SOME THEORETICAL STUDIES ON THE DEFECT STRUCTURES IN LIQUID CRYSTALS

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By

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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. G.S.Ranganath. The subject matter presented in this thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar title.

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CERTIFICATE

I certify that this thesis has been composed by Mr.P.B.Sunil Kumar based on investigations carried out by him at the Raman Research Institute, Bangalore, under my supervision. The subject matter of this thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar title.

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CONTENTS

PREFACE

Topologial defects can be classified according to the symmetry elements of the system in which they are found or theoretically proposed. For example in solids the existence of translational symmetry is ultimately related to the familiar edge or screw dislocations. In principle *rotational dislocations* or *disclinations* are also possible in crystals and are related to the rotational symmetries in the crystals. Defects which are constructed from both the translational and rotational symmetries are called *dispimtions*. All these defect states **exist$** in liquid crystals also. In addition they have defects that are peculiar to them. Also from the topological point of view liquid crystal defects are very important in view of their similarities with topological defects in other ordered systems like superfluids, superconductors and magnetic systems.

This thesis describes theoretical **investigations** carried out on the structure and **properties of** some topological defects in liquid crystals, with particular emphasis on the effects of magnetic and electric fields on them. The important and salient results obtained in different types of liquid crystals are briefly discussed below

1. Nernatics have only orientational order, with the molecules preferentially oriented along a direction described by a unit vector called the director $\mathbf{n}$. The magnetic field profoundly influences defects that are already present in nematics. We also find new defect states in the vector field $\mathbf{n}$. Some of the interesting results obtained are the following.

   (a) It is well known that, in the absence of an external field nematic disclinations interact with a force which varies inversely with the distance of separation between them. Surprisingly, we find that in the presenceof a field these disclinations interact with a force which is independent of distance.

   (b) An important feature of a disclination line is that it ends on itself or on a boundary. Also ± 1 disclinations are non singular. Interestingly, we find a field induced defect which violates both these properties. We get in **one** particular Freedericksz geometry a $+1$ line which is not only singular but also ends inside the body of the material. It's end points are half disclination points.

   (c) In a nematic with negative diamagnetic anisotropy, we find, that in an all circular magnetic field [$H_\alpha = A/r$ generated by a linear current] a bubble domain can exist as a natural solution with a width inversely proportional to the field strength. Interestingly, the energy of the bubble domain is **independent of** its radius. In nematics with positive diamagnetic anisotropy $\chi_a > 0$ however, the bubble domains can exist only above a threshold field. Below the threshold field one gets a singular $+1$ all circular disclination line. This becomes a non-singular collapsed structure when A is below $(k/\chi_a)^{1/2}$, k being the elastic constant.

(d) There also exists in nematics with negative diamagnetic anisotropy a possibility of a new type of wall connecting different types of distortions.

2. These interesting results in nematics naturally leads to a study of the structure and properties of disclinations and dislocations in a magnetic field in liquid crystals with transilational order *viz.,* smectics and discotics. The lattice order present in these systems influences considerably the field induced defects. The significant results are:

(a) It is well known that in the linear elastic theory screw dislocations in smectics do not have self energy and also they do not interact. However, we find that in a magnetic field parallel to the layer normal in $\chi_a > 0$ srnectics they interact with a force inversely proportional to the distance of separation. In other words they interact like screw dislocations in crystals. It is pointed out that the interaction law is also the same for a compressed smectic.

(b) The diamagnetic anisotropy χ_a of smectics can be positive or negative. Interestingly, when χ_a is negative, the smectic A structure becomes unstable in a field along the layer normal leading to a proliferation of screw dislocations. One finds a similar instability for $\chi_a > 0$ materials in an all circular field.

(c) For $\chi_a > 0$, we also find that a $+1$ all radial disclination with a coaxial cylindrical wrapping of layers (mylene sheath structure), will become unstable above a threshold against a spiral disclination which has an helical wrapping of layers.

(d) In smectic C with a negative diamagnetic anisotropy, in an all circular field $(0, H_\alpha, 0)$ acting parallel to the layers, we get not only screw dislocations but in addition a disclination in the in-plane c vector field. Hence we get a dispiration which has both dislocation and disclination characteristics.

(e) In columnar discotics with negative χ_a a $+1$ disclination with the columns bent around in circles becomes unstable in a H_α field. This can result in two structures. In one structure the circular columns, in different planes gets interconnected to result in coaxial helices and in the other structure the circular columns in the same plane get connected to result in a stacks of spirals.

(f) Another problem considered in this chapter is the core structure of a ± 1 line disclination in smectic C near a smectic A-smectic C phase transition. It is well known that on the smectic C side of the transition, the tilt angle is a function of the radial distance from the center of the disclination line and is governed by the Ginzberg-Pitaviski equation. The field effects this core considerably. Interestingly on the smectic A side of the transition an all circular field induces a $+1$ disclination. In the core of this disclination near A-C transition the tilt angle shows a similar behaviour.

