Electrooptic and Dielectric Investigations on some Liquid Crystals

Thesis submitted to

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by

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Bangalore 560 080

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DECLARATION

I hereby declare that this thesis is composed independently by me at the Raman Research Institute, Bangalore, under the supervision of Prof. N. V. Madhusudana. The subject matter presented in this thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or any other similar title in any other University.

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CERTIFICATE

This is to certify that the thesis entitled Electrooptic and Dielectric Investigations on some Liquid Crystals submitted by **Sobha R. Warrier** for the award of the degree of DOCTOR OF PHILOSOPHY of Jawaharlal Nehru University is her original work. This has not been published or submitted to any other University for any other Degree or Diploma.

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Contents

Acknowledgement v

Preface vii

1 Introduction 1

1.1 Nematic liquid crystals 1

1.2 Cholesteric liquid crystals 3

1.3 Smectic liquid crystals 3

1.3.1 Smectic A liquid crystals 3

1.3.2 Smectic C liquid crystals 3

1.3.3 Smectic C* liquid crystals 4

1.4 Twist grain boundary phase 4

1.5 Orientational order parameter of nematics 9

1.6 Elasticity of nematics 11

1.7 Anchoring 13

1.7.1 Easy axis 13

1.7.2 Anchoring energy 13

1.8 Alignment of liquid crystals 14

1.9 Flexoelectric polarisation 15

1.10 Anisotropic physical properties 17

1.10.1 Refractive index 17

1.10.2 Electrical conductivity 17

1.10.3 Dielectric constant 18

1.11 Dielectric relaxation 18

1.12 Cell thickness measurement 19

2 Theoretical analysis of the electrooptic response of a hybrid aligned nematic (HAN) cell 20

2.1 Hybrid aligned nematic (HAN) 24

2.2 Molecular field 24

2.3 Theoretical Analysis 25

2.4 Insulating nematic 28

2.5 Conducting nematic 36

3 AC electrooptic experiments on a hybrid aligned **nematic(HAN)** cell 43

3.1 Earlier experiments 44

3.2 Experimental technique 48

3.3 Conductivity measurement 50

3.4 Experimental results **53**

3.5 Results and discussion 67

3.6 Conclusions 76

4 Confinement effects on a highly polar compound 78

4.1 Introduction 78
4.2 Experimental setup 83
4.3 Birefringence measurement 85
4.4 Measurements using a superconducting magnet 86
4.5 Measurements using electric fields 87
4.6 Results 88
4.7 Conclusions 92

5 Extensions of Landau-deGennes theory of liquid crystals 97

5.1 Landau Theory of Phase Transitions 97
5.1.1 Landau-deGennes Theory for the Nematic-Isotropic Phase transition 98
5.2 Landau deGennes model with the inclusion of order parameter-density coupling 100
5.3 Uniaxial nematic' made of biaxial molecules 103
5.4 Results 106
5.5 Conclusions 116
5.6 Appendix 116

6 Dielectric studies on twist grain boundary phases 118

6.1. Introduction 118
6.2 Measurement geometries 123
6.3 Experimental setup 124
6.4 Dielectric measurements using LIA 128
6.5 Results 130

6.6 Conclusions 148

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Preface

Liquid crystals are anisotropic fluids with some order in the arrangement of molecules [1, 2]. The simplest of liquid crystals namely the nematic liquid crystals possess only long range orientational order. When the nematic is doped with a chiral substance, or when the molecules themselves are chiral, a helical configuration is adopted and the resulting medium is called the cholesteric phase. Smectic phases have a layered structure. In the Smectic A phase the molecules are upright in each layer whereas in Smectic C liquid crystals the molecules are tilted with respect to the layer normal. The chiral smectic C* phase is formed by optically active molecules and they have a helical structure with the twist axis along the layer normal. The twist grain boundary phase consists of a helical stack of smectic blocks separated by grain boundaries made of an array of screw dislocations. The twist grain boundary phase can be classified into TGB_A, TGB_C or TGB_{C^*} in which the smectic slabs are of Smectic A, Smectic C and Smectic C* character respectively [3].

