

VSP project report

On

**MAGNETIC BIREFRINGENCE OF LIQUID CRYSTAL**

Submitted by

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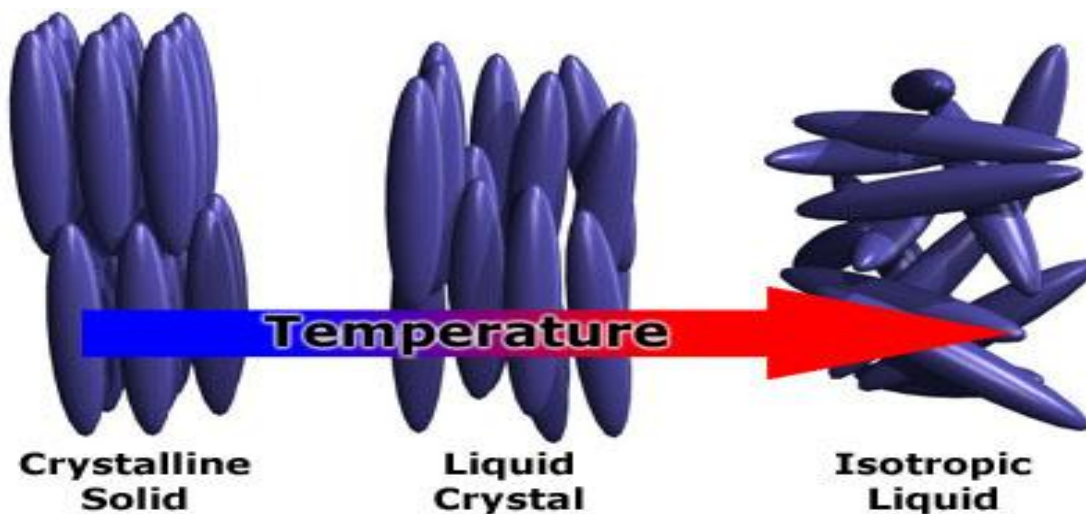
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## LIQUID CRYSTALS

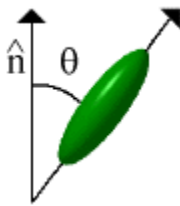
Liquid crystal materials generally have several common characteristics. Among these are a rod-like molecular structure, rigidity of the long axis, and strong dipoles and/or easily polarizable substituents.

The distinguishing characteristic of the liquid crystalline state is the tendency of the molecules (mesogens) to point along a common axis, called the director. This is in contrast to molecules in the liquid phase, which have no intrinsic order. In the solid state, molecules are highly ordered and have little translational freedom. The characteristic orientational order of the liquid crystal state is between the traditional solid and liquid phases and this is the origin of the term mesogenic state, used synonymously with liquid crystal state. Note the average alignment of the molecules for each phase in the following diagram.



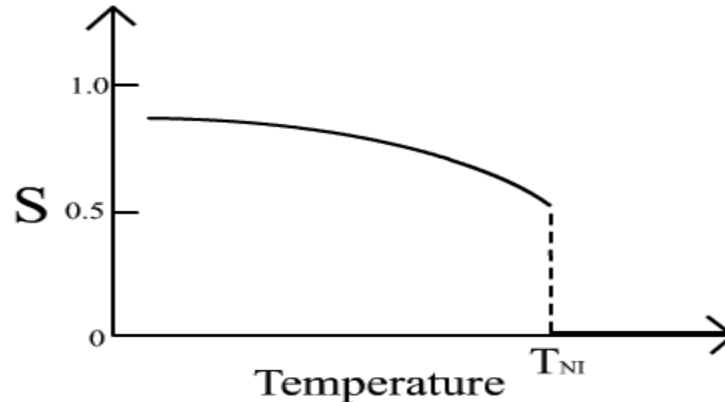
It is sometimes difficult to determine whether a material is in a crystal or liquid crystal state. Crystalline materials demonstrate long range periodic order in three dimensions. By definition, an isotropic liquid has no orientational order. Substances that aren't as ordered as a solid, yet have some degree of alignment are properly called liquid crystals.

