

Liquid Crystals Lab

Objectives:

- To learn about liquid crystals and how they work
- To understand the relationship between a material's nanoscale structure and macroscale behavior
- To test a real liquid crystal system and see how color changes with temperature and pressure

Preparation:

- Read the introduction information and complete the prelab questions.
- Go over the procedure carefully. If there are any questions, ask the instructor before/during the lab.

Introduction

While most people know of the three main states of matter, solid, liquid and gas, few realize that other minor states exist that combine the properties of other states. One of these states is the liquid crystal. As the name suggests, liquid crystals are fluids that are free to flow like typical liquids. The “crystal” part of liquid crystals refers to their degree of crystallinity, or how well the molecules or atoms in a material are ordered. This unique atomic structure allows for interesting macro-scale properties that are not observed in regular solid or liquid phases. In this lab, we will investigate two forms of liquid crystals and see how their structure and physical properties are affected by outside stimuli such as temperature and pressure.

Liquid crystals are usually made up of large organic molecules, which can be viewed as long rods or wide plates (see Figure 1). Because of the stiffness and size of these molecules, they will preferentially orient in certain directions to minimize the energy within the bulk liquid crystal phase. A larger scale example would be how kayakers align on a crowded river to all point in the same direction. Likewise, these large organic molecules align in certain ways.



Figure 1.

There are two main classifications of liquid crystal phases, both based on how the molecules align. **Smectic** liquid crystals align in distinct layers, which can slide past each other. The layers also share long-range directional orientation of the molecules. **Nematic** liquid crystals only share long-range directional orientation of the molecules (see figure 2). Changes in physical conditions, such as temperature and pressure, can change the energy available to the system, which allows liquid crystals to move between phases.

In this lab we will focus on a special form of nematic liquid crystals, called *chiral nematic crystals*. You can think of this phase as being a crossover between smectic and nematic phases. This phase has separate planes of molecules, each rotated slightly from the plane below it (see Figure 2). The amount of space between molecules of the same orientation is called the *pitch*. As the energy of the system changes, the pitch in the liquid crystal phase changes.

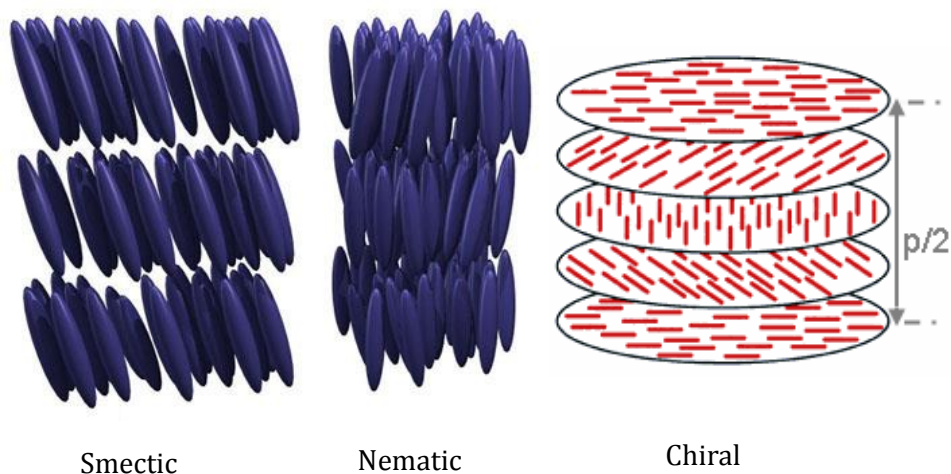


Figure 2. The main phases of liquid crystals. Note that p in the Chiral Nematic phase is the pitch distance

When light enters a liquid crystal phase, it will be reflected if the pitch of the liquid crystal matches the wavelength of the light. For liquid crystals with a small pitch, small wavelengths of light will be reflected (i.e. blue light, see Figure 3). For liquid crystals with a large pitch, long wavelengths of light will be reflected (i.e. red light). You can change the pitch, and thus the color of light reflected by the liquid crystals, by changing the temperature of the liquid crystals phase. The pitch of a liquid crystal is a molecular level property. Thus, any large-scale property changes (like color) you see in the liquid crystal displays are a result of tiny, molecular level properties changing.