The work reported in this thesis is on the electrooptic studies of a nematic, experimental investigation on the confinement effects of a highly polar nematic, development of an extended Landau-deGennes theory of nematics and dielectric studies on TGB phases.

In chapter 1 we have given a general introduction to liquid crystals with emphasis on the topics discussed in the later chapters.

In chapter 2 we have analysed theoretically the dynamic response of a hybrid aligned nematic cell under the action of an AC electric field. In a hybrid aligned nematic(HAN) cell one of the glass plates is treated for homeotropic alignment. The other glass plate is treated for homogeneous alignment.

Nematics are orientationally ordered. The director $\mathbf{n}$ which is a unit vector representing the local direction of average orientation of the long axes of the rod like molecules is apolar in character [1] and the nematic medium does not exhibit spontaneous polarisation. However., if the director field has a splay or bend type of distortion, a macroscopic polarisation $\mathbf{P}_f$ can result [4]:

$$\mathbf{P}_f = e_1\mathbf{n}(\nabla \cdot \mathbf{n}) + e_3(\nabla \times \mathbf{n}) \times \mathbf{n}. \tag{1}$$

As the flexoelectric coupling depends linearly on the electric field the AC response of a HAN cell gives rise to an 'f' signal at the frequency of the applied voltage. The flexoelectricity gives rise to a torque acting mainly on the surfaces.

The surface interaction is usually characterised by two parameters, the easy axis at the interface and the anchoring energy. Easy axis is the direction of $\mathbf{n}$ which minimises the surface energy in the absence of external torques. The anchoring energy is a measure of the strength of the surface interactions to impose a well defined direction on the director of the liquid crystal at the surface.

Under the action of a sinusoidal voltage across the cell the various torques on the nematic in a HAN cell are: a) the anchoring torque at both the surfaces b) the flexoelectric torque acting mainly at the surfaces c) the viscous torque in the bulk of the medium d) the dielectric torque in the bulk of the medium e) the elastic torque acting in the bulk as well as at the surface. By balancing the torques the equilibrium orientation of the director is obtained. The director profile is in turn used to calculate the transmitted light intensity as a function of voltage.

In chapter **3** we have described the experimental setup for the electrooptic mea-

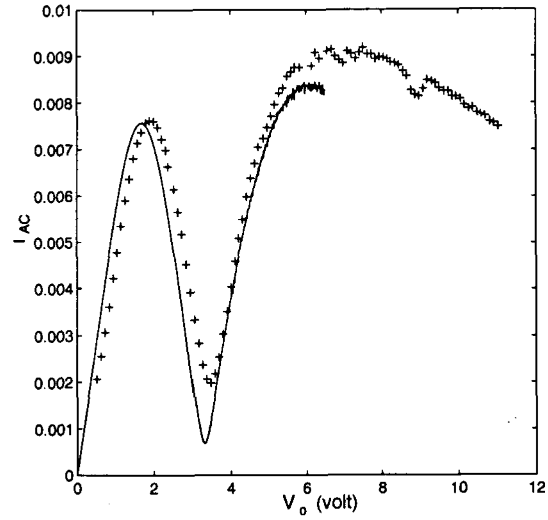

Fig. 1: Transmitted AC intensity coefficient I_{AC} (normalised with respect to **I,) as** a function of voltage of a HAN cell with CCH-7 at T=333.65^{o}K. The '+' symbols indicate the experimental data. The continuous curve shows the theoretical fit in the case of an insulating nematic for W_l=0.0241 ergs/cm^2, W_u=0.026 ergs/cm^2, e_1+e_3=8.0x10^{-04} cgs units and γ_1=0.9 poise.

