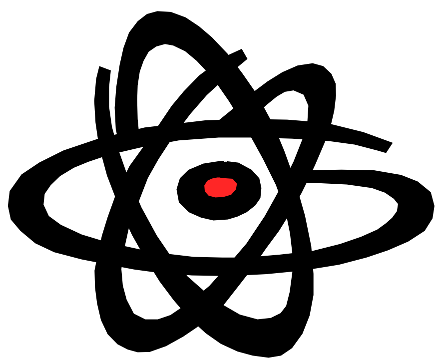
Demoworks



The fine art of materials science demonstrations

Ainissa G. Ramirez
editor

I hear and I forget. I see and I remember. I do and I understand.

- Confucius

Demonstrations make richer science experiences by powerfully delivering information. Although personally it has been over a decade since I sat in my materials science classes, I can still see clearly the first time I saw memory metal or diffraction of laser light. I can't recall exactly the words that were said, but I will always remember these powerful visual aids. It seems to me if you want to leave an indelible mark when teaching, then demonstrations are a key component to getting your message across. Giving lectures is an essential part of the academic experience. However, relying solely on lectures is risky for it hinges on the students' imagination and the teacher's ability to transmit information effectively. Illustrations and demonstrations, however, resonate uniquely with each student and, like music, transcend all communication barriers.

I believe that improving science education, improves the world by creating informed and empowered citizens. As such, expanding a student's science experience with demonstrations can be one avenue to creating such an enlighten population.

The birth of this book came from a need for a demonstrations resource for my own introduction to materials science class. For some time, materials science demonstrations have been scattered over various media from various sources. After complaining that someone ought to do something about it, I eventually realized that that someone was looking at me in the mirror. With the help of the Materials Research Society and its Strange Matter Exhibit family, I decided to follow the advice of Toni Morrison. "If there's a book you really want to read, but it hasn't been written yet, then you must write it." So, this compilation is my attempt to improve the world by creating richer science experiences with demonstrations. I do hope you and your students enjoy them.

Ainissa G. Ramirez

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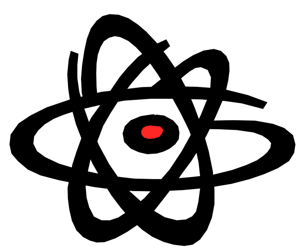
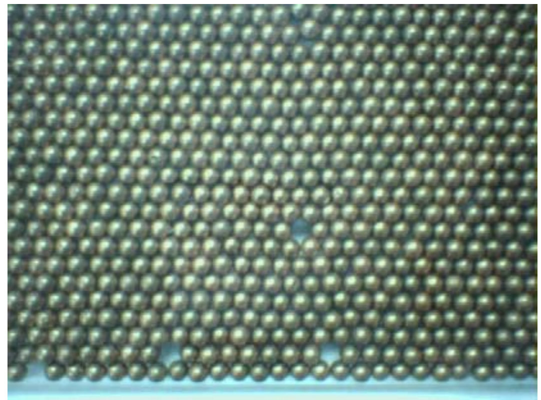
Structures



Closed-Packed Planes—A Ball Bearing Analogy

Objective: To demonstrate closed-pack planes, vacancies, grain boundaries and the effects of temperature on them.

Keywords: microstructure, defects



Materials:

- Ball bearing Overhead Projection Device [teachersource.com (#HS-12)]
- Overhead projector
- **Note:** Construction of a bubble raft can be found in *Ellis et. al. Teaching General Chemistry, American Chemical Society, 1993*

Procedure:

Place the ball bearing board on the surface of the overhead projector and note the microstructural feature such as vacancies and grain boundaries. Hold it horizontally and shake rigorously to represent to heating of a material (or annealing). Look for microstructural feature again and note the change. Shake vigorously again and watch these features disappear**.**

Explanation:

By holding the device on its side, the balls (or atoms) form a periodic array. In some regions, there will be an absent ball bearing, which represents a defect known as a **vacancy**. You will also notice regions where the periodic registry does not match the remaining areas. This separation between the two mismatched areas is a **grain boundary**. If the device is shook vigorously, this represents the heating of a metal. It can be seen that neighboring atoms will move into vacancies, which represents **vacancy diffusion**.

Reference:

C. L. McCabe et. al., Metals, Atoms and Alloys, National Science Teachers Association, 1964 p 120

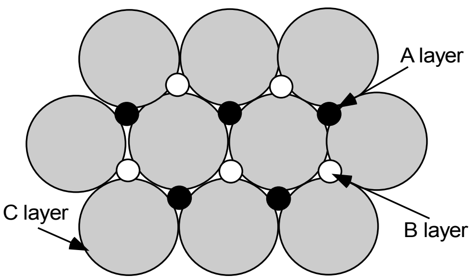
Building Crystal Models

Objective: To gain an understanding of crystal structure, atomic packing, and plane directions by modeling simple atomic arrangements

Keywords: crystal structure, atomic packing

Materials:

- Styrofoam balls (1” diameter) or gumdrops
- round toothpicks

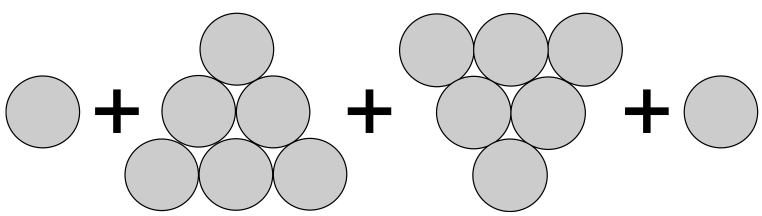


Closed-packed arrangements and the associated positions for each layer.

Procedure:
Assuming the hard sphere model, we will use Styrofoam balls as atoms and toothpicks as the bonds between them to create unit cell models for crystal structures most common in metals.

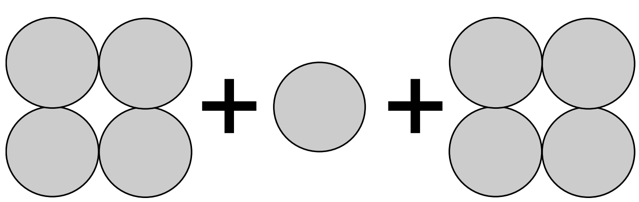
A. Face-Centered Cubic (FCC)

Attach 6 of the balls together with toothpicks to form a triangle with 3 balls at the base. Make two such triangles. These will make layers B and C. To the top and bottom of this structure add another atoms, which will both be on the A layer. Rotate this structure so that 5 atoms in a plane (or 100-plane) are facing you and you should be able to see the FCC structure with ABCABC layers.



