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Study Of Different Phases, Properties And Types Of Liquid Crystal

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ABSTRACT

This paper investigates some of the liquid crystal phases, properties, and types. The study of molecular geometry is essential for understanding the properties of liquid crystals. Certain features of molecular geometry are covered, as well as the classification of liquid crystals. The molecular packings in several liquid crystalline formations are presented and associated with some liquid crystalline state of matter phenomena. Optical features related to liquid crystal applications are described. Liquid crystal applications are concentrated on three areas. These include using cholesteric materials (spontaneously twisted nematic liquid crystals) in non-destructive testing in industrial laboratories and medical clinics, using liquid crystals in displays, and using liquid crystals as solvents.

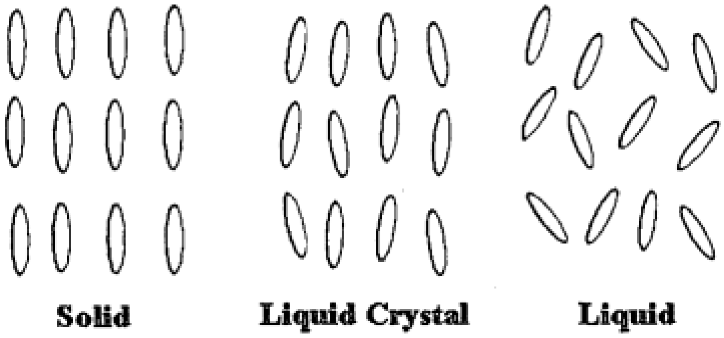
Keywords: Liquid crystals (LCs), Thermotropic, Lyotropic, Metallotropic

1. Introduction

Liquid crystals (LCs) are a state of matter with qualities that fall in between a liquid and a solid crystal. An LC, for example, may flow like a liquid but have its molecules arranged in a crystal-like manner. LC phases come in a variety of shapes and sizes, each with its own set of optical properties (such as birefringence). Different liquid crystal phases appear to have various textures when seen under a microscope with a polarized light source. Domains where the LC molecules are orientated in opposite directions correspond to the contrasting parts in the textures. The molecules, on the other hand, are well organized within a domain. It's possible that LC materials aren't always in the LC phase (just as water may turn into ice or steam).Thermotropic, lyotropic, and metallotropic phases can be found in liquid crystals. Organic molecules make up thermotropic and lyotropic LCs. When the temperature of thermotropic LCs is adjusted, the phase transition into the LC phase occurs. Lyotropic LCs show phase transitions as a function of temperature and LC molecule concentration in a solvent (typically water). Metallotropic LCs contains both organic and inorganic molecules, and their LC transition is influenced not only by temperature and concentration but also by the ratio of inorganic to organic molecules.Liquid crystals can be found in the natural world as well as in technology applications. Liquid crystal displays are used in the majority of current electronic displays. In living systems, lyotropic liquid-crystalline phases abound. Many proteins and cell membranes, for example, are LCs. Soap solutions and related detergents, as well as tobacco mosaic virus, are other well-known LC examples.

The liquid crystal state's characteristic orientation order is intermediate between the traditional solid and liquid phases, which are the origin of the name mesogenic state, which is used interchangeably with liquid crystal state. The average molecular alignment for each step is depicted in the diagram below.

Figure1: The average alignment of the molecules for each phase



It might be difficult to tell whether a material is crystallised or liquid crystallised. In three dimensions, crystalline materials show long-range periodic order. An isotropic liquid, by definition, has no orientation orders. Liquid crystals are substances that aren't as organised as a solid but yet have some degree of alignment.

Friedrich Reinitzer, an Austrian plant physiologist working at Prague's Charles University, investigated the physicochemical properties of several cholesterol derivatives, now known as cholesteric liquid crystals, in 1888. Other researchers had seen unusual colour effects when cooling cholesterol derivatives just over the freezing point in the past, but they hadn't linked it to a new phenomena. Color alterations in a derivative cholesteryl benzoate, according to Reinitzer, were not the most unusual trait. He discovered that cholesteryl benzoate melts differently than other chemicals, with two melting points. It melts into a cloudy liquid at 145.5°C (293.9°F), then melts again at 178.5°C (353.3°F) and the cloudy liquid turns clear. The phenomenon can be reversed. On March 14, 1888, he wrote to Otto Lehmann, a Privatdozent in Aachen, seeking help from a physicist. They corresponded via letters and Samp1es. Lehmann looked at the hazy fluid in the middle and saw crystallites. Von Zepharovich, Reinitzer's Viennese colleague, also stated that the intermediary "fluid" was crystalline. On April 24, the exchange of letters with Lehmann came to an end, leaving many things unresolved. On May 3, 1888, Reinitzer reported his findings at a meeting of the Vienna Chemical Society, giving credit to Lehmann and von Zepharovich.

Reinitzer had discovered and characterised three key characteristics of cholesteric liquid crystals (a term invented by Georges Friedel in 1922) by that time: the presence of two melting points, the ref1ection of circularly polarised light, and the ability to rotate the polarisation direction of light.

Reinitzer did not continue his research into liquid crystals after his unintentional finding. Lehmann resumed his research after realising he had discovered a new phenomenon and was in a position to investigate it: He had learned crystallography and microscopy throughout his postdoctoral years. Lehmann began a thorough investigation into the double-melting phenomena, first with cholesteryl benzoate and then with related compounds. He could observe things in polarised light, and his microscope had a hot stage (a sample holder with a heater) that allowed him to observe things at high temperatures. Although the intermediate foggy phase certainly maintained flow, other characteristics, particularly the signature seen under a microscope, convinced Lehmann that he was dealing with a solid. He presented his findings in the ZeitschriftfürPhysikalischeChemie at the end of August 1889.

Daniel Vorlander, a German chemist who produced most of the known liquid crystals from the turn of the century until his retirement in 1935, maintained and improved on Lehmann's work. Liquid crystals, on the other hand, were not well received by scientists, and the material remained a scientific curiosity for nearly 80 years.

Hans Kelker succeeded in synthesising MBBA, a chemical with a nematic phase at room temperature, in 1969, and it is now one of the most popular liquid crystal research topics. George Gray's creation of more chemically stable compounds (cyanobiphenyls) with low melting temperatures was the next step toward commercialisation of liquid crystal displays.

Pierre-Gilles de Gennes was awarded the Nobel Prize in Physics in 1991, when liquid crystal displays were already well established, "for discovering that methods developed for studying order phenomena in simple systems can be generalised to more complex forms of matter, in particular liquid crystals and polymers."

Liquid crystal materials are one-of-a-kind in terms of their characteristics and applications. Liquid crystals will play an increasingly essential role in modern technology as research into this field develops and new applications are created.