To quantify just how much order is present in a material, an order parameter ( $S$ ) is defined. Traditionally, the order parameter is given as follows:



$$S = (1/2) \langle 3 \cos^2 \theta - 1 \rangle$$

where theta is the angle between the director and the long axis of each molecule. The brackets denote an average over all of the molecules in the sample. In an isotropic liquid, the average of the cosine terms is zero, and therefore the order parameter is equal to zero. For a perfect crystal, the order parameter evaluates to one. Typical values for the order parameter of a liquid crystal range between 0.3 and 0.9, with the exact value a function of temperature, as a result of kinetic molecular motion. This is illustrated below for a nematic liquid crystal material (to be discussed



in the next section).

The tendency of the liquid crystal molecules to point along the director leads to a condition known as anisotropy. This term means that the properties of a material depend on the direction in which they are measured. For example, it is easier to cut a piece of wood along the grain than against it. The anisotropic nature of liquid crystals is responsible for the unique optical properties exploited by scientists and engineers in a variety of applications.

## CHARACTERIZING LIQUID CRYSTALS\

The following parameters describe the liquid crystalline structure:

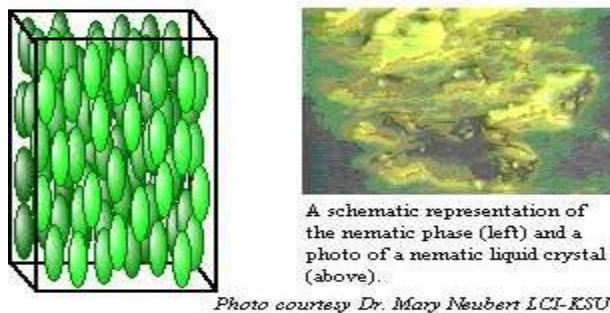
- *Positional Order*
- *Orientalional Order*
- *Bond Orientalional Order*

## THERMOTROPIC PHASES

- Thermotropic liquid crystals can generally be formed by prolate (calamitic) molecules or oblate (discotic) molecules. Liquid crystal phases formed by calamitic molecules fall into three different categories: nematic, chiral nematic, and smectic.

### Nematic Liquid Crystal Phase

The simplest liquid crystal phase is called the nematic phase (N). It is characterized by a high degree of long range orientational order but no translational order. Molecules in a nematic phase spontaneously order with their (for calamitic molecules) long axes roughly parallel. A schematic diagram of a nematic phase is shown in Fig. 1.1. An uniformly aligned nematic has a preferred direction, often described in terms of a unit vector called the director,  $\mathbf{n}$ . More generally a bulk nematic will contain domains. The orientation of the director is constant in each domain but is different in different domains. Viewed under a polarizing microscope the defect regions linking these domains appear as dark threads



**Figure 1.1:** Schematic diagram of a nematic liquid crystal

### Chiral Nematic Liquid Crystal Phase

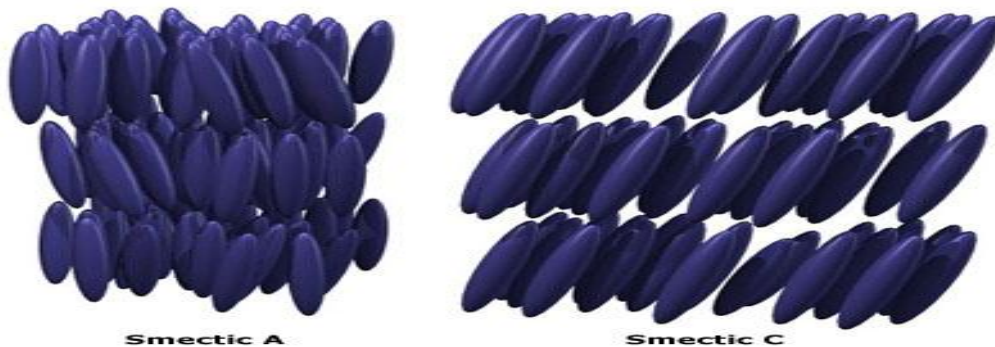
Chiral molecules can also form nematic phases called chiral nematic (or cholesteric) phases (N\*). This phase shows nematic ordering but the preferred direction rotates throughout the sample. The axis of this rotation is normal to the director. An example of this is shown in Fig. . The distance over which the director rotates by  $360^\circ$  is called the chiral pitch and is generally of the order of hundreds of nanometres, the wavelength of visible light. A non-chiral nematic phase can be thought of as a chiral nematic with an infinite pitch.



