# Liquid Crystals

by Walter Glogowski

## Background:

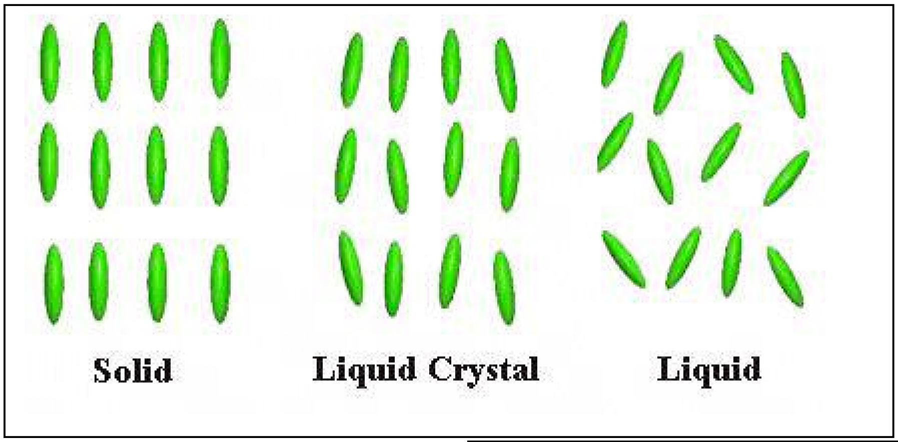
In 1888 an Austrian scientists, Friedrich Reinitzer was experimenting with a cholesterol type compound. He was trying to accurately determine the physical properties of the substance, such as its correct empirical formula and its melting point. The empirical formula is simply a substance's chemical description. It tells you how many of each type of atom is an a substance but nothing about how they are arranged. For example, the empirical formula for water is $H_20$. The melting point of a substance is exactly that -- the exact temperature at which a substance changes states from solid to liquid and melts. In the case of the cholesterol type compound that Reinitzer was experimenting with he discovered it hade two melting points! This was very unusual and he asked for some help from a physicist named Otto Lehmann who was an expert in crystal optics (the study how light and crystals interact). Lehmann discovered that the substance had a very unique property and that it was actually something between a liquid and a solid. He described the new substance as being a "liquid crystal" that is it behaved as both a liquid and a solid (crystal). This idea was very bold! Up to this time all scientist believed that all matter had only three states and one melting point. Lets use water as our example: it has a melting point ($0^o$ C) where it turns from a solid to a liquid, and a boiling point ($100^o$ C) where it turns from a liquid to a gas (three states: solid, liquid, gas).

This new idea of a compound being both a liquid and a solid was not easily accepted by the scientific community. Many people in the scientific community claimed that this new "state" was probably just caused by impurities or contamination from two different substances. It was not until the early 1900's (about 1930) that scientist established conclusively that liquid crystals exist and have a special physical state. Today we take advantage of this 'usual' state and use the properties of liquid crystals for many new technologies such as liquid crystal displays (LCDs), which are found in wristwatches, computer screens, large digital clocks and even thermometers.

GameBoy

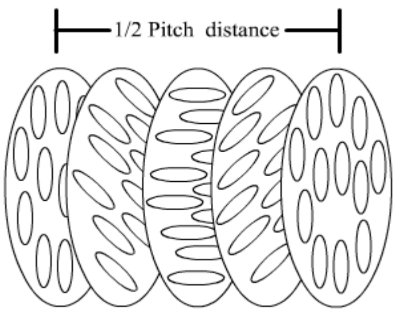
## Liquid Crystal Thermometers

If you have ever held a liquid crystal thermometer in your hand, you have noticed how it starts out black and then changes colors to reds, yellows, greens and blues. Liquid crystal thermometers are made with a substance called cholesteric liquid crystals. If you look at liquid crystals under magnification, they will look like small rod-like structures (sort of like grains of rice). In its solid state, the rod-like structures form layers that are roughly parallel to each other. In its liquid state the rod are shifted at various angels in relationship to each other. In the liquid-crystal state, which is somewhere between solids and liquids, the rods form layers but adjacent layers run in a slightly different directions form those above or below them.