2. Phases of Liquid Crystals

The type of ordering distinguishes the distinct LC stages (known as mesophases). Positional order (whether molecules are arranged in any sort of ordered lattice) and orientational order (whether molecules are mostly pointing in the same direction) can be distinguished, and order can also be short-range (only between molecules close to each other) or long-range (between molecules far apart) (extending to larger, sometimes macroscopic, dimensions). At high temperatures, most thermotropic LCs will have an isotropic phase. That is, heating will cause them to transition to a traditional liquid phase with random and isotropic molecular ordering (little to no long-range organisation) and fluid-lit:e flow behaviour. An LC may inhabit one or more phases with strong anisotropic orientational structure and short-range orientational order while still being able to flow under other conditions (for example, lower temperature).

On a molecular level, the ordering of liquid crystalline phases is comprehensive. This order normally extends up to the domain size, which can be on the order of micrometres, but not to the macroscopic scale, as it does in traditional crystalline solids. In a macroscopic liquid crystal sample, several strategies, such as the use of boundaries or an applied electric field, can be utilised to enforce a single ordered domain. A liquid crystal's ordering may be limited to one dimension, with the material being basically disordered in the other two.

Thermotropic phases:-

Thermotropic phases occur within a specific temperature range. Thermal motion will ruin the precise cooperative ordering of the LC phase if the temperature rise is too high, driving the material into a standard isotropic liquid phase. Most LC materials will form a conventional crystal at too low a temperature. As the temperature is varied, many thermotropic LCs exhibit a variety of phases. As temperature rises, a specific form of LC molecule (called mesogen) may exhibit distinct smectic and nematic (and finally isotropic) phases. Para-azoxyanisole is an example of a chemical that exhibits thermotropic LC behaviour.

Nematic Phase:-

Figure 2: Nematic Phase

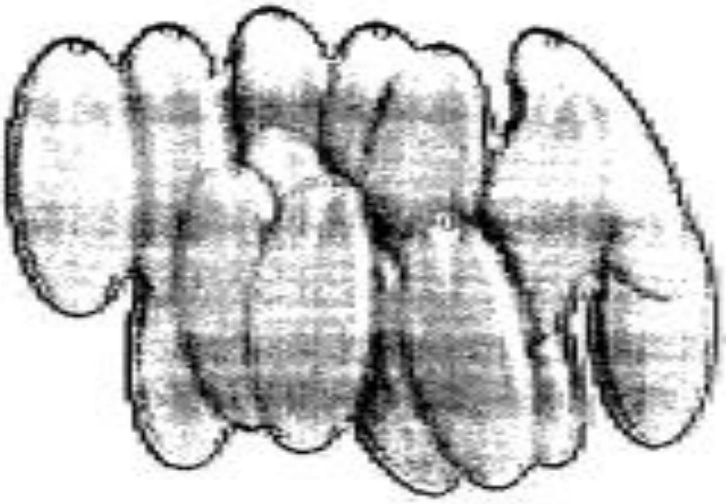
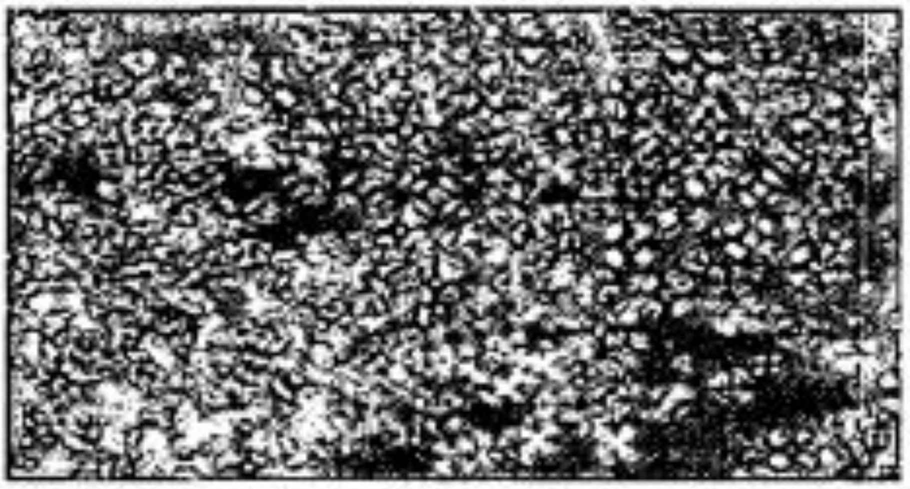


Figure 3: Alignment in a nematic phase

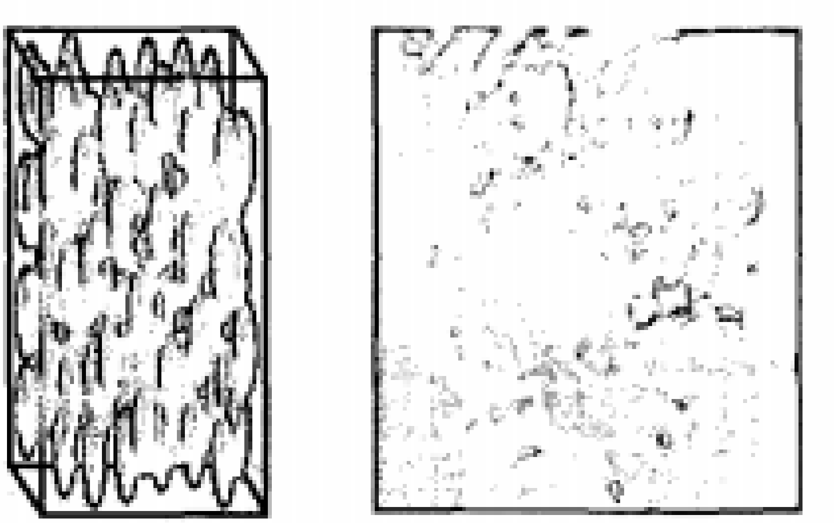


Between crossed polarizers, a phase transition between nematic (left) and smecticA (right) phases was detected. Isotropic medium is represented by the black hue.

The nematic phase is one of the most common LC phases. Nematic is derived from the Greek word nema, which meaning "thread." The phrase comes from the thread-like topological defects found in nematics, which are formally referred to as 'disclinations.' Hedgehog topological flaws are also seen in nematics. The calamitic or rod-shaped organic molecules do not exhibit positional order in the nematic phase, but they self-align to have long-range directional order with their long axes generally parallel. As a result, the molecules are free to move and their centres of mass positions are randomly distributed, just like in a liquid, but their long-range directional order is preserved. The majority of nematics are uniaxial, meaning that one axis is longer and favoured, while the other two are equal (can be approximated as cylinders or rods). Some liquid crystals, on the other hand, are biaxial nematics, which means that in addition to their long axis, they also orient along a secondary axis. Nematics have the fluidity of conventional (isotropic) liquids, but they can be aligned easily by an external magnetic or electric field. Because aligned nematics share the optical qualities of uniaxial crystals, they're ideal for liquid crystal displays (LCD).