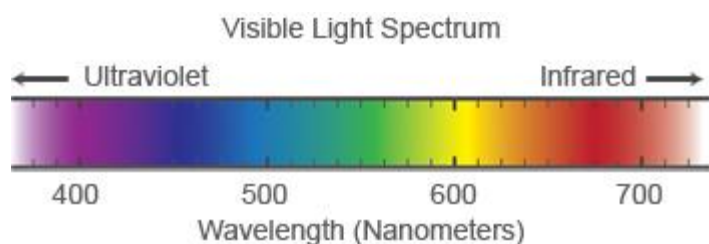


Figure 3. The visible light spectrum with wavelengths

For today's lab, you will be constructing several liquid crystals that change color with temperature. You will make mixtures of several large organic molecules shown in Figure 4. As their name suggests, the molecules we will use today are similar to the cholesterol found in humans. Large molecules will often stack very closely, making them waxy solids at room temperature (which is why cholesterol can build up in your arteries). To mix them effectively, you will heat the components of the mixture until all components melt and mix effectively. After cooling, the mixtures will form liquid crystal phases that show a temperature-dependent change in color.

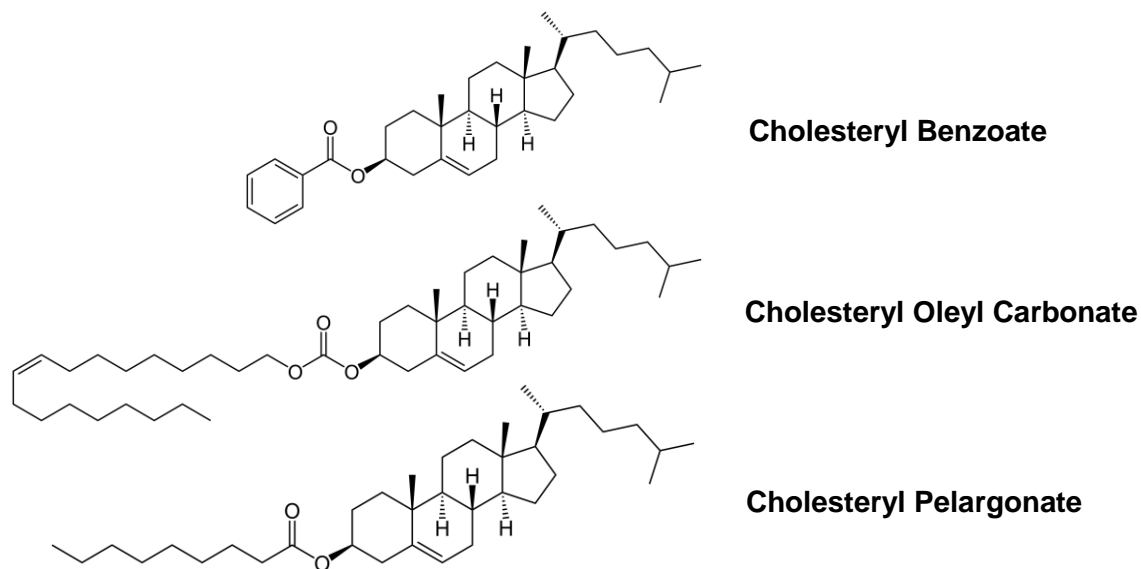


Figure 4

Looking at the structures of the molecules in Figure 4, can you see how they could be approximated as rods? The rod-like shape of the molecules is what allows them to align as liquid crystals. Also, note that each molecule is a slightly different size from the others. When combined, the liquid crystal will act as if it were made up of one molecule with an *average* size. By changing the composition of the mixture, you can change the average size of the molecules in the liquid crystal. This in turn affects the packing of the molecules, which determines what type of light they will reflect back at a given temperature.

