M.Sc. Physics

Study Material for Ordered Phases of Matter

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Ordered Phases of Matter

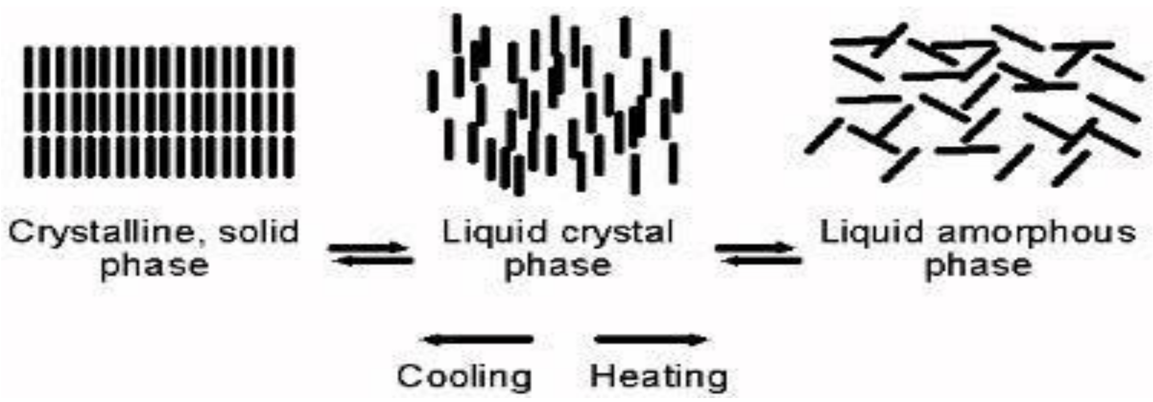
In physics, the terms **order** and **disorder** designate the presence or absence of some symmetry or correlation in a many-particle system. The precise form of order in a solid is **lattice periodicity**: a certain pattern (the arrangement of atoms in a unit cell) is repeated again and again to form a translationally invariant tiling of space. Lattice periodicity implies **long-range order**: if only one unit cell is known, then by virtue of the translational symmetry it is possible to accurately predict all atomic positions at arbitrary distances.

The common states of matter, namely solid, liquid and gas, differ mainly by the types of and degree of order present in the phase. These states of matter, however, are not sufficient to characterize the structures found in all systems. As most substances are heated, they go from a solid (usually crystalline, possessing high order) to an isotropic liquid (highly disordered). Some substances, however, exhibit intermediate states having less order than solids, but possessing more order than found in liquids. These intermediate state partially ordered fluids are called **liquid crystals**.

The following two main parameters describe the crystalline structure of Solid, Liquid Crystal and Liquid:

1. **Positional Order**
2. **Orientational Order**

Each of these parameters describes the extent to which the crystal sample is ordered. Positional order refers to the extent to which an average molecule or group of molecules shows translational symmetry. Orientational order represents a measure of the tendency of the molecules to align along the axis in crystalline solid and along director on a long-range basis in liquid crystal.



Crystals	Mesophases / liquid crystalline phases	Liquids
3D long range order (∞ position- and orientational order)	orientational order, translational long range order in 1 or 2 dimensions	No long range order, Statistical arrangements of molecules

Crystalline solids molecules are ordered in both the ways. They occupy specific sites in a lattice and to a point their molecule axes in specific direction. Thus a crystal has orientational and three dimensional positional order.

Molecules in a liquid diffuse randomly throughout the sample without any orientational order. Therefore a conventional liquids have neither positional nor orientational order. Thus a crystal has orientational and three dimensional positional order, whereas liquid has none.

In contrast to liquid phase, the liquid crystal phase have long range orientational order which usually persists only for a fairly narrow temperature range. The long range positional order of liquid crystal is generally at most two dimensional, except some exceptions like smectic B, and twist grain boundary phase.

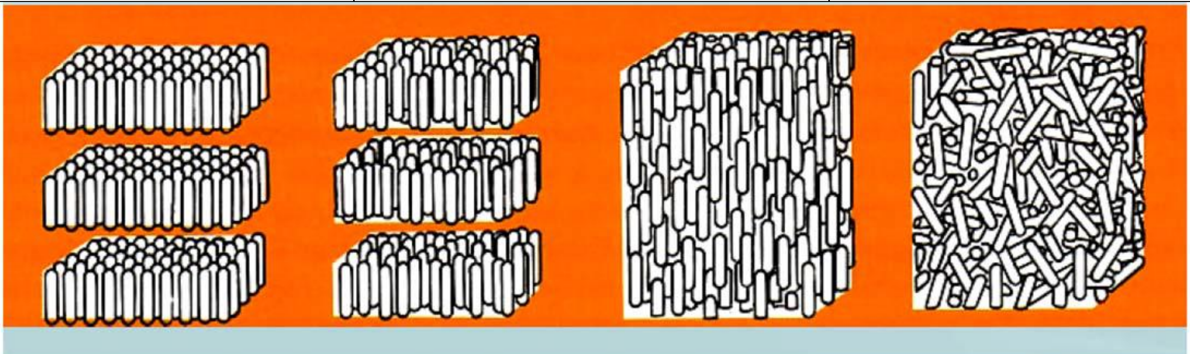
The study of liquid crystals began in 1888 when an Austrian botanist named Friedrich Reinitzer observed that a material known as Cholesteryl benzoate had two distinct melting points. In his experiments, Reinitzer increased the temperature of a solid sample and watched the crystal change into a hazy liquid at 145.5^0 C. As he increased the temperature further, the material changed again into a clear, transparent liquid at 178.5^0 C. Because of this work, Reinitzer is often credited with discovering a new phase of matter - the liquid crystal phase.