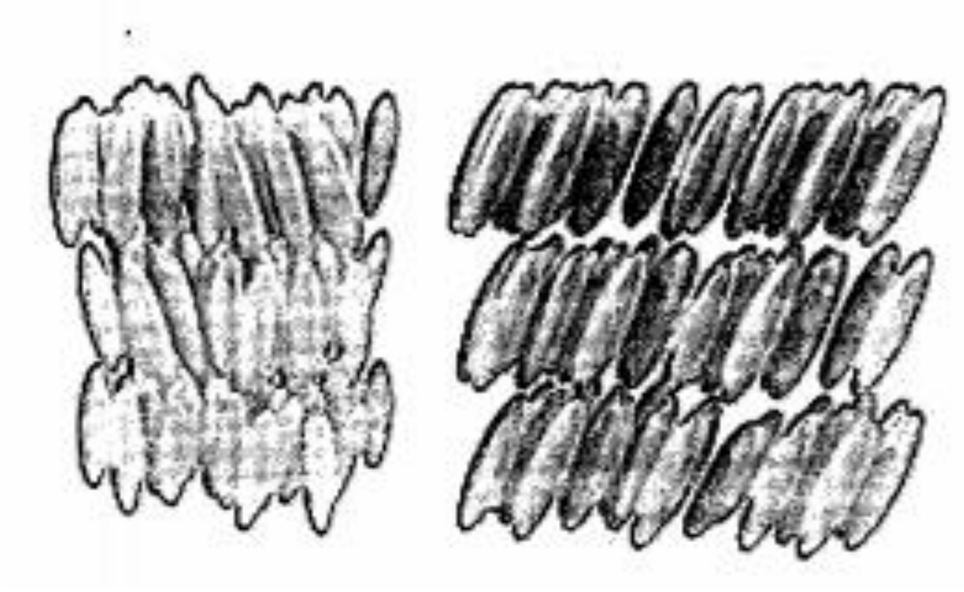
As a result, molecules in the nematic liquid crystal phase have no positional order but tend to point in the same direction (along the director). The molecules in the accompanying diagram point vertically but are not placed in any particular order.

Figure 4: A schematic representation of the nematic phase (left) and a photo of a nematic liquid crystal (right).



Smectic phases:-

Figure 5: Schematic of alignment in the smectic phases.

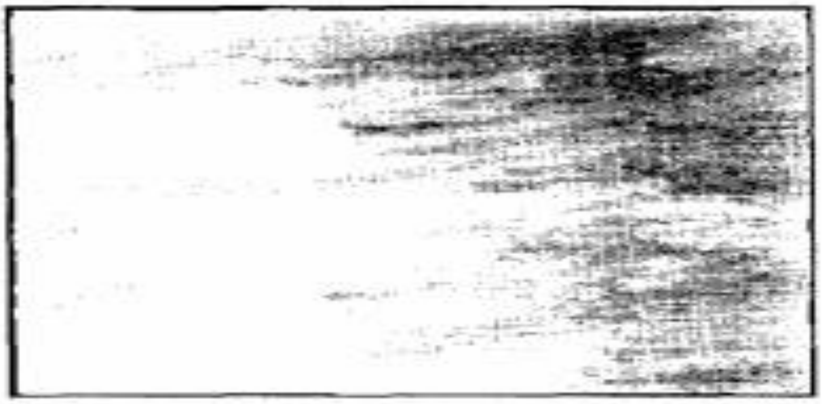


The molecules in the smecticA phase (left) are arranged in layers. The molecules are tilted inside the layers in the smectic C phase (right).

At lower temperatures than the nematic phases, the smectic phases produce well-defined layers that can slide over one another in a manner akin to soap. As a result, the smectics are sorted in one way. The molecules are orientated along the layer normal in the Smectic A phase, but slanted away from the layer normal in the Smectic C phase. Within the layers, these phases are liquid-like. Smectic phases come in a variety of shapes and sizes, with varying degrees of positional and orientational order.

The word "smectic" comes from a Greek word that means "soap." The thick, slippery substance frequently seen at the bottom of a soap dish is actually a sort of smectic liquid crystal, which explains the unclear origin. Another distinct mesophase of liquid crystal solids is the smectic state. Molecules in this phase have a level of translational organisation that is not present in the nematic phase. The molecules maintain the general orientational order of nematics in the smectic state, but they also tend to organise themselves in layers or planes. Separate planes are observed to flow past each other, indicating that motion is restricted to inside these planes. The smectic state is more "solid-like" than the nematic due to the enhanced order.

Figure 6: Photo of a smectic phase (using polarizing microscope)



Many substances have been shown to produce multiple smectic phases. There are as many as 12 different varieties, but only the most distinct phases are mentioned here.

The director is perpendicular to the smectic plane in the smectic-A mesophase, and the layer has no particular positional order. The direction is perpendicular to the smectic plane in the smectic-B mesophase, but the molecules are organised in a network of hexagons within the layer. The molecules in the smectic-C mesophase are arranged similarly to those in the smectic-A mesophase, but the director is tilted at a constant angle to the smectic plane.

Figure 7: Picture of the smecticA phase

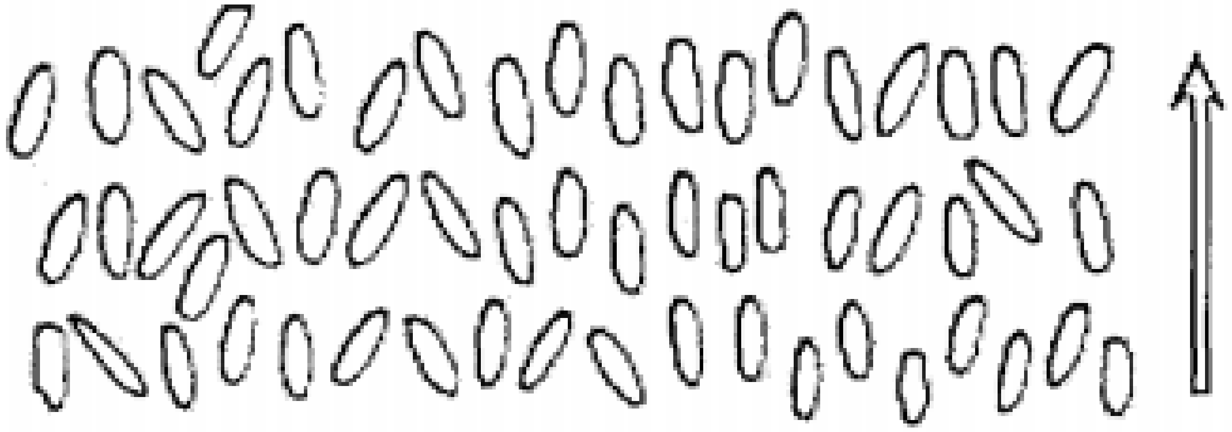


Figure 8: Photo of thesmecticA phase(using polarizing microscope)

