TEACHER INSTRUCTIONS

Hot or Not

Objective: To show how materials can be designed to withstand very high temperatures.

Background Information: There are four different mechanisms by which heat can transfer: conduction, convection, radiation and advection. Conduction occurs when two things are in physical contact with each other. Heat causes the atoms in a material to vibrate which then transfers energy to other atoms in a process called thermal conduction. In the vacuum of space, there is no matter and therefore no conduction of heat. Gases, such as air, contain very little matter in comparison with solids or liquids. They "insulate" heat from flowing. This is why porous materials like foam insulation and ceramic tiles, which contain a lot of air, are used to keep our houses warm.

A refractory material is chemically and physically stable at high temperatures and has good resistance to thermal shock. Refractory bricks are made from ceramic materials that can withstand extreme temperatures without melting. In addition, they contain a great deal of trapped air since they are so porous. When the brick is heated on one side, the heat cannot travel to the other side since there is so much insulating air in between. Tiles, similar to the ceramic refractory brick used in this demo, were used on the outside of the space shuttle to protect the ship and crew from the >1200°C temperatures achieved on reentry into Earth's atmosphere (Figure 1).

Metals can also be refractory materials. These types of refractory materials are often used as tools to work other metals at high temperature, light bulb filaments, and in furnaces used to manufacture steel and glass (Figure 2).

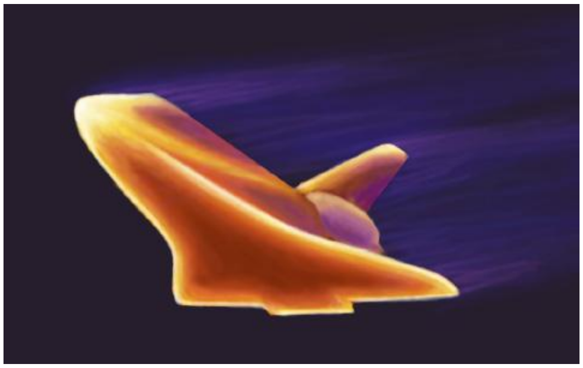

Figure 1. Computer simulation of the space shuttle upon re-entry. The surface reaches extremely high temperatures and is covered in refractory ceramics.
(http://en.wikipedia.org/wiki/File:Stsheat.jpg**)**

Figure 2. Steelmaking- refractory materials are used in the crucible.
(http://en.wikipedia.org/wiki/File:Fotothek_df_n-08_0000320.jpg**)**

Demo Description: In this demo, a propane torch will be used to heat one side of a refractory brick. A thermometer will be used to monitor the other side of the brick, which should remain cool during heating.

Keywords:
Heat: the energy (other than work) that is transferred from one body to another
Temperature: the measurement of the amount of heat present in an object
Insulator: material that resists the flow of heat (e.g. ceramics or plastics)
Thermal conductor: material that aids in the flow of heat (e.g. metals)
Refractory: a substance that is chemically and physically stable at high temperatures and is resistant to thermal shock
Porous: having many small spaces (i.e. pores) that can hold a gas or liquid or allow gas or liquid to pass through

Materials List:
Items provided in the kit
1 Refractory brick
1 Propane torch head

Items to be provided by the teacher/school
Small propane tank (1 liter, generally found in the camping aisle at stores like Wal-Mart®)

Thermometer (a variety of thermometers will work – the easiest to use is probably a meat thermometer since it is made to be 'stuck' in a material)
Spark lighter or matches (also generally found in the camping aisle)

Safety Precautions: Be very careful not to touch the hot side of the refractory brick. Do not look directly at the flames of the torch.

Instructions:

1. Assemble the propane torch (see the Introductory Presentation for assembly instructions).
2. Show students the refractory brick.
3. Explain what refractory materials are and what they are used for.
4. Set up the refractory brick so that both sides can be seen and accessed. It is possible to hold the brick in your hand. The back side will remain cool.
5. Set up the thermometer to measure the side of the brick that will not be heated.
6. Heat the side of the brick without the thermometer.
7. Have a student read the temperature on the thermometer as the other side of the brick is heated.

Demo Delivery Hints:

1. If students are mature/responsible enough, allow a student to control the propane torch to keep them involved in the demo.
2. When the refractory brick is not in use for the demo, be sure to keep it in the included plastic baggie. If the plastic baggie becomes worn or dirty, replace it with a new one (there is nothing special about the baggie included in the kit – feel free to replace it with a similar plastic bag). The refractory brick will slough off in small pieces if handled roughly and may also dent or crack into two pieces if hit against hard surfaces. If the brick cracks into two smaller pieces, the smaller pieces can generally still be used to run the demo as long as the piece is large enough to allow for heating on one side.

Troubleshooting: Do not put the thermometer on the side of the brick you are heating. It may melt! Be sure not to push the thermometer all the way through the brick as this will produce the same result as putting the thermometer on the heated side. If you are unsure of how to properly use the propane torch, see the Introductory Presentation for step-by-step instructions on how to assemble and use the propane tank and torch head. When lighting the propane torch with a grill lighter, keep the flame turned down low or else the torch will blow itself out. Light it on low, and then turn the flame up as desired.

Cleanup/Replacement parts: DO NOT TOUCH THE HOT SIDE OF THE BRICK! Place the brick in a safe place (out of students' reach), and allow it to cool. Do NOT put the brick away until it has cooled completely. Use the thermometer to confirm that the temperature of the heated side has returned to room temperature. Tighten the knob on the propane tank and put everything back in the kit. Be gentle with the refractory brick.

TEACHER DISCUSSION QUESTIONS

Hot or Not

Discussion Questions to Ask Before the Demo

1. What is heat?

   Discussion: The energy (other than work) that is transferred from one body to another.