**Figure 1.2:** Schematic diagram of a chiral nematic liquid crystal

### Smectic Liquid Crystal Phases

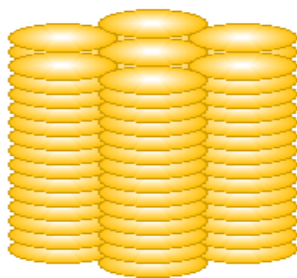
Smectic phases have further degrees of order compared to the nematic phase. In the simplest smectic phase, the smectic-A (SmA) phase, the molecules order into layers, with the layer normal parallel to the director. Within the layers, liquid like structure remains, as shown in Fig. 1.3.



**Figure 1.3:** Schematic diagram of a smectic-A liquid crystal

Closely related to the SmA phase is the smectic-C (SmC) phase. Here the molecules form a layer structure but the long axes of the molecules, and hence the director, lies at an angle to the layer normal, as shown in Fig. 1.4. There are many other smectic phases which have long range order within the layers. Smectic phases can also be formed by chiral molecules, leading to chiral smectic phases.

## Discotic Liquid Crystal Phases



Liquid crystal phases formed by discotic molecules fall into three different categories: discotic nematic, discotic chiral nematic, and columnar. The discotic nematic is similar in structure to the calamitic nematic, although in this case the short axes of the molecules tend to lie parallel. The same holds for the discotic chiral nematic phases.

Columnar phases are the discotic equivalent of the smectic phase. Here the molecules form columns. In the simplest case the short axes of the molecules lie parallel to the axis of the column and the columns are randomly distributed in space. More complicated discotic phases exist, where the short molecular axes lie at an angle to the column and translational order exists between the columns, analogous to the more complicated smectic phases.

### OTHER THERMOTROPIC PHASES

Most of the phases exhibited by low molecular mass liquid crystals are described above. Recently however there has been much interest in the so-called 'banana' phases formed by bent-core molecules. Some of these phases are chiral although the molecules forming them are achiral.

Some high molecular mass polymers, liquid crystalline polymers (LCP), can also form liquid crystal phases. These fall into two categories depending on where the mesogenic part of the molecule is located. If the mesogenic unit is contained within the main polymer chain then it is termed a main chain liquid crystal polymer (MCLCP). If it is attached to a side chain of the polymer then it is termed a side chain liquid crystal polymer (SCLCP). As well as depending on the nature of the mesogenic core, the mesophases formed by these materials are dependent on the flexibility of the polymer backbone and (for SCLCP's) the side chain.

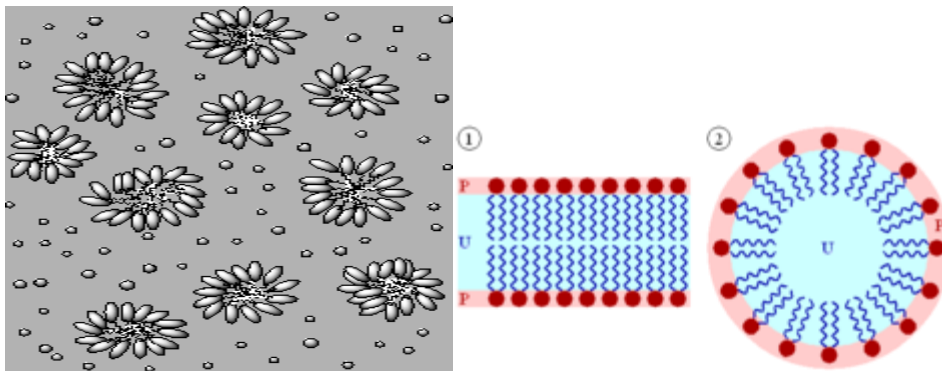
Closely related to LCP's are dendritic liquid crystals. These molecules consist of a central core with the mesogenic units attached to flexible spacers that radiate out from the core.