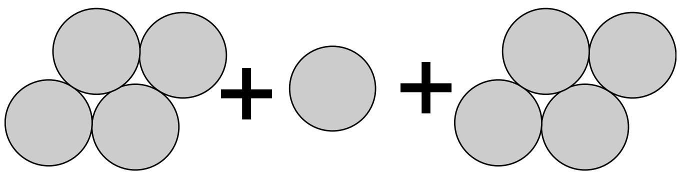
B. Body-Centered Cubic (BCC)

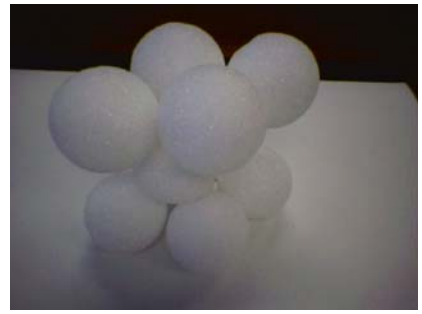
Attach 4 of the balls together with toothpicks to form a square. Make two such squares. Sandwiched between these layers will be one atom. This is not a closed packed structure.



C. Hexagonal Closed Packed (HCP)

Attach 4 of the balls together with toothpicks to form a parallelogram. Make two such arrangements. These will make two A-layers. Sandwiched between these layers will be one atom, located in the B layer position. This will form a unit cell of HCP, with ABAB layers.





D. In-class Assignment

With each structure determine

- number of atoms per unit cell
- closed-packed planes and directions
- the relationship between the atom radius, *r*, and the cube length, a.
- atomic packing factor
- 1^{st} and 2^{nd} nearest neighbors
- for HCP, determine the c/a ratio
- interstitial sites (octahedral and tetrahedral)

Summary Table

Crystal Structure	**Base-Centered Cubic (BCC)**	**Face-Centered Cubic (FCC)**	**Hexagonal Close-Packed (HCP)**
Number of atoms per unit cell	2 atoms	4 atoms	2 atoms
Coordination number (nearest neighbors or touching atoms)	8	12	12
Relationship between the cell edge length, "a" and the atomic radius, r.	$4r = \sqrt{3}a$	$4r = \sqrt{2}a$	2r=a
Percent of space in the unit cell occupied by atoms. (APF)	0.641 or 64% not closed packed	74% closed packed	74% closed packed
Close packed planes & directions	{110} <111>	{111} <110>	Basal / a
Example materials	Cr, Mo, Ta, W, V	Al, Au, Ag, Cu, Ni	Co, Zn

Diffraction (Scattering Light)

Objective: To observe an optical analog to x-ray diffraction.

Keywords: crystal structure, diffraction

Materials:

- laser pointer
- I.C.E. optical transform slides (available at ice.chem.wisc.edu)
- **or** overhead transparency of the slide patterns (see next page)
- overhead projector and screen
- **Variation:** an ordinary plastic ruler with fine black markings spaced at millimeter or one-sixteenth inch intervals will also work.

Procedure:

Mount the slide. In a darken room, shine the laser light through the slide so that it projected diffraction pattern is displayed on the screen. Different crystal structures (on the slide) will give different Fraunhofer diffraction patterns.

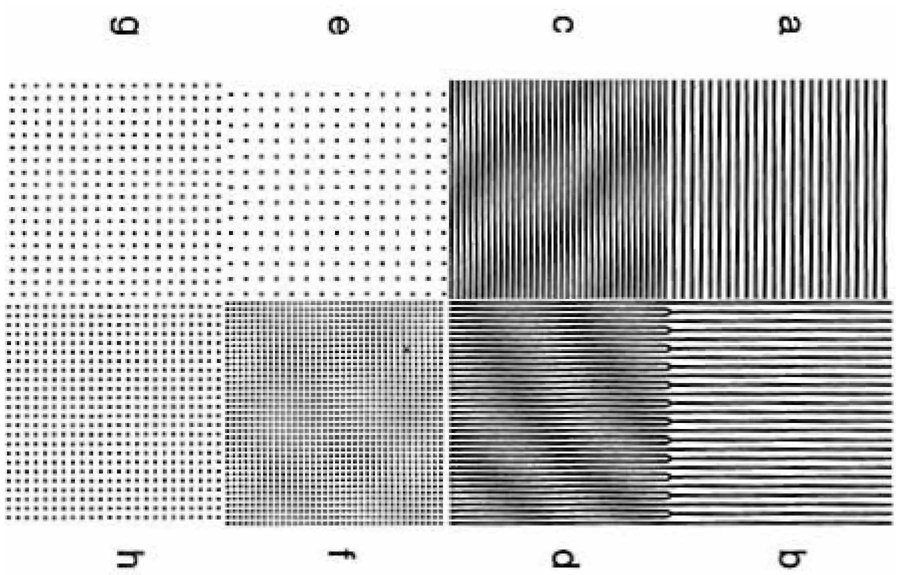
Explanation:

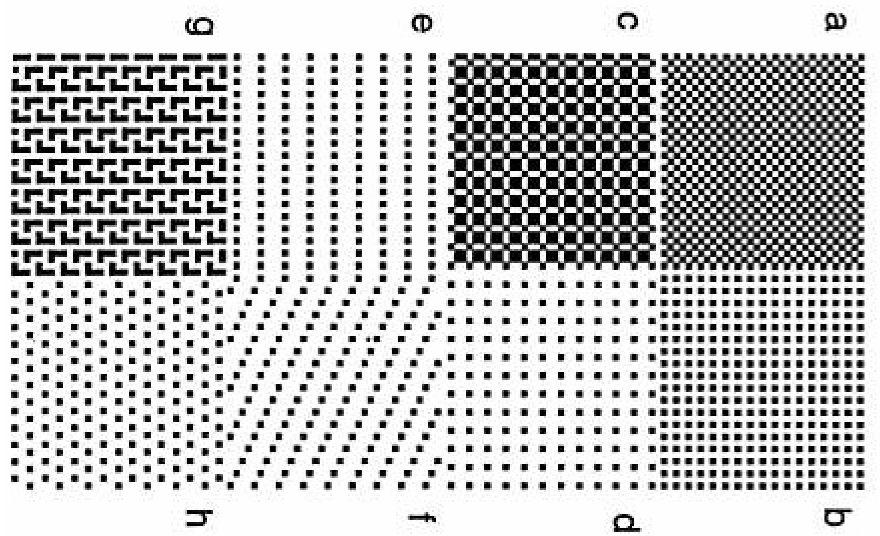
The diffraction pattern observed when x-rays interact with crystals has an analog in optics: the Fraunhofer diffraction pattern seen when a laser beam is diffracted by a regular pattern embossed on a slide.