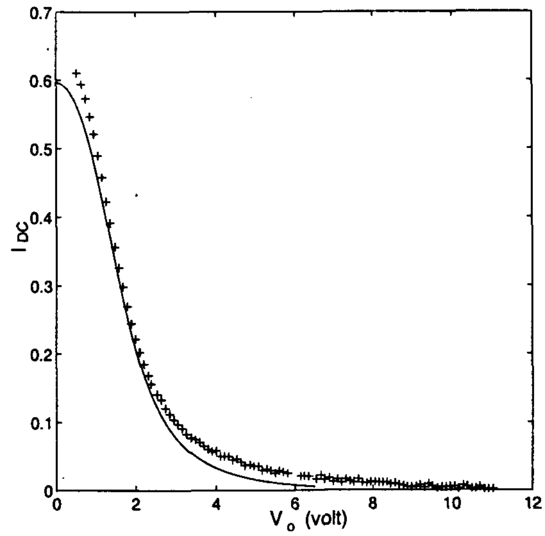

Fig. 2: Transmitted DC intensity coefficient I_{DC} as a function of voltage for the cell described in Fig. 3.4 at T=333.65^{o}K. The '+' symbols indicate the experimental data. The continuous curve shows the theoretical fit. The parameters are the same **as** in Fig. 1.

surements on a hybrid aligned nematic cell. The AC and DC transmitted intensities of a HAN cell are measured as functions of voltage at different temperatures for the compound CCH-7. The calculated intensity profiles are fitted to the experimental data. We have obtained the temperature dependences of the flexoelectric coefficient $(e_1 + e_3)$, the rotational viscosity coefficient γ_1 as well as the anchoring strengths at the two surfaces from a detailed numerical analysis of the electrooptical signal. The calculated AC and DC transmission coefficients are compared with the experimental data in Fig. 1 and Fig. 2 respectively.

Our measurements on CCH-7 show the following results: a) The extrapolation length L_l at the homeotropic surface shows a small decrease as the temperature is increased to 66^{o}C beyond which it shows a sharp increase which we interpret as arising from a softening of the chains of the aligning ODSE layer. b) The slope of the temperature dependence of the extrapolation length L_u at the homogeneous surface changes sign around 72^{o}C. c) $(e_1 + e_3)/S$ is a constant upto 72^{o}C and decreases rapidly beyond this temperature. The last two results are attributed to an increase in the conformational freedom between the rings of CCH-7 molecules beyond that temperature.

In chapter 4 we have performed optical transmission measurements on a highly polar compound . These studies indicate a nematic to nematic phase transition due to the change in the short range order of the medium. The transition temperature increases as the thickness decreases. In a thin cell($\sim 2\mu$m) the transition occurs at ($\sim$ 30 ^{o}C). The transmitted AC intensity profiles for cells of thicknesses 3pm and 1.9μm are shown in Fig. 3 and Fig. 4 respectively. The optical transmission measurements on the same compound are also performed under the action of a moderate magnetic field as well as by applying a transverse electric field parallel to the director. When a magnetic field of 5 Tesla is applied to the cell the transition temperature increased

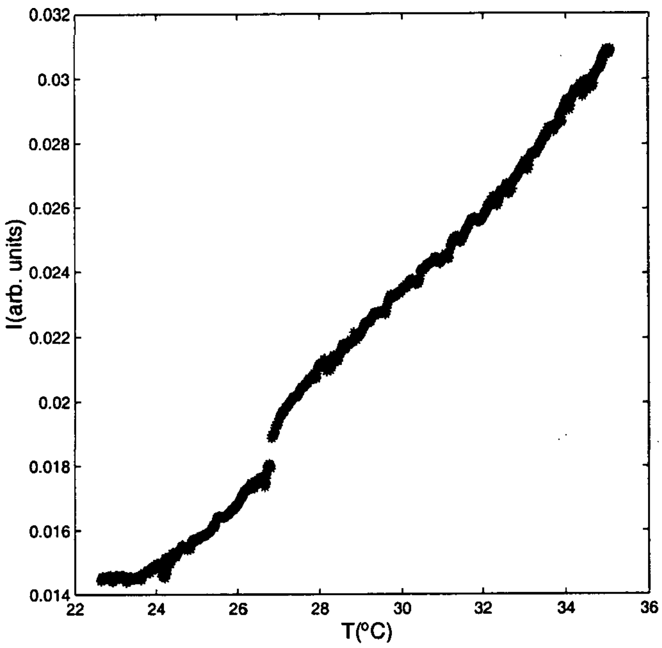

Fig. 3: Transmitted intensity profile as a function of temperature for a cell of thickness $(3.0\mu\mathrm{m})$.