## LYOTROPIC LIQUID CRYSTAL PHASES

Lyotropic liquid crystal phases are formed by amphiphilic molecules. These often consist of a polar head group attached to one or more non-polar chains and are often known as *surfactants* (surface active agents). A schematic is shown in Fig. 1.5. When these are dissolved in an appropriate solvent they self-assemble so the polar (hydrophilic) heads protect the non-polar (hydrophobic) tails. These structures are known as micelles. At low surfactant concentrations these are roughly spherical, as shown in Fig. 1.6. As the surfactant concentration increases then other phases are formed. These include the hexagonal phase where the amphiphiles form cylinders that pack in a hexagonal array and the lamellar phase where the amphiphiles form a bilayer structure.



**Figure 1.5:** Schematic diagram of an amphiphilic molecule



**Figure 1.6:** Schematic diagram of micelles

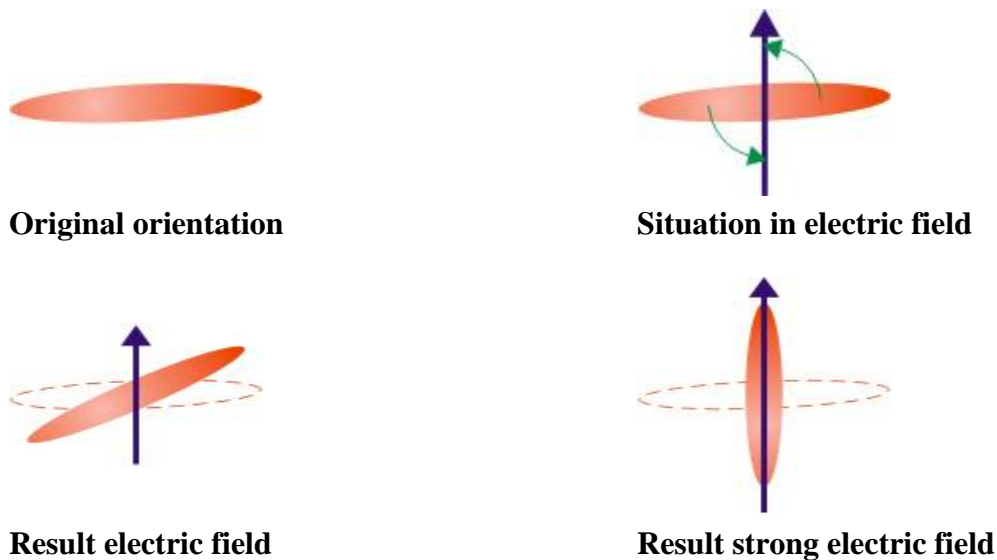
Structure of lyotropic liquid crystal. The red heads of surfactant molecules are in contact with water, whereas the tails are immersed in oil (blue): bilayer (left) and micelle (right)

A generic progression of phases, going from low to high amphiphile concentration, is:

- Discontinuous cubic phase (micellar cubic phase)
- Hexagonal phase (hexagonal columnar phase) (middle phase)
- Lamellar phase
- Bicontinuous cubic phase
- Reverse hexagonal columnar phase
- Inverse cubic phase (Inverse micellar phase).

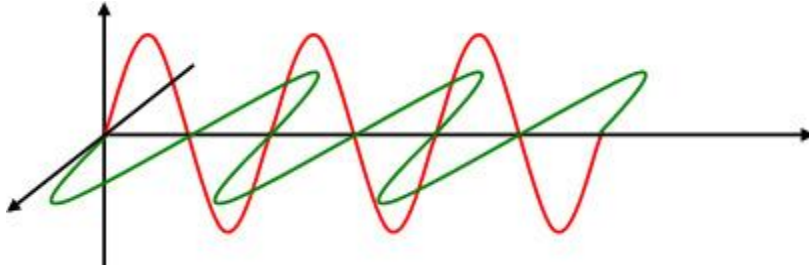
field. As a result, a torque is exerted on the director. For materials with positive anisotropy, the director prefers to align parallel to the electric field. Liquid crystals with a negative anisotropy tend to orient themselves perpendicularly to the electric field.