3. The field effects get greatly enhanced in a liquid crystal doped with ferromagnetic grains. Brochard and de Gennes in the early seventies considered theoretically the possibility of the existence of a two component ferroliquidcrystal. Here ferromagnetic grains are embdded in an aligned state in a liquid crystal matrix. After their pioneering work, considerable experimental as well as theoretical studies have appeared in literature. In the investigations carried out so far the diamagnetic anisotropy of the host matrix has largely been ignored. We find that in ferronematics the diamagnetic anisotropy χ_a of the host matrix alters the field induced structure and their properties. The defect structures are also considerably altered by the elastic anisotropy $\epsilon = (k_{33} - k_{11}) / (k_{33}+k_{11})$ (k_{11} and k_{33} are the splay and bend elastic constants respectively) of the host matrix. This study has lead to the following results in the Freedericksz tra'nsition in ferronematics . (FN):

   (a) In the homogenous geometry with H antiparallel to **magnetization** M, we can have two possible distortions with the same energy. They are the in-plane (4) and out of plane (6) distortions. In fact they can exist simultaneously with a new type of wall connecting them.

   (b) In the homeotropic geometry with the magnetic field applied antiparallel to the magnetization M of the grains, the system becomes unstable above a threshold field. The transition is first order or second order according as the value of **magne**tization M is larger or smaller than a critical value $M_c = \frac{4\pi}{d}\left(\frac{k\chi_a}{3}\right)^{1/2}$, where d is the sample thickness and k is the elastic constant. We also find a tricritical behaviour as M or ϵ changes.

   (c) Interestingly due to elastic anisotropy, we find two successive instabilities of different orders in the homogenous geometry.

   (d) It is pointed out that field induced distortions exhibit a tricritical behaviour even in crossed electric and magnetic fields.

4. Experiments have shown that in FN there exists a strong mechanical coupling between the host liquid crystal and the magnetic grains. In this limit of strong coupling we have studied the structure of topological linear solitons generated in a FN by a magnetic field. Some of the important conclusions are:

   (a) In the χ_a positive FN a 2π planar soliton, *i.e.*, 360^o twist wall becomes unstable above a threshold field splitting into two π solitons (180^o twist wall).

   (b) In χ_a negative FN, below a critical field given by $H_c = M/\chi_a$ we get a linear soliton *i.e.*, cylindrical domains with 2π bend or twist in any radial direction as one goes from $r = 0$ to $r = \infty$. Above H_c the director orientation at $r \to \infty$ is given by $\cos\theta_m = (M/\chi_a H)$. This results in two new types of linear solitons: 'N-flower' and 'W-flower'. In the N-flower, as r goes from zero to infinity θ goes from zero to θ_m, while in the W-flower θ goes from π to θ_m. At very high fields θ_m become $\pi/2$ resulting in a 'U-flower'. The structures of these solitons are very sensitive to the elastic anisotropy of the host matrix.

(c) Point singularities in ferronematics also get transformed into linear solitons by the field. Their structure have also been described.

5. By doping a FN with opticaly active molecules or by suspending magnetic grains in a cholesterics it is possible to obtain a stable ferrocholesteric system wherein the magnetic grains rotate along with the director about the twist axis. We consider a **ferrocholesteric(FCh)** in a magnetic field acting perpendicular to its twist axis. In such cases, it is well known that in a normal cholesteric one gets a π soliton lattice, *i.e.,* periodic array of 180" twist walls. This becomes a nematic above a threshold field. In FCh, at low fields, we get the 2π soliton lattice. Above a threshold field, this will become unstable leading to a π soliton lattice for positive diamagnetic anisotropy $[\chi_a > 0]$ and $N(i.e., -\theta$ to $+\theta_m)$ and W $(i.e., \theta_m$ to $2\pi - \theta_m)$ soliton lattice for negative diamagnetic anisotropy. We have also worked out the consequences of the magnetic grain seggregation in a magnetic field on the transition from the soliton lattice to the nematic and on the instability of 2π soliton lattice. It may be remarked that Brochard and de Gennes did not find a $FCh \rightarrow$ nematic transition as they ignored the effects of χ_a. We find that taking χ_a into consideration naturally leads to a $FCh \rightarrow$ nematic transition.

6. In view of the fact that cholesterics can be probed optically, a study of the optical properties of cholesteric soliton lattices has also been undertaken. We find the following important results.

(a) It is known that the soliton lattice in contrast to normal cholesteric, has multiple Bragg reflections even for normal incidence. At fields close to the nematic-cholesteric transition point we find that the higher order reflections are generally more intense than the primary. It is also known that each Bragg band splits into three sub-bands separated by regions of no reflections. We find that in these three sub-bands the standing waves are very different as regards their polarizations, angle between $\mathbf{E}$ and $\mathbf{H}$, and their relative phases, while in the undistorted structure $\mathbf{E}$ is parallel to $\mathbf{H}$ with a phase difference of $\pi/2$.

(b) Optical diffraction in such soliton lattices have also been worked out for propagation perpendicular to the twist axis. In general we find that higher orders can be more intense than lower orders. Also, in general the diffraction pattern is asymmetric in this case. The technique is so sensitive even the weak twist induced biaxiality in normal cholesteric can be tested since this biaxiality **varies** along the twist axis in soliton lattices. In ferrocholesterics due to grain seggregation alone we predict a diffraction pattern which is peculiar to **FCh** - soliton lattice.

7. During these studies on optical diffraction we also got involved in the general phenomenon of Fresnel diffraction, in particular, the calculations on the diffraction patterns in different geometries, by employing the technique of the geometrical theory of diffraction. Our results are in close agreement with experimental findings. Appendix-A carries a brief presentation of this work.