Finally, all liquid crystals also need a director molecule, or molecule that insures that the other molecules line up properly. Often, this species is only need in small amounts compared to the other molecules. In this lab, cholesteryl benzoate acts as the director molecule.

As you do today's lab, think about the role of the molecules you are combining. Make note of any trends you can detect in how the average molecular size in the mixture changes depending on what components you add. See if you can detect a trend between temperature changes and average molecular size. Also, look for trends between temperature and the wavelength of light reflected by the liquid crystals.

Pre-lab questions

- 1) Read the MSDS sheets for the three chemicals that you will be dealing with. You can find these on Sigma-Aldrich's website. Write down the proper handling and storage, and the personal protection that is necessary when dealing with these chemicals.
- 2) The degree of how well molecules or atoms are ordered within a material is known as what?
- 3) What are the two main types of liquid crystals?
- 4) Name two physical parameters you can change to alter the structure and physical appearance of liquid crystals.
- 5) What does the pitch of a liquid crystal refer to?
- 6) When you shine light on a liquid crystal with a large pitch, what wavelength(s) of light will be reflected?

Experimental Procedure

Materials needed:

- 4 10 mL glass vials
- 1 plastic funnel
- 1 hot plate, thermometer, & water bath
- A sheet of clear contact paper
- 1 clothes peg
- 1 spatula
- 1 pair of scissors
- Sheets of black and white paper
- Gloves
- Safety glasses
- Kim wipes

Procedure:

1. Prepare the different liquid crystal mixtures

Liquid Crystal	Cholesteryl Oleyl Carbonate	Cholesteryl Pelargonate	Cholesteryl Benzoate	Temperature Range (°C)
Type 1	0.65 g	0.25 g	0.10 g	17-23
Type 2	0.45 g	0.45 g	0.10 g	26.5-30.5
Type 3	0.40 g	0.50 g	0.10 g	32-35

- Measure out the three solids for each liquid crystal type according to the table above.
- Transfer the solids into a glass vial using a plastic funnel. The solids, especially cholesteryl oleyl carbonate, may be sticky, so be sure to gently push them down the funnel and get as much into the vial as possible. If there is still a lot of solid on the spatula or funnel, keep them in the vial as you heat the vial up so you don't lose your product.
- Carefully, heat up the glass vial using a hot plate. When the solid is completely melted, the liquid crystal product should be transparent and have the consistency of honey.
- While the sample is still liquid, gently move the vial around so that the liquid crystal coats the vial walls.
- Label each of the vials with the appropriate liquid crystal type.

2. Preparing the different liquid crystal sheets

- Cut two pieces of transparent contact paper to ~10x10 cm, peel off the back, and place on the lab counter, sticky side up.
- Using a spatula, place some of liquid crystal type 1 in the center of one of the sheets (you will need 2-3 spatulas worth of material).
- Place the second piece of contact paper on top (so the sticky sides touch) and *gently* press the middle part to spread the liquid crystal out. Do **not** spread the liquid crystal all the way to the edges of the contact paper, or else it will leak. The goal is to create a thin layer of liquid crystal at the center while the edges of the contact paper act as a seal.
- Label the sheet, and repeat the procedure for the remaining liquid crystal mixtures.

3. Testing the different liquid crystal sheets

Part I.

- a) Place all three liquid crystal sheets on the white sheet of paper, wait a few seconds, and record your observations.
- b) Using one finger (wearing gloves), press against each liquid crystal sheet, and record any observations. Be sure to press your finger for the same amount of time for each test.
- c) Repeat this process on the black sheet of paper.
- d) Rub your hands together and repeat steps b) and c). Note the changes in observations, if any.

Part II.

