65 kbar

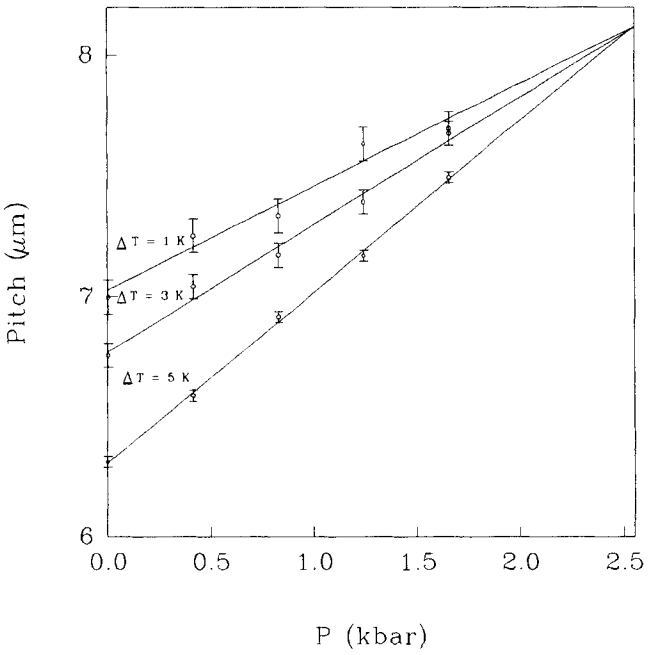


Figure 8: Pitch as a function of pressure at different ΔT. The error bars are one standard deviation errors

According to the generalised mean field model[7], the coupling between polarisation P_s and tilt angle θ influences the temperature variation of pitch. In fact, the constancy of pitch with temperature at 2.5 kbar indicates that at this pressure, P_s is strictly linearly proportional to θ and that the contribution of the biquadratic term is zero. A confirmation of this result would require measurement of P_s and θ as a function of pressure and temperature. With this in mind, we carried out polarisation measurements at the same pressures as mentioned above. Figure 9 shows representative hysteresis loops obtained at 1 bar and 1.24 kbar. Even on a qualitative level one can observe that with increasing pressure the height (and thus P_s) decreases while E_c and E_u increase.

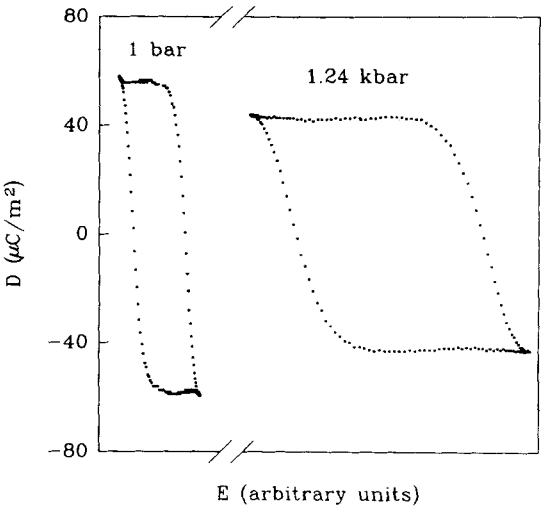


Figure 9: Hysteresis loops obtained at 1 bar and 1.24 kbar

Figure 10 shows P_s at a fixed ΔT=5K, as a function of pressure. P_s is observed to decrease with increasing pressure in agreement with earlier studies[1,2]. A fit of the data to a straight line gives the rate of decrease of P_s with pressure to be $9.7\mu Cm^{-2}kbar^{-1}$. We have also calculated the coercive field and unwinding field from the hysteresis loops at ΔT=5K for the same pressures.

The plot of E_c and E_u as a function of pressure is shown in Figure 11. Both E_c and E_u increase with increasing pressure although at slightly different rates. The slopes for the two fields are: dE_c/dP=2.96 x $10^5 Vm^{-1}kbar^{-1}$; dE_u/dP=4.2 x $10^5 Vm^{-1}kbar^{-1}$. The fact that the difference between E_c and E_u, the two fields, increases at higher pressures indicates that the switching gets slower with pressure, a feature observed in our earlier measurements[1].

