Teacher's Preparatory Guide

Making a Liquid Crystal Thermometer

Purpose: This lesson is designed to introduce liquid crystals, a fourth state of matter.

- Understand liquid crystals in relation to different phases of matter.
- Learn the process of temperature based color change due to twists and turns of liquid crystals

Overview: We know matter can exist in three phases: solid, liquid and gas. Matter can also exist in a phase that is called liquid crystal. Liquid crystals have the particles arranged in a helix, and the color reflected from the liquid crystal depends on the pitch of tightness of the helix. The pitch , which changes with temperature, equals the wavelength of the light reflected which creates the color of the liquid.

Can car companies use the materials to paint cars that change color depending on a person's angle of view or temperature of the day?

Liquid crystals are all around us. They are in the shining exoskeleton of the jewel beetle; they are in the fish tank thermometer; they are in the color-changing labels of some drinks; they are in digital displays; and they are in security labels of many secure documents like checks. All these color changing phenomenon use the same principle. There are nanosize helical structures that reflect light differently depending on the tightness of the helix. Can a scientist use the same principle to make paints that change colors? Can we have colors of our cars change based on the external temperature or humidity?

Time Required: One 55 minute class period

Level: High school or beginning undergraduate chemistry or physical science

Big Idea: Structure of Matter

Teacher Background The differences in the three phases of matter, solid, liquid, and gas lies in the relative closeness of the particles and degree of movement allowed between the particles. At temperatures below the melting point, the particles have thermal vibration but cannot move about freely. The object maintains its shape because of tight packing of the particles. As the temperature is raised, the particles gain more thermal energy and the vibrations increase to the point that the particles break loose and move around in random order. At this point, the particles bump into each other and constantly change direction. The attraction between the particles is still strong and particles cannot move away from each other, unless an additional form of energy or force is applied. The particles still facing the cohesive forces take the shape of the container. As more energy is given to the particles, the positional order is broken and particles start moving in every direction and do not face any force of attraction from other particles (ideal gas behavior). All of this particle interaction occurs at the molecular/atomic level – on the nanoscale. Liquid

Developed by Rano Sidhu

*Development and distribution partially funded by the **National Science Foundation***

NNIN Document: NNIN-xxxx
Rev: 12/00/2012

crystals are matter that has properties between those of a liquid and a solid. Liquid crystals may flow like a liquid but have crystals like a solid.

Table 1: Differences in physical properties of different phases of matter

	Solid	Liquid Crystal	Liquid	Gas
Position order	High	Limited	Random	Random
Orientation order	High	High	Random	Random
Particle interaction	Strongly bound	Bound	Bound	Unbound

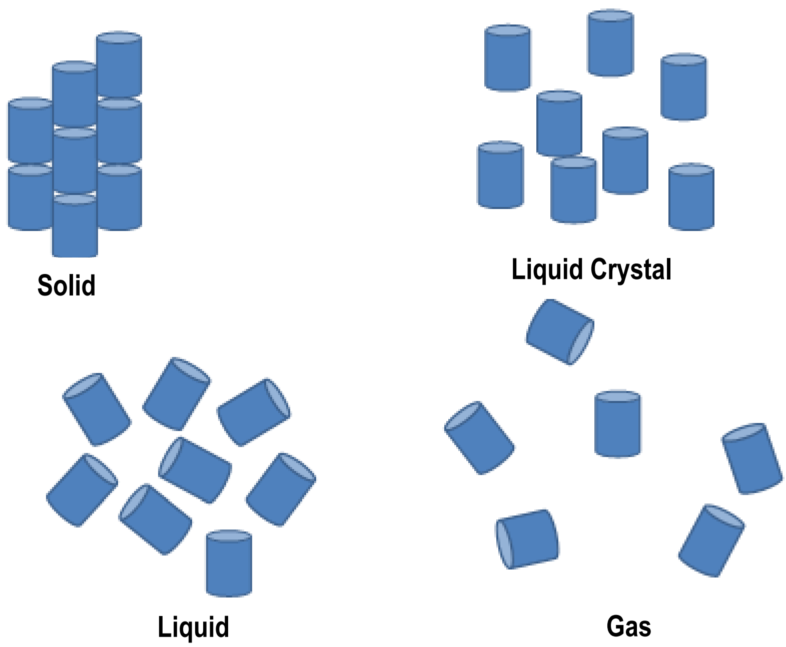
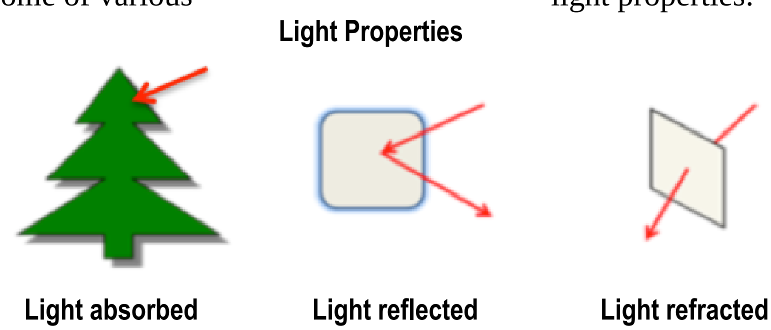


