STUDENT BACKGROUND READING FOR EXPERIMENT B: LIQUID CRYSTALS

Liquid crystals (LCs) are an example of **self-assembled molecules** that are sensitive to external factors, such as temperature, and that change their assembly as a consequence of variations in these factors. In this experiment you will see how some **LCs change colour as their temperature is changed**. You will learn two **fundamental concepts of nanoscience**: (1) that the way a material behaves at the macroscale depends on its structure at the nanoscale; and (2) that LCs are self-assembled molecules that organize themselves into nanostructures which have specific optical properties. These can be employed for making numerous "macro" objects such as displays and thermometers.

In this experiment you will:
- prepare different mixtures of liquid crystals that are sensitive to different temperature windows
- create a number of liquid crystal sheets and test them in different water baths.
- make a liquid crystal thermometer

This document provides the background information for this laboratory exercise.

What is a liquid crystal?

You have probably learned that there are three states of matter: gas, liquid and solid. A liquid crystal is a fourth state of matter: it has properties between those of a liquid and of a solid. The molecules in a liquid crystal can move independently, as in a liquid, but remain a bit organised, as in a crystal (solid).

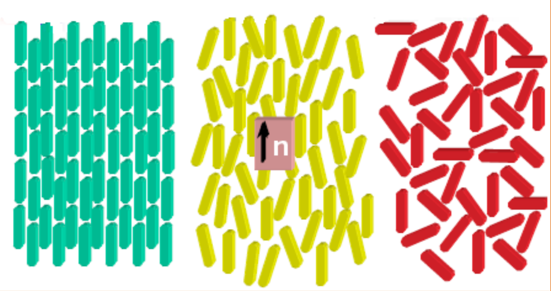

Figure 1. Schematic representation of molecules in a solid (left: molecules are well organised); in a liquid crystal (centre: molecules have a long range distance order) and in a liquid (right: molecules are not ordered. (Image credit: Copyright IPSE Educational Resources, University of Wisconsin Madison)

Liquid crystals are **partly ordered materials**, somewhere between their solid and liquid phases. This means that LCs combine the fluidity of ordinary liquids with the interesting electrical and optical properties of **crystalline solids**.

The order of liquid crystals can be manipulated with mechanical, magnetic or electric forces. What is interesting is that this

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change of order can be obtained with **very small variations of these forces**. The molecules in liquid crystal displays for instance are reoriented by rela*tively weak electrical fields.*

Liquid crystals are **temperature sensitive** since they turn into solid if it is too cold and into liquid if it is too hot. This phenomenon can, for instance, be observed on laptop screens when it is very hot or very cold.

A liquid crystal is an example of a self-assembled nanostructure.

Liquid crystals are made of molecules that have the shape of rods or plates or some other forms that encourage them to **align collectively** along a certain direction. They assume a **self-assembled** (or self-organised) structure. This process is guided by information that is coded into the characteristics of the molecules and the final structure is reached by equilibrating to the form of the lowest free energy. The concept of self-assembly is the basis of natural biological processes, where molecules self-assemble to create complex structures with nanoscale precision. Examples are the formation of the DNA double helix or the formation of the membrane cell from phospholipids.

A **liquid crystal is formed by the self-assembly of molecules into ordered structures**, or *phases*. An external perturbation, such as a change in temperature or magnetic field, even very small, can induce the liquid crystal to assemble in a different way and assume a different phase. Different phases can be distinguished by their **different optical properties**.

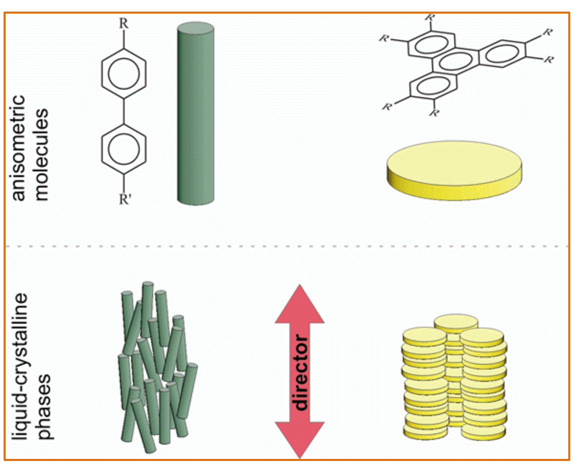

Figure 2. Examples of the self-organisation of anisometric (i.e., with asymmetrical parts) molecules in liquid-crystalline phases. On the left: rod-like molecules form a nematic liquid, in which the longitudinal axes of the molecules are aligned parallel to a common preferred direction ("director"). On the right: disc-like (discotic) molecules arrange to molecule-stacks (columns), in which the longitudinal axes are also aligned parallel to the director. As a result of their orientational order, liquid crystals exhibit anisotropic physical properties, just like crystals. (Image Credit: http://www.ipc.uni-stuttgart.de/~giesselm/AG_Giesselmann/Forschung/Fluessigkristalle/Fluessigkristalle.html).

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Are there any natural liquid crystals?

Yes! Some forms of liquid crystals are **abundant in living systems**, such as biological membranes, cell membranes, many proteins (like the protein solution extruded by a spider to generate silk), as well as tobacco mosaic virus. Soap is another well known material which is in fact a lyotropic LC. The thickness of soap bubbles determines the colours of light they reflect.