2. What causes things to heat up? How does heat transfer?

   Discussion: When heat travels, it must have physical matter to move through. It transfers by vibrating the atoms in a material which then transfers energy to other atoms in a process called thermal conductance. In the vacuum of space, there is no matter and therefore no heat.

3. What could prevent heat from transferring?

   Discussion: Gases, such as air, contain very little matter in comparison with solids or liquids. They "insulate" heat from flowing. This is why porous materials like foam insulation and ceramic tiles, which contain a lot of air, are used to keep our houses warm.

4. What uses would you have for materials that easily transfer heat? For materials that prevent heat transfer?

   Discussion: Kitchen pots and pans are made out of metals, which generally have very high heat transfer coefficients. This is why we use them for tasks such as boiling water on a stovetop. Refractory materials are generally made out of ceramics and are highly porous, meaning they contain a lot of trapped air within the microstructure of the material. Refractory bricks similar to the one supplied for this demo were used on the Space Shuttle to prevent overheating during atmospheric re-entry. Refrigerators and freezers are another example of items in a kitchen which have low heat transfer.

Discussion Questions to Ask During the Demo

1. Why is the heat not transferring through the material?

   Discussion: Gases, such as air, contain very little matter in comparison with solids or liquids. They "insulate" heat from flowing. This is why porous materials, like the refractory brick, do not transfer heat well. It contains so many pores full of trapped air that it significantly slows the transfer of heat to the other side of the brick.

2. What would happen if we exposed something else in the classroom to the heat of the propane torch? (For example the metal leg of a chair.)

   Discussion: The chair leg would begin to glow where exposed to the heat and slowly that glow would spread over a large area of the leg. If the torch is hot enough it would likely cause the leg to melt and deform.

Discussion Questions to Ask After the Demo

1. What are different ways materials are made to stop heat from transferring?

   Discussion: The refractory brick in this demo uses pores, or empty areas filled with air, to prevent heat from transferring via conduction. Double pane windows have a similar concept, using an empty (gas filled) area between the panes. Heat can be prevented from transferring via radiation by blocking the radiation, such as is done by a parasol to keep cool on a sunny day.

2. What would happen if this brick were dense (i.e. did not have pores)?

   Discussion: The refractory brick would allow the transfer of heat from one side to the other. However, due to the refractory nature of the material, no physical or chemical changes would occur. This means that the material would not melt, unlike most other materials exposed to the heat of a propane torch.

STUDENT QUESTION HANDOUT

Hot or Not

1. What is heat? How does it transfer from one object to another?

2. What is the difference between an insulator and a conductor?

3. What is special about the microstructure of the refractory brick?

4. How does that special microstructure impact the way the refractory brick responds to the heat of the propane torch?

5. Identify the mechanism of heat transfer (conduction, convection, radiation or advection) in the following situations:
    a. Cooling your room using a fan
    b. A pan of vegetables on the stove
    c. Your driveway on a sunny summer day
    d. A chicken cooking in the oven

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TEACHER INSTRUCTIONS

Candy Fiber Pull

Objective: To demonstrate the unique properties of glass by examining the solid-liquid and liquid-solid transitions of a glass-like system.

Background Information: Glass is an amorphous solid that is typically brittle and optically transparent. An amorphous solid is any material that has no long-range order of atoms. Crystalline materials (such as a metal) have an orderly arrangement of atoms, while amorphous materials do not (Figure 1). Glass is a unique material because its viscosity slowly decreases as heat is applied until it flows in a similar fashion to water. The temperature at which it transitions from solid to liquid is often referred to as the glass-liquid transition temperature. As the glass is cooled, the viscosity slowly increases. This property allows gaffers (people who 'blow' glass) or machines to work with and shape the glass into products such as vases or bottles. If the glass is cooled too quickly, stresses will form in the glass causing it to crack. The glass-liquid reaction is typically reversible, meaning the solid can move to a liquid state and then back to a solid state. The glass-liquid transition of a solid to a liquid state typically occurs due to heating, and the reverse reaction of a liquid to a solid state typically occurs due to cooling or compression.

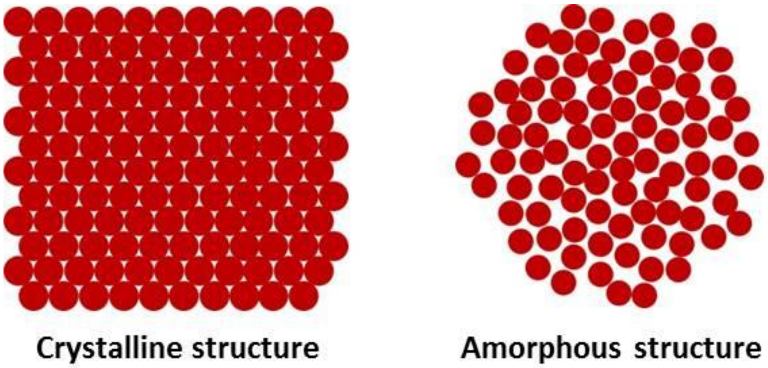

Figure 1. Crystalline vs. amorphous atomic structures

The term 'glass' includes many different materials, some of which you are familiar with. Soda-lime glass – composed primarily of silica (sand) – is used in the production of windows and drinking glasses. Sugar glass – composed of a brittle transparent form of sugar – is used in movies, photographs, and plays to simulate soda-lime glass. It breaks very easily and is less likely to cause injuries, but still has the look and breaking patterns of soda lime glass. Cotton candy and lollipops are two glasses that are made from cane sugar. Cotton candy is made by heating sugar until it reaches a molten state (liquid form) and squeezing it through small holes into a larger bowl that is spinning. The thin sugar fibers solidify almost immediately in the room temperature air and begin to collect on the outer edges of the bowl. When you eat the cotton candy, the heat from your tongue causes the fibers to dissolve into liquid form again. Other candies, such as lollipops and Jolly Ranchers, follow a similar process. Insulation used to keep your house warm in the winter is fiberglass, which is made in a similar fashion to cotton candy. See the Introductory Presentation for additional examples of how glass and the glass-transition temperature are used in real-world applications.