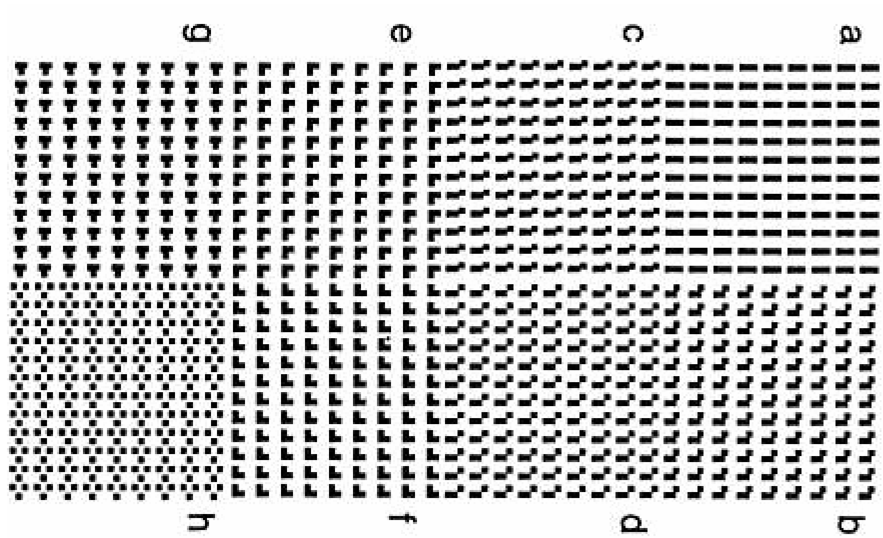
Hazard:
Be very careful not to look into the laser light.

Reference:

- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 85*







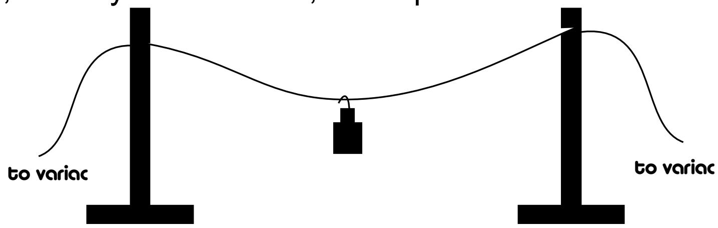
Pattern on the optical transform slides available from ICE. Used with permission (do not distribute).

Phase Changes in Iron

Objective: To demonstrate the allotropic changes in iron that occur during heating.

Keywords: crystalline phase change, iron crystal structure, allotropes

Materials:



Iron has three forms (or allotropes). When heated it changes from BCC to FCC to BCC. FCC is closed packed and has a lower specific volume than BCC. So with heating, the wire lengthens, gets taut and lengthens again.

- Music or Piano wire Gauge 12 (0.029" dia.) (McMaster Inc. (www.mcmaster.com)
- Lab clamps or Wood block with nail
- Variac and leads to attach to wire
- A card with inches on it to monitor sag
- **Optional:** A large strong magnet attached to a wooden ruler

Procedure:
A length of uncoated music or piano wire is suspended horizontally between two supports. Each end of the wire is connected to one of the leads of a Variac. Slowly, the voltage is turned up to heat up the wire. Once the wire glows red hot, it will start to sag. With continued heating, the sagging wire will rise up a little bit, halt momentarily and drop back down again, which indicates a change in phase. This effect is seen more dramatically with cooling. By quickly shutting off the current, the wire will rapidly change: It will dip, get taut and dip again. A background card or meter stick will assist in visualizing the height changes. A small weight suspended from the middle of the wire by a paper clip also aids visibility.

Variation 1: (Curie Temperature) The magnetism in the wire changes with heating. Attach a magnetic to a ruler. At room temperatures, the wire is attracted to the magnet. At high temperatures it is not.

Explanation:
Iron has several allotropes or crystal forms. At low temperatures, the BCC phase (ferrite) is present, with heating the FCC phase (austenite) occurs. With further heating, the BCC phase of δ exists. These phases have different densities and a volumetric change accompanies the phase change, which is seen by the wire's change in length with heating.

Hazard:
Touching the hot wire can be lethal!!

Reference:

- *R.M. Sutton, Demonstration Experiments in Physics, (McGraw-Hill, NY, 1938) p 197.*
- *Jearl Walker, Scientific American Magazine, The Amateur Scientist, May 1984, p. 148*

Shape Memory Metals (Metals that Recollect)

Objective: To observe a crystal phase change in NiTi demonstrated by its change in shape

Keywords: austenite, martensite, crystalline phase change

Materials:

- NiTi shape memory wire (Educational Innovations teachersource.com)
- Steel wire (McMaster Inc. (www.mcmaster.com))
- Boiling water in a beaker
- Overhead projector
- **Optional:** Crystal models of cubic and monoclinic

Procedure:

Show the initial shape of the wires by placing them on a overhead projector. Give the two pieces of wire to volunteers to bend. Confirm with the shapes again by placing them on the projector. Place both wires into the hot water. The NiTi will unravel; the steel wire will not.

Variation: Place hot water in a petri dish on the overhead projector and submerge the wires for a large audience to view.

Explanation:

NiTi experiences a low-temperature solid-state phase change. In it, the crystal form of one arrangement of atoms to another. At room temperature, the low temperature phase (or martensite) is present. When the wire it bent, atoms shear passed each other. When, the wire is placed in hot water, the atoms undergo a phase change and go back to their original positions in the high temperature phase (or austenite).

Steels do not experience transformations at these temperatures.

Hazard:
Touching hot water can be harmful.

Amorphous Metal (Follow the Bouncing Ball Bearings)

Objective: To observe the impact of atomic periodic arrangements on mechanical properties.

Keywords: crystal structure, amorphous materials

Materials:

- Amorphous metal kit (http://ice.chem.wisc.edu/)
    - a stainless steel base
    - a stainless steel base with a 1/8 inch thick disk of Liquidmetal ($Zr_{41.2}Be_{22.5}Ti_{13.8}Cu_{12.5}Ni_{10.0}$) glued to it
    - two clear plastic tubes which slide over the top of the bases
    - two hardened steel ball bearings

Procedure:

Drop one ball bearing down the center of the tube with the stainless steel base and count how many times it bounces. Then, take the same ball and repeat the experiment using the base with the amorphous metal. Again, count how many times the ball bearing bounces. The ball bearing bounces on the amorphous metal should bounce many many more times.

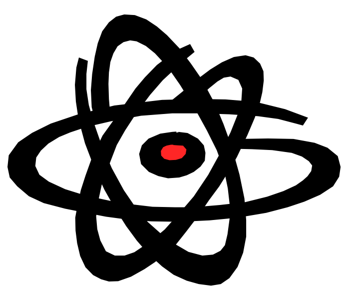
Explanation:

A crystalline material has slip planes that are activated when impacted by the steel ball. Within the amorphous material, atoms are randomly oriented, so slip planes don't exist. Therefore, when the metal ball hits the amorphous metals surface, the kinetic energy cannot be transferred. So, the ball bearing continues to bounce until this energy dissipates.