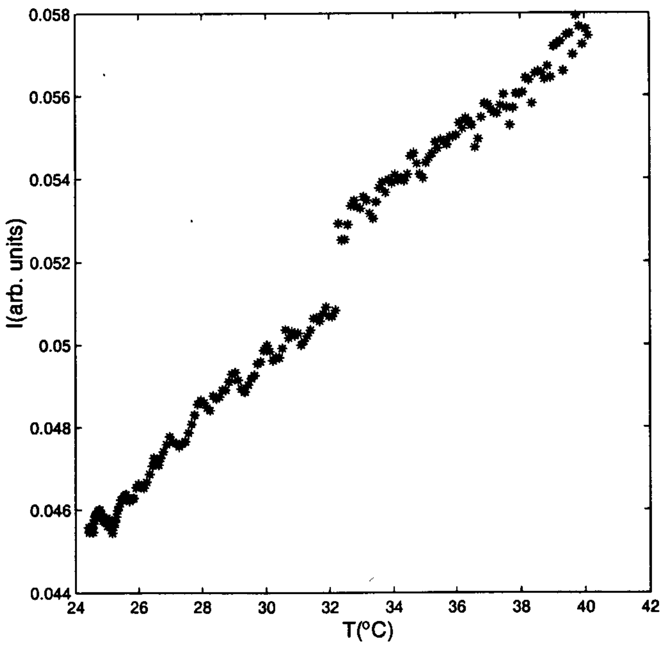

Fig. 4: Transmitted intensity profile as a function of temperature for a cell of thickness $(1.9\mu\mathrm{m})$.

by $\sim$4.5^{o}C. Similarly when a square wave of 300 volts is applied across a gap of 1mm the transition temperature increased by $\sim$0.5^{o}C. Such shifts in the transition temperature under the action of moderate fields is quite unusual.

In chapter 5 the Landau-deGennes model has been modified to take into account the coupling of the order parameter with density. This coupling renormalises the coefficient of the fourth order term, making it negative. A sixth order term with a positive coefficient is then required for stability. This in turn leads to a relatively slow variation of the order parameter with temperature as seen in experiments. The Landau theory has also been modified to describe a *uniaxial* nematic made of biaxial particles which interestingly gives rise to a relatively large value for the correlation length of the order parameter. We believe that the latter model can plausibly explain the enhancement in the order parameter in thin cells as well as the significant increase in the order parameter under the action of a moderate magnetic field, implied by an increase in the nematic-nematic transition point measured in some compounds mentioned in the previous paragraph.

In chapter 6 dielectric measurements have been performed on Twist Grain Boundary phases. Binary mixtures of the chiral compound 4-(2'- methyl butyl phenyl 4$'$-n-octylbiphenyl-4-carboxylated (CE8)) and 2-cyano-4-heptyl-phenyl-4$'$-pentyl-4-biphenyl carboxylate (7(CN)5) exhibit a new TGB phase namely UTGB$_C$* phase which was recently discovered [5]. It also exhibit the usual TGB$_A$ phase. In the UTGB$_C$* phase the tilted molecules are arranged in a helical fashion within the smectic slabs. These slabs exhibit a 2D undulation in the form of a square lattice. The dielectric studies were undertaken in cells treated for both homeotropic and homogeneous alignments. In both the cases the phase transitions from the TGB$_A$ phase to the UTGB$_C$* phase and from UTGB$_C$* phase to smectic C* phase are clearly seen (see Fig. 5 and Fig. 6). The dielectric measurements in the homoge-