Demo Description: During this demo, Jolly Ranchers® will be melted in a beaker using a hot plate. Once the Jolly Ranchers® have reached a molten state, candy fibers can be pulled from the beaker. When a fiber is pulled, it is almost instantly cooled because of the small diameter of the fiber and how cool the air is in relation to the molten Jolly Ranchers®. This simulates the production of glass-like fibers.

Keywords:
Glass: an amorphous, brittle solid which exhibits a glass-liquid transition when heated
Liquid: fundamental state of matter characterized as having a definite volume, but no shape
Solid: fundamental state of matter characterized by structural rigidity
Amorphous: non-crystalline material that lacks a long-range atomic order
Glass-liquid transition: reversible reaction in amorphous materials from a hard, brittle state to a semi-liquid, molten state

Materials List:
Items provided in the kit
1 Beaker
Beaker tongs

Items to be provided by the teacher/school
Hotplate (can also use a microwave if no hotplate is available)
Jolly Ranchers®
Wooden skewers or popsicle sticks (something to pull fibers with)

Safety Precautions: The hot plate and the beaker will get very hot. Caution should be used when handling the beaker during the demo. Allow the beaker and hot plate to cool before cleaning and returning to the kit. It may be helpful to clean some of the Jolly Ranchers® while it is still warm and fluid, but be sure that the beaker is not hot to the touch. If the Jolly Ranchers® cool and harden, they can always be removed with soap and warm water (allow the Jolly Ranchers® to melt away in the warm water rather than trying to scrub it).

Instructions:

1. Be sure that the beaker is clean and dry.
2. Place 4-6 Jolly Ranchers® into the beaker.
3. Place the beaker on the hotplate, and set the hotplate to a medium temperature setting.
4. Stir the Jolly Ranchers® while heating for approximately 10-15 minutes. The Jolly Ranchers® should begin to melt into a more fluid form.

Note: The Jolly Ranchers® can burn! Pay close attention while melting the Jolly Ranchers® and be sure to stir them throughout the heating process. If they start to burn, reduce the heat (or remove the beaker from the heat) and continue to stir. If you have a microwave available in your classroom, it is easier to heat the Jolly Ranchers® in this fashion. You may have a shorter time period to pull the fibers before the Jolly Ranchers® harden again, but you are less likely to burn them.

5. Once the Jolly Ranchers® are in liquid form, use the wooden skewer/popsicle stick to pull one fiber from the beaker by dipping the skewer into the molten Jolly Ranchers® and removing it slowly.
6. Allow students to take turns pulling fibers.
7. Pick 4-5 students and have each one of them pull a fiber and quickly move away. Have the other students take rough measurements of how long the fiber gets before it breaks. See who can get the longest fiber.
8. Have students compare the flexibility and texture of a short, fat pulled fiber; a long, skinny pulled fiber; and a solid Jolly Rancher®.

Demo Delivery Hints:

1. Turning the fiber pulling into a game to see who can get the longest fiber makes this demo fun. Most of the time, it helps to remove the beaker from the hotplate and tilt it so that the fiber doesn't contact the side of the beaker while the student is moving away. Do not touch the beaker with your bare hands, always use the beaker tongs or hot pads/gloves.
2. The Jolly Ranchers® do take a little time to heat up and turn to a liquid form. This portion of the demo can be started early, and the Jolly Ranchers® can continue to heat while you are explaining the background information and what is going to be done during the demo. Just make sure to stir the Jolly Ranchers® as they are heating.
3. If you have other beakers readily available in your classroom, it is recommended that you use the beaker included in the kit for ***this lesson only*** and designate it as a ***'food-only' beaker***. This will allow students to eat the fibers without having to worry about contamination from the beaker. Be sure to clearly label the beaker as 'food-only' and thoroughly wash and dry the beaker each time before using it for this lesson.

Troubleshooting: It may take some time for the hot plate to heat up. Make sure to test the hot plate prior to the demo to ensure that the heating elements and temperature settings are working correctly (you can do this by placing some water in the beaker and checking to see that it boils after 10-15 minutes of heating on the hot plate). Alternatively, you can melt the Jolly Ranchers® in a microwave if one is available.

Cleanup/Replacement parts: This demo can get very messy. The easiest way to clean the beaker is to run hot water over it until all of the sugar is dissolved. Fibers that end up sticking to the desk or floor can also be dissolved by scrubbing with a paper towel moistened with hot water or using a mop with hot water. The used wooden skewers/popsicle sticks should be replaced after every demo. A damp paper towel should also be used to clean the hotplate once it has cooled.

Make sure that the beaker and hot plate are clean and dry before returning them to the kit. Should you need to purchase/replace your hotplate, they are available from a variety of different websites, such as Amazon (http://www.amazon.com/Aroma-AHP-303-Single-Plate-Black/dp/B0007QCRNU).

TEACHER DISCUSSION QUESTIONS

Candy Fiber Pull

Discussion Questions to Ask Before the Demo

1. Ask students what they know about the formation of glass, glass fibers, or glass-like fibers (such as cotton candy)?

   Discussion: Students most likely will not know much about how glass and glass fibers are made. Describe the process outlined in the Background Information section of the Teacher Instructions.

Discussion Questions to Ask During the Demo

1. Before pulling a fiber for the first time, ask students what they think will happen when you remove some of the Jolly Rancher® from the heat and 'pull' a fiber.