Reference:

www.liquidmetaltechnologies.com

Mechanical Properties



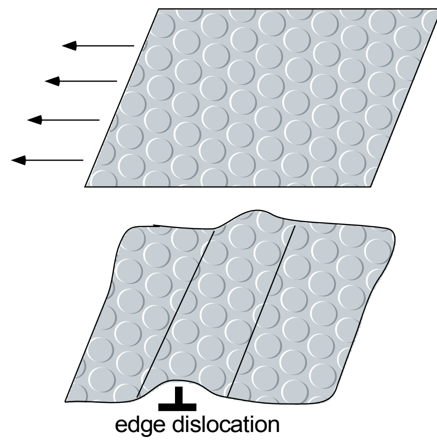
Edge Dislocations—A Carpet Analogy

Objective: To display the motion of dislocations with a household article.

Keywords: dislocations, plastic deformation

Materials:

- A small rug



Procedure:

Place a small rug on a table or floor and create a wrinkle (or ruck) in it. Move this wrinkle across the floor. This represents the movement of edge dislocations across a shear plane.

Optional: Have two wrinkles at different angles meet. Their movement is impeded (this represents work hardening)

Optional: Have an object sit on the carpet as you pass a wrinkle across. This represents the pinning effect of precipitates.

Explanation:

The movement of dislocations is key to plastic deformation. The wrinkle represents an edge dislocation—an incremental breaking and making of bonds across a shear plane. The passage of the wrinkle allows the run to move an incremental distance. Moving a small part of the rug require less energy than moving the entire rug in one pull. This illustrates the power of dislocations to make change is smaller increments.

Optional: The two wrinkles that impede each other represent work hardening—where dislocations interact and slow down each others movement. When dislocation movement is slowed, the materials are stronger.

Reference:

- *Barrett, Nix, Tetelman; The principles of Engineering Materials, Prentice-Hall, 1973, p 228*
- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 168*

Bending Paper Clips (Metallic Contortionists)

Objective: To show the number of dislocations drastically changes mechanical properties.

Keywords: work hardening, dislocations, heat treatments

Materials:

- paper clips
- paper clips annealed to 500ºC in a furnace

Procedure:

Take a sample of paper clip and an annealed paper clip. Bend the regular paperclip, and then bend a paper clip that has been annealed. The annealed paper should be softer and easier to bend.

Explanation:

These thin wires are formed by extrusion. As such, they are work-hardened and full of dislocations. Dislocations interact with each other and impede each other from moving, thus hardening the material. With heating, the dislocations are annealed out and the material becomes softer.

Crying Tin (Hearing Atoms Move)

Objective: To observe the impact of shear stress in the propagation of twins in metals

Keywords: twinning, mechanical deformation

Materials:

- Zinc, Tin or Indium Rods (www.sigmaaldrich.com)
- A microphone

Procedure:

Place a rod next to your ear and bend it. A snapping or cracking sound may be heard. For a large lecture room, place the rod next to a microphone and bend it.

Explanation:

The twinning process is a result of a coordinated movement of atoms. Under a load, a mechanical twin may form. When the bar is bent, atoms slip (or shear) passed each other. The breaking of bonds in some metals creates loud ticking noise, which is also known as "tin cry."

Mechanical twins occur usually in HCP or BCC crystals, but may occur in some FCC crystals. [Zinc is HCP; Tin is BCT; and Indium is Tetragonal].

Reference:

- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 166*
- *G. E. Dieter. Mechanical Metallurgy, 3rd edition, McGraw-Hill, NY,1986 p133*

Bending Coat Hangers (Work hardening)

Objective: To illustrate how metals get harder as work harden them (or bend them).

Keywords: work hardening

Equipment:

- A wire coat hanger
- **Optional:** propane torch

Procedure:

Give a wire coat hanger to a student and ask them to bend the bar. They should be able to bend the bar with some ease. Pass the rod to another student and ask them to try and straighten it. They will find this very difficult to do because of the work hardening effect. The bar becomes harder with bending. (Mention that this is the effect that the strong man in the circus employs.)

Optional: Reheating the wire hanger, straightening it back out, then reheating again and repeat the bending experiment.

Explanation:

The mechanical properties of a metal are directly related to the atomic structure. A metal that has been heated to high temperatures will remain soft, since the atomic structure is uniform and has fewer defects. When the metal is bent, defects or dislocations are formed. Their interactions with each other impede the flow of atoms and thus harden the metal.

Creep in Solder (The Waiting Game)

Objective: To demonstrate that small loads can deform certain metals (by creep)

Keywords: creep, plastic deformation

Materials:

- commercial solder wire (no flux or resin) about 1/8 inch in diameter
- A weight (10 to 15 pounds)
- A ruler
- a support for the solder (a large A-frame ladder works fine)
- A timer or watch

Procedure:

Mount a ruler where the solder will hang. Cut about one foot of the solder and attach it to the support and weight assembly. As soon as the solder assembly is mounted, start the clock. Record the length and time at 3 hour intervals for the first 12 hours. Afterwards, measure every 8 to 12 hours until fracture. Graph a creep diagram of extension versus time.

Variation: Repeat the same experiment heating the solder with a heat gun. Monitor the time and extension as before. Fracture will occur much more rapidly and underscore the impact of temperature on creep behavior.

Explanation:

Creep is characterized as plastic deformation that occurs with small loads over long periods of time. This behavior is more prevalent the closer these conditions are to a materials melting point. Solder's low melting point renders atomic flow able to occur quite readily at room temperature. As such, we are able to see the lengthening of solder under ambient conditions. This process is sped up by high temperatures induced by the heat gun.

Reference:

C. L. McCabe et. al., Metals, Atoms and Alloys, National Science Teachers Association, 1964 p 111

Composites (Teamwork in Materials)

Objective: To observe the combined efforts of components to generate materials with new properties.

Keywords: composite, mechanical properties

Materials:

- Two 8x10 trays (photography darkroom equipment)
- Newspaper
- A hammer

Procedure:

Fill one tray with water and freeze it. Fill the second tray about a third of the way and freeze it. After ice has formed, add a sheet of newspaper and fill it with water again another third of the way. After this layer has been frozen, add another ice and newspaper layer until an ice-newspaper composite is formed. In class, ask a student to hit a sheet of newspaper with a hammer and note its resistance. Hit the ice block from the first tray with a hammer and note its resistance to fracture. Lastly, hit the newspaper-ice composite with a hammer and compare how difficult it is to break it.