All these problems were worked out by the author. Many of these investigations have been already published in the following papers:

1. P.B.Sunil Kumar and G.S.Ranganath, Ferronematics in magnetic and Electric fields, *Mol. Cryst.* Liq. *Cryst.,* **177, 123 (1989)**
2. P.B.Sunil Kumar and G.S.Ranganath, On certain liquid crystal defects in a magnetic field, *Mol. Cryst. Liq. Cryst.,* **177, 131 (1989)**
3. P.B.Sunil Kumar and G.S.Ranganath, On some topological solitons in ferronematics, Mol. *Cryst.* Liq. *Cryst.,* **196, 27 (1991)**
4. P.B.Sunil Kumar and G.S.Ranganath, Optical diffraction in cholesteric soliton lattices, Presented at the 14th International Liquid Crystal Conference, **(1992)**
5. K.A.Suresh, P.B.Sunil Kumar and G.S.Ranganath, Optical diffraction in twisted liquid crystalline media-phase grating mode Liquid Crystals, **11, 73-82 (1992)**
6. P.B.Sunil Kumar and G.S.Ranganath, Geometrical theory of diffraction *Pramana,* **37** (6), 4457 **(1991)**
7. P.B.Sunil Kumar and G.S.Ranganath, Geometrical theory of diffraction - A historical perspective, *Current* Science, **61** (1), **22 (1991)**
8. P.B.Sunil Kumar and G.S.Ranganath, Structure and optical properties of cholesteric soliton lattices, *J.Physics (paris)-II* — to appear in October 1993

CHAPTER I

INTRODUCTION

Liquid crystals are mesophases that exist as thermodynamicaly stable states with a moleculer order between the positionally and orientationally ordered crystals and that of isotropic liquids [1,2]. They are made of highly anisotropic molecules. Liquid crystals can be classified into lyotropics and thermotropics. Lyotropics are multicomponent systems where the liquid crystalline phases appear in a range of compositions. The thermotropics are single component systems where the liquid crystalline phases appear in a temperature range. One also finds polymorphism in these systems. All liquid crystalline phases exhibit typical optical textures under a polarizing microscope. These are nothing but topological clefects that are char-'acteristic of the mesophases. In this thesis we have undertaken a study of these topological defects. In this chapter we briefly review the important topological defects that exist in the different liquid crystalline phases.

1.1 Classification

Liquid crystals can be further classified into structures with and without lattice order. Nematic liquid crystals fall into the second group. While cholesterics, smectics and columnar phases come under the first category. Smectics have a one dimensional lattice ordering with a nematic like ordering in the layers while columnar discotics have a two dimensional lattice order and one dimensional liquid like order. Depending on the molecular orientation in each layer smectics are further classified. Here we briefly describe the important liquid crystaline phases.

Nematics: The usual nematic phase has uniaxial symmetry with the point group symmetry $D_{\infty h}$. It is centrosymmetric. This phase is generally formed by highly anisotropic rod like or disc like molecules, with the rod like molecules nearly oriented in a particular direction specified by an apolar vector n called the "director". In the case of disc-like molecules all the molecules are nearly aligned in a particular plane. The normal to this plane is the director n (Fig 1.1a and Fig 1.1b). Recently even

