Liquid Crystals:

An Investigation into the Practical Application of Liquid Crystal Substances

NYSCATE
NEW YORK STATE CURRICULUM
for Advanced Technology Education
Integrated MST Design Activities for High School and Community College Students

Partners in New York State Curriculum for Advanced Technology Education

Hofstra University
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Liquid Crystals for Design
The Practical Application of Liquid Crystal Substances

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I. INTRODUCTION AND OVERVIEW

ABSTRACT

The distinctions between solid, liquid, and gas states are not always clear-cut. The unique properties associated with these distinctions have produced some great practical benefits in a number of fields, including electronics and medicine. Before 1960, liquid crystals were virtually unknown. The invention of liquid crystal displays (LCDs) in the 1970s led to an explosion in the discovery of liquid crystalline materials. Today, such substances are all around us. They are used in high-strength fibers, thermometers, and optical displays. Their impact on optical devices alone has led to rapid advances in laptops, handheld communication devices, and most recently, flat-panel televisions.

This module integrates mathematics, science, and technology (MST) through the design and development of a liquid crystal device. Students are challenged to develop knowledge and skills necessary to design, construct, and test an object that demonstrates an effective use for a liquid crystal device in the form of a display.

Students, working in design teams, are expected to make their design decisions on the basis of mathematical and scientific principles in an informed design process rather than through trial and error alone. Mathematical, scientific, and technological Knowledge and Skill Builder (KSB) activities are completed by student design teams to provide the information they need to guide them as they design, construct, and test their device. Topics in the KSBs include: the informed design cycle; properties of matter; the effects of electric and magnetic fields, and temperature, on liquid crystal properties; thermotropic concepts; use and combination of chemicals.

PEDAGOGICAL FRAMEWORK REFERENCE

A separate document, the NYSCATE *Pedagogical Framework* (www.nyscate.net), provides an in-depth understanding of the NYSCATE challenge statements, the FOCUS on Informed Design pedagogical model for teachers, student Knowledge and Skill Builders (KSBs), the informed design loop for students, and more.

GRADE LEVEL

This module is designed for the 11^{th}- or 12^{th}-grade high school student.

TIME ALLOCATION IN 45-MINUTE PERIODS: 23 periods

EXISTING COURSES ENHANCED BY THIS MODULE

This module is intended for use in chemistry, physics, and technology education courses that address the MST learning standards of New York State. The module could be taught as part of a high school stand-alone chemistry course, physics course, or technology education course; or it could be team taught in an interdisciplinary course.

Chemistry students, in addition to developing skill in experimental design, become knowledgeable in the areas of chemical properties, mixtures of chemicals, and the effects of temperature change on these chemicals.

Physics students, in addition to developing skill in experimental design, gain knowledge in the areas of phase changes, energy transfer and conversion, electrical concepts and applications, and optical properties of liquid crystal displays and thermotropic substances.

Technology education students, in addition to developing skill in engineering design, gain knowledge in the areas of electrical concepts and applications, electrical circuit design and application, use of tools and materials, and design and construction of a practical device using polymers as well as other materials.

TYPICAL SOURCES

Liquid Crystal Chemicals:

Sigma-Aldrich (314-771-5765)
PO Box 14508
St. Louis, MO 63178

15,115-7	25 grams cholesteryl oleyl carbonate
C7,880-1	25 grams cholesteryl perargonate

Liquid Crystal Sheets:

Edmund Industrial Optics (856-547-3488)
101 E. Gloucester Pike
Barrington, NJ 08007-1380

L61-161	Liquid Crystal Sheet Assortment

II. DESIGN CHALLENGE OVERVIEW

SETTING THE CONTEXT FOR STUDENTS

Introduction

The ability to design a new device by applying an existing technology is an important, creative engineering skill. For example, basic technological inventions such as Velcro, lasers, LEDs, or CRTs have been put to many uses. In this module, you will be challenged to take a technology, liquid crystals, and use it to design a new device.

Each day we come into contact with many objects for which a display or indicator is an important component—temperature, electric fields or current, and information are a few phenomena that may be displayed or indicated.

- Some things function best, or taste best, at a particular temperature. A refrigerator and a cup of coffee are examples.
- A battery is another example. Knowing how much charge is left in a battery can be very helpful. Battery-testing strips serve this purpose. Electric current passing through the medium generates heat. In cases such as this, measuring the temperature of one thing indirectly measures something else that is difficult to measure directly.
- We rely on information from LCDs on watches, clocks, calculators, and computer screens.

A device providing a quick and inexpensive means of providing information or monitoring temperature or current can be used in many ways in today's world. This module challenges students to create such a device.

Design Challenge

As part of a team, you are to design, construct, and test a device that will demonstrate a practical use for liquid crystals in the form of a liquid crystal display.

Specifications

The device constructed must be able to detect either heat or electric fields. The display must be used to do one of the following:

- indicate a particular temperature, temperature range, or change in temperature
- indicate the presence of current or an electric field
- display information

Constraints

Each team must use only materials approved in advance by your teacher. The display should be no larger than 2 inches by 2 inches, and no more than 1/2 inch thick. If the purpose of the liquid crystal device is to measure temperature, it should be used to measure heat liberated or absorbed in a physical or chemical change. For example, the device could measure heat generated by friction, a chemical reaction, or an electrical current.

III. GOALS AND LEARNING OUTCOMES

The student outcomes developed in this module are listed below. These are based on the NYS learning standards in mathematics, science, and technology (MST), as well as the standards for technological literacy (STL) and the national standards for the study of technology.

As students learn to apply the process of informed design in *Liquid Crystals for Design*, they acquire and develop knowledge and skills. Specifically, they:

- carry on informed design (MST Learning Standards 1 & 5);
- conduct controlled experiments (MST Learning Standard 1);
- solve various mathematical problems (MST Learning Standard 1);
- obtain and communicate solutions (MST Learning Standards 2 & 5);
- apply formulas and develop measurement skills (MST Learning Standard 3);
- develop concepts related to the properties of matter and its interactions, through the specific example of liquid crystals; thermotropic properties; chemical compound concentrations; and the effects of temperature on color changes of thermotropic displays (MST Learning Standard 4);
- learn how chemicals and energy combine to form a reaction (MST Learning Standard 4);
- learn how technological systems function (MST Learning Standard 5);
- learn how mathematics, science, and technology interact (MST Learning Standards 6 & 7);
- learn how various fields of study interconnect (STL Standard 3);
- apply and understand the process of engineering design (STL Standards 9 & 11);
- research, develop, experiment, and invent while problem solving (STL Standard 10); and understand, select, and use energy and power technologies (STL Standard 16).

In this module the teacher:

- facilitates mathematical analysis, scientific inquiry, and the informed design process (MST Standard 1, STL Standards 9 & 11);
- provides background information regarding the chemical composition and terminology, development, and uses of liquid crystal compounds;
- fosters cooperative learning as students work in teams (MST Standards 1–6, STL Standard 10);
- fosters development of communication skills through the use of a Design Journal or Design Folio; a Design Report; and a team presentation (MST Standard 2);
- introduces students to the design process through an engaging Design Challenge (MST Standards 1 & 5, STL Standards 9–11); and
- guides individuals as they research, design, construct, test, redesign, and present their final design solutions (MST Standards 1–5, STL Standards 9–11).

IV. TIMELINE CHART

The recommended order for the completion of the KSBs and Design Challenge by students is as follows:

PERIOD	FOCUS MODEL COMPONENT (for teacher)	INFORMED DESIGN LOOP COMPONENT (for students)	ACTIVITY
1	Focus Discussion on Problem Context	Clarify Design Specifications and Constraints	Begin discussion of the problem, identify needs, and provide overview of the module.
2–3	Organize for Informed Design		Complete and discuss KSB 1: The Informed Design Cycle. Form design teams.
4–14	Coordinate Student Progress	Research and Investigation	Complete and discuss KSB 2: Matter. Complete and discuss KSB 3: States of Matter. Complete and discuss KSB 4: Web Search for Information about Liquid Crystals. Complete and discuss KSB 5: Investigating Liquid Crystal Sheets. Complete and discuss KSB 6: Color-Temperature Relationships in Mixtures. Complete and discuss KSB 7: Ohm's Law. Complete and discuss KSB 8: Effects of Voltage and Current on Liquid Crystal Substances.
15	Coordinate Student Progress	Generate Alternative Solutions	Brainstorm and generate ideas, sketches, or models of alternative design solutions.
16	Coordinate Student Progress	Choose and Justify the Optimal Design	Select and justify the choice of the final design solution.
17–20	Coordinate Student Progress	Construct a Working Model	Teams plan and construct a model of the final design solution and evaluate it.
21–22	Unite Class Thinking and Accomplishments	Test and Evaluate the Design Solution	Teams share and discuss their design solutions through class presentations.
23	Sum up Progress on Learning Goals		Evaluate student work, assign grades, and provide and receive feedback.

V. MATERIALS AND RESOURCES

MATERIALS

Provide each team with materials required to complete each of the KSBs and successfully address the Design Challenge. Items might include:

safety goggles
wire
switches
analog/digital multimeter
battery holder
black spray paint
wooden stirrers
hot plate
cholesteryl nonanoate/perargonate (CN)
cholesteryl oleyl carbonate (COC)
beakers
nichrome wire
rubber gloves
wire cutter
various resistors
plastic transparencies
1.5-volt, 6-volt, 9-volt batteries
soldering iron and solder
small bottles
tape
thermometer – standard & infrared if possible
test tube holder
aluminum foil
electronic simulation software

If a team needs tools or materials not listed above, the teacher must approve them in advance. (Note: Standard classroom materials and supplies do not require the teacher's prior approval.)

Students will use additional tools and materials during completion of the KSBs in this module. They are listed in each KSB or in the Procedural Suggestions section below.