Explanation:

Both the newspaper and ice have different properties. The ice can hold some weight, but fractures easily; the newspaper can sustain some tension, but cannot support any weight and eventually tears. Together these materials create a more robust structure that is tough and able to withstand impact.

Hazard:
Eye protection for shattering ice

Paper Clip Fatigue

Objective: To explore the impact of cyclic fatigue and determine the number of cycles-to-failure in metals.

Keywords: mechanical properties, fatigue , S-N curves

Materials:

- A box of Jumbo Smooth Paperclips

Procedure:

Bend a paperclip repeatedly to 45º and record the number of cycles until failure. A cycle starts at the bending angle and finishes at 0º. Repeat this experiment to bending angles of 90 and 180º. Caution must be taken to assure that the rate at which the paper clips are cycled remains the same across the experiment. Using a spreadsheet program, plot the number of cycles versus the angle. The angle represents the stress amplitude.

Explanation:

Failure due to repeated loading is known as fatigue. Fatigue can occur at stress levels considerably lower than the tensile or yield strength for a static load. The cyclic loading causes a crack to initiate. With continuous cyclic loading, the crack grows, and eventually the material fails. The fatigue life curve (or S-N curve) can be graphed by plotting the stress amplitude versus the number of cycles the material undergoes before failure.

Stress in Balloon Inflation

Objective: To explore the stress and strain behavior of elastomers. (To explore why the difficulty in inflating balloons changes as they gets bigger)

Keywords: mechanical properties, elastomers

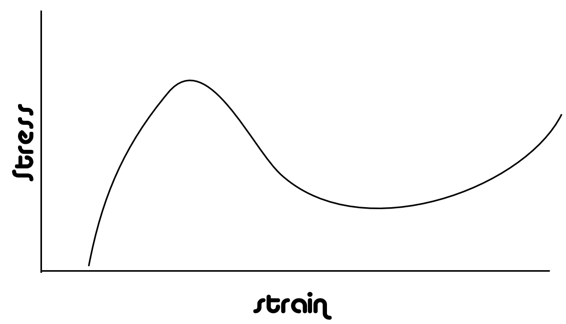
Materials:

- a balloon

Procedure:

Blow up a balloon and notice that it is difficult at first and at some point it gets easier once the balloon is partially filled.

Explanation:



Balloons are made up of rubber, which is an elastomer. The applied pressure from inflation causes the balloon to be in tension in two directions (biaxial tension). Initially, the balloon is difficult to blow up. Here, the elastomer behaves **elastically**, where bonds are stretched. With continued inflation, it is easier to blow up the balloon and the elastomer behaves plastically.

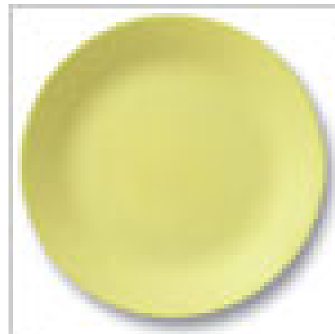
In elastomers, the polymer chains are highly kinked and twisted. With tension, they simply uncoil and align. Here, only stretching of the polymeric chains takes place. Upon release of the stress, chains spring back into their original shape. With continued stretching, chains slide past each other and the materials begins to plastically deform.

Reference:

- *Jearl Walker, Scientific American Magazine, The Amateur Scientist, Dec 1989, p. 136*

Strengthen Ceramic Dishes (Ceramic Composites)

Objective: To show that properties of a whole (composite) are stronger than the parts



Keywords: tension, compression, composite

Materials:

- Corelle Dish

Procedure:

Hold up the Corelle dish and smack it against a table. Be sure the table doesn't have sharp points or particles on it (which may cause it to fracture). Place a nick in the plate and smash it again. This time the plate should break into many pieces.

Explanation:

Ceramics are strong in compression. This dish is made with an outside coating that is in compression, which is stronger than that applied tension from impact. Think of this material as a laminate of tensile and compressive layers. When you apply a nick, you relieve some of the stress in the compressive layer. The compressive stress is no longer greater than the applied stress and the plate fails by cracking.

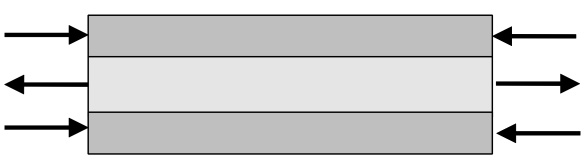


Figure. This plate is a composite material made of layers under different degrees of stress. The outer layers are in compression; the inner layer in tension.

Necking in Polymers

Objective: To observe the mechanical properties of polymers

Keywords: mechanical properties, necking

Materials:

- Parafilm (1x4") (sargentwelch.com #WLS65710-A)
- A sheet of newspaper or any page with text.

Procedure:
Pickup a length of Parafilm and set it over a page of text. Pull the ends of this length. As you pull, you'll notice a narrowing perpendicular to the pulling direction (or necking). Continue to pull the plastic and let the neck progress a bit further.

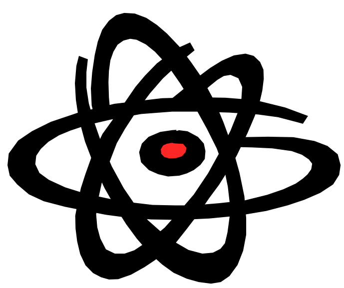
Hold this stretched length of plastic about a half an inch over the text. Notice that the text under the necked region seems blurry, while the region under the necked region is clear. This is a very subtle effect, with some interesting science behind it.

Explanation:
A polymer is made up of long molecule chains that are randomly oriented. When you pull on the plastic, the polymer chains align. The aligned molecules increase the scattering of light, which causes the cloudiness.

Reference:

- *Jearl Walker, Scientific American Magazine, The Amateur Scientist, Feb 1990, p. 100*

Kinetics



Diffusion (Watching Atoms Move)

Objective: To observe the motion of atoms

Keywords: diffusion, atomic motion

Materials:

- A Petri dish
- Overhead projector
- Food coloring dye
- **Optional:** perfume bottle

Procedure:

Place water in a Petri dish and set it on the overhead projector. Inject a small drop of coloring into the water and observe the dye spreading with time until it is uniform across the entire Petri dish.

Optional: Open a perfume bottle and ask students in different parts of the room when they smell its scent.

Explanation:

Atoms are in constant motion and collide with other atoms and surfaces as they migrate over a period of time. They move from regions of high concentration to lower ones. As such, the dye moves away from its concentrated region to regions where the dye is absent. With time, all regions of the Petri dish have the same concentration.

