Colors in Liquid Crystals

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In this Activity students investigate the relationship between temperature and composition and the reflected and transmitted colors of a common nanoscale material, the cholesteric liquid crystal.

Background

Cholesteric-phase liquid crystals contain molecules aligned in layers *(1)* rotated with respect to one another (Figure 1, p 1360B). The rotation angle from one layer to the next increases with temperature, so the distance between layers with the same orientation, called the pitch, decreases with temperature. The helical structure selectively diffracts light *(2)* according to the Bragg condition modified by Snell's Law *(3)*, $\lambda = np(1 - \cos^2\theta / n^2)^{1/2}$ where λ is the reflected wavelength, n is the mean refractive index (~1.5 for these materials), p is the pitch, and θ is the angle with respect to the surface. Squeezing these soft materials changes the spacing between molecules, changing the reflected color.

Figure 3 shows the wavelength of reflected light as a sample cools through its liquid crystal phase *(4)*. The colors span the visible spectrum from blue to red.

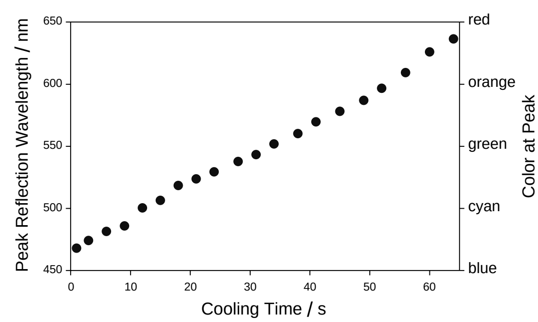

Figure 3. The wavelength of reflected light *(4)* as a sample cools through its liquid crystal phase. (Cooling time does not directly represent temperature; reflection wavelength is not expected to be linear with temperature *(5)*.)

Integrating the Activity into Your Curriculum

This Activity is suitable for exploring relationships between color, wavelength, reflection, and transmission and illustrates how temperature changes the Bragg reflection wavelength in liquid crystals. This Activity can also be used to explore the relationship between melting point and crystal packing. (See Question 3).

About the Activity

Ahead of time combine 0.65 g cholesteryl oleyl carbonate (Aldrich 151157), 0.25 g cholesteryl pelargonate (Aldrich C78801), and 0.10 g cholesteryl benzoate (Aldrich C75802) in a glass vial with a screw-on lid. Melt the contents with a hair drier to form a liquid crystal mixture with a phase transition just above ambient temperature *(6)* that can be divided amongst 20–30 students to spread between two layers of contact paper to make a "liquid crystal sandwich". Replacing some of the cholesteryl oleyl carbonate with cholesteryl pelargonate (keeping a combined mass of 0.90 g) raises the transition temperature as the molecules pack together better. For example, reversing the masses raises the transition temperature by 20 °C *(7)*. Cholesteric liquid crystals can degrade when exposed to moisture or air, but if stored in a sealed container the mixture can be prepared months in advance. Use these materials with normal chemical precautions. Do not inhale solids; avoid contact with skin, eyes, or clothing. Wash thoroughly after handling.

Answers to Questions

1. Reflected and transmitted colors are opposites (e.g., purple/yellow). The color changes with angle. If you observe red perpendicular to the surface (l = 630 nm) you would observe yellow 45° from the surface (l = 556 nm).
2. The colors change through red, orange, yellow, green, blue to purple as the sample's temperature increases. This order of decreasing wavelength corresponds to decreasing pitch.
3. The shape of cis-unsaturated fatty acids such as cholesteryl oleyl carbonate (see structure in this issue of *JCE Online*) makes them less able to pack together; the melting temperature of the liquid crystal mixture decreases as the percent composition of cholesteryl oleyl carbonate increases.

References, Additional Related Activities, and Demonstrations

1. Liberko, C. A.; Shearer, J. *J. Chem. Educ.* **2000**, *77,* 1204–1205; supplemental material suggests the fish analogy to phases in liquid crystals *(http://www.jce.divched.org/Journal/Issues/2000/Sep/abs1204.html).*
2. Palffy-Muhoray, P. *Nature* **1998**, *391*, 745–746.
3. Nassau, K. *The Physics and Chemistry of Color;* Wiley: New York, 1983; pp 430–431.
4. Reflectance data were obtained using an Ocean Optics USB 2000 spectrometer equipped with a fiber optic oriented perpendicular to a 0.15-mm thick sample mounted between two microscope slides with cover slips as spacers over a black background and illuminated with a white LED light source.
5. Pindak, R. S.; Huang, C. C., Ho, J. T. *Phys. Rev. Lett.* **1974**, *32,* 43–46.
6. This procedure assumes that room temperature will be below 25 °C and thus below the liquid crystal phase transition. If room temperature is warmer, the composition should be adjusted to give a higher transition temperature.
7. Cholesteryl Ester Liquid Crystals. *http://www.mrsec.wisc.edu/Edetc/nanolab/LC_prep/index.html* (accessed June 2005)

We thank the National Science Foundation Materials Research Science and Engineering Center (MRSEC) on Nanostructured Materials and Interfaces (award #DMR-0079983) and the Beloit College Sanger Program for support of this project.