SAFETY CONSIDERATIONS

Students need to wear safety glasses for many of the procedures. Some activities may require students to apply heat to prepare or mix chemicals, or to heat water. Be sure students are aware that burns may result from such procedures, and that they know what to do should burns occur.

Students will be working with chemicals as well, and will need instruction in the safe handling of chemicals and related materials. They must wear rubber gloves and safety glasses, and avoid breathing fumes, while working with chemicals.

RESOURCES

http://invsee.asu.edu/nmodules/liquidmod/welcome.html Excellent introductory source. Provides links to other sites that feature interactive activities.

http://www.howstuffworks.com/lcd1.htm Excellent explanation of how liquid crystal displays work. Provides links to other websites for additional research opportunities.

http://www.bsu.edu/eft/gems/activity11.html Activity involving the study of liquid crystals.
http://mrsec.wisc.edu/edetc/cineplex/LC_prep.html

http://www.materials.ac.uk/resources/browse.asp?browseid=141

http://www.chemheritage.org/EducationalServices/FACES/poly/home.htm

VI. PROCEDURAL SUGGESTIONS

PEDAGOGICAL FRAMEWORK REFERENCE

A separate document, the NYSCATE *Pedagogical Framework* (www.nyscate.net), provides an in-depth understanding of the NYSCATE challenge statements (p. 6), the FOCUS on Informed Design pedagogical model for teachers (p. 7), student Knowledge and Skill Builders (KSBs) (p. 6), the informed design loop for students (p. 10), and more.

SUGGESTIONS

In this section strategies are presented within the context of the NYSCATE FOCUS on Informed Design, a pedagogical model for teachers. The FOCUS components are: **Focus** discussion on the problem context, **Organize** for informed design, **Coordinate** student progress, **Unite** the class in thinking about what has been learned and accomplished, and **Sum** up progress on the learning goals (see the NYSCATE *Pedagogical Framework* for more on this model).

Period 1: Focus Discussion on the Problem Context

Even though liquid crystals are all around us, students typically do not identify them as such. **Therefore, before you introduce the problem, it is advantageous to acquaint students with liquid crystals and some of their physical properties.** In the ”1-2-3” activity found in the introductory packet, students identify what they already know about liquid crystals and design. In most cases, they will have naive knowledge or none at all about liquid crystals.

Have students share their responses to the items in the 1-2-3 activity with the class. Then have them begin “Properties and Uses of Liquid Crystals (LC).” They should record all of their observations on the activity sheet, as they have not been introduced to the Design Journal or Design Folio at this point.

After students have recorded their observations, bring the class back together and write their observations on the chalkboard or an overhead projector transparency. This will allow all of the students to learn more about the properties of liquid crystals. See that each student has a color spectrum for each LC sheet.

Have each group of students agree on a hypothesis for whether evaporation is a cooling or warming process. Allow students to try different things with various materials to see what happens. If they fail to see that alcohol works well, direct them to the extent that they see that it works well. Then have them design and carry out an experiment that makes use of alcohol to test their hypothesis. If they need help, ask them to suggest some examples of where evaporation takes place. The color changes on the LC sheet will take place on the edges of the drop of alcohol. Have each group report out on results.

The problem. The Problem Context section of the Design Challenge is helpful when introducing the problem. Check that students understand:

- that, in general, technology typically is applied through the design process to address a variety of human needs
- properties of liquid crystals, which include indicating temperature by changing color, or indicating an electric field by polarizing light, are examples of applications of technology.

Students are challenged to propose a new application of one of these properties through the informed design process.

> **Introductory Packet (continued)**
> **Overview of the Module Including the Design Challenge**
>
> **HERE'S WHAT YOU WILL DO**
>
> In the NYSCATE module *Liquid Crystals for Design*, you will work as part of a team to:
>
> - investigate possible solutions to a given problem;
> - complete Knowledge and Skill Builder (KSB) activities;
> - …
>
> **PROBLEM CONTEXT**
>
> **Introduction**
>
> The ability to design a new device by applying an existing technology is an important, creative engineering skill. For example, basic technological inventions such as Velcro, lasers, LEDs, or CRTs have been put to many uses. In this module, you will be challenged to take a basic technology, liquid crystals, and use it to design a new device.
>
> Each day we come into contact with many objects for which a display or indicator is an important component—temperature, electric fields or current, and information are a few phenomena that may be displayed or indicated.
>
> - Some things function best, or taste best, at a particular temperature. A refrigerator and a cup of coffee are examples.
> - A battery is another example. Knowing how much charge is left in a battery can be very helpful. Battery-testing strips serve this purpose. Electric current passing through the medium generates heat. In cases such as this, measuring the temperature of one thing indirectly measures something else that is difficult to measure directly.
> - We rely on information from LCDs (liquid crystal displays) on watches, clocks, calculators, and computer screens.
>
> A device providing a quick and inexpensive means of providing information or

Conduct a discussion that focuses student thinking on the design process and properties of liquid crystals. As they work through the KSBs and review the literature, they can be looking at current and past uses of liquid crystals and considering uses of liquid crystals for their design project.

Discuss the need for an inexpensive way to optically monitor the temperature of an object or the presence of an electric field. For instance, since our economy is becoming more global in scope, there is a greater need for products that are not dependent on a particular language. Examples of such products are visual indicators of temperature and/or electrical fields that anyone can understand easily.

Periods 2–3: **Organize for Informed Design**

Informed design. (See the NYSCATE *Pedagogical Framework* for a more detailed discussion on familiarizing students with the process of informed design.)

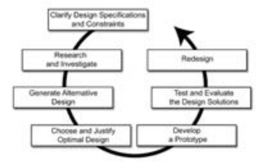
Start by engaging students in a discussion of how engineers and technicians design items to address human needs and wants. Have students make a list of elements of good design and elements of poor design. Discuss the consequences of poor design in today's world.

At this point, explain to the class that the KSBs are intended to provide them with just-in-time skills and knowledge that, when applied, will enhance their design solution. Introduce and have students read KSB 1: The Informed Design Cycle. Discuss the importance of the informed design cycle and the need to apply it when addressing the Design Challenge for this module. Help students become aware of the usefulness of informed design in problem solving.

Since students will be maintaining a Design Journal or Design Folio, they should keep careful notes as they proceed. These notes may be referred to as needed. Point out that many engineering and scientific careers require the use of some sort of daily journal or log to track work completed over extended periods of time.

KSB 1: THE INFORMED DESIGN CYCLE

A method is shown (see informed design loop below) for you to achieve informed technological design. The cycle includes several phases. In this model, the phases together are referred to as the design cycle. The model involves repeatable phases that engage you in the design process.



You are to work in a manner similar to that of professionals who do engineering design for a living. Engineers and other designers rarely follow these phases in order. Instead, they move back and forth from one phase to another as needed. You also are not expected to go through the phases in the order presented each time you design something. Additionally, some decisions are made without complete knowledge and as a result phases must be revisited later on. The designer arrives at solutions, monitoring performance against desired results and making changes as needed. Usually, applying design criteria leads to trade-offs taking place. Seldom is true perfection obtained.

During the process of informed design, new knowledge is necessary to assist in the development of the final design solution. This information is gathered during investigation into the development, use, or application of liquid crystal substances or devices. Knowledge gained during such research helps guide students through the informed design process, thus resulting in a better overall solution to the challenge.

Student requirements. Discuss with students two required written products of this module: the Design Journal or Design Folio and the Design Report. Help students realize the importance of the journal or folio as well as the final design solution. Each student on the team will be individually responsible for keeping a Design Journal or Design Folio and completing a Design Report. Students must document data derived, information gathered, and steps followed during the informed design process. Students should realize that keeping a careful record of work done along the way is a requirement of many jobs. Such a record helps in remembering something that was done earlier and is valuable in solving the overall challenge.

Also discuss with students the format of the final presentation of their design solution, and explain how the presentation models real-world practices. Tell students that you and their classmates will ask questions during the presentation and that these questions will probe the methods each team used and attempt to ascertain how the design solution was reached. Let students know that they should be prepared to address such questions, and that this collegial practice is common throughout the scientific and technical community. Help them see that they should expect such questions and respond to them on the basis of the knowledge and skill developed while completing the KSBs and addressing the Design Challenge. When discussing the presentation requirements, point out that a variety of delivery methods (presentation software, models, tables, graphs, drawings, etc.) should be used to support and enhance the information they present.

Assigning and informing teams. Two of the difficult parts of having students working in teams include the formation and maintenance of the teams. Sometimes student-assigned teams work out well; other times, teacher-assigned teams work better. In all situations, review rules of teamwork and provide details of what will be required of each team member. The ideal number of students per team is three. See the *Pedagogical Framework* (p. 12) for more information on forming cooperative learning teams.

Discuss how a team should function and point out that every member of the team is valuable in one way or another. Assign roles for individual team members, or have students make the assignments themselves. Emphasize that they should rely on the individual strengths of each team member and value these strengths as necessary for addressing problems that arise as work progresses. Even though problems are to be resolved through teamwork, make it clear that individuals are expected to work on their own as they pursue some aspects of the challenge. However, each student should keep other team members informed of individual work. Information gathered by a team member on his or her own might be the clue another team member needs to ultimately contribute to the resolution of the problem.

As students proceed, stress that all members of each team needs to understand the information learned, ideas developed, and steps taken during the overall informed design process. Students who feel they are doing most of the work might benefit from being reminded that teaching others is an excellent way to retain what they have learned. Sharing the workload equitably is perhaps the most difficult part of teamwork at this level. Conduct frequent spot checks to monitor and promote the desired process.