http://www.iq.usp.br/wwwdocentes/mralcant/AboutLC.html

Think of the rods in liquid crystal as if they are the stairs of a spiral staircase (on its side in the diagram). "The spiral staircase rises some distance before the molecules twist



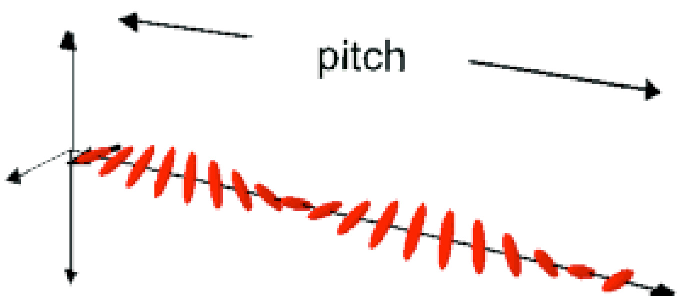
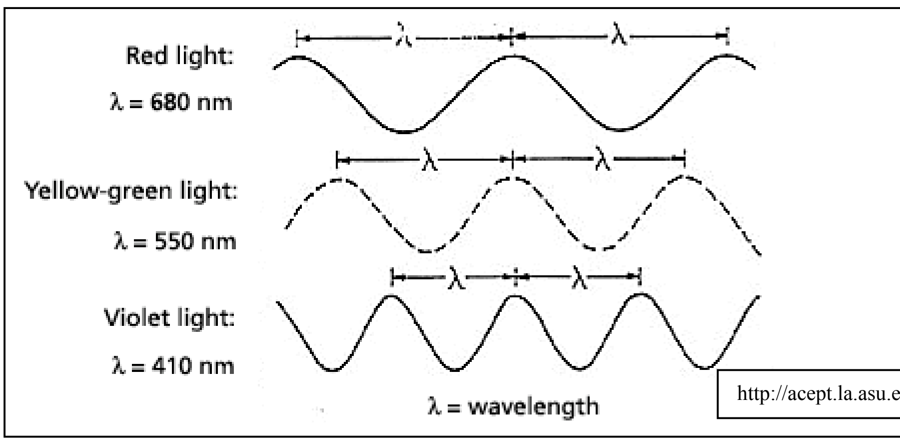




Image credit: http://plc.cwru.edu/tutorial/enhanced/files/lc/phase/phase.htm

around parallel to their original direction." (http://isaac.exploratorium.edu/~pauld/activities/liquidcrystal/liquidcrystal.html). The distance that the liquid crystals twist over is called the pitch, and it determines the color of the light that will be reflected. For example, when the distance equals half of the wavelength of red light the liquid crystal will reflect red light. If the distance is shortened to half a wavelength of blue light, it will reflect blue.




http://acept.la.asu.edu/PiN/rdg/color/color.sh

## What causes liquid crystals to change orientation?

Liquid crystals, like all matter, are made up of atoms. When we warm matter up, the atoms within it move about more quickly. This heat induced increase in movement also explains why substances have melting and boiling points. As the atoms move quickly enough the substance will change state progressing from solid to liquid to gas. The same type of explanation works for liquid crystals. If it is cold, the crystals are more ordered and closely spaced, as the crystals get warm the spacing increases. This does not entirely explain why liquid crystals that are cool and tightly spaced reflect red light and ones that are warmer and more loosely spaced reflect blue light. The change in reflected color is, in fact, primarily due to this increase in angle of the twisting and corresponding decrease in the pitch distance as the liquid crystal is heated up.

## Calibrating Liquid Crystal Thermometers

## Introduction

To use liquid crystals as temperature measurement devices we need to calibrate the changes in color that we notice to actual temperature changes that we measure. Once we accomplish this, we will be able to tell temperature by looking at color change!