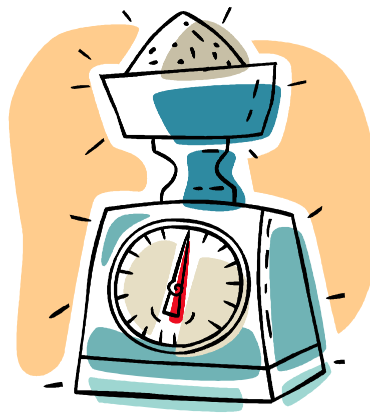
Reference:

- *M. F. Ashby and D. R. H. Jones, Engineering Materials, Pergamon Press, 1980, p267*

Metal Oxidation (Weight Gain in Metals)

Objective: To observe the effects of oxidation in metals.

Keywords: kinetics, oxidation



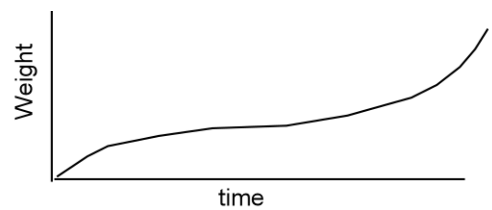
Materials:

- A piece of stainless steel 0.1x 5 x 5 mm
- A piece of mild steel 0.1x 5 x 5 mm
- Bunsen burner
- A scale with milligram resolution

Procedure:

Clean and degrease the pieces of metal. Weigh them both and record. Heat them for approximately one minute in air (until bright red). Cool them and record the weight. The mild steel will gain weight (~0.05 grams). The stainless steel will not significantly increase in weight.

Variation: The steel can be reheated and weighed several times. A plot of the weight change as a function of time will have a significant change initially, plateau, and then increase again after a long time (see Figure).



Explanation:

The metal in the flame reacts with the air. The iron and oxygen combine creating an iron oxide. This layer grows and the weight increases in proportion to the amount of material that has been oxidized. Oxidation is initially rapid then slows down due to a protective layer. However, after a long time, the metal oxidizes rapidly again.

Hazard:
Touching the hot steel can be harmful.

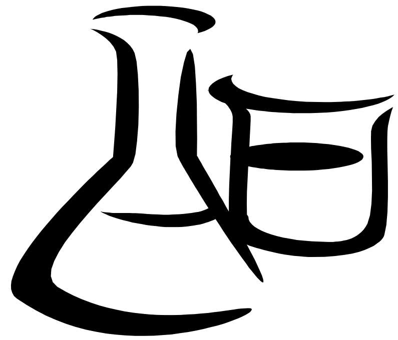
Reference:

- *M. F. Ashby and D. R. H. Jones, Engineering Materials, Pergamon Press, 1980, p194 & 286*

Sugar Crystal Nucleation (A Sweet Reaction)

Objective: To demonstrate the nucleation tendencies of crystals from supersaturated solutions.

Keywords: crystallization, nucleation



Materials:

- Small bowl
- 250 ml beaker
- 1 cup water
- ½ cup of sugar
- Pencil with string attached to it

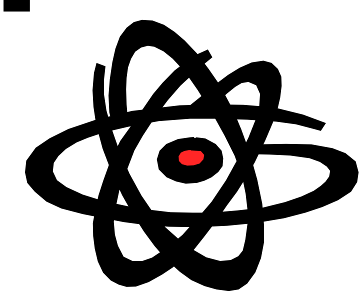
Procedure:

Heat the water on a stove or microwave and add the sugar to the hot water. Stir until all the sugar is dissolved. Pour the contents into a beaker and set the pencil onto it with the string suspended in the liquid. The string should reach about half-way into the beaker. Cover the beaker with plastic wrap or aluminum foil. After a week, sugar crystals should form on the string.

Explanation:

When the sugar and water mixture cools, the water contains more sugar than it is able to hold. As such, the mixture precipitates out the excess sugar. It is easier for the solution to precipitate the excess sugar on a surface (heterogeneous nucleation), rather than in the middle of the liquid (homogeneous nucleation). This is why sugar crystals exist along the string and bottom of the cup. **Aside:** This phenomenon can be paralleled to the seeding of clouds. It is easier for water-saturated clouds to rain when dusted.

Electrical Properties



Electron Motion and Heat (Resistivity in Metals Changes with Temperature)

Objective: To observe a change in resistivity in a metal at various temperatures.

Keywords: resistivity, temperature dependence

Materials:

- Two choke coils or inductors
  (mouser.com # 43LJ415—150mhenry RF choke)
- Liquid Nitrogen
- Multimeter
- Shallow Styrofoam container
- Cutting tool
- **Optional:** A light bulb, battery

Procedure:

Remove the casing off the inductor with a cutting tool. Connect the two ends of the wire to the multimeter and measure the resistance. Submerge the coil into liquid nitrogen and measure the resistance again. The resistance should reduce with lower temperature.

Optional: Place the light bulb copper coil and battery in a ciruit and note the brightness of the bulb. Submerge the copper coil in liquid nitrogen and notice that the bulb gets brighter.

Explanation:

In metals the atoms are bound together by a sea of electrons that are free to move about. When a material is heated, electrons move more and collide with each other more frequently. In addition, atoms vibrate around their equilibrium position more frequently (and cause elastic waves or phonons) and impede the motion of electrons. At lower temperature, less scattering takes place since electrons and atoms vibrate less and the resistivity is lower.

Hazard:
Liquid nitrogen is extremely cold. Do not allow it to touch your skin. It will burn initially and cause frostbite. Wear gloves when handling it.

Reference:

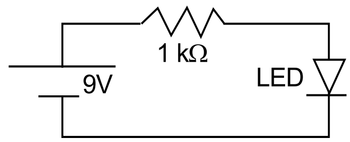
- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 199, 492*

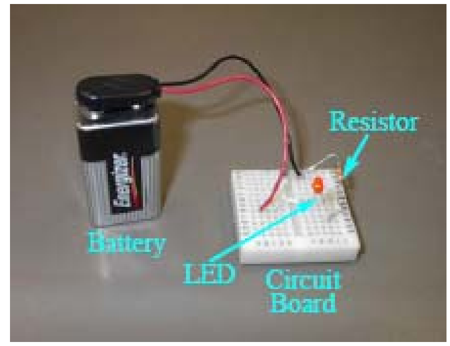
Color Change in LEDs

Objective: To illustrate that effect of temperature on band gaps of semiconductors

Keywords: band gap, optical properties

Equipment:





- Red LEDs (Radio Shack)
- Liquid nitrogen
- a Styrofoam cup
- A circuit contain a 9 Volt battery &1 kΩ resistor

Procedure:
Attach the lead of the LED to the battery and resistor. The LED will be red at room temperature. Submerge the LED in the liquid nitrogen-filled Styrofoam cup. The LED will get brighter and change color to a bright orange or yellow.