Periods 4–14: **Coordinate Student Progress**

Coordinate work by individuals. During this portion of the module, students experience a sequence of KSBs that inform their solution to the challenge. Explain to students that the module is designed as a learning experience—not a competition among teams—and that everyone in the class should benefit and grow from each other's contributions. To that end, plan time for teams to revisit the challenge and share findings as students complete the KSBs.

Remind students to document information in their Design Journals or Design Folios. Encourage them to keep careful notes as they complete each phase of the activity. This will help them arrive at the best solution to the problem, and will also help them remember work they did over an extended period of time. The notes will be useful as they complete their final Design Report.

Team research and investigation through KSBs:

Students begin the investigation phase of this module by completing the following KSBs:

KSB 2: Matter

This KSB may seem overly fundamental, but experience indicates that the concepts of atoms, molecules, pure substances, and mixtures are very difficult for many to grasp. Students also seem to have a hard time distinguishing between heterogeneous and homogeneous mixtures.

Students should work in teams for this KSB except when responding to the first item, the purpose of which is to identify their prior knowledge of atomic structure. It is important to check students' answers as they work.

Comparing an atom and its nucleus to a golf course and a golf ball on the course seems to work very well for an analogy for item 3 in activity 1.

Watch out for the fallacious idea that any molecule is a compound.

When students draw the mixtures, emphasize that their drawings of heterogeneous mixtures must be very obvious. When there are just a few particles, it is difficult to distinguish between heterogeneous and homogeneous mixtures.

KSB 2: MATTER

When you address the Design Challenge for this module, liquid crystals are going to be used as sensors. Therefore, you must be familiar with some of their physical properties. To learn about these properties, it is important to review matter and its makeup. This takes us to the submicroscopic world of the atom.

Students individually and in teams draw, label, fill in tables, and answer questions to:

- Distinguish among atoms, ions, and molecules
- Identify the parts of an atom and their charges
- Distinguish between pure substances and mixtures
- Distinguish between homogeneous and heterogeneous mixtures

ACTIVITY 1: ATOMS

Matter is made up of atoms, molecules, and ions. Atoms and molecules are neutral microscopic particles. Ions are atoms or groups of atoms that have gained or lost electrons. Ions are charged particles.

Develop your understanding

1. a) Individually draw a picture of an atom.

b) The remaining activities are to be completed as a group. After you all have drawn your pictures, compare your picture with those of the rest of the group. Redraw that picture that the group agrees on. Label the following components of the atom: nucleus, electrons, neutrons, and

KSB 3: The States of Matter

The terms *states* and *phases* are sometimes used loosely. However, they do have precise meanings. The states of matter are solid, liquid, and gas. A phase not only denotes its physical form (solid, liquid, gas) but also different varieties of the state. For example, carbon as a solid can be in the diamond or graphite phase. The liquid crystal state can be in the nematic or smectic phase.

> **KSB 3: STATES OF MATTER**
>
> The divisions among solid, liquid, and gas states are not always clear-cut. Liquid crystals are a class of substances that have received great attention in recent years. Their name seems to be self-contradictory but liquid crystals are substances that can have both the ordered arrangements of a solid and the partial randomness of a liquid.
>
> **Students use a table and phase diagrams to:**
>
> - Identify states of matter on the basis of their macroscopic and submicroscopic properties
> - Learn about the mesophase in liquid crystals
> - Identify the characteristics of liquid crystals
>
> **ACTIVITY 1: STATES OF MATTER**
>
> If you asked a number of scientists to list the states of matter, you would get a number of different answers. The three states most commonly named are solid, liquid, and gas. Some scientists would also list the **plasma** and **Bose Einstein Condensate** states, and others would list the **mesophase** of liquid crystals. The truth is that scientists still do not agree whether to include any or all of these three states (plasma, Bose Einstein Condensate, and mesophase) in the list of states of matter.
>
> Liquid crystals fall in between liquids and crystalline solids. The following table[1] compares these states at the macroscale and microscale levels.

Most students know that matter can exist in one of three states: solid, liquid, or gas. Thus the term *liquid crystal* may be very confusing. How can a liquid be crystalline solid? The feature that distinguishes one phase from another is the type of order the molecules possess. For example, atoms, ions, or molecules of a solid occupy fixed positions (this is known as *positional ordering*) that are repeated over and over again. The molecules are also constrained to orient themselves with respect to one another (this is known as *orientational ordering*). There is a small amount of variation from molecular vibration. When a solid melts, it loses its positional and orientational ordering. It becomes isotropic.

Molecules in a thermotropic liquid crystal phase (mesophase) have properties of both the liquid and solid phases. These molecules move around and lose their positional ordering; however, they maintain some degree of orientational order. In the nematic phase, they orient along a specific direction (nematic director). The degree of orientation is not as high as it is in the crystalline state. The liquid crystal is a fluid (like a liquid), but it is anisotropic in its optical and electromagnetic characteristics (like a solid). It is the orientational ordering that accounts for these anisotropic properties of the substance.

Students should learn phases and phase changes because it is in the mesophase that liquid crystal materials have their unique anisotropic properties.

Phase diagrams are optional. However, as visual tools, they illustrate phase changes nicely. They are also helpful because they offer students an opportunity to read diagrams (students often skip over diagrams when reading). In technological fields, reading diagrams is especially important.

When copying this KSB, leave a page between the table and the items so that students do not have to keep flipping back and forth.

KSB 4: Web Search for Information about Liquid Crystals

Investigating liquid crystal substances and their uses may be difficult using available printed materials such as texts. In the activities for this KSB, students benefit from using the Internet to obtain facts and up-to-date information on the LC topic.

Discuss methods and techniques for using search engines effectively to find information. Remind students to take enough time to successfully complete an Internet search, and stress that they should use time wisely during the search. Have individual team members work independently and then share findings with the team and among teams when time permits.

KSB 4: Web Search for Information about Liquid Crystals

There are many properties and uses of liquid crystals to be investigated. Some should be useful as you address the Design Challenge for this module.
Students individually and in teams search the web and other sources, and answer questions, to:

- Develop a brief history of liquid crystals
- Learn about intermolecular forces
- Distinguish between thermotropic and lyotropic liquid crystals
- Identify uses of liquid crystals
- Determine the reliability of a website

ACTIVITY 1: WEB SEARCHES FOR INFORMATION ABOUT LIQUID CRYSTALS AND THEIR USES.

Using the World Wide Web or other available sources, investigate the chemical and physical properties of liquid crystal substances, as well as their current and potential uses. List all sources found useful during your research. Use a format acceptable to your teacher in referencing books and magazines, as well as Internet sources. For all Internet sources, give the URL and title of the website visited.

Remind students once again that even though they may have become accustomed to teams competing against teams, sharing information among teams is mutually beneficial. Several sources of Internet information are listed in the Materials and Resources section of this module.

The website **http://invsee.asu.edu/nmodules/liquidmod/welcome.html** is helpful, but you may not want to reveal this source to students until they all have found some adequate sources on their own.

KSB 5: Investigating Liquid Crystal Sheets

In KSB 5, students investigate various commercially produced liquid crystal materials that change colors at different temperature ranges. These LC materials are given to the students as unknowns, so they should label each sheet with a letter or number. The teams heat the unknowns and record the temperatures at which each changes color. They must also record the colors produced.

This activity provides the first opportunity for students to become familiar with the materials and equipment that they might use as they address the Design Challenge for this module.

> **KSB 5: Investigating Liquid Crystal Sheets**
>
> In this KSB, you explore changes that occur in various commercially available liquid crystal sheets.
>
> **Students work in teams to:**
> - Discover how liquid crystals respond to heat
> - Make careful observations of color changes
> - Propose a practical use for these sheets
>
> **Safety**
> **Be careful when using the hot plates. Serious burns can result from contact with the hot plate or with the hot water.**
>
> **Materials (per group):** hot plate, 6 1" x 1" liquid crystal sheets (labeled A-F), 2" packaging tape, scissors, 250 mL beaker, and an infrared digital or glass thermometer and infrared thermometer
>
> **Procedure:**
> 1. Obtain up to six different LC sheets from your teacher. Note that they are labeled A-F. Make a data table in your lab notebook. The data should include the sheet letter, the temperature range of the color changes, and the colors observed.

Discuss safe habits during this phase of the investigation and whenever students are working with items that could cause personal injury or harm. Chemical safety should be reviewed at this point and whenever potentially hazardous chemicals are to be used. All individuals must understand the importance of safe handling and use of chemicals and electricity, and must be aware of injuries that might result from their misuse. Review first aid procedures to be followed in case of injury.

KSB 6: Color-Temperature Relationships in Mixtures

This KSB provides the second opportunity for students to become familiar with the

> **KSB 6: Color-Temperature Relationships in Mixtures**
>
> As you now know, liquid crystal substances are currently being used in many different applications. Many of these applications involve thermotropic liquid crystals; that is, heat causes a change in appearance of the liquid crystal. How do scientists and engineers find liquid crystals that have mesophases at a temperature they need for their application?
> **Students work in teams to:**
> - Prepare mixtures of cholesteryl oleyl carbonate (COC) and cholesteryl nonanoate/perargonate (CN)
> - Explore the properties of mixtures of liquid crystals
> - Etc.
>
> **Materials:** small glass screw-top vial or test tube; two 1" x 1" pieces of acetate transparency, one clear and one black; liquid crystal

tools and materials that they might choose to use when they address the Design Challenge for this module.

When creating the liquid crystal transparency, students must exercise caution in sealing the edges to prevent the solution from leaking. Attaching the transparency securely to the side of the beaker may be a challenge as well. Once this phase is completed, students should take care not to melt the transparency or the tape used for attachment.

Providing students with an accurate color chart will assist them in identifying the various colors that occur during the investigation.