Liquid Crystals are pure substances in a state of matter that shows properties of both liquids and solids over a specific temperature range. At temperatures lower than this range, the liquid crystals are only like solids. They do not flow and their molecules maintain a regular arrangement. At temperatures above this range, the liquid crystals behave only like liquids. They can flow and the molecules have no special arrangement. Within the temperature range, different for every liquid crystal, liquid crystals are able to flow but they still keep their molecules in a specific arrangement.

Mesophases
In a crystalline solid, the molecules are well ordered in a **crystal lattice**. When a crystal is heated, the thermal motions of the molecules within the lattice become more vigorous, and eventually the vibrations become so strong that the crystal lattice breaks down and the molecules assume a disordered liquid state. The temperature at which this process occurs is the melting point. Although the transition from a fully ordered structure to a fully disordered one takes place in one step for most compounds, but this transition is not a universal behaviour. For some compounds, this process of diminishing order, as temperature is increased occurs via one or more intermediate steps.

The intermediate phases are called mesophases (from the Greek word mesos, meaning "between"), or liquid crystalline phases. Liquid crystalline phases have properties i**ntermediate** between those of fully ordered crystalline solids and liquids. Liquid crystals are fluid and can flow like liquids, but the magnitudes of some electrical and mechanical properties of individual liquid crystals depend on the direction of the measurement (either along the main crystal axis or in another direction not along the main axis).

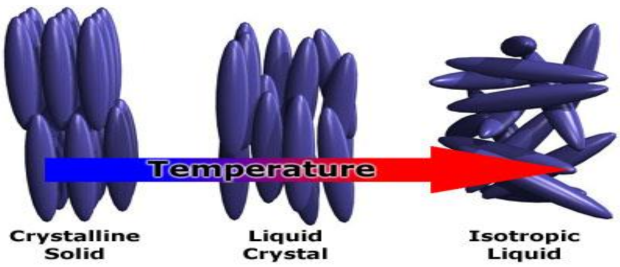
Crystalline Phases	Mesophases	Amorphous Phases
3D-Order	2D-, 1D- Order	No Long Range Order



Crystal	**Smectic**	**Nematic**	**Liquid**
	Liquid Crystalline		
3D	**2D**	**1D**	**0D**

Typical liquid crystals have rodlike or disk like shape, with a central rigid portion and flexible ends. Classes of liquid crystalline states or mesophases can be distinguished according to degrees of internal order. The least ordered liquid crystalline **phase** for rodlike molecules is the nematic phase (N), in which the long axes of individual molecules have an approximate direction (which is called the director, n). A nematic phase material has a low viscosity and is therefore very fluid. The term "nematic" is derived from the Greek word for thread (threadlike microscopic textures exhibited by nematic phase substances).

In the smectic phases, the molecules have more order than molecules existing in the nematic phase. The term "smectic" is derived from the Greek word for soap (owing to the fact that smectic liquid crystals have mechanical properties similar to those of concentrated aqueous soap solutions). **Mesogens** are highly anisotropic in shape. For example, let us see some of the phases observed for rod-like mesogens.



Comparison of Ordered Phases of Matter: Crystal, Liquid Crystal, Liquid and Gas.

1. **Solid Crystal State:** Molecules are highly ordered and have little translational freedom.

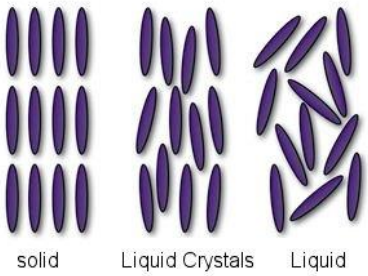
2. **Nematic State /Phase of Liquid Crystal**: It has no positional order but tend to point in the same direction (along the director, the axis). The molecules point vertically but are arranged with no particular order. Orientational order of the long axes of the molecule about a particular direction referred as direction n.

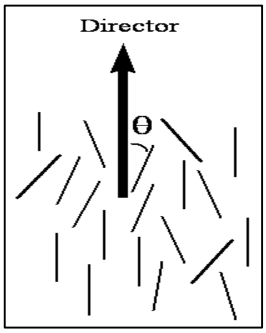
3. **Smetic State/ Phase**: One dimensional positional order exists in the smectic state of liquid crystal. Molecules in this phase show a degree of translational order. In this state, the molecules exhibit long range orientational order.

