Introduction to Liquid Crystals

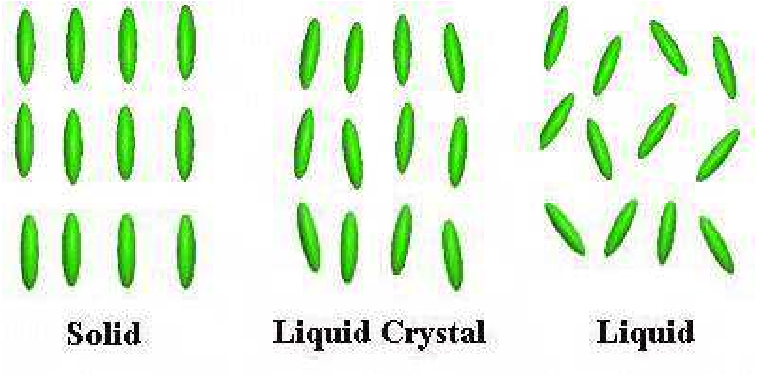
The study of liquid crystals began in 1888 when an Austrian botanist named Friedrich Reinitzer observed that a material known as cholesteryl benzoate had two distinct melting points. In his experiments, Reinitzer increased the temperature of a solid sample and watched the crystal change into a hazy liquid.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

Liquid crystal materials are unique in their properties and uses. As research into this field continues and as new applications are developed, liquid crystals will play an important role in modern technology. This tutorial provides an introduction to the science and applications of these materials.

What are Liquid Crystals?

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

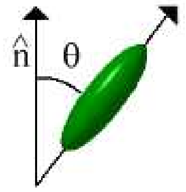
The distinguishing characteristic of the liquid crystalline state is the tendency of the molecules (*mesogens*) to point along a common axis, called the *director*. This is in contrast to molecules in the liquid phase, which have no intrinsic order. In the solid state, molecules are highly ordered and 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.



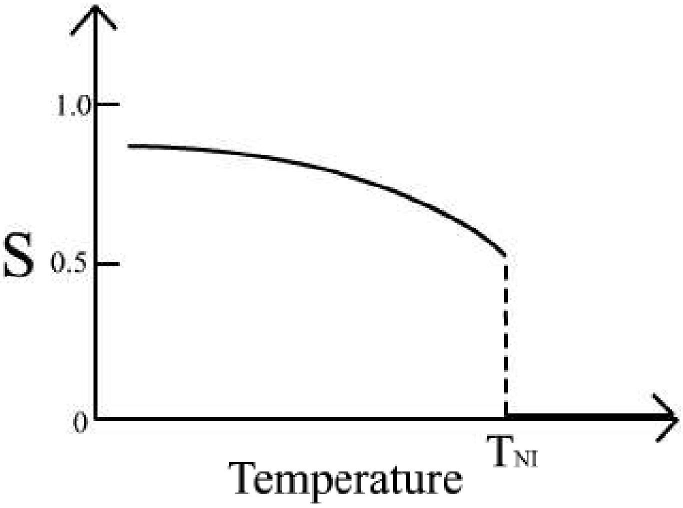
It is sometimes difficult to determine whether a material is in a crystal or liquid crystal state. *Crystalline* materials demonstrate long range periodic order in three dimensions. By definition, an *isotropic* liquid has no orientational order. Substances that aren't as ordered as a solid, yet have 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
- Orientational Order
- Bond Orientational Order

Each of these parameters describes the extent to which the liquid crystal sample is ordered. *Positional order* refers to the extent to which an average molecule or group of molecules shows translational symmetry (as crystalline material shows). *Orientational order*, as discussed above, represents a measure of the tendency of the molecules to align along the director on a long-range basis. *Bond Orientational Order* describes a line joining the centers of nearest-neighbor molecules without requiring a regular spacing along that line. Thus, a relatively long-range order with respect to the line of centers but only short range positional order along that line. (See discussion of hexatic phases in a text such as Chandrasekhar, *Liquid Crystals*)

Most liquid crystal compounds exhibit *polymorphism*, or a condition where more than one phase is observed in the liquid crystalline state. The term *mesophase* is used to describe the "subphases" of liquid crystal materials. Mesophases are formed by changing the amount of order in the sample, either by imposing order in only one or two dimensions, or by allowing the molecules to have a degree of translational motion. The following section describes the mesophases of liquid crystals in greater detail.

Liquid Crystal Phases