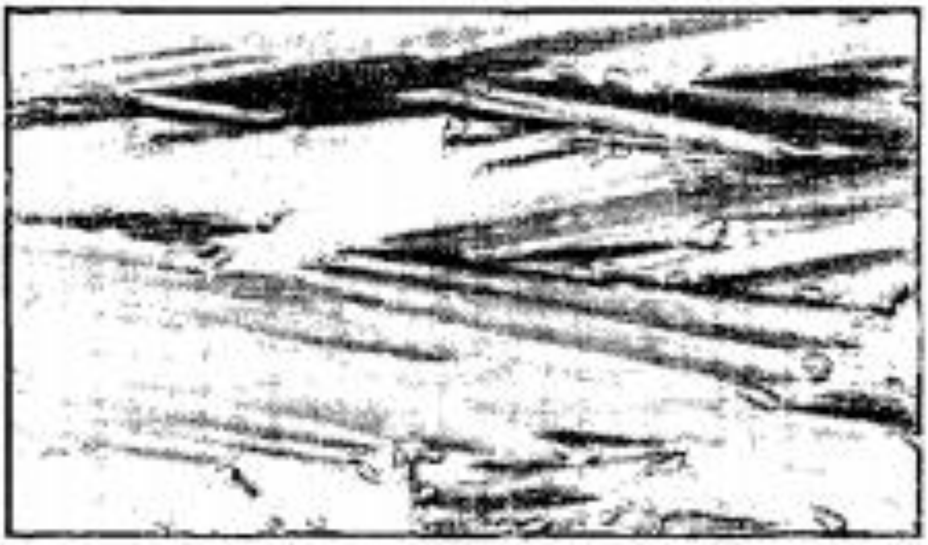


Figure 9: Picture of the smectic C phase

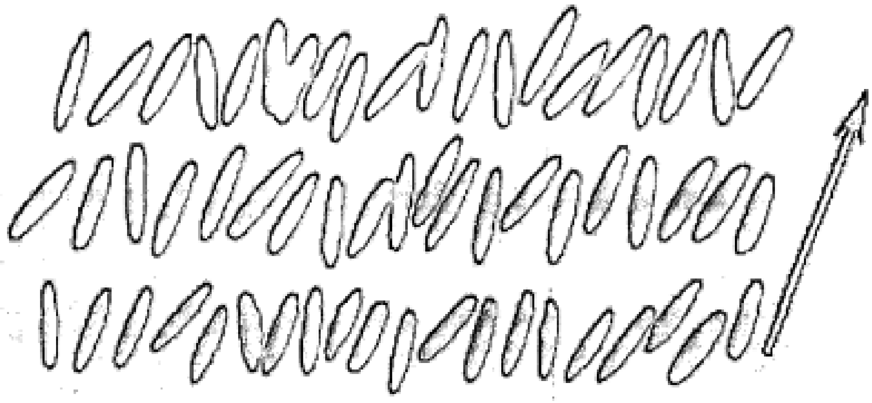
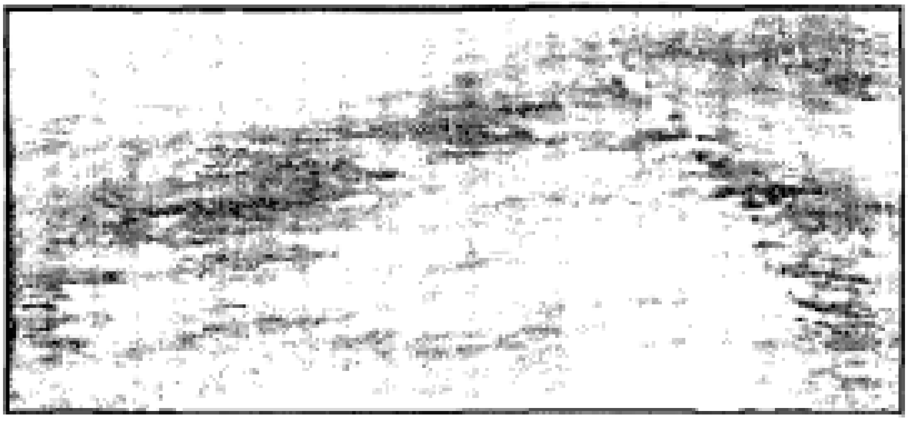
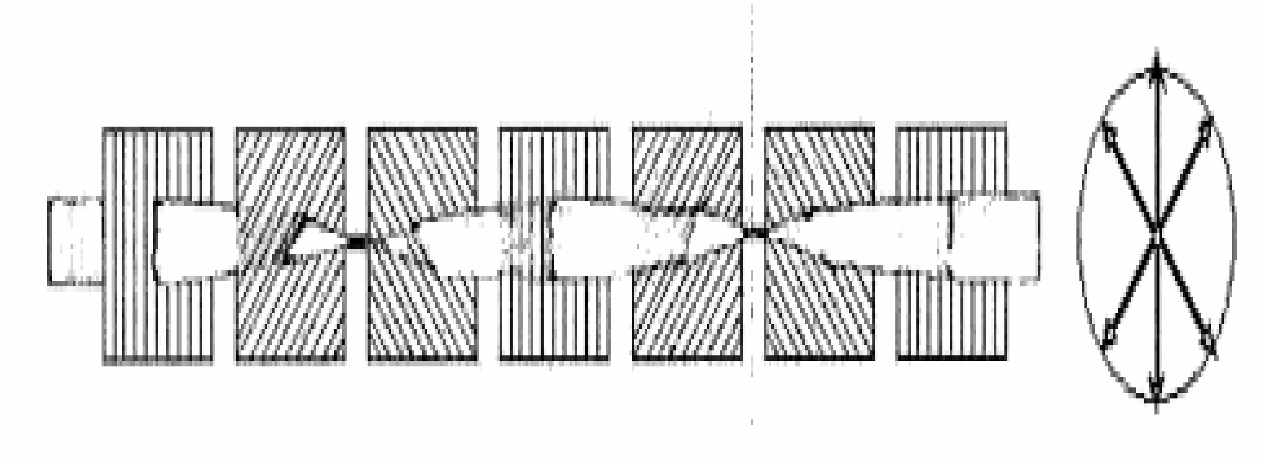


Figure 10: Photo of the smectic C phase (using polarizing microscope)



The smectic-C mesophase, like the nematic, features a chiral state labelled C*. The director makes a tilt angle with respect to the smectic layer, as per the smectic-C. This angle differs in that it rotates from layer to layer, forming a helix. In other words, the smectic-C* mesophase's direction is neither parallel nor perpendicular to the layers, and it rotates from one to the next.

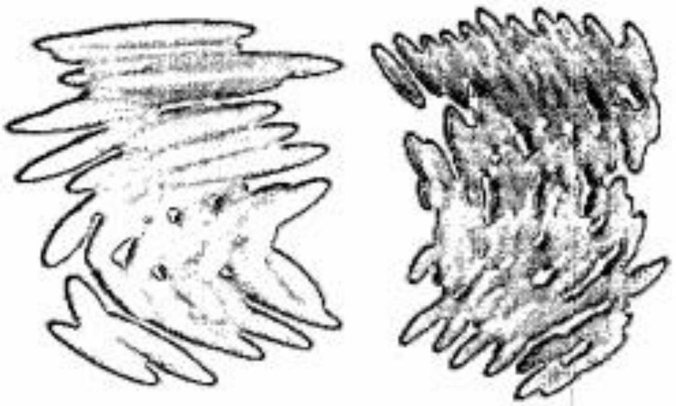
Figure 11: A schematic representation of a smectic C* phase (left), and a view of the same phase, but along the axis (right).