4. **Cholesteric State/Phase**: The phase molecules in liquid crystal do not exhibit any positional order, but they do possess a certain degree of orientational order.

5. **Columner State/Phase**: The liquid crystal ``phase'' maintains two dimensional positional order. But as in case of Cholesteric State, they also possess a certain degree of orientational order.

The properties of mesogens are not identical and are different in different directions. The distinguishing characteristic of the liquid crystalline state is the tendency of the mesogens (molecules) to point along a common axis as depicted in figure below, called the director. For, liquid phase, there is no director tendency or intrinsic order of molecules.

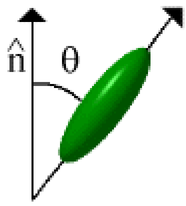




Since Crystalline materials demonstrate long range periodic order in three dimensions, its orientational order is not in doubt. But, an isotropic liquid has no orientational order and to study and to quantify just how much order is present in a material, an order parameter (S) is defined.

Traditionally, the order parameter is given as follows:

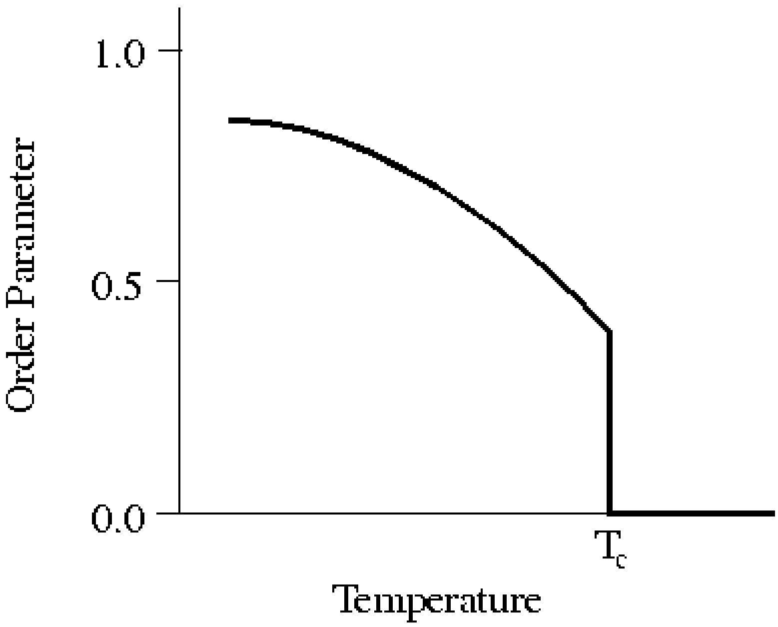
$$S = (1/2) \langle 3\cos^2\theta - 1 \rangle$$



Where θ (theta) is the angle between the director and the long axis of each molecule.

- 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.**
- The typical values for the order parameter of a **liquid crystal ranges** between **0.3 and 0.9,** and this value is a function of temperature (as a result of kinetic motion of molecules).

This order parameter is highly dependent on the temperature of the sample. Figure 1, shows the relationship of order vs. temperature.



- **Figure 1:** *Order parameter vs. temperature for a typical liquid crystal. Tc is the temperature of transition between the liquid crystal and liquid states.*

Liquid crystals are essentially more like liquids than they are like solids. This is evident from the *latent heat* of transition, the amount of energy needed for a phase transition to occur. In cholesteryl myristate, the latent heat for changing from a solid to the liquid crystal state is 65 calories per gram, whereas the latent heat for the liquid crystal to liquid transition is only 7 calories per gram.

Besides structural order which we have discussed above, we can think and explore about charge ordering, spin-ordering, magnetic ordering, and compositional ordering and Magnetic ordering also.

Application:

The most important use of **liquid crystals** is in displays because the molecules of a **liquid crystal** can control the amount, colour, and direction of vibration of the light that passes through them. This means that by controlling the arrangement of the molecules, an image in light can be produced and manipulated.

Important applications of ordered phase of matter comes from liquid crystal. Liquid Crystal Display (LCD) is most common name nowadays in display of devices. Liquid crystal displays are used in **mobile phone screens**, **Watches, Calculators, Laptop and Computer screens, and**

for instrumentation in **cars, ships, and airplanes**. The best-known LCD is the twisted nematic display.

Liquid crystals can serve as **thermometers,** as **temperature sensors** also. A liquid crystal thermometer attached to the skin can measure temperature variations of the skin. This can be useful in the detection of skin cancer, as tumours have different temperatures than surrounding tissues.

In electronics, liquid crystal temperature sensors can pinpoint bad connections within a circuit board by detecting the characteristic local heating.

Key Words:

Long Range Order: In **long range order**, as in crystalline solids, there is a regular pattern of arrangement of particles which repeats itself periodically over the entire crystal. In other words, a solid is considered crystalline if it has **long range order**.

Short Range Order: **Short range order** refers to the regular and predictable arrangement of the atoms over a **short distance**, usually with one or two atom spacings. However, this regularity **does** not persist over a long **distance**.