## Material

- One liquid crystal strip per student (3-cm x 15-cm)
- Watch or room clock
- Metric ruler
- One piece of white cardboard per student (10 cm x 20 cm)
- Two-sided tape
- Fine tip waterproof pen
- Toothpicks
- Small white Styrofoam © plates
- Access to water
- One beaker (250 ml) per group
- Large plastic spoon (table spoon size)
- Centigrade (alcohol) thermometer one per group
- Acrylic school paints (primary colors) red, yellow, blue one 16-oz bottle each
- One-gallon jug to hold water
- Pot or large beaker to warm water for class
- Bag of ice chips
- Hot plate
- Coffee stirrers

## Student Objectives:

- Record and make careful observations of both temperature and color.
- Explain the concept of calibration.
- Explain why color change occurs when cholesteric liquid crystals change temperature.
- Use your liquid crystal thermometer to determine the temperature of an unknown liquid or the room in which you are conducting this experiment.
- Explain how to convert from Fahrenheit to Celsius.
- Check to see if the other groups thermometers are calibrated the same as yours.
    - Formulate an explanation for any differences.

## Procedure:

1. Put a pot of water on a hot plate and warm to 75-90$^o$ C ('bathwater hot')

| Safety Note: Caution water this hot can burn. Use caution and proper protection. |
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2. Hold a liquid crystal strip in your hand and describe what happens when you touch and hold the strip.

**Teachers note:**

*Write down all the observations and explanations on a white board or paper and save for future discussion at the end of the laboratory.*

3. Tape a liquid crystal strip to a piece of white cardboard so the liquid crystal strip is at least half off the cardboard (see fig 1)
4. Mark a 'C' on the left side of the cardboard corresponding to the type of thermometer you are using (Celsius). Make division marks on the cardboard starting from the bottom every 2-mm with the water proof pen (see fig 1)
5. Place your liquid crystal strip/cardboard on the outside of the beaker with a piece of two sided tape and then fill a 250-ml beaker with cool water ( about 20$^o$ C) so the water is slightly above the liquid crystal strip.
6. Place a thermometer in the beaker and record the temperature. (If the liquid crystal is not completely black add a small amount of ice, and allow the water to equilibrate until the strip is black).
7. Record the temperature in your lab notebook and on the bottom of the cardboard (the side with the '$C^0$ ') with the waterproof pen when the strip is black.
8. Add one tablespoon of hot water to the beaker at a time and stir (WITH THE COFFEE STIRRER NOT THE THERMOMETER!) Wait a few seconds and see if the color of the liquid crystal changes. Be sure to look straight on at the liquid

crystal when making observations). If the color does not change after 30-45 seconds add one tablespoon more until you observe a change.

9. Observe any color change, record the temperature on the white cardboard and quickly mix paint to match the color seen on the liquid crystal strip. (Use a toothpick and small amount of red, yellow and blue on a small white Styrofoam © plate.) Quickly place the correct color paint on the cardboard next to the temperature.
10. Continue to add water to the beaker (one tablespoon at a time) recording the liquid crystal color changes and the temperature of each change until the liquid crystal does not change anymore.
11. Repeat steps 5-10 with the same liquid crystal strip and make any adjustment in color on the cardboard as needed until you feel that you have accurately calibrated a liquid crystal strip.
12. Once you are confident of your calibration, 'trade' your thermometer with another groups and check each others calibration.

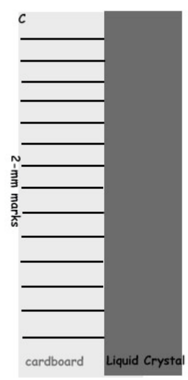


Figure 1

## Going Further

A. Answer the following questions in your laboratory notebooks:

- Why do liquid crystals change color?
- How did you calibrate your liquid crystal strip and why you are confident you could use it as a thermometer?
- Why might there be discrepancies between two groups calibration of liquid crystal strips?
- Explain the pattern of color change for your liquid crystal as the water becomes warm.
- Check with other groups and ask them if they have the same color pattern for similar temperature changes.
    - Do they have a similar color changes?
    - What does this tell you about how liquid crystals "measure" temperature?

- Do the color changes you observe correspond to the colors changes in the optical band of the electromagnetic spectrum?

**Teachers note:**

*You may have to help your students make this discovery.*

**Useful Equations**

$(F-32) * (5/9) = C^o$

$9/5*C + 32 = F^o$