The molecules in some smecticmesophases are influenced by the layers above and below them. As a result, only a few three-dimensional orders are detected. This type of arrangement is demonstrated by Smectic-G.

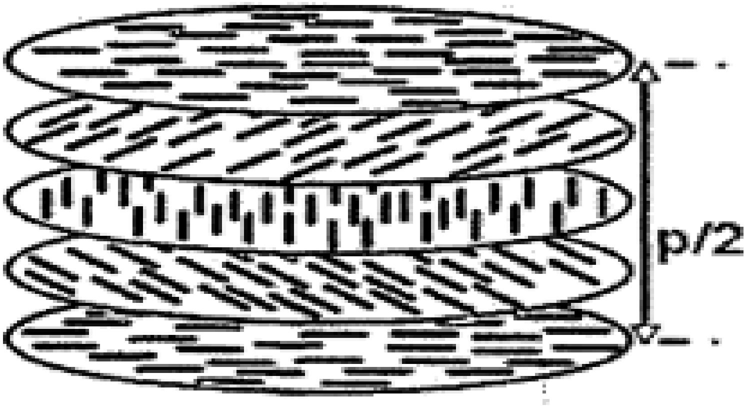
Chiral phases:-

Figure12: Schematic of ordering in chiral liquid crystal phases. The chiral nematic phase (left), also called the cholesteric phase, and the smectic C* phase (right)



The chirality of the chiral nematic phase is visible (handedness). Because it was first identified for cholesterol compounds, this phase is often referred to as the cholesteric phase. Only chiral molecules (those without inversion symmetry) can produce such a phase. The molecules twist perpendicular to the director in this phase, with the molecular axis parallel to the director. Because of their asymmetric packing, nearby molecules have a finite twist angle, resulting in longer-range chiral order. The molecules in the smectic C*phase (a chiral phase denoted by an asterisk) have positional ordering in a layered structure (as in the other smectic phases), with the molecules tilted by a limited angle with respect to the layer normal (as in the other smectic phases). From one layer to the next, chirality produces a limited azimuthal twist, resulting in a spiral twisting of the molecule axis along the layer normal.

Figure 13:Chiral nematic phase; p **refers to the chiral**



The chiral pitch, p, is the distance across which the LC molecules perform a full 3600 twist (however note that the structure of the chiral nematic phase repeats itself every half-pitch, so directors at 0° and 180° are equivalent in this phase). When the temperature is changed or other molecules are added to the LC host (if an achiral LC host material is doped with a chiral material), the pitch, p, changes, allowing the pitch of a particular material to be modified accordingly. The pitch of some liquid crystal devices is on par with the wavelength of visible light. This results in unique optical features in these systems, including as Bragg reflection and low-threshold laser emission, which are used in a variety of optical applications. When the light is incident along the helical axis, only the lowest-order reflection is allowed, however when the light is incident obliquely, higher-order reflections are allowed. Cholesteric liquid crystals also have the unusual property of reflecting circularly polarised light when incident parallel to the helical axis and elliptically polarised light when incident obliquely.

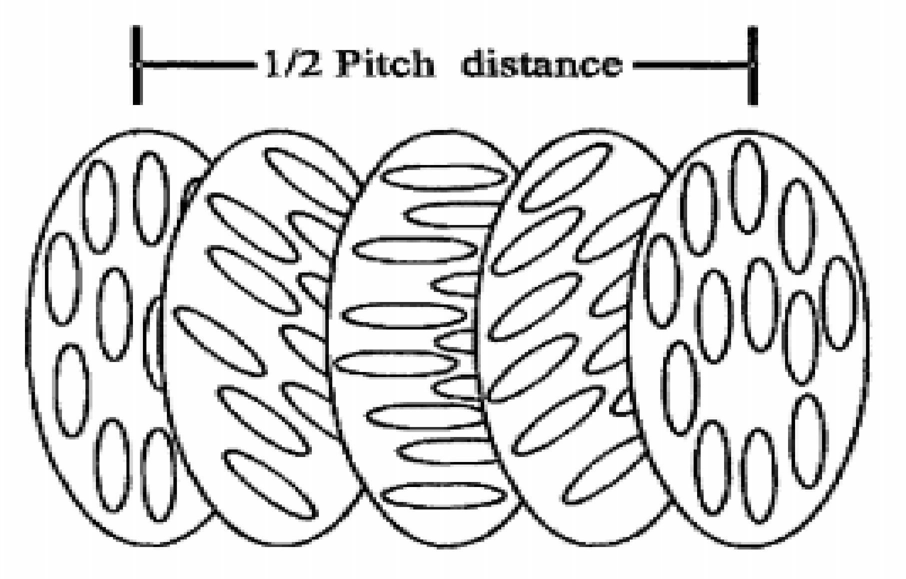
Blue phases:-
Blue phases are a sort of liquid crystal phase that occurs between a chiral nematic phase and an isotropic liquid phase at temperatures in between. Blue phases feature a regular three-dimensional cubic structure of defects with lattice periods of several hundred nanorrieters, resulting in selective Bragg reflections in the wavelength range corresponding to the cubic lattice. The very small temperature range within which blue phases exist, usually less than a few kelvin, has long been a difficult for rapid light modulators or adjustable photonic crystals. Blue phase stability has recently been established throughout a temperature range of more than 60 K, including room temperature (260-326 K).

At normal temperature, electro-optical switching with response times in the order of 10-4 s for stabilised blue phases has also been demonstrated.
It was stated in May 2008 that the first Blue Phase Mode LCD panel had been created.

Discotic phases:-
The discotic nematic phase describes how disk-shaped LC molecules can organise themselves in a layer-like pattern. A discotic columnar phase occurs when discs pack into stacks. The columns themselves can be arranged in hexagonal or rectangular patterns. Chiral discotic phases, which are comparable to chiral nematic phases, have also been discovered.
Between the crystalline (solid) and isotropic (liquid) phases, there is a separate phase of matter known as liquid crystal. Depending on the amount of order in the material, there are many different sorts of liquid crystal states.

Cholestric phases:-
The cholestric (or chiral nematic) liquid crystal phase is made up of nematicmesogenic molecules with a chiral core, which causes intermolecular forces that favour molecules aligning at an angle to one another. This results in the creation of a structure that resembles a stack of very thin 2-D nematic-like layers, each with a twisted direction in relation to the layers above and below. The directors form a continuous helical pattern around the layer normal in this construction, as seen by the black arrow in the following image.