- e) Turn on the hot water bath, set the temperature to 15°C. In order to be able to see any color changes, place the black paper behind the water bath as a background.
- f) Holding the first liquid crystal sheet with a clothes peg, immerse it in the water and note any changes in color that occur.
- g) Slowly increase the water temperature to 23°C and note any changes in color as the temperature increases.
- h) Place sheet 2 in the water bath (still at 23°C) and gradually increase the temperature of the water bath to 30°C. Record your observations as the temperature changes.
- i) With the water bath still at 30°C, place sheet 1 back in the water bath and record your observations.
- j) With the water bath still at 30° C, now place sheet 3 into the water bath and gradually increase the temperature of the bath to 35 °C. Record your observations.

4. Creating your own system

- a) Looking at the mixtures and temperature ranges, propose and test a system that would work in a temperature range higher than liquid crystal sheet 3. Be sure to use less than **1 g** of total material.
- b) Prepare a similar table to the ones used before in which you record the changes in color through your proposed temperature range:

Worksheet

Preparing the liquid crystal sheets:

1. What is the room temperature?
2. Can any of the liquid crystal mixtures you've made be used for sensing the temperature of this room? If yes, which?

Testing the liquid crystal sheets:

Part I.

	White Paper	Black Paper
Sheet 1 (Type 1)		
Sheet 2 (Type 2)		
Sheet 3 (Type 3)		

3. Why do you get a different result when you test the liquid crystal sheets against the white paper versus the black paper?
4. Did all 3 sheets display the same color? If not, why? What can you do to make them display color?
5. When you rubbed your hands together, did any of the sheets change in appearance?

Part II.

Sheet 1 (Type 1)		
Temperature (°C)	Color	Comments
16		
17		
18		
19		
20		
21		
22		
23		

6. At what temperature do you start to see some color? Does this correspond to the predicted temperature (from Table 1 in the procedure)?
7. When you take the liquid crystal sheet out of the water bath, does the color vanish immediately? If not, why do you think this happens?
8. If you placed the liquid crystal sheet in a water bath of unknown temperature and it became orange, what temperature would the water bath be?

Sheet 2 (Type 2)		
Temperature (°C)	Color	Comments
22-23		
23-24		
25		
26		
27		
28		
29		
30		

9. Can sheet 1 detect temperatures around 30°C? Why or why not?

Sheet 3 (Type 3)		
Temperature (°C)	Color	Comments
30		
31		
32		
33		

34		
35		

10. When you take the liquid crystal sheet 3 out of the water bath, does it behave similarly to sheet 1? What changes do you see? Why or why not?

11. Could you use one of these liquid crystal sheets for checking whether or not you have a fever? If yes, which one? Note: a healthy human body temperature is $\sim 37\text{ }^{\circ}\text{C}$.

Creating your own system:

Sheet 4 (Your Type)		
Temperature ($^{\circ}\text{C}$)	Color	Comments

12. What weights of solids did you choose? What is the proposed temperature range for them to work in?

13. Did your system work according to your expectations? Why or why not?

Post Lab Questions

- 1) In this lab, you changed the temperature and pressure, which changed the orientation of the liquid crystals. What is another external parameter you could change that would affect the orientation? (Hint: the molecules are charge-sensitive)

- 2) A liquid crystal display (LCD) is a common technology that utilizes the alignment of liquid crystals to polarize (or filter) light. From what you learned in the lab, what do you think would happen if you applied a large amount of heat or pressure to your calculator or computer monitor? What is happening to the liquid crystals?

- 3) Rank the average size of the molecules in the four different liquid crystal mixtures you made today. Is there a trend between average molecular size and temperature at which they turn color?

Average Molecular Size	Liquid Crystal Mixture	Color Change Temperature Range
Largest		
Next Largest		
Next Smallest		
Smallest		

- 4) Does the recorded scale of observed colors match a wavelength scale? Why? For reference, a visible wavelength scale is shown in Figure 3 of the instructions.