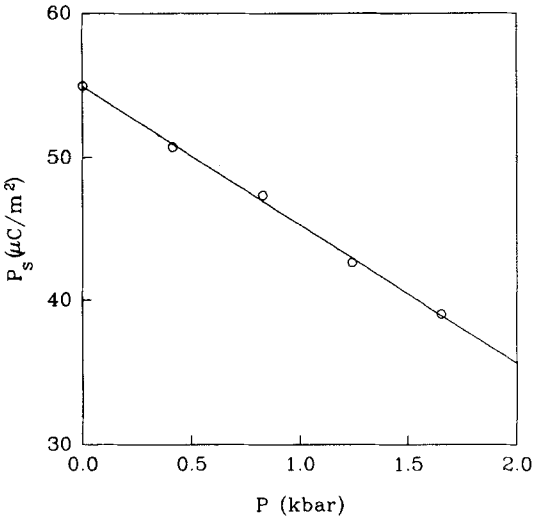


Figure 10: P_s vs pressure at a fixed ΔT=5K.
(o): experimental data; (–) fit to a straight line

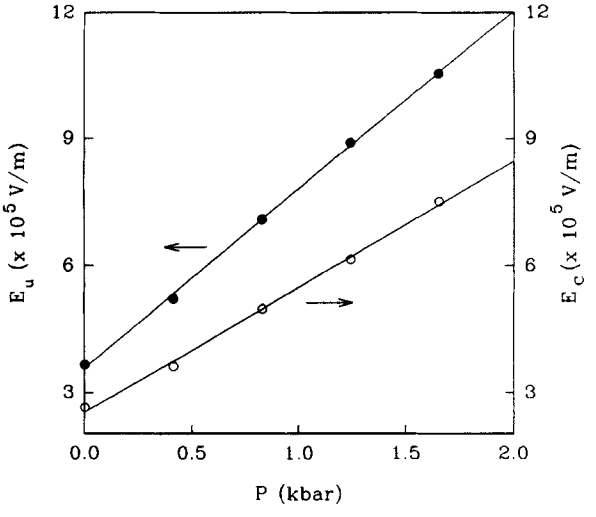


Figure 11: Variation of E_c and E_u at ΔT=5K as a function of pressure

The experimentally found values of P_s, E_u and pitch p can be used to determine the magnitude of the twist elastic energy $K_3\theta^2$. A simple mean field analysis[8] yields

$$K_3\theta^2 = P_s E_u p$$

A plot of $K_3\theta^2$ calculated in this manner at different pressures is shown in Figure 12. The increase in $K_3\theta^2$ as pressure is increased could mean either the elastic coefficient K_3 or the tilt angle θ gets increased; since the P_s is observed to decrease with pressure the latter would imply that the polarisation–tilt coupling becomes stronger on application of pressure. Measurement of tilt angle at high pressures are expected to clarify these matters. Experimental studies in this direction are being undertaken in our laboratory.

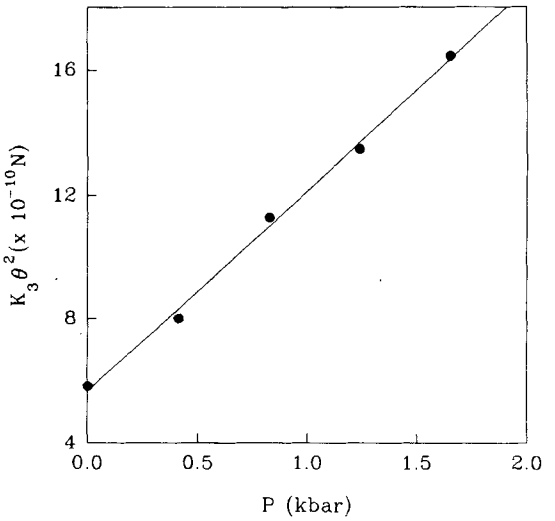


Figure 12: Variation of $K_3\theta^2$ as a function of pressure at ΔT=5K

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