The effect of an electric field on a liquid crystal medium with positive anisotropy is illustrated in the pictures below. Originally the orientation is almost horizontal. When an electric field with direction along the blue arrow is applied, a torque (represented in green) rising from the dielectric anisotropy, acts on the molecule. The torque tends to align the molecule parallel to the field. When the field strength is increased, the molecule will reorient parallel to the field.



The technological importance of the reorientation is obvious: it gives a switchable medium by simply varying the applied electric field in the liquid crystal medium. In most applications a liquid crystal is used in a thin layer between two glass surfaces. To generate the electric field, thin electrodes layers are deposited on the bottom and/or top glass surface. For optical devices transparent electrodes are used, made from Indium Tin Oxide (ITO). If the generated field is strong enough, the molecules will reorient to follow its direction.

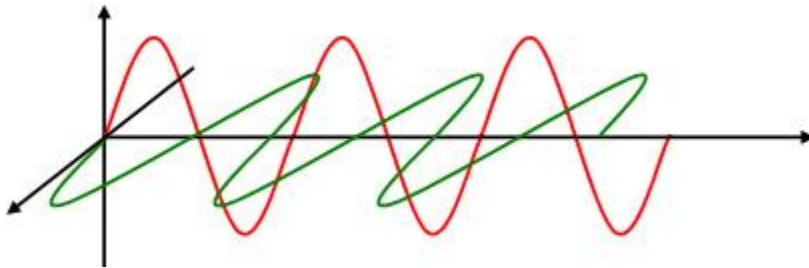




### **Light propagation in an isotropic medium**

For the uniaxial liquid crystal medium, an electric field feels a different refractive index when it oscillates in the plane perpendicular to the director or along the director. This uniaxial anisotropy of the refractive index is called birefringence. Birefringence allows to manipulate the polarization of the light propagating through the medium.

The elliptical polarization of light entering a liquid crystal medium must be decomposed into two linear polarizations called the ordinary and the extra-ordinary mode. Along these two directions, the two linearly polarized modes feel a different refractive index. Therefore, they propagate through the liquid crystal with a different speed as illustrated in the picture below.



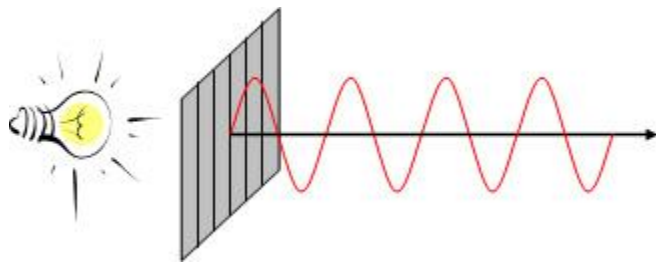
### **Light propagation in a birefringent medium**

In the isotropic medium, the two parts propagated with the same speed. Combining them back together will result in the same polarization ellipse as the original. In birefringent media, the different speed of the ordinary and extra-ordinary waves results in a phase difference between the two modes (= retardation). At the end of the medium this phase difference between the two oscillations will result in a different polarization ellipse.

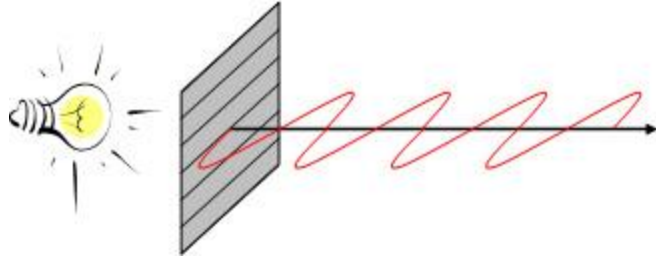
## Switchable birefringence

To observe the influence of birefringence, polarized light must be used. Most light sources such as a light bulb or a fluorescent lamp produce unpolarized light. Optical applications often require polarized light with a known oscillation direction of the light. To obtain polarized light, ordinary light sources can be used in combination with polarizers.