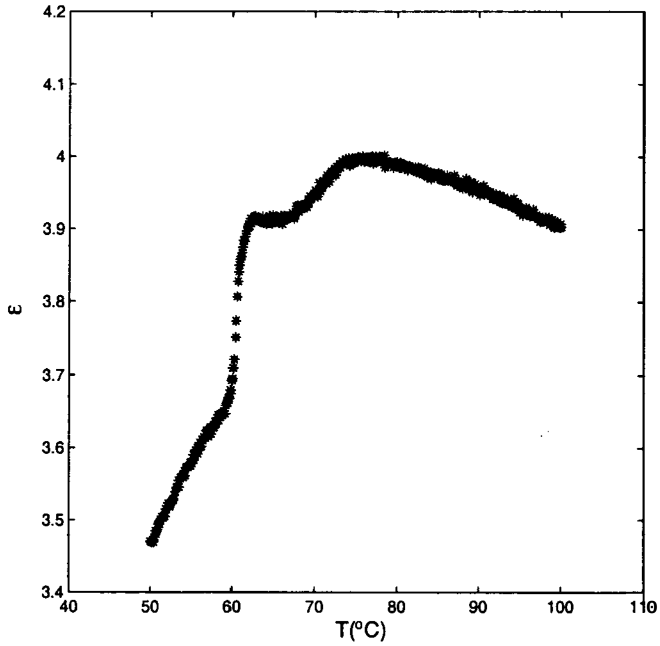

Fig. 5: Dielectric constant as a function of temperature for a cell treated for homeotropic alignment.

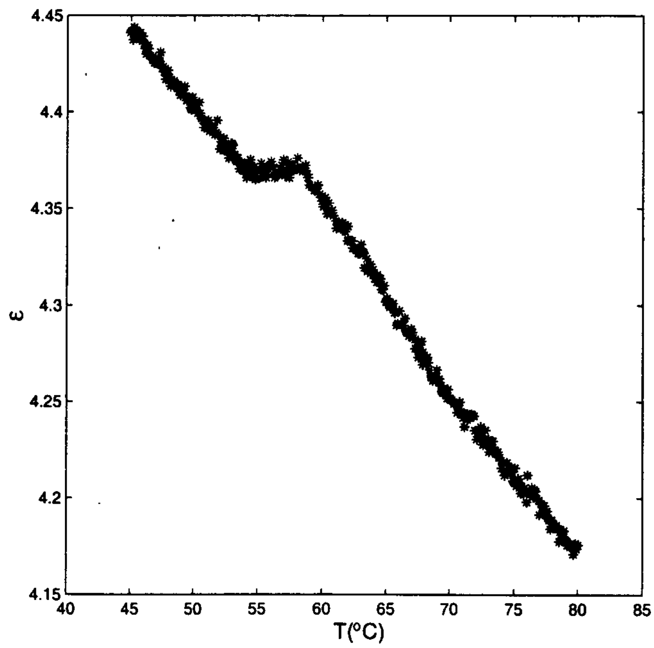

Fig. 6: Dielectric constant as a function of temperature for a cell treated for homogeneous alignment.

neous geometry clearly indicates that the contribution from $\epsilon_{||}$ is much higher in the UTGB$_{C^*}$ phase compared to the other phases.

The following papers contain the work described in this thesis.

1. Sobha R. Warrier and N. V.Madhusudana, " An AC Electrooptic Technique for Measuring the Flexoelectric Coefficient (e1+e3) and Anchoring Energies of Nematics." **, J.** de. *Physique.* 2 , **7,** 1789, 1997.

2. Sobha R. Warrier , D. Vijayaraghavan and N. V.Madhusudana, "Evidence for a nematic-nematic transition in thin cells of a highly polar compound". (Europhys. Lett. in press).

3. Sobha R. Warrier and N. V.Madhusudana, "Landau-deGennes theory of uniaxial nematic made of biaxial molecules". To be published.