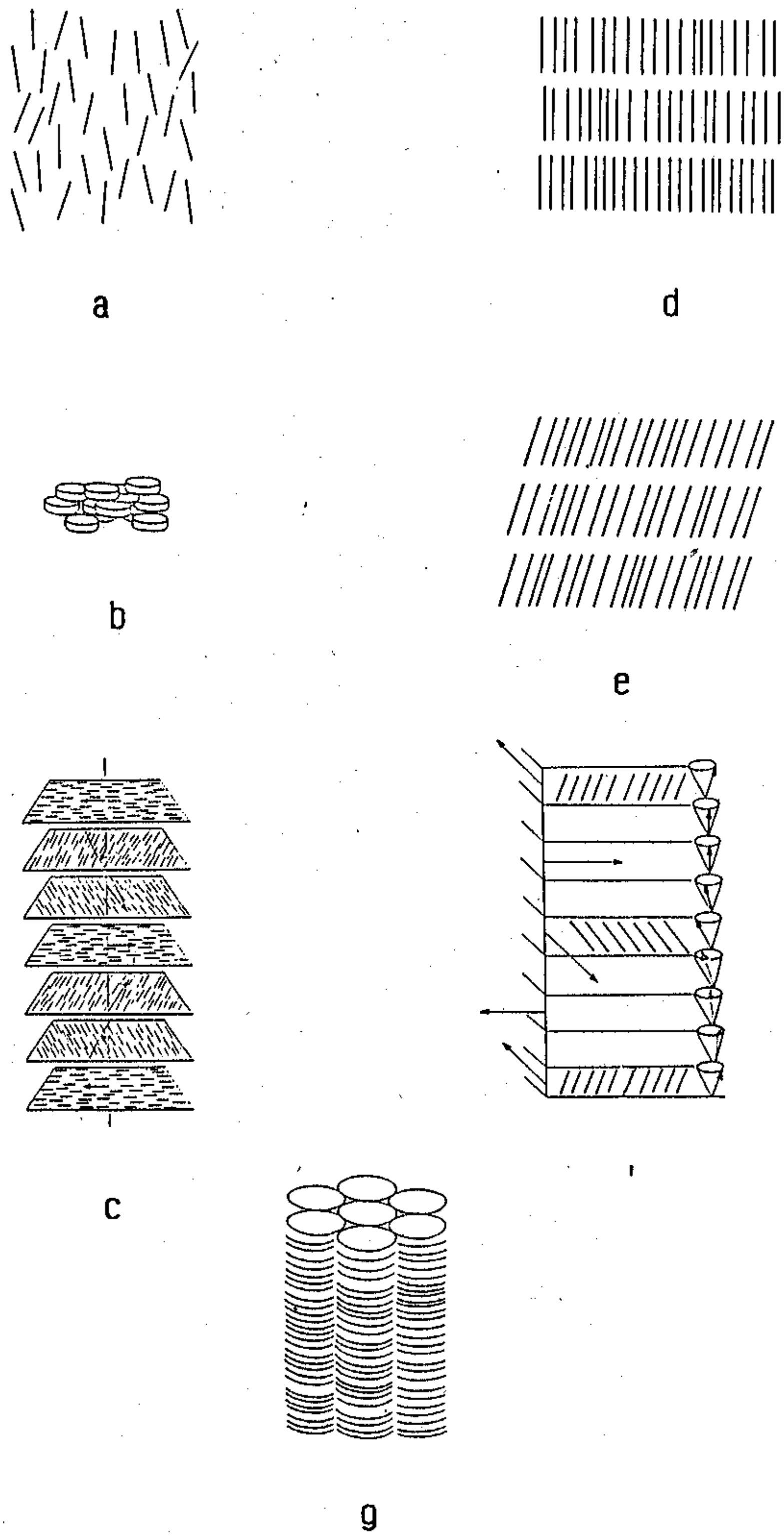


Fig 1.1: (a),(b) Nematic (c) Cholesteric (d) Smectic **A** (e) Smectic C (f) Smectic C* and **(g)** Columnar discotic

biaxial nematic phases have been realized in the laboratory.

Cholesterics: With rod-like highly anisotropic non-centrosymmetric molecules we can get a modification of the above phase. This is shown in Fig 1.c. Here the director twists spontaneously in a direction perpendicular to itself. This phase is known as a cholesteric. They can also be got by doping a nematic with an optically active molecules. The distance over which the director turnes through 2π is called the pitch. This twist gives the cholesteric a lattice structure.

Blue phases: These are therrnodynarnicaly stable phases appearing in low pitch cholesterics, in a small temperature range, just before it melts into the isotropic phase. These are in reality a three dimensional lattice of line defects. Blue phases are classified into three distinct forms called BP-I,BP-II arid BP-III depending on their lattice structure.

Smectics: In a smectic A phase which is shown in Fig 1.1d the molecules in each layer are nearly perpendicular to the layers. When the molecules are preferentially tilted and are at an angle with respect to the layer normal the phase is called smectic C. Then the projection of the molecule onto the layer plane defines a polar vector called the c-director. This is shown in Fig 1.1e. The smectic C phase is centrosymmetric. Here with non-centrosymmetric molecules we get a structure shown in Fig 1.1f wherein the c-director twist along the layer normal with the molecules spiraling from layer to layer.

Hexatic smectics: Smectic B phases are like smectic A but with a lattice ordering in the layer. Here at higher temperatures one gets a phase with long range bond oricntational order and short range positional order in each layer. These are called hexatic smectics.

Columnar phases Unlike the srnectics where there is a one dimensional lattice of liquid planes here we have a two dimensional lattice of liquid columns. A hexagonal lattice formed by this columns is shown in Fig 1.1g.

1.2 Topological defects

When looked under a polarizing microscope liquid crystals exhibit a variety of textures. These textures are characteristic of the topological defects present in them. A sludy of these defects has become a discipline by itself. The structure and properlics of these defects have been studied over the years using methods of algebraic topology, geometry and continuum mechanics [3,4]. While the first two methods give a very good description of the topological properties of these defects continuum mechanics answers the important questions pertaining to their energetics.

Topological defects in ordered systems are intimately related to the inherent global symmetries present in these systems. For example a dislocation is a topological defect peculiar to the translational symmetry of a crystal. A rotational symmetry leads to a different type of topological defect called a disclination. But in crystals disclinations have prohibitively high energies. In addition the translalional and rotational symmetry elements together can lead to dispirations also, which in simple terms are dislocation with disclination components. In liquid crystals we find not only all these topological defects but also a few others peculiar to them.

It should bc remarked that duc lo the diamagnetic or dielectric anisotropy of the molecules the structure of topological defects in liquid crystals can be very different in the presence of external magnetic or electric fields [5,6,7]. In this thesis we study the effects of external fields on the structure and energetics of topological defects in nematics, cholesterics, smectics and columnar discotics. In view of this we will first briefly discuss the topological defects that are peculiar to the different liquid crystalline phases.