   Discussion: Emphasize the fact that the diameter of the fiber is very small compared to the amount of molten Jolly Ranchers® in the beaker. This facilitates an instant cooling of the Jolly Rancher® fiber as it is removed from the heat and exposed to room temperature air, which causes it to take on a glass-like fiber quality.

2. Have students guess at how long of a fiber they think they can pull.

   Discussion: If this demo is done correctly, students should be able to pull a fiber that runs a good distance across the room. Most of them will not guess a number this high for the length. The key is to have them move very quickly away from the beaker so that the fiber continues to be pulled, otherwise it will start to sag. Once the fiber makes contact with any other surface (a desk, the floor, etc.), it will not be able to be pulled much longer.

3. Once several fibers have been pulled, ask students to compare the texture and flexibility of the fiber to the solid Jolly Rancher®. Are there any changes in the properties of the fibers as a function of length (i.e. do shorter fibers feel or look different than longer fibers)?

   Discussion: The fibers should be fairly flexible when they first start to cool, but may start to harden after being at room temperature for a while. In general, the thinner and longer the fiber, the greater the flexibility. The fibers may also have a different texture and color (transparency) compared to the original Jolly Rancher®.

4. Hold a short competition to see who can pull the longest fiber.

   Discussion: This is best done in groups of 2-3 students. First, have each student (or each group) make a guess at the longest fiber they think will be pulled. Record the guesses on the Student Question Handout. Have one student from each group pull the fiber, while the other students help measure the length of the fiber as it is being pulled. Use a meter stick, or have students walk alongside the fiber being pulled and count the number of steps taken along the length of the fiber. If you have enough space in your classroom, you can have each group take their fiber in a different direction (although this will make for some additional clean-up – a mop and warm water are suggested to help clean the floor if a lot of fibers end up on the floor). This allows all of the fibers to be pulled so that each student can evaluate the other groups' fibers to determine which is the longest. Give the student/group with the closest guess to the longest fiber pulled a reward, such as extra Jolly Ranchers® to take home.

Discussion Questions to Ask After the Demo

1. Allow the students to eat the fibers that haven't been in contact with the floor. Ask them what is happening to the fibers as they are eaten.

   Discussion: Emphasize that the heat from your tongue as well as the pressure of you sucking on the candy will cause the fiber to go from a solid form back to the liquid form. This is the reverse reaction of what happened when they pulled the molten Jolly Ranchers® from the beaker.

STUDENT QUESTION HANDOUT

Candy Fiber Pull

1. What do you think will happen when you pull some of the molten Jolly Ranchers® out of the beaker?

2. What is the longest length of fiber that you *think* you can pull?

3. What was the length of the longest fiber pulled?

4. How does the Jolly Rancher® fiber differ (in terms of texture, flexibility, shape, etc.) from the original solid Jolly Rancher®?

5. What happens when you eat the Jolly Rancher® fibers?

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TEACHER INSTRUCTIONS

Piezoelectric Materials

Objective: To demonstrate the piezoelectric effect in several materials and explain why this property exists in certain materials.

Background Information: Piezoelectric materials are everywhere. Piezoelectric materials are used in a wide variety of applications. Sensors, amplifiers, and ultrasonic transducers are just a few examples. They are a necessary component in all electronics and can be made very small (so your electronics can be compact as well).

The piezoelectric effect describes the relationship between a mechanical stress and an electric voltage in solids. Certain materials (e.g. quartz and barium titanate ($BaTiO_3$)) exhibit this effect. When a mechanical stress is applied to these materials, they generate a voltage. This is shown schematically in Figure 1. The effect is reversible as well. When a voltage is applied to the material, the shape of the material will change by a small amount (up to 4% in volume change).

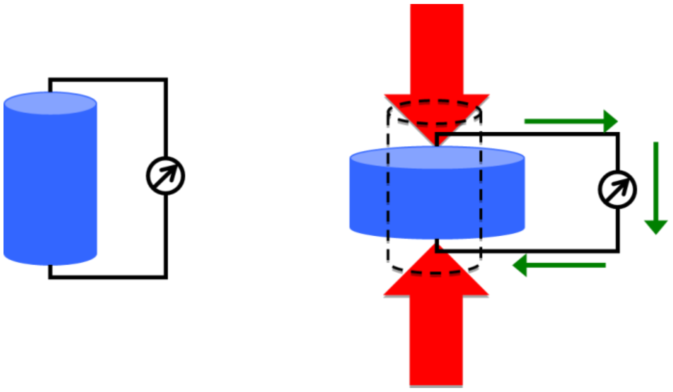

Figure 1. Schematic of the piezoelectric effect. When a force is added to the material (red arrows), it generates a voltage (green arrows). It also works in reverse.

This is how the speaker in a greeting card or the speaker in an mp3 player's headphones works. The material is electrically vibrated at certain frequencies that we then hear as sound. This sound can be amplified with the use of a diaphragm.

The piezoelectric effect is caused from the structure of the material. Sometimes atoms are arranged in such a way that they can be physically forced towards each other when the material experiences a compressive force. The change in the material's structure causes an electric dipole, or change in potential (voltage). The opposite is also true. When a potential is applied to the material, like a battery, then the atoms are driven apart and a force is created. See the

Introductory Presentation for examples of how the piezoelectric effect is used in real-world applications.

Demo Description: In this demo, the piezoelectric effect of a ceramic disk and a polymer film will be demonstrated through the use of LEDs. Two of each piezoelectric material have been included in the kit so that you may keep one to demonstrate and pass one among the students.