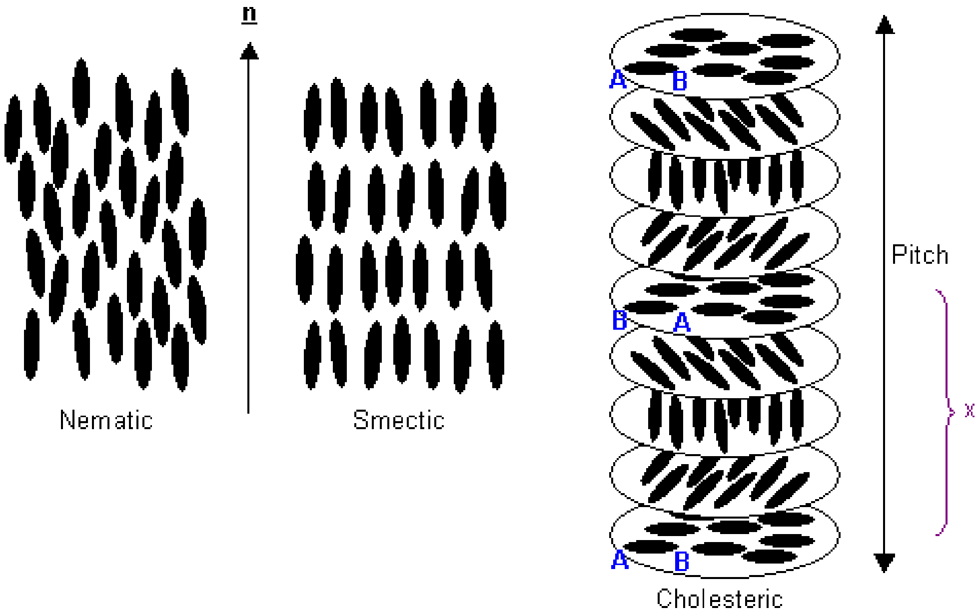
Figure 1: A visual representation of position and orientation order of particles in different phases of matter

The colors of the objects are the outcome of various light properties: absorption, refraction, or reflection. Any opaque or non-transparent object shows color due to different wavelengths in a visual spectrum being reflected, refracted, or absorbed. The ultimate color depends on the wavelength.



In the case of liquid crystals, the reflection and refraction takes place from the nanosize helices. As the stimulus changes (temperature, humidity, etc.) the pitch of the helix changes and so does the reflection. These helices are actually stacks of layers of liquid crystals that rotate in response to temperature. The different rotations result in different pitch and, hence, a different color. Research has found that when the width of one complete turn of the helix in cholesteric liquid crystals is close to the wavelength of visible light, the materials reflect light with specific wavelengths, resulting in bright metallic colors. Below is a schematic of the three types of liquid crystals with the cholesteric version indicating the pitch.

Development and distribution partially funded by the ***National Science Foundation***



[http://www.doitpoms.ac.uk/tlplib/anisotropy/images/image24.gif(creative](http://www.doitpoms.ac.uk/tlplib/anisotropy/images/image24.gif) Creative Commons Attribution.

Change in pitch changes the color of reflected light. 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.