1.2.1 Nematics

Disclinations:- Nematics are the simplest of the liquid crystals with only π rotational symmetry perpendicular to the director n. This can give rise to defects in the director field of n. These are called diclinations. These are the only defects present in nematics. The schlieren texture of nematics is due to the line diclinations present in them. In the case of line disclinations when we go around the line the director rotates by $2S\pi$ where S is a positive, or negative integer or half integer and is designated as the strength of the defect. The director configuration in some of these

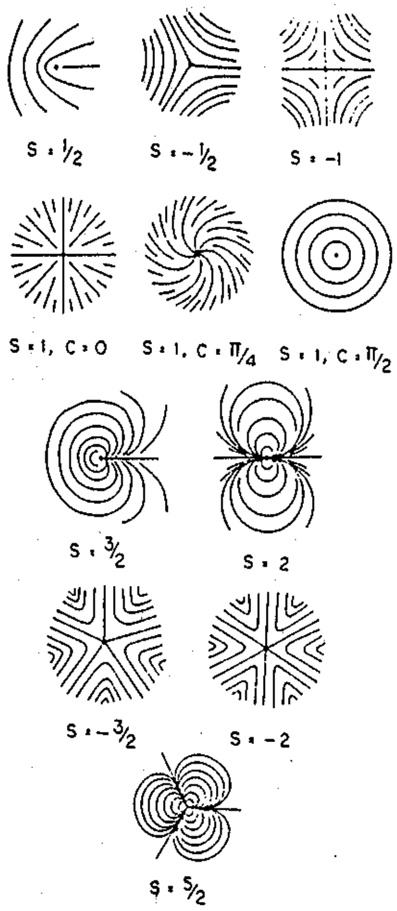


Fig 1.2: Director field around the disclination lines in Nematics

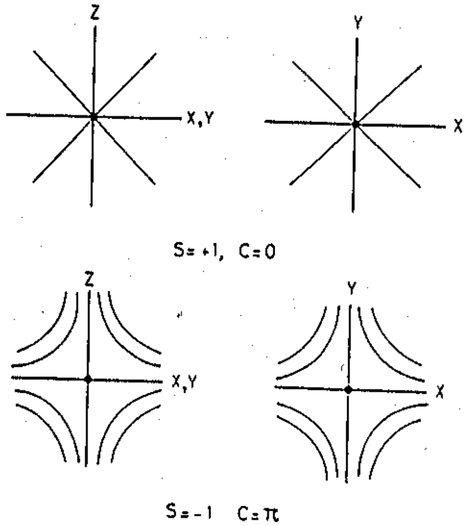


Fig 1.3: Director pattern of nematic point disclination for two orthogonal planes

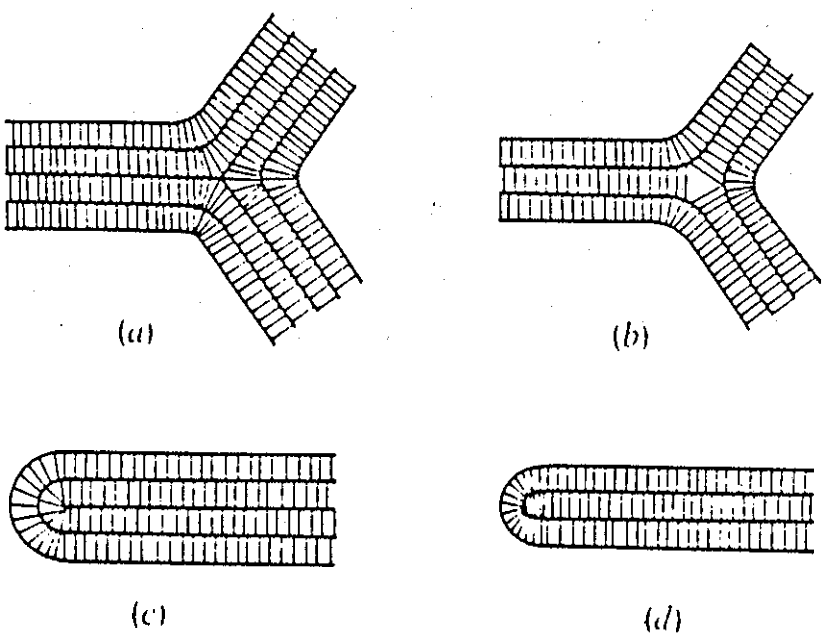


Fig 1.4: Disclinations in smectic A. (a) arid (b) for N = 1, (c) and (d) for N = −1. (a) and (c) have the singular line in between two layers while (b) and (d) have the singular line at the center of a layer