Explanation:

The color of light that is emitted for LEDs is roughly the bad gap of the semiconductor material. When p-type and n-type semiconductors are joined together in the LED, the Fermi levels become equalized. When a field is applied, the electrons of the conduction band from the n-side migrate to the p-side and drop to the valance band. A photon is emitted in this process. The band gap of a LED varies with temperature because the crystalline lattice of the semiconductor contracts at low temperatures. This causes the atom to become closer together and the increased atom-atom overlap widens the band gap. A shift in the emission peak of the LED to higher values of Eg (lower wavelength) can then be measured at low temperature such as liquid nitrogen temperatures.

Hazard:
Liquid nitrogen is extremely cold. Do not allow it to touch your skin. It will burn initially and cause frostbite. Wear gloves when handling it.

Reference:

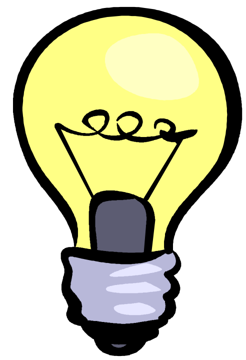
- *M. A. White, Properties of Materials, Oxford University Press, p. 41*
- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 223*

Photoconductivity (Shedding light on semiconductors)

Objective: To observe the effects of light on the electrical properties of semiconductors

Keywords: band gap, photoconductivity, carriers, energy bands

Materials:



- Cadmium Sulfide Photoresistor (Radio Shack # 276-1657)
- An Ohmmeter
- Light source (sunlight, TV, candle, flashlight)
- **Variation:** Build or use an audible conductivity test

Procedure:

Connect the leads of the photocell to the ohmmeter (or conductivity tester) and measure the resistance. Apply illumination to the photocell and measure the resistance again. The resistivity should decrease when the photocell is illuminated. The light source induces electrons to move across the energy band gap and increase the conductivity by introducing more carriers of charge.

Explanation:

Photoresistors (or photocells) consist of semiconductor materials that have resistances proportional to illumination. Incident light is absorbed by the semiconductor which produces a change in the number of carriers, and thus, the resistance.

Reference:

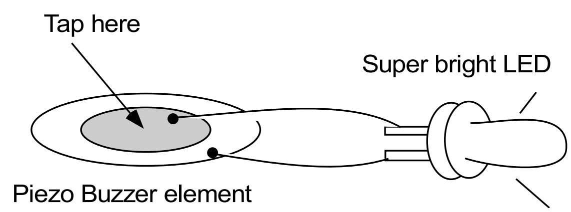
- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 214*
- Forest M. Mims III *Engineer's Mini Notebook (Sensor Projects) Radio Shack (Cat No. 62-5026) p 35*

Piezoelectric Effect (Crystals with a kick)

Objective: To observe the interrelationship between pressure and charge in a special class of ceramics (the piezoelectric effect)

Keywords: piezoelectric effect, electrical polarization by mechanical stress

Materials:



- Piezo buzzer element (Radio Shack)
- Super bright LEDs
- **Optional materials :** Flash rocks (Edmund Scientific scientificsonline.com # 3037474); piezoelectric lighter (Aldrich or Flinn Scientific); Rochelle Salt Crystal (Sodium Potassium Tartrate), empty Scripto cigarette lighter

Procedure:

Connect the LED and piezoelectric element. Tap the piezoelectric element with a pencil and watch the LED. Each tap will cause the LED to flash.

Variation: Strike piezoelectric materials and watch the sparks fly from the generation of electricity.

Explanation:

Piezoelectricity is the formation of an electrical charge by mechanical stress. In certain crystals and ceramics, a voltage is generated when they are bent. These materials are built of ions that are symmetrically position and leave the material as neutral. When the symmetry is broken by compression, a net dipole moment is created which causes a movement of charge, or current.

Hazard:
Eye protection for sparks

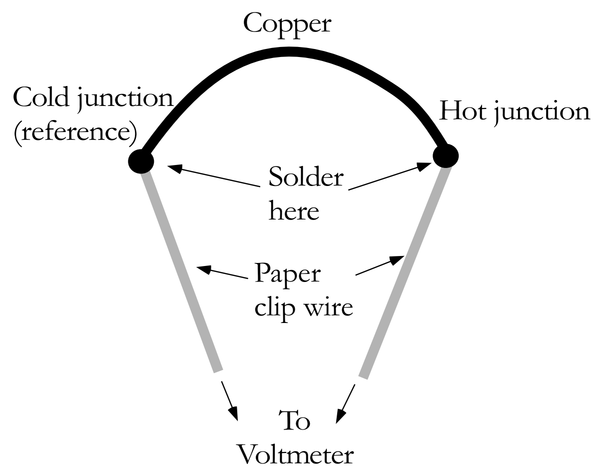
Reference:

- Forest M. Mims III *Engineer's Mini Notebook (Sensor Projects) Radio Shack (Cat No. 62-5026) p 15*
- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 44*
- *scitoys.com*

Build a Thermocouple (Downwardly-mobile electrons)

Objective: To observe the direct conversion of a temperature difference to an electric voltage in metals—the Seeback effect.

Keywords: Seebeck effect, thermocouple, thermoelectric power, diffusion



Materials:

- copper wire
- paper clip wire
- solder / soldering gun
- a match
- digital Multimeter (able to read millivolts (0.001 Volt))
- **Optional:** Omega.com sells thermocouples

Procedure:

Between two pieces of paper clip wire solder a piece of copper wire at two joints. Heat one solder joint with a match and keep the other one at room temperature. Note the reading on the multimeter.

Explanation:
When ends of a metal bar are at different temperatures, electrons at the hotter end have more kinetic energy than those on the colder end. As such, the electrons travel from the hot end to the cold end. As electrons accumulate on one end of the bar, a Seebeck voltage is produced to drive away addition electrons from the hot end to the cold end. Each material generates different Seebeck voltages within the same thermal gradient, so this voltage can be measured when dissimilar metals are bonded together. This is the principle mechanism behind a thermocouple, which is use to determine temperature.

Reference:

- Forest M. Mims III *Engineer's Mini Notebook (Science Projects) Radio Shack (Cat No. 62-5018) p 14*
- *Barrett, Nix, Tetelman; The principles of Engineering Materials, Prentice-Hall, 1973, p 451*

Thermistors (Materials that take the heat)

Objective: To observe how heat affects the electrical properties of semiconductors

Keywords: band gap, photoconductivity, carriers, energy bands

Materials:

- Thermistor (Omega.com # 44004 or #AD590; Radio Shack # 271-110A)
- A Multimeter
- thermometer
- hot water on a hot plate
- Cold bath (ice in water)

Procedure:

Connect the leads of the thermistor to the multimeter and measure the resistance. Put the thermistor in hot water, measure the temperature, and measure the resistance in the hot water. The resistivity should fall when the thermistor is heated. Submerge the thermistor in cold water and see the response.