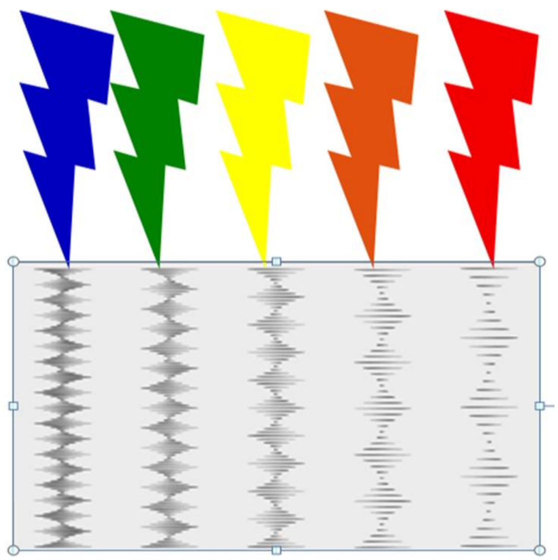


Figure 2: Change in pitch of the reflected light

Liquid crystals are commonly used in a variety of electronic displays including watches, calculators, battery testing strips, and thermometers. Because of their unique electro-optic properties they are used in several photonic components such as optical filters and switches, optical waveguides, and lasers.

Materials per lab group of 3 students each:

- 3 cm × 5 cm liquid crystal sheets, one each for the 3 different temperature ranges (see *Advance Preparation* section)
- 3 pieces of card stock paper with visible light spectrum preprinted per group (see *Advance Preparation* section)
- Beaker with approximately 300 mL water
- Beaker 250 ml (to warm water)
- hot plate
- 250 ml beaker to test the temperature strip
- 15 cm of double-sided tape to tape the crystal sheets onto beaker
- large plastic spoon (tablespoon size)
- iCelsius^{o} thermometer probe or any other thermometer (if using the iCelsius^{o} probe, you will need an iPad, iPod, or iPhone)
- Plastic cup with about 8-10 ice cubes

Source/Website	Material
Educational Innovations http://www.teachersource.com	• liquid crystal sheets in three temperature ranges: 20-25^{o}C; 25-30^{o}C; 30-35^{o}C
iCelsius° http://www.icelsius.com/	• iCelsius^{o} Pro thermometer (any thermometer will work)

Advance Preparation: Purchase materials, which may be found here:

1. ***Cut the different temperature ranges of liquid crystal sheets into 3 in x 5 in pieces.***
2. ***Print the visible light spectrum sheets on card stock (provided at the end of the guide, each 8 in x 11 in sheet has enough spectrum ranges for 2 student groups).*** You may also laminate these and reuse for future. If you are laminating the sheets, provide transparency markers to write on these.

Safety Information: Take care when using the hotplate. Hot water and steam can cause severe burns. Wear protective clothing and eye protection.

Suggested Instructional Procedure:

Time	Activity
Day 1	**The day before the lab**
50 min	Introduce students to the topic of phases of matter and the heating curve to prepare students for understanding the position and orientation order in different phases of matter. Connect previous knowledge of the electromagnetic spectrum and wave properties to prepare students for understanding the relationship between pitch and wavelength. Discuss that these physical changes result from interactions of matter at the nanoscale.
Day 2	**The day of the student lab**
5 min	Ask students warm-up questions regarding previous day's content to ensure students understand the relationship between the color changes associated with liquid

	crystals.
45 min	Distribute *Student Worksheets* to students. Have students follow the procedures for the lab.
5 min	Clean up.

Teaching Strategies: The lab should be done in groups of 3 students: two to do experiment and one to record the data.

Guided Dialog *Before* beginning the lab, review the meaning of these terms:

Wave *A disturbance or variation that transfers energy progressively from point to point in a medium and that may take the form of an elastic deformation or of a variation of pressure, electric or magnetic intensity, electric potential, or temperature.* [R1]

Wavelength *The distance between two successive, repeating parts of a wave.*[R2]

Wavespeed *The speed at which a wave passes any fixed point over time; expressed as speed = frequency × wavelength.*[R2]

Refraction *The bending of an oblique ray of wave when it passes from one medium to another.*[R2]

Frequency *For a body undergoing simple harmonic motion, the number of vibrations it makes per unit time. For a series of waves, the number of waves that pass a particular point per unit time. (Frequency = 1/Period -or- Period = 1/Frequency)* [R2]