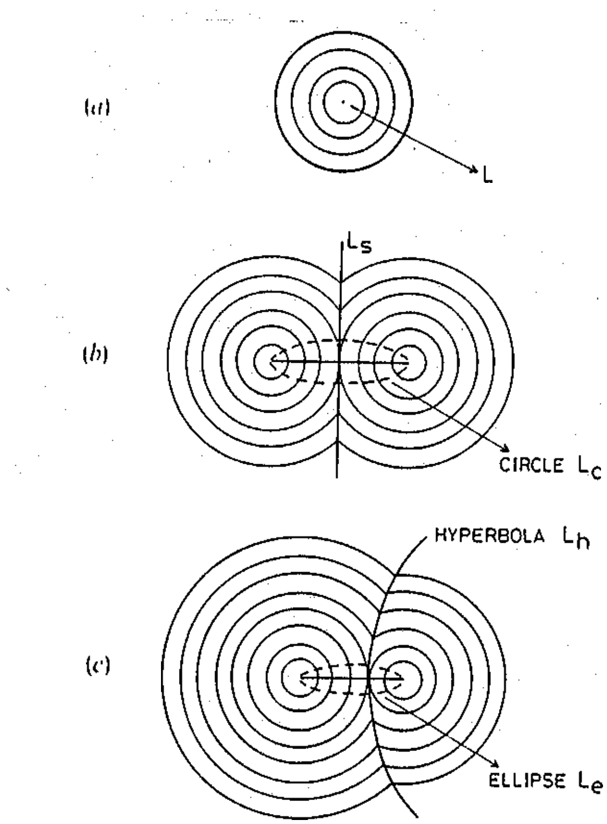


Fig 1.5: (a)Smectic layers in concentric cylinders to form a rnyeline sheath with a singular line along the axis;(b) the cylinders are closed to form tori;(c)the general case when the smectic layers form Dupin cycloids.

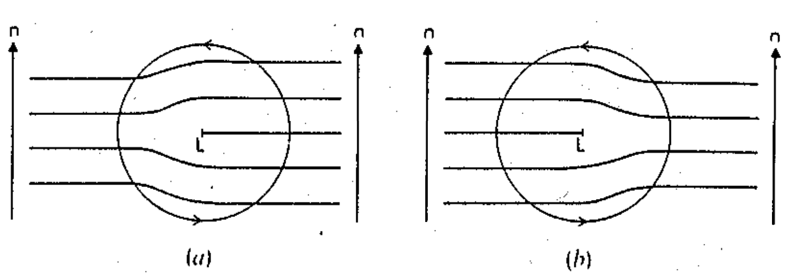


Fig 1 (a)Positive (N = $1) and (b)negative (N = −1) edge dislocations of unit strength in Smectic **A**

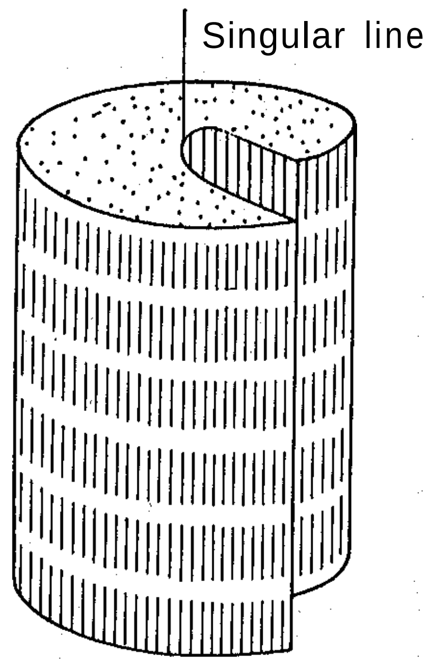
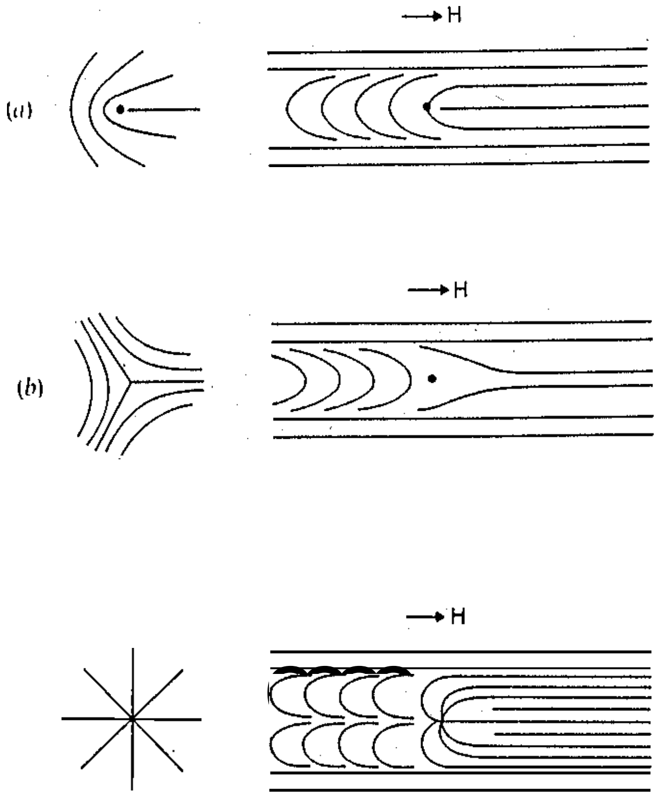


Fig 1.7: Screw dislocation in Smectic A



1 1.8: (a,b)Planar solitons and (c)linear soliton produced by a field acting along the disclination lines

defects are shown in Fig 1.2. For integral values of S these defects become non-singular through an escape in the third dimension. Disclinations can also be point singularities. These are shown in Fig 1.3. Any unlike pair of defects attract and like pairs repel.

1.2.2 Smectic A

Disclinations:- The two fold symmetry of the smectic **A** molecules allows almost all nematic disclinations to be present here also. In these defects the smectic layers are rotated through $\pm N\pi$ about the line perpendicular to the layer normal. These are shown in in Fig 1.4 for N = ± 1. It must be noticed that the two fold axis can be either between the layers or at the center of a layer.