Keywords:
Piezoelectric: effect of generating electric charge from applied force
Ceramic: classification of materials which are inorganic, non-metal solids
Polymer: classification of materials which are characterized by long, chain-like molecules that typically have repeating sub-units
Structure: arrangement of atoms within a material
Potential: difference in electric charges resulting in the capacity to do work
Force: influence exerted on an object, such as pressure or tension

Materials List:
Items provided in the kit:
2 Piezoelectric ceramic disks
2 Piezoelectric polymer films
4 LEDs
8 Alligator clip sets

Items to be provided by the teacher/school:
9 Volt battery
Musical greeting card
Headphones
Voltmeter

Safety Precautions: Too much force on either piezoelectric material can permanently damage them.

Instructions:

1. Test both piezoelectric materials prior to starting the demonstration to make sure neither is damaged or needs to be replaced.
2. Connect 1 LED to each piezoelectric material so that the long wire of the LED is connected to the red wire coming from the piezoelectric material, and the short wire on the LED is connected to the black wire of the piezoelectric material. Use the supplied alligator clips to make these connections (Figure 2).

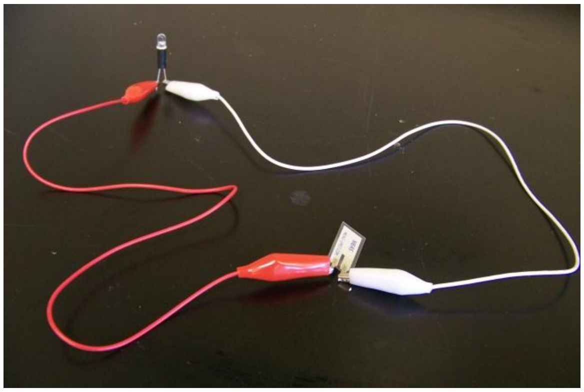

Figure 2. LED and piezoelectric polymer film connected by alligator clips

3. Place the ceramic disk on a flat surface and tap down on the white center (Figure 3). Start with a very light tap and slowly increase the force until the LED visibly flashes with each tap. Show effect to students.

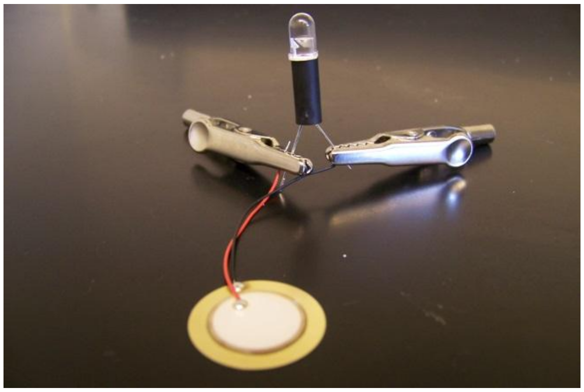

Figure 3. Piezoelectric disk ready to be tested

4. Pass the other ceramic disk with LED among the students and let them try it at their own desk (you can also pass both ceramic disks if you are done demonstrating). Caution students not to use too much force as this will damage the disk. This is why it is best to start with a light tap and slowly increase the force until the LED visibly flashes.
5. Bend the polymer film back and forth slowly (Figure 4), increase the speed at which you are bending the material until the LED lights up with each bending motion. Show the effect to the students.

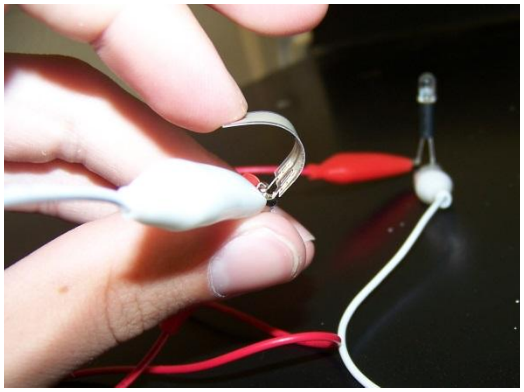

Figure 4. Bending the polymer film

6. Pass the polymer film(s) among the students and let them try it at their own desk. Caution students not to fold the film, but rather to bend it. Folding and creasing the film will damage it.
7. Open the musical greeting card and explain the use of piezoelectric materials as a speaker. Take apart the card so that students can see the actual piezoelectric 'buzzer'. Supply students with the Background Information on piezoelectric materials. A reproduction of Figure 1 should be created as a demonstration aid, linking it to the ceramic disk and polymer films used.
8. Attach the two wires of the polymer film to a 9 volt battery and show the students the effect of the battery's potential on the piezoelectric polymer film.

OPTIONAL ADDITIONS TO THE DEMO

9. Use a voltmeter in place of the LED to measure the voltage generated by the piezoelectric. This provides a better indication of the piezoelectric effect as the light generated by the LED is very minimal.
10. Connect the two piezoelectric materials in series and try to generate more voltage by simultaneously activating both materials.
11. Create a simple circuit by connecting the ceramic disk directly to the polymer film. Attempt to make the polymer film bend by striking the ceramic disk.

Demo Delivery Hints: Interest is key. This demonstration can be boring if you are not interested in it yourself. Try to be excited about the piezoelectric affect. The video "How a quartz watch works" can be used as an introduction:

http://www.youtube.com/watch?feature=player_embedded&v=1pM6uD8nePo

Troubleshooting: If either piezoelectric material is damaged or not working, then replacements should be purchased. If the demonstration isn't functioning, then the piezoelectric materials are most likely the cause (the LEDs are nearly indestructible).

Clean-up/Replacement parts: Disconnect the LEDs from the piezoelectric materials and return all materials to the kit. LEDs can be found at any electronics store for very little cost if they are lost or stolen. Piezoelectric ceramic disks can be purchased from online electric suppliers, including eBay. They are typically referred to as "transducers". It is recommended to purchase the disks with wires already attached (for ease of use). Piezoelectric polymer films can also be purchased from online electronic suppliers. They are commonly referred to as "piezoelectric vibration sensors". It is also recommended to purchase films with wires already attached (for ease of use).