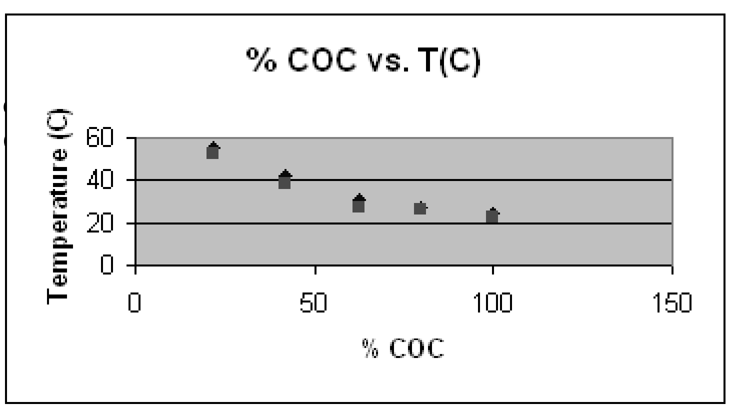
Preparation of the mixtures

The accurate preparation of mixtures is important, particularly for students who might later choose to use a mixture as a component as they address the Design Challenge for this module. You might have to prepare the mixtures yourself, unless students have use of a milligram balance and have good massing skills. Students should at least do the calculations for the mixtures (the amount of each liquid crystal to be used). It has been shown that an amount of 0.500 g total for each mixture works well. You might also provide students with your experimental data and have them do the calculations. The percentages do not have to be exact as long as students use the calculated values instead of the theoretical values.

<u>Teacher preparation</u>

Cholesteryl oleyl carbonate (COC) and cholesteryl nonanoate/perargonate (CN) are the two liquid crystals to be used in this activity.

For these two sets of data, a minimum of 6 data points is recommended: 0, 20, 40, 60, 80, and 100% COC. If more data points are used, they should be selected from the lower end of the concentration range because the curve flattens out at lower temperatures. Some students have chosen to use 0%–100% with intervals of 10%.



Mass (weigh) the mixture into small test tubes or capped vials that you have placed on a balance through these steps: Zero the balance; add 0.1 g of COC and 0.4 g of the other LC into the vials or test tubes that you have previously massed. Heat the mixtures in boiling water and stir to thoroughly mix the solution. You should be sure to have the students do this part so that they can see the behavior of the LC mixture as it melts and becomes homogeneous. The mixtures must be melted and mixed before they can be applied to the transparency. The graph provided above will give you an idea of the temperatures of the mixtures in the mesophase.

KSB 7: Ohm's Law

This is the first of two KSBs that involve electric circuits. Students examine qualitative and quantitative relationships between current, voltage, and resistance in direct current (DC) series circuits. A thorough understanding of circuits, however, is not the intent of this activity. Rather, students are expected to learn how to use a voltmeter and an ammeter. Placement of these meters is very important. Ammeters go in series and voltmeters are placed parallel to the object being measured for potential drop.

KSB 7: OHM'S LAW

In this KSB, you examine the quantitative relationship between current, voltage, and resistance. This most applied relationship in circuits is known as Ohm's law.

Students work in teams to:

- Discover the relationships among current, voltage, and resistance
- Learn to use ammeters and voltmeters in DC circuits
- Plot data of voltage versus current, and determine whether voltage and current are directly proportional, inversely proportional, or neither
- Interpret the slope of the graph

Materials:
batteries or power supply, resistors, wires, light bulb, ammeter, voltmeter

The resistor for step 7 of model 2, Ohm's Law Investigation, could be made an unknown by you.

KSB 8: Effects of Voltage and Current on Liquid Crystal Substances

This KSB provides opportunities to apply concepts from the previous KSBs. By combining various resistors, switches, and conductors, students determine how to indicate the relative strength or charge of a common 1.5-volt, 6-volt, or 9-volt battery.
Be sure that students come to understand that resistance electron flow produces heat.

KSB 8: EFFECTS OF VOLTAGE AND CURRENT ON LIQUID CRYSTAL SUBSTANCES

Now that you have the new knowledge and skills from the first seven KSBs, it is time to make applications in another area. What effect does the length of a wire have on its resistance? What effect does the amount of current in a wire have on the wire? What effect does the voltage have on the wire? Consider how the connectors, the length of the wire used, and other items used during design and construction relate to the resistance for the circuits you create.

By considering the results of your investigation, and applying your knowledge of electrical circuits gained in KSB 7: Ohm's Law, you may now choose to create appropriate circuit(s) to address the Design Challenge for this module.

Energy is dissipated as heat when current flows through a resistance. The heat, or power, dissipation for current flow through a resistor is the product of voltage across the resistor times current flow through it.

$$P = Vi$$

Noting that $V = iR$ from Ohm's law, then $P = (iR)\, I = i^2 R$.

Period 15: **Coordinate Student Progress**

In successfully completing the KSBs, students have gained knowledge and skill necessary for addressing the Design Challenge for this module. Engage the class in discussion, encouraging them to share their knowledge and skill to ensure that all students have processed and have access to this information. Again, stress that this is not a competition among teams, but a learning experience for all.

Guide teams through development of final solutions, sketches, or other elements that lead them to their final designs. Monitor the groups to ensure that all members are actively engaged in, and understand and support, the final solution. Revisit the informed design cycle, reminding students that the solution they arrive at today is not necessarily the best one. They probably will find reasons to refine their design as they continue into the final phases of the challenge.

Period 16: **Coordinate Student Progress**

Students should select and justify their final design, and explain how they arrived at it. They might need to be reminded to refer to their Design Journals or Design Folios, the recorded results of the completed KSBs, and notes related to analyses of that information.

Periods 17–20: **Coordinate Student Progress**

Assist students as they develop and build a working model of their final design. They may need individual instruction in areas specific to their final design, such as soldering, chemical handling and mixing, or simply using the materials required to do these tasks. Keep in mind that multiple solutions are possible and preferable. Continue to be aware of the safety issues that may arise during this phase, reminding students to be careful as they work so they do not harm themselves or others.

Help students see that initial ideas inevitably need to be altered as they work with and create their model. Iterative revision of ideas is an important part of the informed design process.

Students should test and evaluate their design solution, document their final design, and prepare what they will share with the total class.

Periods 21– 22: **Unite Class Thinking and Accomplishments**

Design Report. This report is a major component of the teacher's assessment of student learning and accomplishment and also serves as a valuable summarizing experience for the students. Remind students that reports documenting work completed are an expectation listed in the job descriptions for many career fields.

Each student is responsible for the submission of his or her individually developed report. Reports should include:

1. The goals and purpose of their work, a summary of the KSBs completed and the importance of them in terms of the overall problem
2. The materials used
3. The method used to arrive at the design solution
4. A justification of the design
5. A detailed explanation of the final design, and changes or redesign that took place during the informed design process.

In a final section, students should reflect on what they might do differently if given the opportunity to repeat their work. Stress the importance of referring to the Design Journal or Design Folio for guidance throughout the activity. Refer to the NYSCATE *Pedagogical Framework* (p. 27) for further information on student reporting.

Team presentations. Discuss with the class the proper way to design and deliver a team presentation. Remind students that a good presentation features not only a good script but also a variety of visual aids or other media for support and enhancement. The guidelines found in the NYSCATE *Pedagogical Framework* (p. 27) might be copied and distributed to students for use at this time.

Students who are observing the presentations should be made aware that they are expected to ask questions that are appropriate to the topic at hand and provide constructive feedback to help presenters improve their presentation skills. Reveal that such skills are essential to many career fields today.

Period 23: **Sum up Progress on Learning Goals**

After the teams have made their presentations and individual students have submitted their written work (Design Journals or Design Folios, and Design Reports), complete your evaluation of their progress toward meeting the learning goals. In addition to assigning grades, give feedback to the class, and to individuals, regarding the progress they have made and the areas that would have benefited from further effort.

Solicit feedback from students about how the module itself and your delivery of it might be improved.

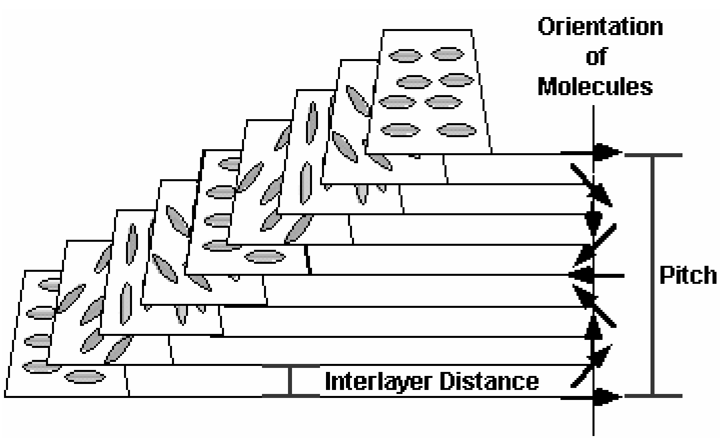
VII. ADDITIONAL SUPPORT FOR TEACHERS

Also see *Liquid Crystals* teacher resource items in the NYSCATE website www.nyscate.net.

Twisted nematic of choloesteric liquid crystals

Many liquid crystals of technological significance have the arrangement called **twisted nematic** or **choloesteric**. They are used in temperature-sensing devices that change color. They are also the most common type used in the liquid crystal displays (LCDs) found in calculators and watches. Both of these applications depend on the way liquid crystals interact with light.

In this arrangement, twisted nematic, the layers contain the long axes of the molecules and the long axes rotate by a small angle from one layer to the next. These liquid crystals exhibit selective reflection and polarization of light (http://invsee.asu.edu/nmodules/liquidmod/spatial.html).