Hertz (Hz) *Unit of frequency; one vibration per second is 1 Hz.* [R2]

Liquid crystal *Liquid crystals form from organic compounds and is thought of as the phase of matter between the solid and liquid state of a crystal. For instance, a liquid crystal may flow like a liquid, but its molecules may be oriented in a crystal-like way.* [R3]

Emission spectrum *The distribution of wavelengths in the light from a luminous source.* [R2]

Ask students questions to provoke thought and review what they already know:

1. How does adding heat to an exothermic reaction affect the equilibrium? *Adding heat will make the reaction go in reverse direction and will favor the formation of reactants.*
2. How can labels on some drinks tell when the drink is at right temperature to drink? *The chemicals in the label go through a change and the new product has a different color.*

Going Further: Students who have a good grasp of the content of the lab can be further challenged with these questions:

1. 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. *The colors change through red, orange, yellow, and green, blue to purple as the sample's temperature increases. This order of decreasing wavelength corresponds to decreasing pitch.*
2. What is repeatability and reproducibility? *Repeatability is the consistency of results obtained by one member of the group. Reproducibility is the consistency of results obtained by different members of the group.* (Make sure students carry out sufficient tests to be able to judge the repeatability and reproducibility of data.)
3. Why should your results be repeatable and reproducible? *Answers will vary.*

Assessment:

Students will be able to**:**

- formulate a focused problem/research question and identify the relevant variables, design a method for the effective control of the variables, and develop a method that allows for the collection of sufficient relevant data.
- record appropriate quantitative and associated qualitative raw data including units, process the raw data correctly, present processed data appropriately and, where relevant, include errors and uncertainties.
- state a conclusion with justification based on a reasonable interpretation of the data, evaluate weaknesses and limitations, and suggest realistic improvements in respect of identified weaknesses and limitations.

Resources: You may wish to use these resources either as background or as a resource for students to use in their inquiry-based design.

1. Merriam-Webster, Inc. “Dictionary: wave.” (accessed August, 2012) http://www.merriam-webster.com
2. Mark Foster. “Physics Definitions.” (accessed August, 2012) http://mark.foster.cc/school/phys100.html
3. Mr. Kim. Florida State University. “Liquid Crystal.” (accessed August, 2012) http://www.physics.fsu.edu/Users/Dobrosavljevic/Phase%20Transitions/Liquid%20crystal_younghee%20Kim.pdf
4. ThinkQuest. “ Solutions and Colligative Properties: Phase Diagrams” (accessed October, 2012) http://library.thinkquest.org/C006669/data/Chem/colligative/phase.html
5. Case Western Reserve University. “Introduction to Liquid Crystals” (accessed August, 2012) http://plc.cwru.edu/tutorial/enhanced/files/lc/intro.htm
6. The World of Liquid Crystals (accessed August, 2012) http://invsee.asu.edu/nmodules/liquidmod/good.html

National Science Education Standards (Grades 9–12)

Content Standard A: Scientific as Inquiry

- Abilities necessary to do scientific inquiry

Content Standard E: Science and Technology

- Abilities of technological design

Content Standard F: Science in Personal and Social Perspectives

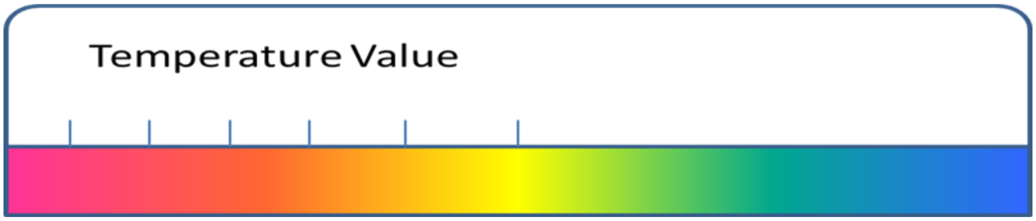
- Science and technology in local, national, and global challenges