TEACHER DISCUSSION QUESTIONS

Piezoelectric Materials

Discussion Questions to Ask Before the Demo

1. How do we as a society make electricity?

   Discussion: We typically use generators powered by water or steam pressure, wind, solar, coal, or nuclear power.

2. What objects or materials generate electricity?

   Discussion: Magnets (generator), batteries (chemical reaction)

Discussion Questions to Ask During the Demo

1. Why does the LED have to be polarized (red and black wires)?

   Discussion: The charge only moves in one direction when the material is compressed.

2. What do these piezoelectric materials have in common?

   Discussion: A similar structure that allows atoms to be forced together.

3. What is generating the charge observed as light from the LED?

   Discussion: The movement of atoms within the material causing an electric dipole to light the LED.

Discussion Questions to Ask After the Demo

1. What are potential applications this material could be used for?

   Discussion: Sensors, speakers, actuators, buzzers, switches, and power generation.

2. Is human hair a piezoelectric material?

   Discussion: It is…ever statically charge a balloon by rubbing it on your head?

STUDENT QUESTION HANDOUT

Piezoelectric Materials

1. What is the piezoelectric effect?

2. What causes the piezoelectric effect?

3. Name a type of material that can have the piezoelectric effect.

4. Name one current use of this material property.

5. What is a potential application of this material? Where could you use the piezoelectric effect?

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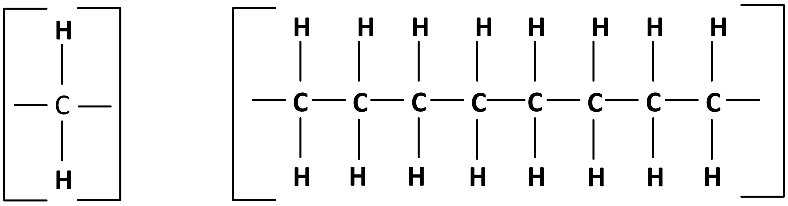
TEACHER INSTRUCTIONS

Making Plastic

Objective: To demonstrate the process of making a polymer (plastic) from common ingredients.

Background Information: The word polymer is derived from two Greek words: polus, meaning 'many', and meros, meaning 'parts'. Therefore, the literal meaning of polymer is 'many parts,' which refers to the fact that a polymer is composed of many repeating subunits. The subunits of a polymer are often referred to as monomers, or 'mers' for short. Figure 1 shows the structure for a typical mer and polymer.



(a) Mer **(b) Polymer**

Figure 1. Atomic structure of a (a) mer and (b) polymer

The atoms found in the mer and polymer typically form the same number of bonds, or connections to other atoms. For example, a hydrogen atom forms one bond, an oxygen atom forms two, and a carbon atom forms four bonds. In water (H_20), each hydrogen has one bond and the oxygen in the middle has two bonds. Atoms can combine in a number of different ways to form molecules. Water is a smaller molecule, but most molecules are typically bigger. For example, one molecule of vitamin C ($C_6H_8O_6$) is made up of 20 atoms: 6 carbon, 8 hydrogen, and 6 oxygen. Molecules are groups of atoms bonded together, AND polymers are really just large molecules arranged in different ways. Polymers tend to form long, chain-like molecules. Similar to a bowl of spaghetti noodles, the long chain molecules can become intertwined and tangled to form a strong, yet ductile, material. Common polymer materials include plastic, vinyl, and rubber.

Demo Description: In this demo, milk and vinegar will be added together under heat treatment to create a polymer (plastic), which students can then mold into various shapes. Milk contains organic compounds which can be broken down and recombined with other molecules (vinegar) to form polymers. Organic compounds are formed of molecules containing carbon, hydrogen, oxygen, nitrogen, and sulfur. Living organism are collective systems of organic molecules, including humans! This demo will show one way that organic compounds can be used to form a new polymer material that is different from the original milk or vinegar components.

Keywords:

Polymer: chemical compound with a structure of many repeating sub-units

Molecule: a group of 2 or more atoms that is electrically neutral and characterized by covalent chemical bonds

Organic molecule: a molecule that contains carbon atoms

Chemical reaction: the change of one substance or molecule into a new one that usually has different chemical properties than the original substance or molecule

Materials List:

Items provided in the kit

2 Candy molds – you may want to cut the molds into separate pieces so that each student can have their own mold

Items to be provided by teacher/school:

2 colors of construction paper (need multiple sheets of each color)
Tape
Hotplate
Milk (preferably whole milk)
Vinegar
2 Large pots
Metal or plastic spoon
Strainer/colander (a fine mesh strainer/colander works best)
Tin foil (a few sheets for easy clean-up of the candy molds)
Wax paper (a few sheets to dump the plastic on after the heating process)
Popsicle sticks
Paper towels

Items students need to provide

Fibers to reinforce the plastic during molding (hair, thread, sticks, paper, etc.) - OPTIONAL

Safety Precautions: This demonstration requires the cooking of milk on a hotplate. Precautions should be taken to prevent contact burns or spilling of hot material. The process can have a distinct odor.

Instructions:

1. Label the construction paper with either a C for carbon or H for hydrogen. Use a different color for carbon and hydrogen. Make twice as many H papers as C papers.
2. Give each student one of the papers and a piece of tape. Have them tape the paper to the front of their shirt.