The color observed comes from a process of selective reflection, with white room light reflecting off a black backing. Only light with a wavelength equal to the spacing between layers of similar orientation is reflected. As the temperature of the liquid crystal changes, the spacing between the layers also changes. The color change generally progresses from red to blue; red indicates cooler temperatures and blue indicates warmer temperatures. Note that this is actually the opposite of normal illustrations of heat and universal visual indicators. Each twisted nematic liquid crystal changes color at different temperature ranges; therefore, several substances are required should wide temperature ranges be desired.

These crystals can also be used with polarizers in LCD displays.

http://sharp-world.com/sc/library/lcd_e/s2_1_1e.htm
http://scifun.chem.wisc.edu/chemweek/liqxtal/liqxtal.html

Phase changes

http://server.chem.ufl.edu/~itl/2045_s99/lectures/lec_f.html

ASSESSMENT STRATEGIES FOR *LIQUID CRYSTALS FOR DESIGN*

Assessment of student design work should consider many factors and focus on the design process as well as the finished product (design solution). Each component of design-related student activity is represented in preliminary rubrics (scoring guides) found in the NYSCATE *Pedagogical Framework*. That set of rubrics is generic to all NYSCATE design activities. However, the rubrics can be tailored to a particular assignment and should be discussed with students in advance so that they are aware of your evaluation criteria.

A sample from the set of rubrics is presented here for the design solution:

The Design Solution

A. An accurate sketch of your final design, as built, was drawn.

4. Drawing was on graph paper to scale with all elements included. Isometric view or multiple views (top, side, and front) were shown.
3. Drawing was on graph paper to scale with all elements included. Drawing showed the design in two dimensions (a flat view).
2. Drawing was on graph paper approximately to scale with most elements included.
1. Drawing was not to scale and important elements were missing.

B. Materials and tools were planned and used appropriately in constructing project.

4. Listed materials and tools are present, as well as a description of how they should be used.
3. Prepared complete list of materials required and tools necessary to fabricate with these materials.
2. List of materials was essentially complete; some tools required were not mentioned.
1. Mentioned only a few materials and no tools.

C. The solution worked. It met the design specifications and constraints.

4. The solution solved the problem statement; this was explained in the write-up along with how the specifications and constraints were addressed and/or how the design was modified to assure their being met.
3. The solution solved the problem statement and the constraints and specifications were met.
2. The solution solved the problem but not all constraints and specifications were met in doing so.

1. The solution did not solve the problem; constraints and specifications were not met.

D. The design was creative.
4. The solution was unique; never or seldom has this design been formulated.
3. The solution was functional, but not unique. Similar solutions were common.
2. The solution was similar to others; it may have been a modification or interpretation of someone else's solution.
1. The solution appears to have been copied from someone else's work.

In addition to your assessment of team design process and products, you should assess the quality of individual students' Design Journals or Design Folios, Design Reports, and team presentations to the class. You might use multiple choice, short answer, or extended response items to provide assessment of design understandings, content knowledge, and/or technical skill.

VIII. STUDENT HANDOUT SECTION

(STUDENT HANDOUT SECTION FOLLOWS)

Introductory Packet

WHAT DO YOU ALREADY KNOW?
(A “1-2-3” Activity)

WHAT DO YOU ALREADY KNOW?

1. List one thing that you are sure you already know about liquid crystals.

2. From your experiences, list two things you already know about design.

3. List three examples of modern technology.

Introductory Packet (continued)
PROPERTIES AND USES OF LIQUID CRYSTALS (LC)

1. Identify your liquid crystal (LC) sheets as A and B. Using no chemicals besides cold water, examine the sheets. What do you discover about the properties of the LC sheets? Record all of your observations below.

2. Using water and/or ethanol, and the LC sheets, determine if evaporation is a cooling or a warming process in this situation. State your hypothesis (as an if-then statement) first, and then test your hypothesis through an experiment you design. Record your results.

Develop your understanding

1. Can the LC sheets be used to indicate a temperature change? Explain.

2. If you have a chemical reaction or a phase change, how might you use the LC sheets to determine whether it was an endothermic or an exothermic reaction?

Introductory Packet (continued)

OVERVIEW OF THE MODULE INCLUDING THE DESIGN CHALLENGE

HERE'S WHAT YOU WILL DO

In the NYSCATE module *Liquid Crystals for Design*, you will work as part of a team to:

- investigate possible solutions to a given problem;
- complete Knowledge and Skill Builder (KSB) activities;
- use appropriate tools and materials to design a solution to the given problem;
- base your design upon scientific, mathematical, and technological concepts;
- ensure that your design addresses the specifications and constraints of the problem;
- collect, document, and analyze test data;
- use data collected to develop and improve your overall design and problem solution;
- develop and produce a repeatable and reliable method for testing your design;
- maintain a written record of your work; and
- present written and oral reports of your work.

PROBLEM CONTEXT

Introduction

The ability to design a new device by applying an existing technology is an important, creative engineering skill. For example, technological inventions such as Velcro, lasers, LEDs, or CRTs have been put to many uses. In this module, you will be challenged to take a basic technology, liquid crystals, and use it to design a new device.

Each day we come into contact with many objects for which a display or indicator is an important component—temperature, electric fields or current, and information are a few phenomena that may be displayed or indicated.

- Some things function best, or taste best, at a particular temperature. A refrigerator and a cup of coffee are examples.
- A battery is another example. Knowing how much charge is left in a battery can be very helpful. Battery-testing strips serve this purpose. Electric current passing through the medium generates heat. In cases such as this, measuring the

temperature of one thing indirectly measures something else that is difficult to measure directly.

- We rely on information from LCDs (liquid crystal displays) on watches, clocks, calculators, and computer screens.

A device providing a quick and inexpensive means of providing information or monitoring temperature or current can be used in many ways in today's world. This module challenges students to create such a device.

Design Challenge

As part of a team, students are to design, construct, and test a device that will demonstrate a practical use for liquid crystals in the form of a liquid crystal display.

Specifications

The device constructed must be able to detect heat or electric fields. The display must be used to do one of the following:

- indicate a particular temperature, temperature range, or change in temperature
- indicate the presence of current or an electric field
- display information

Constraints

Each team must use only materials approved in advance by your teacher. The display should be no larger than 2 inches by 2 inches, and no more than 1/2 inch thick. If the purpose of the liquid crystal device is to measure temperature, it should be used to measure heat liberated or absorbed in a physical or chemical change. For example, the device could measure heat generated by friction, a chemical reaction, or an electrical current.

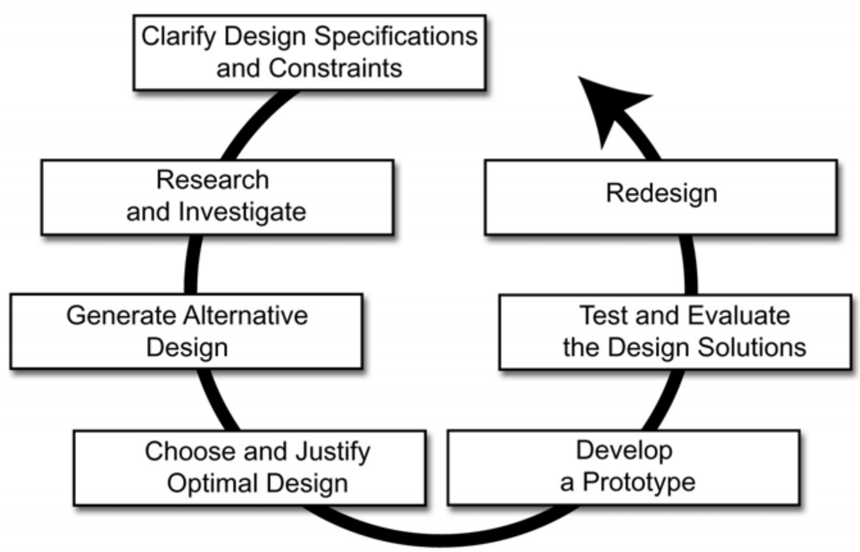
STUDENT REQUIREMENTS

Each member of your team will:

- maintain a Design Journal or a Design Folio in which they record information daily as the team works to complete each KSB and the Design Challenge of this module;
- complete a final Design Report that documents and summarizes their work, findings, and ultimate solution to the Design Challenge;
- work to develop a team presentation that explains how the team developed the solution to the Design Challenge;
- be assessed on the quality of their work on the Knowledge and Skill Builders, Design Journal or Design Folio, Design Report, and team presentation; and
- complete a pretest and posttest regarding all aspects of the module.

KSB 1: THE INFORMED DESIGN CYCLE

A method is shown (see informed design loop below) for you to achieve informed technological design. The cycle includes several phases. In this model, the phases together are referred to as the design cycle. The model involves repeatable phases that engage you in the design process.



You are to work in a manner similar to that of professionals who do engineering design for a living. Engineers and other designers rarely follow these phases in order. Instead, they move back and forth from one phase to another as needed. You also are not expected to go through the phases in the order presented each time you design something. Additionally, some decisions are made without complete knowledge and as a result phases must be revisited later on. The designer arrives at solutions, monitoring performance against desired results and making changes as needed. Usually, applying design criteria leads to trade-offs taking place. Seldom is true perfection obtained.

Further information on the phases of the informed design cycle follows:

- *Clarify design specifications and constraints.* Describe the problem clearly and fully, noting constraints and specifications. Constraints are limits imposed upon the solution. Specifications are the performance requirements the solution must meet.

- *Research and investigate the problem*. Search for and discuss solutions that presently exist to solve this or similar problems. Identify problems, issues, and questions that relate to addressing this Design Challenge.

- *Generate alternative designs*. Don’t stop when you have one solution that might work. Continue by approaching the challenge in new ways. Describe the alternative solutions you develop.

- *Choose and justify optimal design.* Defend your selection of an alternative solution. Why is it the optimal choice? Use engineering, mathematical, and scientific data, and employ analysis techniques to justify why the proposed solution is the best one for addressing the design specifications. This chosen alternative will guide your preliminary design.