A polarizer is a special type of birefringent layer. The ordinary wave propagates unmodified through the medium, whereas the extra-ordinary wave is absorbed in the medium. An arbitrarily polarized wave entering such a medium will result in a linearly polarized wave at the back of the medium. In the picture above the effect of a polarizer is illustrated for two different orientations of the absorbing direction.

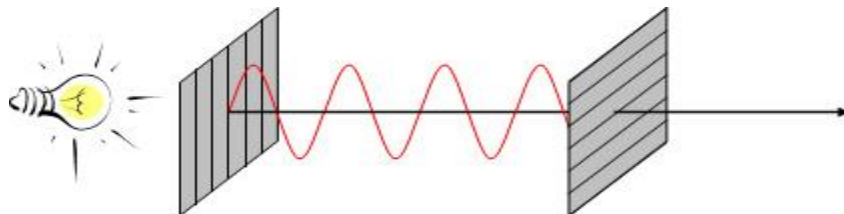


**Polarizer with vertical transmission axis**



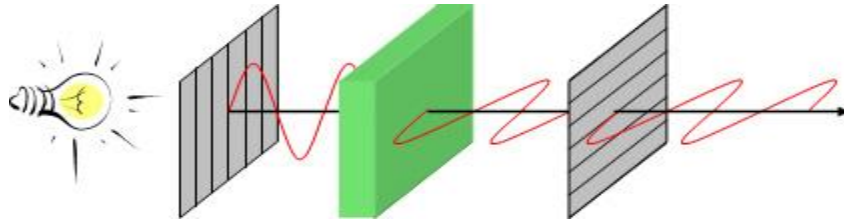
**Polarizer with horizontal transmission axis**

If two polarizers with orthogonal absorption direction are used, all light emitted by the light source is absorbed. This is typically referred to as a set of crossed polarizers.



## Crossed polarizers

Birefringence is important for modifying and controlling the polarization of light propagating through the medium. A liquid crystal layer inserted between crossed polarizers can change the polarization of the light propagating through, which results in light transmission after the crossed polarizers.



### A liquid crystal layer between crossed polarizers

Because the director can be controlled using an electric field, a liquid crystal is a controllable birefringent medium. Therefore, the polarization state of the light after the liquid crystal layer can be changed and hence the intensity of the transmission through the crossed polarizers is adapted.