3. Have groups of 3 students (two H's and one C) form the structure of the mer shown in the Background Information section. Have the students use their arms to represent the bonds between the hydrogen and carbon (straight lines shown in the diagram). Emphasize that they have just formed a 'mer', the repeating sub-unit of a polymer.
4. Next, have the groups of 3 line up to form the polymer shown in the Background Information section. Again, have students use their arms to represent the bonds. Make sure that every bond is represented. If there is no arm between an H and a C, then there is no bond there (it may take students a few moments to ensure that every bond is there as they need to carefully choose where to place their arms so that there are enough bonds to complete the polymer structure). Emphasize the fact that they have just formed a chemical compound of many repeating sub-units, also known as a polymer.
5. Have students return to their seats and place tin foil inside their mold, wrapping or taping it in place. The molds should be labeled with their names and ready to receive liquid plastic before the cooking process starts.
6. OPTIONAL: Place fibers inside each mold to reinforce the plastic. The plastic will be poured on top of the fibers.
7. Heat milk in a large pan on the hotplate (1 gallon per 20 students). Keep the heat low and stir occasionally to keep milk from burning. In this step, you are breaking down the organic compounds in the milk to small molecular units called mers.
8. Measure vinegar (1 TBSP per each cup of milk used, 1 gallon = 16 cups) into a cup and wait for the milk to come almost to boiling. When the milk is close to boiling, steam will be visible and a small froth on the surface will form. Continue stirring occasionally until the froth forms.
9. Turn off the hot plate and add the vinegar while stirring continuously. In this step, you are causing a chemical reaction that allows the mers to connect and form long chains (also known as polymers).
10. Continue to slowly stir the mixture for about one minute. Chunks will start to form. This is your plastic!
11. Pour the hot liquid/chunks through a strainer into another pot.
12. Once you've poured the hot liquid/chunks out (don't worry about what's left in the bottom), gently shake the strainer, and swirl it around a little. Most of the plastic will lump up in the bottom, pulling itself out of the holes.
13. Make sure a majority of the liquid is strained out, but don't press it out! Dump the chunks out on some wax paper and soak up excess liquid with a paper towel, but don't press it out!

14. Place a small amount in each student mold. Allow each student to use a popsicle stick to push and shape the plastic into their mold.
15. Allow the plastic to dry in the mold for 2 days.
16. Encourage students to examine the structure of the homemade plastic by breaking the individual pieces.

Demo Delivery Hints:

1. The process of creating a human polymer (described in steps 2-4 above) can be repeated for many different polymers. You can search 'atomic structure of polymers' online and find a number of different structures that your students could create. Be creative!
2. The process of heating the milk takes some time. Rushing the heating process can cause the milk to burn and ruin your plastic. To maximize time, start heating the milk and pick a student to stir while you teach the class about a polymer material and the reactions taking place in the milk.
3. Silicone molds should not be used for this demo. This type of mold prevents the plastic from drying completely, and the plastic may become (or smell) moldy. It is recommended that a hard plastic candy mold (should feel very stiff instead of bendable like the silicone molds) be used instead. The candy molds included in the kit are a good example of a stiff plastic mold, but you are encouraged to try other plastic candy molds depending on the interests of your students.

Troubleshooting: The heavier the milk, the more plastic and the more vinegar is required. The recommended vinegar/milk ratio in step 7 is for whole milk. If using milk with less fat, use less vinegar (you will need to experiment to determine the appropriate amount of vinegar).

Cleanup/Replacement parts: Care should be taken to keep the homemade plastic out of sinks and drains. Wipe out all dishware with paper towels before washing in the sink or dishwasher and dispose of the paper towels in the trash can. Supplied molds can be reused if covered in tin foil prior to filling the mold with plastic. More molds of various shapes and sizes can be purchased through Amazon under the category of candy molds.

TEACHER DISCUSSION QUESTIONS

Making Plastic

Discussion Questions to Ask Before the Demo

1. What are life forms made of?

   Discussion: Most life forms are a collection of different organic (carbon-based) molecules.

2. What is a plastic made of?

   Discussion: Plastic is composed of atoms which form small subunits called mers that can be connected into long, repeating chains of organic molecules. These long, repeating chains of organic molecules are often referred to as polymers.

Discussion Questions to Ask During the Demo

1. What is milk made of?

   Discussion: Organic Compounds: (ex: Vitamin D, Lactose, Glucose….)

2. What is happening when the milk is heated to near boiling?

   Discussion: The organic compounds are being broken down into smaller mer units.

3. What is happening when the vinegar is added to the hot milk?

   Discussion: A reaction occurs between the mer units to form long chain-like organic compounds.

Discussion Questions to Ask After the Demo

1. Why isn't all plastic made from milk?

   Discussion: It would not be an efficient use of resources. Milk is costly in terms of energy and labor to produce, and it only makes a small amount of plastic compared to the amount of material used during production. Crude oil (petroleum) is a much cheaper and efficient source of organic compounds.

STUDENT QUESTION HANDOUT

Making Plastic

1. What is a polymer?

2. What is happening when the milk is heated to near boiling?

3. What happens when vinegar is added to the hot milk?

4. How long does it take the plastic to dry?

5. What does the dried plastic from the mold feel like?

6. What happens when you try to break the plastic into pieces?

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TEACHER INSTRUCTIONS

Shape Memory Alloy

Objective: To learn how the motion of atoms under added heat can change the shape of metals.

Background Information: Nitinol is a nickel titanium alloy (~50% Ni, ~50% Ti) which has 2 phases, a high temperature (austenite) and a low temperature (martensite), shown in Figure 1. The low temperature phase is weaker, allowing the material to be bent and pulled out of shape. When deformed at a low temperature and then heated, nitinol will return to the shape established when in the high temperature, stronger phase. By heating the material, the atoms are given enough energy to rearrange themselves back to their high temperature phase. The composition of the wire can be varied slightly to change the transformation temperature. This ability to remember and revert to the original shape gives this material the name "shape memory".