- *Develop a prototype.* Make a model of the solution. Identify possible modifications that would lead to refinement of the design, and make these modifications.

- *Test and evaluate the design solution*. Develop a test to assess the performance of the design solution. Test the design solution, collect performance data, and analyze the data to show how well the design satisfies the problem constraints and specifications.

- *Redesign the solution with modifications*. In the redesign phase, critically examine your design and note how other students’ designs perform to see where improvements can be made. Identify the variables that affect performance and determine which science concepts underlie these variables. Indicate how you will use science concepts and mathematical modeling to further enhance the performance of your design.

Develop your understanding

1. Review the informed design cycle and explain how you might use the various phases to guide your design efforts. Identify procedural changes you would add, delete, or change. Defend your recommendation(s).

2. Review the NYSCATE Design Folio (DF) and with the help of your teacher, decide whether you will select it or the Design Journal to help you document your work.

3. Pick one example of a product or system that you think was poorly designed. Explain why the manufacturer of the product might have allowed design flaws. Explain consequences (both positive and negative) that might result from a less-than-optimal design.

4. Provide an example of a product or system that you think could benefit from an improved design.

KSB 2: MATTER

When you address the Design Challenge for this module, liquid crystals are going to be used as sensors. Therefore, you must be familiar with some of their physical properties. To learn about these properties, it is important to review matter and its makeup. This takes us to the submicroscopic world of the atom.

Students individually and in teams draw, label, fill in tables, and answer questions to:

- Distinguish among atoms, ions, and molecules
- Identify the parts of an atom and their charges
- Distinguish between pure substances and mixtures
- Distinguish between homogeneous and heterogeneous mixtures

ACTIVITY 1: ATOMS

Matter is made up of atoms, molecules, and ions. Atoms and molecules are neutral microscopic particles. Ions are atoms or groups of atoms that have gained or lost electrons. Ions are charged particles.

Develop your understanding

1. a) Individually draw a picture of an atom.

b) **The remaining activities are to be completed as a group.** After you all have drawn your pictures, compare your picture with those of the rest of your group. Redraw that picture that the group agrees on. Label the following components of the atom: nucleus, electrons, neutrons, and protons. Confirm the accuracy of your drawing with your teacher.

2. Indicate the charges of the protons, neutrons, and electrons:

   proton ____ neutron _____ electron ______

3. How does the size of the nucleus compare to the size of the atom?

4. How does the number of protons compare to the number of electrons in an atom?

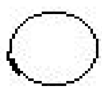
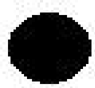
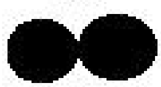
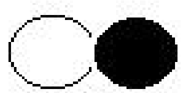
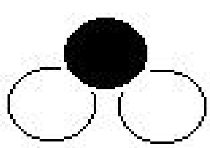
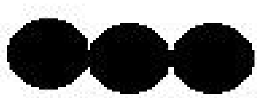
5. How does the number of protons compare to the number of electrons in an ion?

ACTIVITY 2: CLASSIFICATION OF MATTER

Atoms can combine to form molecules. These molecules can be elements or compounds.

Develop your understanding

1. Fill in the following table to indicate which are:
a) atoms or molecules b) elements or compounds.

	ATOM or MOLECULE	ELEMENT or COMPOUND
	Atom	Element
	Atom	________
	Molecule	Element
	________	Compound
	________	________
	________	________

2. How do you distinguish between an element and a compound?

3. Are all molecules compounds? Explain.

4. Draw a picture of an element that is made up of:

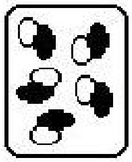
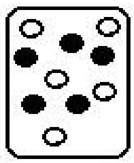
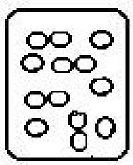
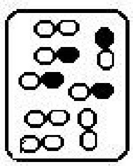
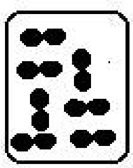
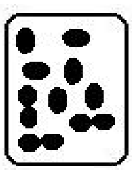
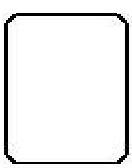
only atoms **only molecules**

5. Draw a picture of a compound.

a **compound**

ACTIVITY 3: MIXTURES AND PURE SUBSTANCES

DO NOT FILL IN THE TABLE UNTIL THE Develop your understanding ITEMS BELOW TELL YOU TO DO SO.

		Pure Substance or Mixure	Homogeneous or Heterogeneous
1		Pure	Homo
2		Mixture	Homo
3		Mixture	Homo
4		Mixture	Hetero
5		____________	____________
6		____________	____________
7		Mixture	Homo

Develop your understanding

1. a) What is a pure substance?

b) What is a mixture?

2. Why are the contents of figure 1 considered a pure substance and the contents of figure 2 a mixture?

3. Figures 2 and 3 are both homogeneous mixtures composed of elements, but figure 2 contains only___________, whereas figure 3 contains both _____________ and______________. (Fill in the lines with the words *molecules* or *atoms*.)

4. Complete the table above by filling in the categories for figures 5 and 6.

5. What is the difference between a heterogeneous mixture (figure 4) and a homogeneous mixture (figures 1–3)?

6. In the figures below, draw both a homogeneous mixture and a heterogeneous mixture composed only of molecules.

homogeneous mixture	**heterogeneous mixture**

ACTIVITY 4: IONS

Ions are particles formed when an atom or group of atoms gains or loses an electron.

$$:\!Br\!: \quad + \quad e^{-} \quad \text{------>} \quad [\, :\!Br\!: \,]^{-1}$$

Atom — Ion

Develop your understanding

1. If an atom with 11 protons and electrons loses an electron, what is its charge?

2. If an oxygen atom with 8 electrons and 8 protons gains two electrons, what is its charge?

3. Lithium batteries contain lithium atoms and ions. If a lithium atom loses one electron, what is its charge?

4. Can the number of electrons equal the number of protons in an ion? Explain.

KSB 3: STATES OF MATTER

The divisions among solid, liquid, and gas states are not always clear-cut. Liquid crystals are a class of substances that have received great attention in recent years. Their name seems to be self-contradictory but liquid crystals are substances that can have both the ordered arrangements of a solid and the partial randomness of a liquid.

Students use a table and phase diagrams to:

- Identify states of matter on the basis of their macroscopic and submicroscopic properties
- Learn about the mesophase in liquid crystals
- Identify the characteristics of liquid crystals

ACTIVITY 1: STATES OF MATTER

If you asked a number of scientists to list the states of matter, you would get a number of different answers. The three states most commonly named are solid, liquid, and gas. Some scientists would also list the **plasma** and **Bose Einstein Condensate** states, and others would list the **mesophase** of liquid crystals. The truth is that scientists still do not agree whether to include any or all of these three states (plasma, Bose Einstein Condensate, and mesophase) in the list of states of matter.

Liquid crystals fall in between liquids and crystalline solids. The following table[1] compares these states at the macroscale and microscale levels.

Macroscopic Behavior					Microscopic Behavior			
Phase	**Retains Volume**	**Retains Shape**	**Com-pres-sible**	**Flow Rate**	**Orientational Ordering**	**Positional Ordering**	**Intermolecular Forces**	**Separation Distance**
Crystal-line Solids	Yes	Yes	No	Slowest ↓	Yes	Yes	Strongest ↑	Smallest ↓
Liquid Crystals	Yes	No	No		Yes	No		
Liquids	Yes	No	No		No	No		
Gases	No	No	Yes	Fastest	No	No	Weakest	Largest

Develop your understanding

1.
a) What are the three most common states of matter? Draw a picture, arranging 10 circles within each rectangle to represent the particles, for each of these states of matter. Label each state.

b) Which state(s) retains its shape when placed in a different container?

c) The intermolecular forces of the particles in matter are one factor that determines the matter's state. What do you think scientists mean by *intermolecular forces*?

d) Intermolecular forces are forces between molecules or between ions and molecules. The key word is *between,* not *within.* Which of these states has the strongest intermolecular force? Explain.

2.
a) At the macroscopic level, is there a difference in the physical properties of solids and liquids? Explain.

b) At the macroscopic level, is there a difference in the physical properties of liquids and liquid crystals? Explain.

c) At the macroscopic level, is there a difference in the physical properties of solids and liquid crystals? Explain.

3.
a) At the submicroscopic level, is there a difference in the behavior of liquids and liquid crystals? Explain.

b) At the submicroscopic level, is there a difference in the behavior of solids and liquid crystals? Explain.

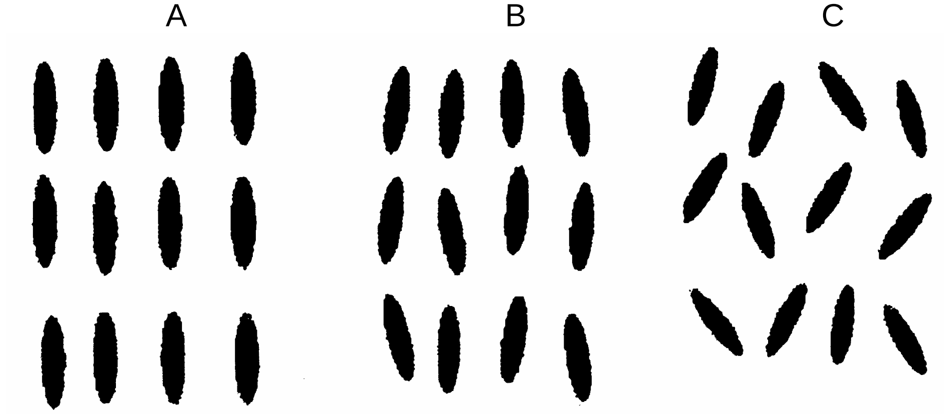
4. What do you think is meant by the term *positional ordering*?