The smectic layers are extremely flexible. But a compression of the layers is difficult. Thus N = -1 defects are energetically unfavorable. N = $+1$ have no layer distortions. Another simple defect where the compression of the layers is completely absent is shown in Fig 1.5a. Here the layers are wrapped around in concentric cylinders to form what are called a myeline sheath with a $+1$ singular line on the axis. This sheath could be closed to form a torus, the singular line become a circle L_s and as a consequence another singular line L_c appears at the center. This structure which is shown in Fig 1.5b is observed very rarely. In general the smectic layers lay on dupin cycloids. The circle then becomes an ellipse and the line L_c becomes a hyperbola,[Fig 1.5c]. These structures give rise to the focal conic texture of smectic A. We can also have point disclinations with smectic layers wrapped around in concentric spheres with a singularity at the center. It should be mentioned that disclinations associated with the focal conics can be seen experimentally.

Dislocations:- The layer structure of smectic A allows dislocations to be present in them. Fig 1.6 shows a simple edge dislocation with the singular line parallel to the layers. As we go in a loop around the line we gain or loose by N lattices. $\pm Nb$ is the Burgers vector. Where b is the layer spacing arid N is an integer. N = $+1$ in Fig 1.6a and -1 in Fig 1.6b. We can also have the Burgers vector parallel to the dislocation line. The resulting structure shown in Fig 1.7 and is called a screw dislocation.

Topologicaly these defects are very similar to their counterparts in crystals but differ considerably in their energetics.

1.2.3 Smectic C

Two types of disclinations are possible in smectic C, *viz.,* disclinations in the layer system as in smectic A and disclinations in the c director (vector representing the projection of the molecules in the layer plane). The two fold axis of smectic C is in a direction perpendicular to the plane containing the c director and the layer normal. Thus smectic **A** type lattice disclinations are possible only in this direction. The **c** director field is confined to the smectic layer and is similar to the nematic. But unlike nematic director the c vector is polar. Thus a $\pm 1/2$ disclinations are not possible in the c field. Also, all these disclination lines are singular in these structure.

1.3 Effects of external fields

Liquid crystals are diamagnetically and dielectrically anisotropic. This anisotropy χ_a which could be positive or negative causes appreciable changes in the director pattern in the presence of a magnetic or electric field. In nematics this has been studied by many. I-Iowever, smectics have not attracted as much attention.

Nematic liquid crystals have two permissible states of orientation in an external magnetic field. If the diamagnetic anisotropy (χ_a) of the nematic is positive then the director can either be parallel or antiparallel to the magnetic field . Thus in the presence of a field these two states can be connected by a wall. On crossing the wall the director turnes through f a . This distortion can be a twist, or a splay rich or a bend rich configuration. The properties of these walls were first studied in detail by Helfrich [8] and are called Helfrich walls. In a magnetic field a half-integral disclination line will get transferred to a wall terminating in a singular line. Such walls have also been referred to as planar solitons [5]. The director patterns in the walls resulting from disclination of strength $S = 1/2$ and $S = -1/2$ are shown in Fig 1.8a for $\chi_a > 0$. In the case of a point defect with all radial configuration the magnetic field give rise to a cylindrical domain ending in a singular point. This cylindrical wall has been termed as a *linear* soliton. This is shown in Fig 1.8b. Making use of the analogies with the magnetic systems many more structures which are possible have been pointed out by Ranganath [6]. We can expect similar defects in $\chi_a < 0$ nematics.

Since the magnetic field affects the structure of the defects it will also affect the interaction between them. This had not been studied in detail so far. In this thesis we undertake an investigation of this problem. We also discuss the possibilities of field induced defects in nematics,smectics and columnar phases.

1.4 Ferromagnetic liquid crystals

The magnetic field effects described above are due to the diamagnetic anisotropy (χ_a) of the molecules. Because of the small magnatude of χ_a it requires large fields (of the order of 10^3 G) to produce an appreciable distortion. In 1970 Brochard and de Gennes [1] proposed the possibility of having ferromagnetic liquid crystals with ferromagnetic grains suspended in the host liquid crystal. The suspensions are assumed to be so dilute that no interaction between the grains exist. These authors also worked out the effect of magnetic field on these systems. Considering the grain .magnetization to be very high (of the order of 1G) they neglected the intrinsic diamagnetic anisotropy of the host. These systems were made in the laboratory with needle-like grains by Rault at *al.* [10] and later by others [13,11,12]. The grains had a length of a few $100A^0$ and an aspect ratio of 1/10. Ferronematic phase with plate like grains have also been made [14]. Recently a ferrosmectic phase too was reported [15]. It was shown that it is possible to get a ferrocholesteric also by doping the ferronematics by chiral molecules [16]. All the studies undertaken so far indicate that there is a good mechanical coupling between the host and the grains. The magnetization of the grains in these examples is quite small ($10^{-4}G$). Thus χ_a of the host can be important. This is further suggested by the experimental observation of Chen and Amer [13]. They have reported a classical Fredericks transition in homogeneous geometry with the magnetization perpendicular to the director and parallel to an applied field. This result indicates that the intrinsic diamagnetic anisotropy of the host cannot be neglected. Further, the implications of elastic anisotropy can also be expected to be important. We have considered the effect of magnetic field on ferronematics taking into consideration the diamagnetic anisotropy and the elastic anisotropy of the host nematic.