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Colors in Liquid Crystals

Liquid crystals, such as those in watches, calculators, fish tank thermometers, mood rings, and battery test strips, have a phase in between liquid and solid: the molecules can move independently, as in a liquid, but remain somewhat organized, as in a crystal. A good analogy is a school of fish; in any region all fish swim in the same direction, but the fish can change position with respect to each other and the orientation can respond to external stimuli.

In the liquid crystals you will use there are mixtures of long, thin molecules related to cholesterol that align parallel to one another in layers. The alignment of molecules in one layer is at an angle to that in the next layer. The orientation of the layers approximates a helix (Figure 1) similar to DNA, a spiral staircase, or a screw. The angle between layers increases with temperature, changing the *pitch*, the distance between layers that have the same orientation. The wavelength of light reflected by the liquid crystal is approximately equal to the pitch, so changing the temperature changes the color reflected by cholesteric liquid crystals. Thus liquid crystals can be used as sensors that can map regions of different temperature. In this Activity, you will create a liquid crystal "sandwich", and investigate its properties.

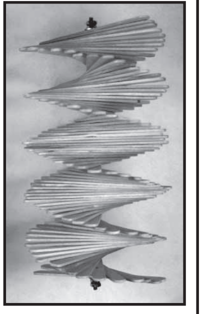
photo: George Lisensky

Figure 1. Model showing orientation of layers.

Try This

You will need: vial of cholesteric liquid crystal components (from your instructor), spatula, scissors, ruler, transparent contact paper, dark surface, white light source, beaker of water, thermometer, and hot plate.

A. Preparation of the Liquid Crystal Sandwich

__1. Cut two 10 cm × 10 cm squares of transparent contact paper.

__2. Peel the backing off one of the contact paper squares. Use a spatula to transfer a small volume of the liquid crystal mixture onto the center of the sticky side of the square and to spread the mixture into a very thin layer. Leave at least a centimeter of sticky area around the edge (Figure 2).

__3. Peel the backing off the other square of contact paper and make a liquid crystal sandwich with the sticky sides of the paper facing together. All edges of the sandwich should be sealed together.

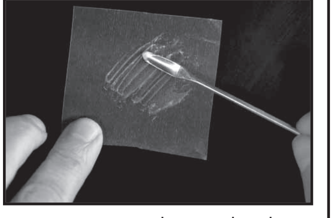
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Figure 2. Spreading a thin layer of liquid crystal mixture.

B. Transmission versus Reflection of Light

__1. Warm the liquid crystal portion of the sandwich by touch until you observe bright colors.

__2. Hold the sandwich in front of a dark surface. What color do you see reflected if you look straight at the sandwich? You are viewing reflection of one wavelength with all other wavelengths absorbed by the dark background.

__3. Now look at an angle. Do you see the same color?

__4. View a white light source through the sandwich. What color do you see as transmitted light?

C. Cholesteric Liquid Crystals as Indicators of Temperatures

__1. Submerge the liquid crystal sandwich in a beaker of water and gently heat the water with a hot plate.

__2. Measure and record the temperature at which the liquid crystals first change color. What color do you see first?

__3. Measure and record the temperature at which the liquid crystals become colorless. What color do you see last?

__4. Cool the sample by removing it from the water. Repeat steps 2–3 as necessary to list the order of colors observed while heating the sample.

Questions

1. In Part B you observed the difference in reflected and transmitted color. If the reflected color was purple, what would be the transmitted color? If the reflected color was yellow, what would be the transmitted color? Does the reflected color change with angle, that is, do you and a partner sitting next to you see the same color?
2. In Part C, which color indicated the coolest temperature and which color indicated the warmest temperature? What is the order of colors you saw going from coolest to warmest? Explain your observations by matching color with wavelength and the pitch of the liquid crystal.
3. If your class tried more than one composition, what is the relationship between the mass of cholesteryl oleyl carbonate in your mixture and the transition temperature at which your mixture initially changed color? What happens at the molecular level that causes the change in transition temperature?

Information from the World Wide Web *(accessed Jun 2005)*

Introduction to Liquid Crystals. *http://www.barrettresearch.ca/teaching/liquid_crystal/LC02.htm*

Liquid Crystal Phases. *http://plc.cwru.edu/tutorial/enhanced/files/lc/phase/phase.htm*

What are liquid crystals? *http://www.mc2.chalmers.se/pl/lc/engelska/tutorial/contents.html*

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