5. What do you think is meant by the term *orientational ordering*?

6. Do liquid crystals fit into any of the three states of matter? Explain.

7. Using the information you gathered from the table, label the following figures as representative of solid, liquid, or liquid crystal.

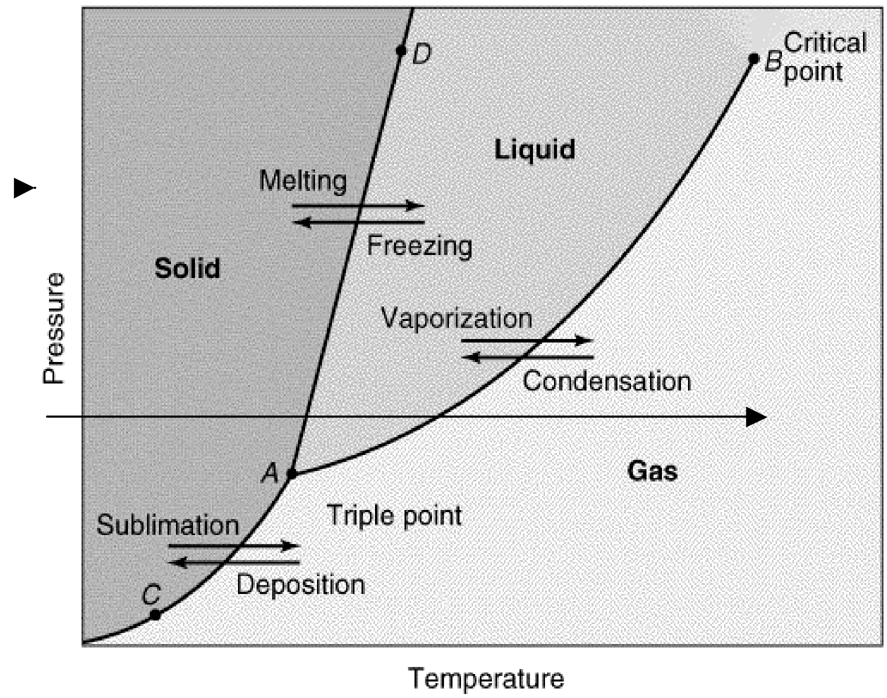
A B C



8. In item 7 above, A (solid) has positional and orientational ordering, B (liquid crystal) has orientational ordering but not positional ordering, and C (liquid) has neither. Go back to items 4 and 5 and look at your definitions of *positional* and *orientational ordering*. Redefine the two terms if you need to do so.

ACTIVITY 2: THE PHASE DIAGRAM

The following phase diagram is a plot of all the equilibrium curves between any two phases.



- The shape of the phase diagram depends on the substances.
- The triple point is the one place where all three phases of a pure substance are at equilibrium.
- The critical point (B) is the critical temperature and pressure on the liquid-vapor equilibrium curve where gases and liquids are indistinguishable fluids.
- At points C and D, two phases are in equilibrium. At a point off the line entirely, there is only one stable phase of the substance.

Develop your understanding

1. What point on the graph is the triple point?

2. Is there any point(s) on the diagram where, if there were warming, the pure substance would not melt but go directly from a solid to a gas? If so, identify the point(s).

3.

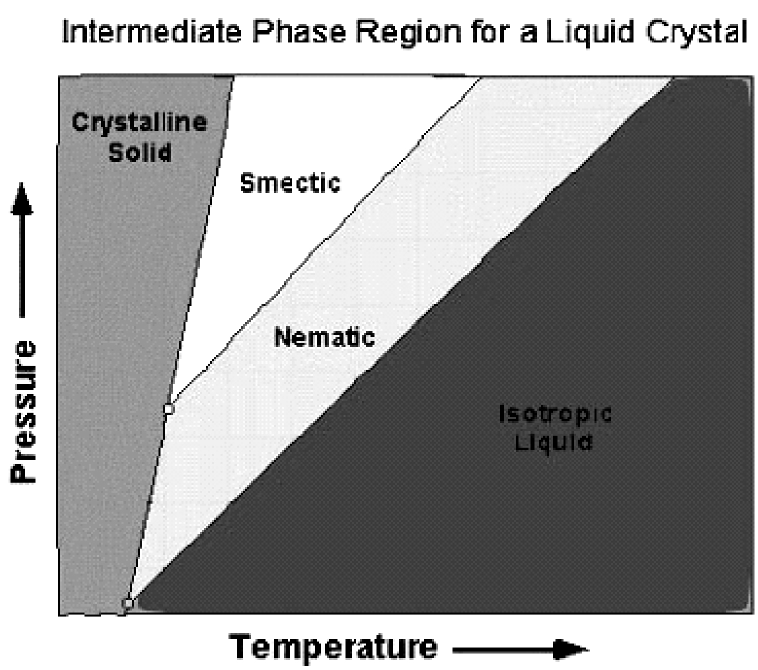
a) If the line with the arrow represents the pressure at one atmosphere, label the points on the graph that would indicate the normal boiling point (bp) and the normal melting point (mp) of the substance. Explain your answers.

b) Is heat given off (an exothermic reaction) or is heat absorbed (an endothermic reaction) by a pure substance when it freezes? Explain.

c) Is heat given off (an exothermic reaction) or is heat absorbed (an endothermic reaction) by a pure substance when it boils?

ACTIVITY 3: INTERMEDIATE PHASE REGION FOR A LIQUID CRYSTAL

The smectic phase and the nematic phase are liquid crystal phases. They are called mesophases. You will learn more about them as you continue to investigate liquid crystals.



Develop your understanding

1. Between what two phases are the nematic and smectic phases?

2. Is there a pressure where there would be no smectic phase? Explain.

3. Is it possible for a liquid crystal to have two mesophases? Explain.

KSB 4: WEB SEARCH FOR INFORMATION ABOUT LIQUID CRYSTALS

There are many properties and uses of liquid crystals to be investigated. Some should be useful as you address the Design Challenge for this module.

Students individually and in teams search the web and other sources, and answer questions, to:

- Develop a brief history of liquid crystals
- Learn about intermolecular forces
- Distinguish between thermotropic and lyotropic liquid crystals
- Identify uses of liquid crystals
- Determine the reliability of a website

ACTIVITY 1: WEB SEARCHES FOR INFORMATION ABOUT LIQUID CRYSTALS AND THEIR USES

Using the World Wide Web or other available sources, investigate the chemical and physical properties of liquid crystal substances, as well as their current and potential uses. List all sources found useful during your research. Use a format acceptable to your teacher in referencing books and magazines, as well as Internet sources. For all Internet sources, give the URL and title of the website visited.

Develop your understanding

Respond to the following items and cite all references.

1.
a) Develop a brief history of the discovery of liquid crystals that includes the following:
- When were LCs first discovered and when was the first LC synthesized?
- What is Reinitzer known for? What type of materials was he working with?
- Who is Brown and what is he noted for?
- What company developed the first LC display and in what year was this technology first released?
- List two or more other pieces of information about liquid crystals that you believe are important.

b) About how many liquid crystals are known or have been synthesized since the discovery of the first liquid crystal?

2. What is an intermolecular force? What is an intramolecular force? Compare the magnitude of inter- and intramolecular forces.

3. Describe the two shapes of most of the liquid crystal molecules.

4. The intermolecular forces in the crystalline phases of materials that form liquid crystals are not the same in all directions; in some directions, the forces are weaker than in other directions. As such a material is heated, the increased molecular motion overcomes the weaker forces first, but its molecules remain bound by the stronger forces. This produces a molecular arrangement that is random in some directions and regular in others.
a) What is a mesophase?
b) Draw pictures of some of the mesophase arrangements of the molecules in the nematic, smectic A and C, and choloesteric phases.

5. What is the difference between an isotropic and an anisotropic fluid?

6. Liquid crystals can be thermotropic or lyotropic. What is the difference between these two types of liquid crystals?

7. The optical properties of liquid crystals have led to what important applications?

8. What are additional uses of liquid crystals today?

9. What are the potential uses for liquid crystal substances?

10. Now that you have investigated a number of websites, how do you know if the information from a particular website is reliable?

KSB 5: INVESTIGATING LIQUID CRYSTAL SHEETS

In this KSB, you explore changes that occur in various commercially available liquid crystal sheets.

Students work in teams to:

- Discover how liquid crystals respond to heat
- Make careful observations of color changes
- Propose a practical use for these sheets

Safety

Be careful when using the hot plates. Serious burns can result from contact with the hot plate or with the hot water.

Materials (per group): hot plate, 6 1" x 1" liquid crystal sheets (labeled A-F), 2" packaging tape, scissors, 250 mL beaker, and an infrared digital or glass thermometer

Procedure:

1. Obtain up to six different LC sheets from your teacher. Note that they are labeled A-F. Make a data table in your lab notebook. The data should include the sheet letter, the temperature range of the color changes, and the colors observed.

2. Tape two of the 1" x 1" liquid crystal squares to your beaker. They should be placed next to each other and in the middle of the beaker. Try to maximize the amount of the LC square that is in contact with the beaker.

3. Slowly heat the beaker. Observe the temperatures where colors appear and also observe the corresponding colors. Record both the temperature and the color changes that occur.

4. Repeat, using the other LC squares.

Develop your understanding

1. In what ways did the commercially available sheets react to the increase in temperature?

2. How could these sheets be adapted for use in the design of a thermometer?

KSB 6: COLOR-TEMPERATURE RELATIONSHIPS IN MIXTURES

As you now know, liquid crystal substances are currently being used in many different applications. Many of these applications involve thermotropic liquid crystals; that is, heat causes a change in appearance of the liquid crystal. How do scientists and engineers find liquid crystals that have mesophases at a temperature they need for their application?