Figure 14: Representation of many chiral nematicmesogens lying in the slabs

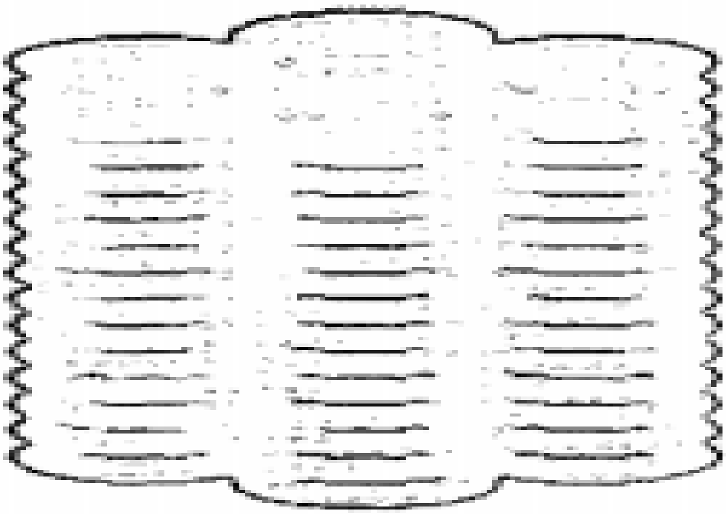


The molecules depicted are essentially models of the numerous chiral nematicmesogens found in infinitesimal-thickness slabs with a distribution of orientation around the director. The pitch is an important feature of the cholesteric mesophase. As shown in the animation, the pitch, p, is defined as the distance it takes the director to rotate one full round in the helix. The capacity of the chiral nematic phase's helical structure to selectively reflect light of wavelengths equal to the pitch length means that when the pitch is equal to the appropriate wavelength of light in the visible spectrum, a colour will be reflected. The effect is based on the temperature dependency of the progressive change in director orientation between successive layers, which changes the pitch length, resulting in a temperature-dependent change in the wavelength of reflected light.

By increasing the temperature of the molecules, and therefore providing them more thermal energy, the angle at which the director changes can be made bigger, tightening the pitch. Similarly, lowering the temperature of the molecules increases the chiral nematic liquid crystal's pitch length. This allows for the creation of a liquid crystal thermometer that uses reflected colour to represent the temperature of its surroundings. Sensors having a wide range of reactions to temperature change are often made from mixtures of different types of liquid crystals. These sensors are commonly employed in thermometers in the form of heat sensitive films to detect defects in circuit board connections, fluid flow patterns, battery state, radiation presence, or novelty like "mood" rings.

Columnar phases:-

Figure 15: Columnar Phases



Because they are shaped like discs rather than lengthy rods, columnar liquid crystals differ from the previous varieties. Stacking columns of molecules characterise this mesophase. A two-dimensional crystalline array is formed by packing the columns together. New mesophases result from the arrangement of molecules within the columns and the layout of the columns themselves.

Phase Transition Simulation:-
The phase behaviour of liquid crystal materials is demonstrated in the simulation below. Temperature, as previously demonstrated, determines the material's phase.

Macroscopic View:-
Optical polarising microscopy is a common tool for identifying liquid crystal phases and phase transitions, but it takes a lot of practise, especially when working with new and unfamiliar materials.

3. Properties of Liquid Crystals

Liquid crystals are somewhat organised materials that exist in the transition between solid and liquid states. Their molecules are frequently formed like rods, plates, or other shapes that help them to align in a specific orientation. Mechanical, magnetic, and electric forces can all be used to change the order of liquid crystals. Finally, liquid crystals are temperature sensitive, since they solidify when it gets too cold and liquidise when it becomes too hot. This phenomenon can, for instance, be observed on laptop screens when it is very hot or very cold.

3.1 Chemical Properties:-

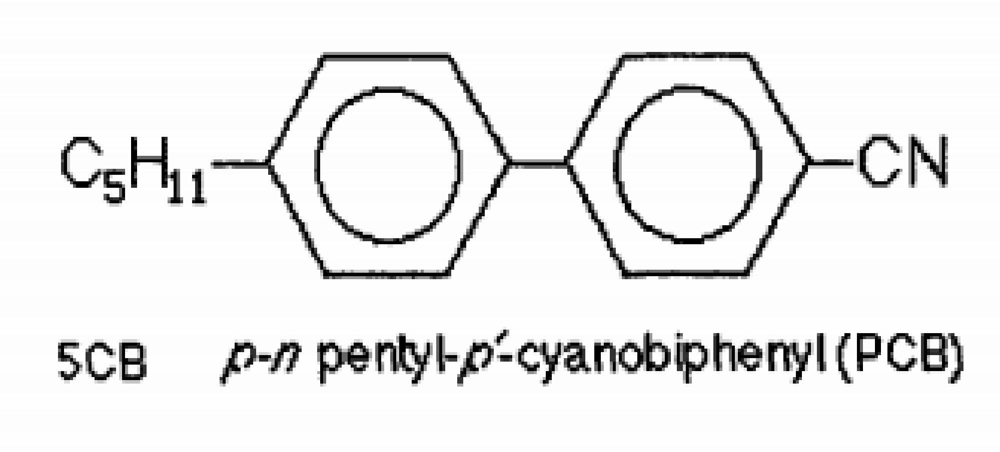
Thermotropic liquid crystals and lyotropic liquid crystals are the two primary kinds of liquid crystals. The mechanisms that drive the self-organization of these two types of liquid crystals differ, yet they are comparable in many aspects.

Most liquid crystals have thermotropic transactions, which are defined by the fact that transitions to the liquid crystalline state are caused thermally. That is, by raising the temperature of a solid and/or lowering the temperature of a liquid, one can achieve the liquid crystalline condition. Enantiotropic liquid crystals can be changed into the liquid crystal state by either lowering the temperature of a liquid or raising the temperature of a solid, while monotropic liquid crystals can only be changed into the liquid crystal state by either increasing the temperature of a solid or decreasing the temperature of a liquid, but not both. In general, thermotropicmesophases form as a result of anisotropic dispersion forces and packing interactions between molecules.

Unlike thermotropicmesophases, lyotropic liquid crystal transitions are caused by solvents rather than a change in temperature. Solvent-induced aggregation of the constituent mesogens into micellar structures produces lyotropicmesophases. Lyotropicmesogens are often amphiphilic, containing both lyophilic (solvent-attracting) and lyophobic (solvent-repelling) components. Because the lyophobic ends will stay together while the lyophilic ends extend outward toward the solution in the presence of a solvent, they will form micellar structures. The micelles grow in size and eventually coalesce as the concentration of the solution rises and the solution cools. The newly produced liquid crystalline state is now separated from the solvent.

Rod-like low molar mass (LMM) liquid crystals, such as 5CB, necessitate a prolonged conformation of the molecule, which must be maintained through the rigidity and linearity of its constituents. That is, a molecule must be stiff and rod-shaped in order to have the properties of a liquid crystal. The coupling of two stiff cyclic units does this. The linking group should result in a linear planar conformation in the final product. Linking units containing multiple bonds such as -(CH=N)-, -N=N-, -(CH=CH)n-, -CH—N-N=CH-, etc. are used since they restrict the freedom of rotation. These groups can conjugate with phenylene rings, enhancing the anisotropic polarizability. This increases the molecular length and maintains the rigidity.