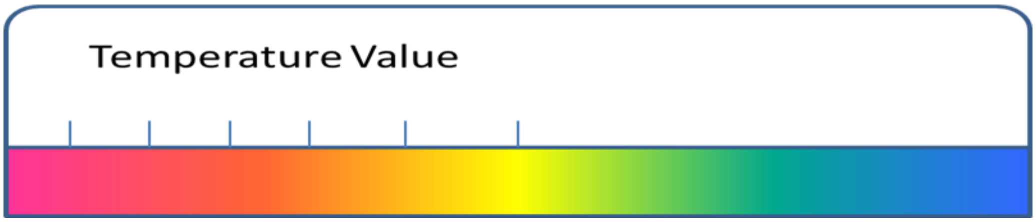
Next Generation Science Standards

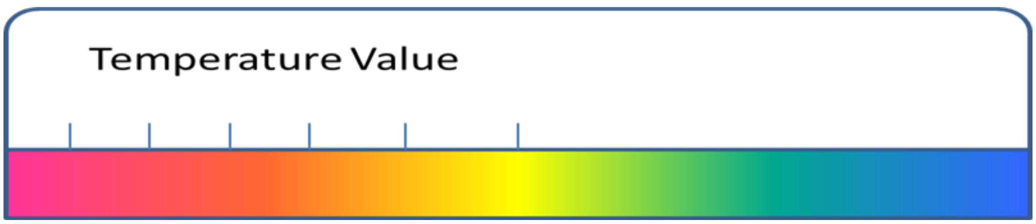
- HS-PS1A. Structure and properties of matter
- HS-PS2-6 Communicate scientific and technical information about why the molecular-leve structure is important in the functioning of designed materials

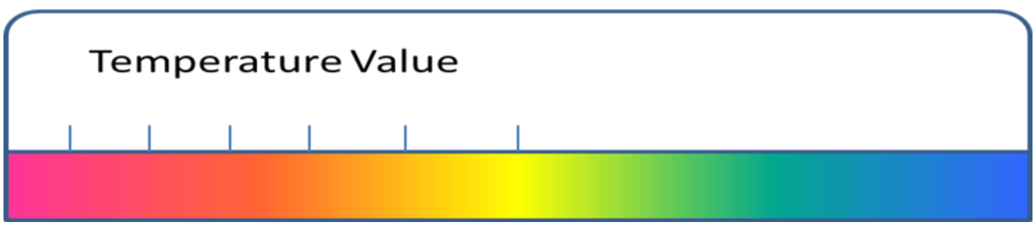
*Development and distribution partially funded by the **National Science Foundation***

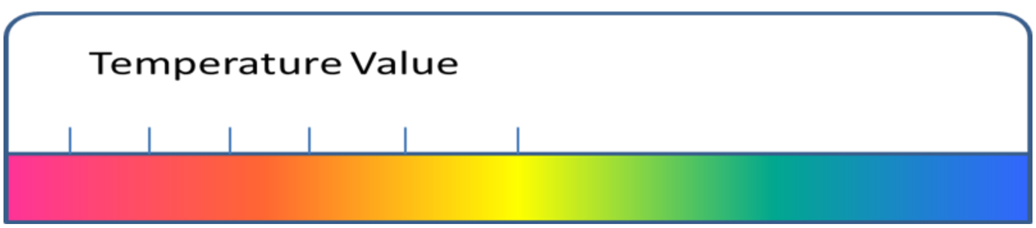
Visible Light Spectrum Sheet

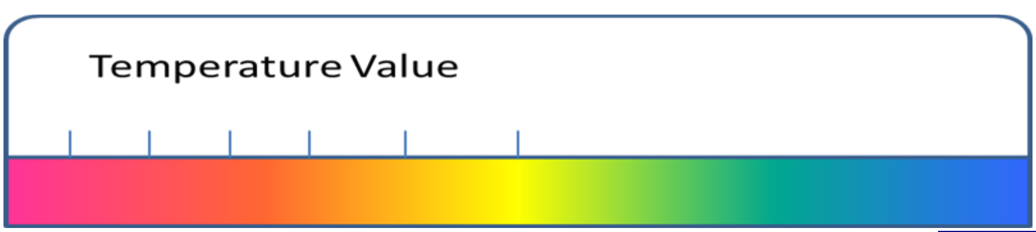












Developed by Rano Sidhu

*Development and distribution partially funded by the **National Science Foundation***

NNIN Document: NNIN-1371

Rev: 10/2013

Development and distribution partially funded by the ***National Science Foundation***