Students work in teams to:

- Prepare mixtures of cholesteryl oleyl carbonate (COC) and cholesteryl nonanoate/perargonate (CN)
- Explore the properties of mixtures of liquid crystals
- Investigate how a change in concentration relates to a change in temperature of the mesophase
- Graph and analyze the class's data
- Relate liquid crystal mixtures to homogeneous and heterogeneous mixtures
- Look at pure substances versus mixtures

Materials (per group):

Small glass screw-top vial or test tube
Two 1" x 1" pieces of acetate transparency, one clear and one black
Liquid crystal solution, cholesteryl oleyl carbonate (COC) and cholesteryl nonanoate/perargonate (CN). A different concentration of a mixture of liquid crystals will be assigned to each group.
250 mL beaker
Hot plate
Thermometer or a temperature probe
2" packaging tape
Scissors

SAFETY

Note: Care should be taken to avoid direct physical contact with these chemical substances.

Procedure

1. Cut a 1" x 1" clear transparency and a 1" x 1" black transparency (the black transparency should be slightly larger than the clear transparency).

2. Fill a 250 mL beaker about ¾ full of water and bring it to a boil on the hot plate. While waiting for the water to boil, prepare your LC mixture as directed by your teacher.

3. Heat the mixture to over 90°C. Make observations as the mixture is heated. Stir to mix thoroughly. What do you observe?

4. Apply a small amount (a drop or less) of the liquid crystal solution to the center of the black transparency (glossy side up). Place the clear transparency patch over the drop and flatten the drop out, trying to remove all of the air bubbles and keeping the solution away from the edges. **Note: Care should be taken to avoid physical contact with these chemical substances.**

5. Cover the two transparencies with a 3" piece of the packaging tape. Try not to stick the tape to the table any more than is necessary.

6. Attach the transparency to the side of a beaker, black side toward the beaker. It should be below the ¾ full line. Keep the majority of the transparency in contact with the beaker for accurate results.

7. Carefully fill the beaker with boiling water, measure the temperature, and record the color(s) and temperature in a table as instructed by your teacher. **Note: Safety glasses should be worn when working with hot solids or liquids.**

8. Allow the water to cool and carefully record **all** color changes and the temperature at which they take place. Note the initial and final temperatures of the color changes. Stir the water in the beaker often to keep the temperature throughout the beaker uniform.

Develop your understanding

1. What is a mesophase?

2.
a) In step 3, was your sample a pure substance or a mixture? Explain.

b) When the two liquid crystals were first put together, was the mixture homogeneous or heterogeneous? Explain.

c) When the two liquid crystals were stirred together, was the mixture homogeneous or heterogeneous? Explain.

3. Did you have more than one region of color changes? If you had more than one region of color changes, identify the region with the most noticeable color changes. What were the temperatures at which you observed the first and last color changes in this region? These will be the temperatures you will report to the class for your mixture. Record your data on the board as directed by your instructor.

4. What is the independent variable in this experiment? What are the two dependent variables?

5. a) Graph the minimum and maximum temperatures versus temperature for the class data. The graph should have two lines.

b) What are the shapes of the two lines?

6. Does the temperature curve indicate a direct relationship between the concentration of COC and temperature of the color changes? Explain.

KSB 7: OHM'S LAW

In this KSB, you examine the quantitative relationship between current, voltage, and resistance. This most applied relationship in circuits is known as Ohm's law.

Students work in teams to:

- Discover the relationships among current, voltage, and resistance
- Learn to use ammeters and voltmeters in DC circuits
- Plot data of voltage versus current, and determine whether voltage and current are directly proportional, inversely proportional, or neither
- Interpret the slope of the graph

Materials:
batteries or power supply, resistors, wires, light bulb, ammeter, voltmeter

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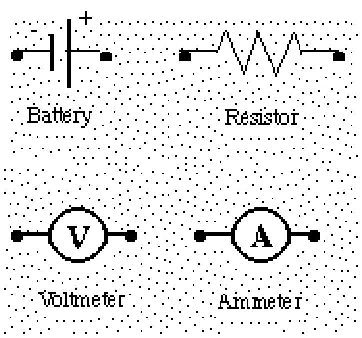
MODEL 1: Components of Circuits



An electrical circuit may include various components in a variety of configurations. A *battery* is an electrical device whose terminals maintain a potential difference. The unit used to measure this difference in potential is the *volt* (V). When the terminals are connected, an electrical current will flow. The potential difference of the battery "pumps" the current (electrons) through a closed electrical path or circuit.

The flow of electrons through a conductor is called *current.* The unit used to measure current is the *ampere* (A). This is a measure of the rate of flow of electrons. The flow of current generates heat, which indicates that current is flowing. (Note that this may be useful information that could help you address the Design Challenge for this module.)

Resistors are electrical circuit components that resist the flow of current. The unit of resistance is the **ohm** (Ω).

An **ammeter** measures the value of the current that passes through it. If you want to measure the current at some point in a circuit, you must *insert* the ammeter into the point at which you desire to know the current.

A **voltmeter** measures the value of the potential difference between two points of a circuit. In order to use a voltmeter, you must connect the voltmeter leads (wires) at both ends of the region of circuit across which you wish to determine the voltage.

Develop your understanding

1. Using the symbols in model 1, draw a simple circuit that includes only a battery and a resistor.

2. On your circuit, indicate the + and – terminals on the battery and indicate the direction of electron flow.

3. Redraw your circuit and include an ammeter and a voltmeter. The voltmeter should measure the potential drop across the resistor. Carefully note the required connections of the ammeter and the voltmeter in the model above.

MODEL 2: Ohm's Law Investigation

1. Select a resistor whose resistance is between about 500 ohms and 1,000 ohms.

2. Using your circuit diagram from item 1 of model 1, make a closed circuit from your DC power source and the resistor.

3. Introduce the ammeter (in series) so that it measures the current flowing through the resistor. See item 2.

4. Introduce the voltmeter so that it measures the potential difference across the resistor. See item 2. Set the voltage to approximately 10 V. Record your value in the table below.

5. Record the current in the circuit. Turn off the power source when not collecting data.

6. Repeat this procedure for four more voltages.

Approximate Voltage (V)	Voltage Reading (V)	Current Reading (mA)
10		
8		
6		
4		
2		

7. Use a different resistor assigned to you by your teacher, and repeat the procedure.

Approximate Voltage (V)	Voltage Reading (V)	Current Reading (mA)
10		
8		
6		
4		
2		

8. Transfer your data to an Excel spreadsheet for graphing. Enter the current in the first column. Convert mA to A in column 2 for the *x*-axis. Enter the voltage in the third column for the *y*-axis. Label your graphs and find the equation for the line and the Rvalue of each graph. Ohm's law states that the resistance in ohms in a circuit is

equal to the voltage drop across it, measured in volts, divided by the current flow through it, measured in amperes or $R = V/i$. When you plot voltage drop versus current flow through a resistor, the slope of the resulting line is the resistance.

Develop your understanding

1. Enter values of your resistors and the corresponding slopes of the graphs in the following table:

	Printed R (ohms)	Slope of graph	Tolerance of resistor	% difference
Trial 1				
Trial 2				

% difference = [(printed value) – slope]* 100/(printed value)

2. Is the relationship between voltage and current direct or indirect (inverse)?

3. What effect does the resistance have on the current? Is this a direct or indirect relationship?

4. Draw a circuit, which contains a 1.5 kΩ resistor and a 9-volt battery. Calculate the current through the resistor.

KSB 8: EFFECTS OF VOLTAGE AND CURRENT ON LIQUID CRYSTAL SUBSTANCES

Now that you have the new knowledge and skills from the first seven KSBs, it is time to make applications in another area. What effect does the length of a wire have on its resistance? What effect does the amount of current in a wire have on the wire? What effect does the voltage have on the wire? Consider how the connectors, the length of the wire used, and other items used during design and construction relate to the resistance for the circuits you create.

By considering the results of your investigation, and applying your knowledge of electrical circuits gained in KSB 7: Ohm's Law, you may now choose to create appropriate circuit(s) to address the Design Challenge for this module.

Energy is dissipated as heat when current flows through a resistance. The heat, or power, dissipation for current flow through a resistor is the product of voltage across the resistor times current flow through it.

$$P = Vi$$

Noting that $V = iR$ from Ohm's law, then $P = (iR)\, I = i^2 R$.

Materials: liquid crystal sheets, nichrome wire, 1.5-volt cell, 6-volt battery, 9-volt battery, wire, alligator clips, various resistors as needed, and a digital multimeter

Procedure: (record all results in your journal or folio)

1. Cut a length of nichrome wire longer than the width of the liquid crystal sheet. This will allow you to connect the batteries to it to begin your test.

2. Connect the 1.5-volt cell to the nichrome wire, which is on top of the LC sheet, and observe any change in the color of the liquid crystal sheet. If there was a color change, what might have caused it?

If there was no color change in the LC sheet, what variables might you change to observe a color change?

3. Try different lengths of wire and different liquid crystal sheets. Record your observation in your journal or folio.

4. Using a multimeter, measure the voltage and current flowing through the circuit you have created as you observe any changes, and record the data collected.

5. Use several 1.5-volt cells of known different levels of charge and observe the changes. This will help you better calculate the resistance needed to produce the maximum effect with a fully charged cell.

6. Repeat steps 1–5 with both the 6-volt and 9-volt batteries. Once again, pay careful attention and record important information for possible later use.

Develop your understanding

1. Do the location and/or position of the nichrome wire alter the results? What seems to be the best placement for reliable, consistent results?

2. How could a circuit be designed that would allow you to test all three voltage sources?

3. How could you change or select the circuits needed for each voltage source?