Figure16: PCB

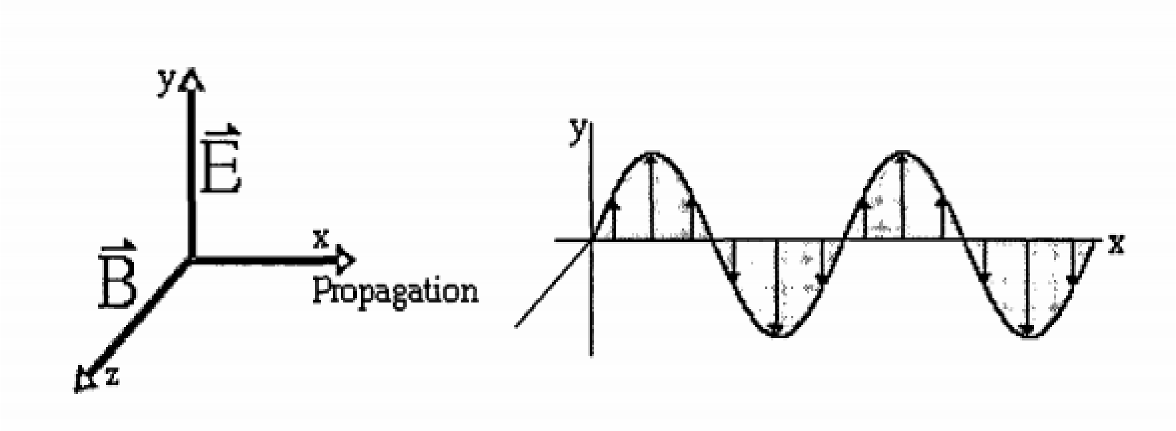


3.2 Optical Properties

Light and Polarization:-

Light is a transverse electromagnetic wave made up of fluctuating electric and magnetic fields that are mutually perpendicular. The electric field in the xy plane, the magnetic field in the xz plane, and the propagation of the wave in the x direction are shown on the left side of the accompanying diagram. A line tracing out the electric field vector as it propagates is shown in the right side. Traditionally, only the electric field •zector is dealt with because the magnetic field component is essentially the same.

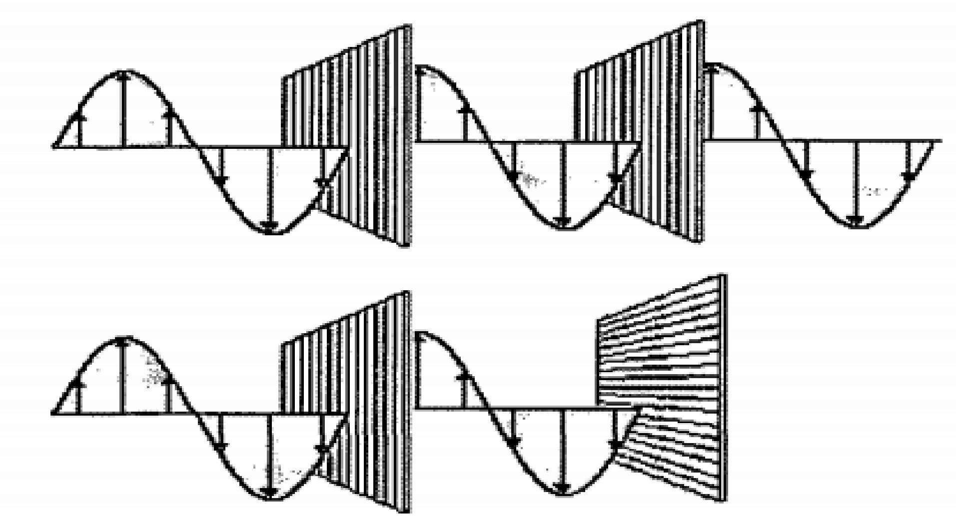
Figure 17: Light and Polarization



Ordinary white light is made up of waves that move around in all directions. When light contains waves that only fluctuate in one plane, it is said to be "linearly polarised." The wave can go up and down, but mobility in any other direction is stopped by the rope strung through a picket fence. A polarizer is a type of material that enables only light with a specified vibration angle to pass through. The "easy" axis is the direction of fluctuation passed by the polarizer.

Light travels through both polarizers when they are connected in series with their optical axes parallel. The polarized light from the first is smothered by the second when the axes are 90 degrees apart (crossing). The amount of light transmitted decreases as the angle rotates from 0 to 90 degrees. The following diagram illustrates this effect. At the top, the polarizers are parallel, while at the bottom, they are crossed.

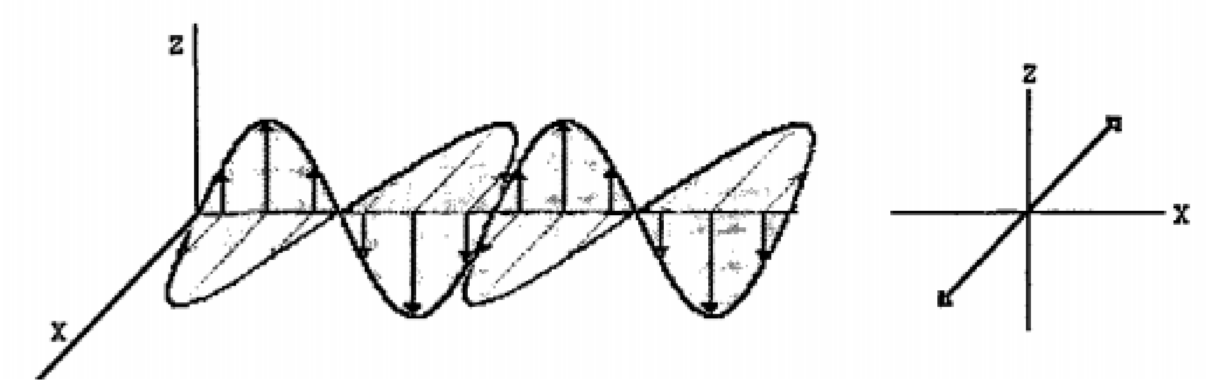
Figure 18: Effect of Polarized Light



Polarized Light:-

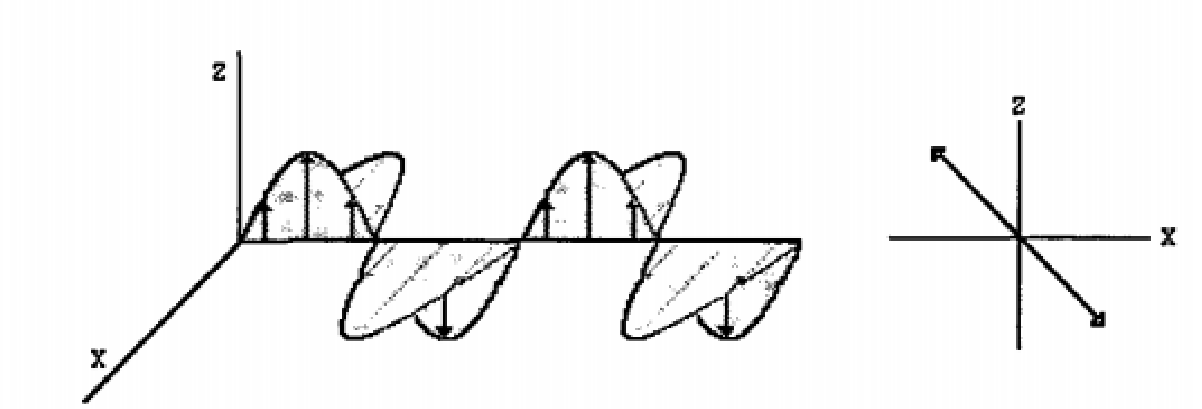
Circularly polarised light is a specific instance of linear polarization. Consider two polarised light waves, one in the YZ plane and one in the XY plane. When the waves reach their greatest and minimum positions at the same moment (in phase), their vector sum produces a single wave with a 45-degree linear polarisation. This is depicted in the diagram below.