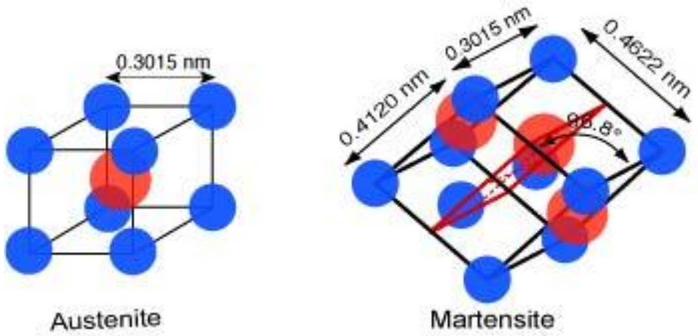

Figure 1. Nitinol's crystal structures - red circles represent Ni and blue circles represent Ti (http://en.wikipedia.org/wiki/File:Nitinol_Austenite_and_martensite.jpg)

In this demo, a nano-scale change is impacting the macro-scale. When heated, nitinol wire that has shape memory properties will return to its original shape due to changes that are happening on the nano-scale. See the Introductory Presentation for a top view of the atomic arrangements during this transition. In comparison, a piece of normal steel wire (whose composition is generally iron and carbon) will be unaffected by the addition of heat and maintain its deformed shape. Nitinol is an ordered intermetallic compound. This means that the atoms have very specific locations in the crystal structure. Nitinol is a popular choice for a variety of applications: as a material in temperature control systems, retractable antennas in cell phones, springs in orthodontic braces, and for eyeglass frames! See the Introductory Presentation for examples of real-world applications of shape memory alloys.

Demo Description: During this demo, students will see how a shape memory alloy can return to its original shape when heat is applied.

Keywords:

Phase: region of a material that is chemically uniform, physically distinct and usually mechanically separable
Phase change: a change from one phase to another (often caused by a change in temperature)
Thermal shape memory: ability of a material to remember its original, cold-forged shape and return to it when heated
Alloy: a metal containing two or more elements
Nanoscale: features smaller than 1/10 of a micrometer
Macroscale: features measurable and observable with the naked eye
Crystal structure: unique and orderly arrangement of atoms or molecules in a crystalline solid

Materials List:

Items provided in the kit
6 inches of nitinol wire
6 inches of steel wire
Glass beaker
Beaker tongs

Items to be provided by the teacher/school
Hotplate
Water

Safety Precautions: Safety glasses should be worn in case of water splashing. The beaker and hot plate can get very hot. Use the beaker tongs to handle the beaker during the demo to avoid accidental burns. After the demo, be careful not to touch the wire, water, beaker or hot plate until they have completely cooled!

Instructions:

1. Fill the beaker with water.
2. Place the beaker on the hot plate and turn to 'High'. The water should be heated to just below boiling.
3. Bend the nitinol wire to a desired shape.
4. Place the nitinol wire in the hot water.
5. The nitinol wire should immediately return to its original shape.

6. Remove the nitinol wire from the beaker using the tongs and show it to the students.
7. Repeat steps 3-6, trying different shapes and amounts of deformation.
8. Repeat steps 3-6 with the steel wire.

Demo Delivery Hints: Try coiling the wire into a tight spring and tossing it into the water. If done correctly, the nitinol wire will "jump" out of the beaker. Students can be asked to bend the wire or place it in the water for a more interactive demonstration.

Troubleshooting: Do not make sharp corners in the nitinol wire or tie it into knots. The wire is limited on how much deformation it can recover from.

Cleanup/Replacement parts: Turn off the hot plate and allow it, the beaker, and the water to cool down. Pour out the water. Do not return the supplies to the kit until they are cool to the touch.

TEACHER DISCUSSION QUESTIONS

Shape Memory Alloy

Discussion Questions to Ask Before the Demo

1. Can nano-scale changes impact the macro-scale?

   Discussion: Yes, this demo shows how the movement of atoms just a very small distance can cause the macroscale shape of the metal to change.

2. What do you expect to happen when the nitinol wire is placed in the water?

   Discussion: Encourage the students to discuss what they think. Do they think the wire will stay the same, expand, or return to its original shape?

3. What is a phase?

   Discussion: A simple definition is a region of material that is physically distinct, and has its own state (solid, liquid or gas), own arrangement of atoms (crystal structure), and composition.

Discussion Questions to Ask During the Demo

1. Once the nitinol wire is placed in the water, what do you see?

   Discussion: The nitinol wire should start straightening out. Depending on what shape you bent the wire in (such as a spring-like shape), the wire may tend to 'jump' or 'pop' out of the water.

2. Why did the nitinol wire change?

   Discussion: The atoms are rearranging themselves back to the positions for the high temperature phase.

3. Does the same thing happen with the normal steel wire?

   Discussion: The steel wire should remain in the same shape as it was bent. No change or reactions take place, therefore the wire does not return to its original shape.

Discussion Questions to Ask After the Demo

1. Why does the nitinol wire change shape, but not the steel wire?

   Discussion: The nitinol wire has two distinct, ordered phases. The high temperature phase is called austenite and the low temperature phase, martensite. During this demo, the atoms in the nitinol wire are undergoing a phase transformation between the low temperature martensite and the high temperature austenite. The steel wire remains the same, regardless of temperature, as it does not undergo any phase transitions and is not an ordered intermetallic.

2. What uses can you think of for materials that have this special behavior?

   Discussion: Nitinol is a popular choice for a variety of applications: as a material in temperature control systems, retractable antennas in cell phones, springs in orthodontic braces, and for eyeglass frames! It was even used in the Mars Rover as part of a sensor used to close delicate ports and prevent damage.

STUDENT QUESTION HANDOUT

Shape Memory Alloy

1. Define the following keywords:

   Phase:

   Phase change:

   Thermal shape memory:

   Alloy:

   Nanoscale:

   Macroscale:

   Crystal structure:

2. What is happening to the atoms as the Nitinol wire heats up?

3. What is the difference between the Nitinol wire and the steel wire?

The American Ceramic Society Materials Science Kits

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