### Choosing the preferential direction of the molecules

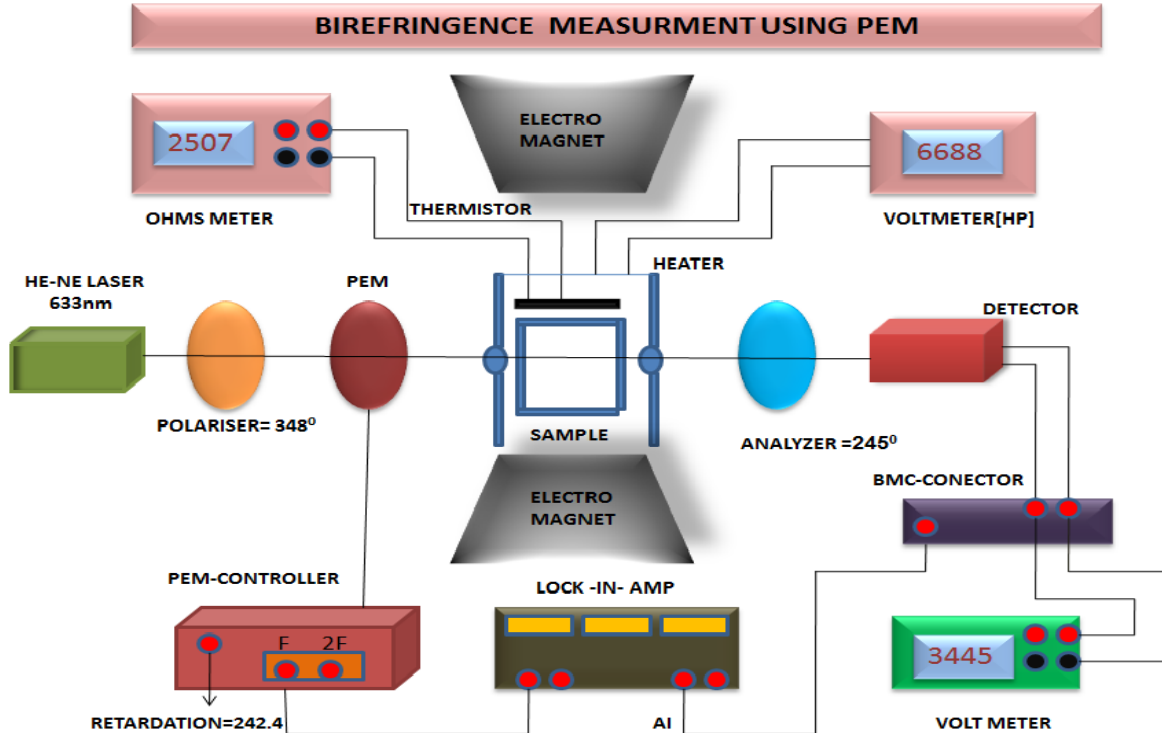
In a glass vessel a liquid crystal appears as an opaque milky fluid. The random variation of the director in the material on a micrometer scale is the main cause of the light scattering.

For applications, it is important to obtain a region free of defects with a known director distribution. Therefore, liquid crystals are usually handled in thin layers between two substrates. Control of the director at the surfaces allows reproducible director orientations as illustrated below. The fixed orientation of the surface director forces the director in the bulk to follow this direction. Two commonly used types of alignment are planar and homeotropic alignment. In planar alignment the surface director is oriented parallel to the surface, for homeotropic alignment it is oriented perpendicular to the surface.

- The sample will split the beam coming from polarizer through the PEM, both light beam propagate at different velocities.
- The light passing through the optical system is registered by photodiode.[Detector]
- The detector output is split with one branch going to a Lock-in-Amplifier for detection of an AC signal and another branch going to a DC signal.
- The photodiode converts the light intensity into an electrical signal. DC signal strength is independent of the orientation of the sample with respect to the analyzer.
- Lock-in-Amplifier has another one connection from PEM controller.[PEM-F port connected to Ref<sub>in</sub> port of Lock-in amplifier. PEM controller connected to the PEM crystal.
- Magnetic field kept at 2 Tesla.

This arrangement is very suitable for the measurement of very low birefringence level since the sensitivity of PEM is less than  $0.01^\circ$

### BLOCK DIAGRAM



- The profile of transmitted intensity on cooling or heating the sample in equal temperature step is recorded from isotropic phase down to appropriate temperature.
- The transmitted intensity is an oscillatory function within maxima minima occurring for  $\Delta\phi = (2m+1)\pi$  and  $2m\pi$  respectively. The consecutive maxima minima get broadened with lowering of temperature. The value of transmitted intensity is nearly zero in the isotropic phase as expected.
- Now isotropic phase is taken as nil phase difference and the first maximum occurs at  $\pi$  and minimum at  $2\pi$  and so on. From isotropic to first maximum, we calculated  $\Delta n$  directly from the formula. In going from  $\pi$  to  $2\pi$ , we have subtracted 360 from the  $\Delta\phi$  using  $I = I_0 (1 - \cos\Delta\phi)/2$ . In going from  $2\pi$  to  $3\pi$ , we added  $2\pi$  to  $\Delta\phi$  and in going from  $3\pi$  to  $4\pi$  we subtracted  $\pi$  from  $\Delta\phi$  and then added  $3\pi$  to it. This  $\Delta\phi$  value is used to calculate  $\Delta n$ . then we plotted the graphs between  $\Delta n$  and temperature.

### BLOCK DIAGRAM