Figure 19: Linear Polarization



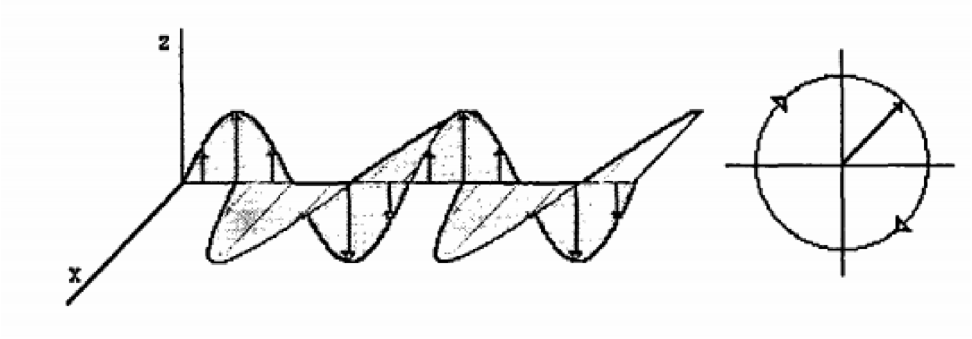
Similarly, if the two waves are 180 degrees out of phase, the resultant is linearly polarized at 45 degrees in the opposite sense.

Figure 20: Linearly polarized at 45 degrees



If these two waves are 90 degrees out of phase (one is at an extremum and the other is at zero), the resulting wave is circularly polarized. In effect, the resultant electric field vector from the sum of the components rotates around the origin as the wave propagates. The following diagram shows the sum of the electric field vectors for two such waves.

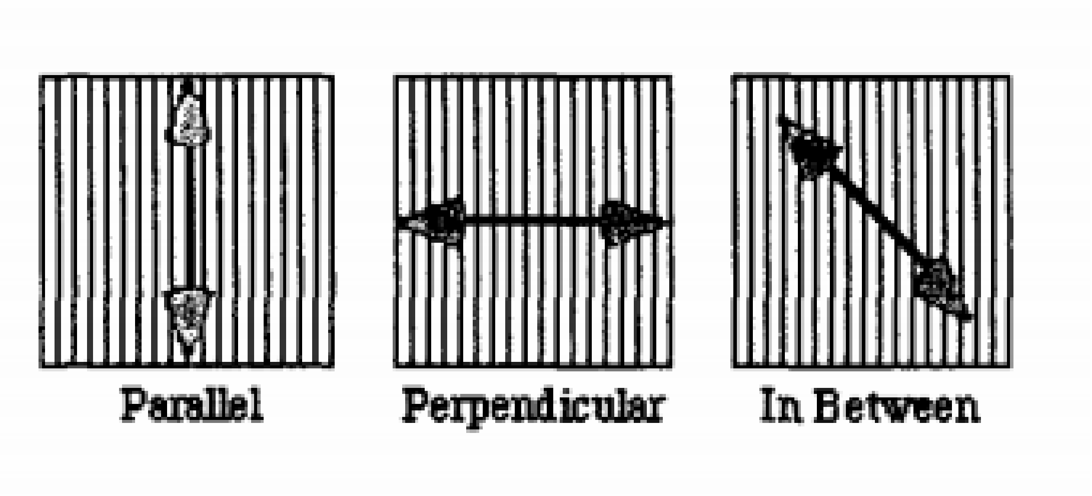
Figure 21: Electric Field Vectors



The most general case is when the phase difference is at an arbitrary angle (not necessarily 90 or 180 degrees.) This is called elliptical polarization because the electric field vector traces out an ellipse (instead of a line or circle).

Birefringence:-
Due to their anisotropic structure, liquid crystals are discovered to be birefringent. They exhibit double refraction, in other words (having two indices of refraction). Light polarised parallel to the director has a different index of refraction than light polarised perpendicular to the director (that is, it travels at a different velocity). The director field is shown by the blue lines in the diagram below, while the polarisation vector is represented by the arrows.

Figure 22:Representation of Polarization vector



When light reaches a birefringent material, such as a nematic liquid crystal sample, it is divided up into fast (called the ordinary ray) and slow (named the extraordinary ray) components. The waves become out of phase because the two components travel at different speeds. Because of the phase difference, the polarisation state of the rays as they depart the birefringent material has changed.

4. Types of Liquid Crystals
Thermotropic, lyotropic, and metallotropic phases can be found in liquid crystals. Organic molecules make up thermotropic and lyotropic LCs. When the temperature of thermotropicLcs is altered, the phase transition into the LC phase occurs. Lyotropic LCs show phase transitions as a function of temperature and LC molecule concentration in a solvent (typically water). Metallotropic LCs contain both organic and inorganic molecules, and their LC transition is influenced not only by temperature and concentration but also by the ratio of inorganic to organic molecules.

Liquid crystals can be found in the natural world as well as in technology applications. Liquid crystal displays are used in the majority of modern electronic displays. In living systems, lyotropic liquid-crystalline phases abound. Many proteins and cell membranes, for example, are LCs. Soap solutions and related detergents, as well as tobacco mosaic virus, are other well-known LC examples.

Liquid Crystal are of various types, some are:
- Polymer Liquid Crystal
- Polymer Dispersed Liquid Crystal
- Polymer Stabilized Liquid Crystal

- Lyotropic Liquid Crystal
- Ferroelectric Liquid Crystal

5. CONCLUSION

We usually think of matter as having three states: solid, liquid, and gas. There are, however, states of matter that do not fulfil the criteria of any of these three categories. Liquid crystals are similar to liquid crystals in that they are neither liquid nor solid. Physically, they behave like liquids, but they also have some crystalline solid qualities. Liquid crystals are crystals that have lost some or all of their positional order but still have complete orientational order.

The nematic phases, which have no positional order, are the most basic liquid crystalline phases. Layered formations are found in smectic stages. Liquid crystals are a broad word that encompasses a wide range of chemical structures, physical properties, and technical uses. LCD displays, dyes (cholesterics), optical imaging membranes, temperature sensing (by changing colours), and other uses are among them.

Liquid crystal technology has influenced a wide range of scientific and engineering fields, as well as gadget technology. Liquid crystals will become increasingly important in industrial and scientific applications as new qualities and varieties are studied and developed.

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