Thermotropic liquid crystals

In this experiment you will study and test the properties of a **thermotropic liquid crysta**l. This type of liquid crystal responds to changes in temperature by changing its colour. As the temperature increases, the colour of the liquid crystal changes from orange, to yellow, green, blue and purple. The change in colour is a direct consequence of the change of the molecular organisation of the liquid crystal as the temperature is increased.

How does this work? Liquid crystals are made of molecules that are shaped like rods or plates which tend to align collectively along a certain direction and assume a somewhat **ordered molecular structure**, called a *phase*. The type of liquid crystal that you will study here is made of long molecules that tend to organise in rotating layers, like a spiral staircase (a helix). This phase is a *chiral phase* because the overall structure lacks inversion symmetry. This phase is often called the **cholesteric phase** because it was first observed for cholesterol derivatives.

Figure 3. Schematic representation of ordering in chiral liquid crystal phases: a chiral nematic phase (also called the cholesteric phase) in an LC (Image credit: Wiki Commons, Creative Commons Attribution ShareAlike 3.0).

In each "step" of the staircase the molecules are arranged in a specific order, but there is a finite angle between each "step" and the next (**Figure 4**).

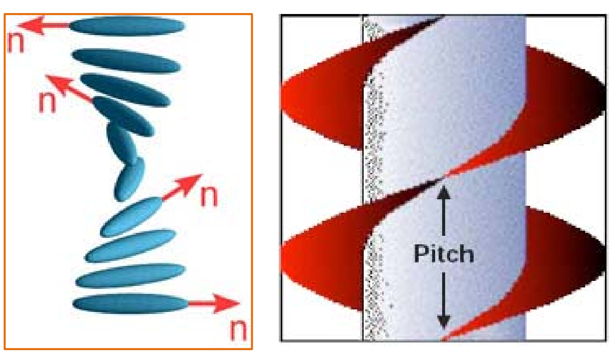

Figure 4 (Left): Schematic representations of stacked rotating layers in a chiral LC forming a "spiral staircase" having a pitch *p*. (Right) schematic representation of the pitch in a chiral LC. Images credit: Wiki Commons, Creative Commons Attribution ShareAlike 3.0)

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The chiral **pitch**, *p*, refers to the distance over which the LC molecules undergo a full 360° twist. As the temperature of the liquid crystal changes, so the pitch changes, which leads to more tightly or more loosely twisted helixes.

How is this related to the colour change?

When light strikes a liquid crystal, some of the light is reflected. **What we see is the reflected light**. The colour (i.e. the wavelength) of the reflected light depends on how tightly twisted the helix is.

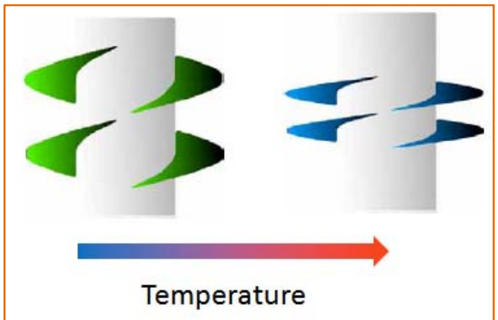

Figure 5. Representation of a pitch change in a chiral LC as the temperature is changed. (Image credit: Image adapted from IPSE Educational Resources (Liquid crystals), University of Wisconsin Madison).

If the pitch in the liquid crystal is of the same order as the **wavelength of visible light (400-700 nm)**, then interesting optical interference effects can be observed. The colour of the light reflected depends on the pitch in the liquid crystal, that is, on how tightly twisted the helix is. When the helix is tightly twisted, the pitch is smaller, so it reflects smaller wavelengths (blue end of the spectrum); when the liquid crystal is less twisted, it has a larger pitch, so it reflects larger wavelengths (red end of the spectrum).

An increase in temperature leads to a decrease of the pitch, therefore by increasing the temperature of the liquid crystal one should expect a colour change from the red end of the spectrum to the blue end of the spectrum, so from orange to yellow, green, blue and violet.

HOW IS THIS "NANO"?

The properties of materials at the macroscale are affected by the structure of the material at the nanoscale. Changes in a material's molecular structures are often too small to see directly with our eyes, but sometimes we can see changes in the materials' properties. Liquid crystals are an excellent example, in particular the type used in this experiment, since their optical properties (colour) change visibly as the temperature of the liquid crystal is changed. In nanotechnology, scientists take advantage of the peculiar properties of materials at the nanoscale to engineer new materials and devices.

Liquid crystals are an example of self-assembled molecules which change their spatial organisation depending on external factors such as temperature. Self-assembly is another fundamental concept in nanoscience.

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Applications of liquid crystals

The chiral twisting that occurs in chiral liquid crystal phases also makes the system respond differently from right- and left-handed circularly polarised light. These materials can thus be used as polarisation filters. Liquid crystals are routinely used in displays for mobile phones, cameras, laptop computers and other electronics. In these displays, an electric field changes the orientation of the molecules in the liquid crystal, and affects the polarisation of light passing through them.

Because of their sensitivity to temperature, and the property of changing colour, they are also used in thermometers. In miniaturised sensors, liquid crystals can detect certain chemicals, electric fields and changes in temperature.

Researchers are now investigating the addition of nanoparticles to liquid crystals to induce new electrical and optical properties in the liquid crystal, for applications in photovoltaics, optical waveguides, light emitting diodes and sensors.

In this experiment **you will make a room thermometer** which you can use in class though the year to check the temperature of your class, or the temperature outside!

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