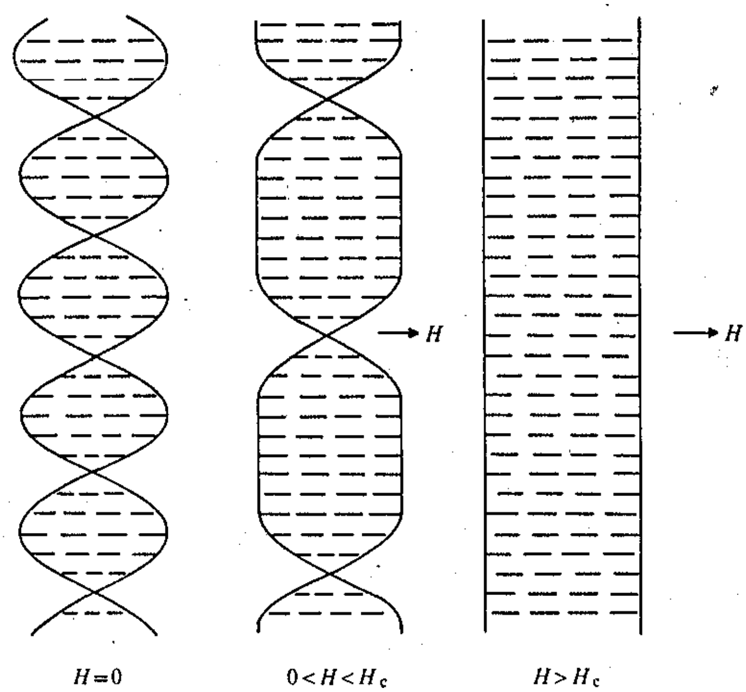


Fig 1.9: The unwinding transition of cholesteric in a magnetic field

1.5 Unwinding of cholesteric helix

When a magnetic field is applied perpendicular to the twist axis of a cholesteric the complete unwinding of the helix takes place at a critical field H_C. De Gennes [17] and independently Meyer [18] showed that for fields $0 < H < H_C$ there exists a lattice of π twist walls [shown in Fig 1.9]. Interestingly unlike nematic walls the width of this walls are independent of the field strength and is nearly the same as the pitch of the cholesteric.

Brochard and de Gennes discussed the problem of unwinding in ferrocholesterics [1]. Their calculations were done by neglecting the diamagnetic anisotropy of the host. They find that a complete unwinding does not take place even at high fields. The grains migrate out of the twisted regions resulting in a structure with magnetic domains separated by twisted regions without magnetic grains. Interestingly a complete unwinding results from the inclusion of the diamagnetic anisotropy of the host. The resulting structure is in many ways similar to that obtained in smectic C* in an electric field [19,20].

It is quite possible to study the unwinding of cholesterics and ferrocholesterics using an optical technique. This could also be used to study the grain segregation in ferrocholesterics. With this in mind we undertook a study of the optical behavior of these lattices for light propagation parallel (Bragg mode) and perpendicular (Phase grating mode) to twist axis.

References

[1] *de* Gennes,P.G., *1974, The Physics of Liquid Cryatals* (Oxford:Clarendon *Press)*

[2] Chandrasekher,S., *1977, Liquid Crystals (Cambridge University Press)*

[3] Mermin,N.D., *1969, Rev. Mod. Phys, 51, 591*

[4] Chandrasekher,S. *and* Ranganath,G.S., *1986, Advances in Phys., 35, 507*

[5] Mineev,V.P., *and* Volovik,G.E., *1978, Phy. Rev., B18, 3197*

[6] Ranganath,G.S., *1988, Mol. Cryst. Liq. Cryst, 154, 43*

[7] Sunil Kumar,P.B. *and* Ranganath,G.S., *1989, Mol. Cryst. Liq. Cryst, 177, 131*

[8] Helfrich,W., *1968, Phy. Rev. Lett., 21, 1518*

[9] Brochard,F. *and de* Gennes,P.G., *1970, J. Phys. Paris, 31,691*

[10] Rault,J., Cladis,P.E. *and* Burger,J.P., *1970, Phys. Lett,* **32A**, *199*

[11] Chen,S.H. *and* Chiang,S.H., *1987, Mol. Cryst. Liq. Cryst, 144, 359*

[12] Raikher,Yu.L., Burylov,S.U. *and* Zakhleunych,A.N., *1987 J. Mag. Mag. Mater, 65, 173*

[13] Chen,S.H. *and* Amer,N.M., *1983, Phys. Rev. Lett, 51, 2298*

[14] Deuling,H.J. *and* Helfrich,W., *1974, Appl. Phys. Lett, 25, 129*

[15] Fabre,P., Casagrande,C. *and Veyssie, 1990, Phys. Rev. Lett, 64, 539*

[16] Arnold,H. *and* Rondelez,F., *1974, Mol. Cryst. Liq. Cryst, 26, 11*

[17] *dc* Gennes,P.G., *1968, Sol. State Commun., 6, 163*

[18] Meyer,R,B., *1968, Appl. Phys. Lett., 12, 281*

[19] Dmitrienko,V.E. *and* Belyakov,V.A., *1980, Sov. Phys. JETP, 51, 787*

[20] Hudák,O., *1983, J. Phys. (Paris),* 44, *57*