Variation: In another beaker of water, insert the thermistor and thermometer. Record the resistance at 5ºC intervals to 70ºC, while stirring gently. Plot ln [1/R] vs. temperature.

Explanation:

Thermistors are temperature sensitive resistors that have resistances proportional to temperature. The word thermistor is derived from THERMally sensitive resistor. Thermistors are generally composed of semiconductor materials. The characteristics that make thermistors most useful are their sensitivity, small size, and ease use in use in electronic circuitry. They are ideal for measuring small changes in temperature.

Hazard:
Be very careful with the heated surfaces.

Reference:

- *Forest M. Mims III Engineer's Mini Notebook (Science Projects) Radio Shack (Cat No. 62-5018) p 32*

Superconductivity (Materials out in the cold)

Objective: To illustrate the principles of superconductivity and the Meissner effect

Keywords: superconductivity, electrical properties

Equipment:

- Superconductivity kit (Edmund Scientific, #3053602), which consists of:
  - Superconducting pellet
  - nonmagnetic tweezers
  - rare-earth (FeNdB)magnet
- Liquid nitrogen
- a Petri dish or the bottom ¼ of a Styrofoam cup

Procedure:

Place the superconductor pellet in a Petri dish or Styrofoam cup. Cool the pellet by pouring liquid nitrogen onto it. Mark a side of the FeNdB magnet with a marker or white out. Place a small magnet over the top of the superconductor with the tweezers and watch it levitate. Spin the levitated magnet with the tweezers.

Explanation:

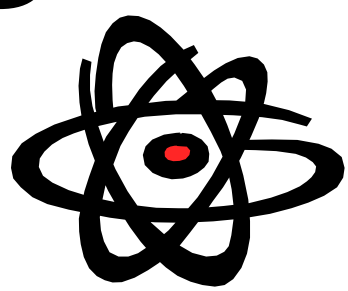
A superconductive material carries an electrical current with no loss of electricity due to resistance. Superconductive materials also repel magnetic fields. This is termed the Meissner effect.

Hazard:
Liquid nitrogen is extremely cold. Do not allow it to touch your skin. It will burn initially and cause frostbite. Wear gloves when handling it.

Reference:

- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 308*

Magnetism



Electromagnets (Temporary Attractions)

Objective: To observe the interrelationship between electricity and magnetism .

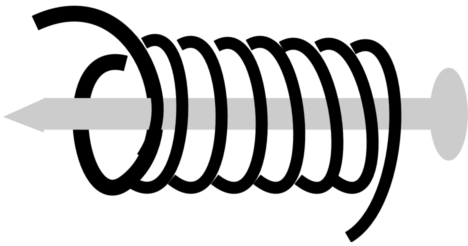
Keywords: electromagnetism, current, domains, magnetism.

Materials:

- A 3-foot length of 24 gauge enameled wire
- a 3 inch nail
- paper clips
- 1 "D" or "C" size battery
- electrical tape (masking tape works fine too)
- 1-inch square of sand paper or wire strippers
- **Optional:** a compass

Procedure:

Strip off about an inch of the wire coating at the ends with the sandpaper or strippers. Coil the wire around the nail leaving about 2 inches of length at the ends. Tape each of the one wire end to one of the battery ends Hover this nail part of the assembly over paper clips and see them elevate to it.



Optional: Remove one end of the wire from the battery and watch the paper clips fall back down.

Optional: Place the compass near the nail and watch the compass needle change position.

Explanation:
Magnetic fields originate from the movement of electrons. When electric current (or electrons) passed through a wire, a magnetic field is created around the wire. Looping the wire many times increases this magnetic field and is called a solenoid. Magnetism is operation within the nail too. The nail has some iron, which is a ferromagnetic material. Electrons are spinning around iron atoms in up and down directions. An equal number of up and down electrons will cancel each other out. But, iron has an unpaired number of electrons and thus has magnetic properties. The iron atoms in the nail line up to amplify this magnetic effect, in regions called domains.

Hazard:

The wire gets hot if the electromagnet is connected to the battery for a few minutes.

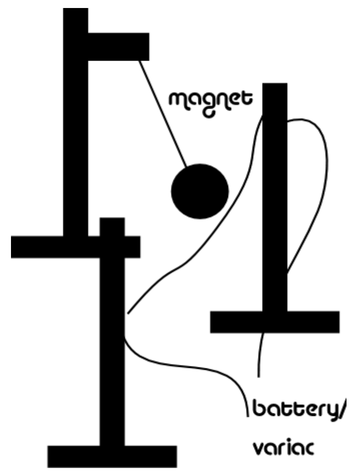
Curie Temperature (Attractions decrease with heat)

Objective: To demonstrate the change in magnetic properties with temperature.

Keywords: Curie temperature, iron, ferromagnetism, exchange energy

Materials:

- Steel wire 28-Gauge (McMaster Inc. (mcmaster.com)
- ring stand and lab clamps
- Wood block with nails
- Variac and leads to attach to wire
- A small magnet attached to a string



Procedure:
Suspend the iron wire between two supports and connect the ends to a Variac. Suspend the magnetic from the ring stand above the wire so that the magnet pulls toward the wire assembly but does not touch. Turn on the power supply and slowly increase the voltage. (The voltage should not surpass 5 V). The Curie temperature occurs when the wire turns orange. At this point the magnet will fall away from the wire assembly. With cooling the magnet is attracted again. This experiment can be repeated several times.

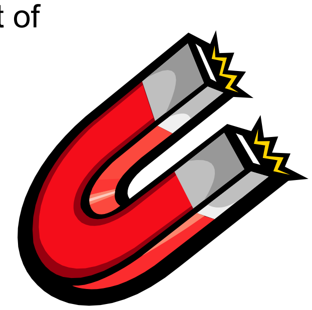
Explanation:
Iron is a ferromagnetic material with parallel magnetic dipoles is alignment. As the temperature increases, the alignment is randomized. With further heating, there are enough thermal fluctuations to overcome the effects of exchange energy between dipoles. Above the Curie temperature, a material behaves paramagnetically, where dipoles are in partial alignment with an external magnetic field.

Hazard:
Touching the hot wire can be lethal!!

Reference:

- *Meiners (editor), Physics demonstration experiments, The Ronald Press, 1970 p 908*
- *Barrett, Nix, Tetelman; The principles of Engineering Materials, Prentice-Hall, 1973, 470*
- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 32*

Ferrofluids (Making fluids stand with magnets)



Objective: To explore magnetorheological fluids and observe the effect of magnetic fields on them.

Keywords: magnetism

Materials:

- iron fillings (found in machine shops or toy stores or sciplus.com)
- corn oil
- A very strong magnet
- Glassware: Petri dish, a plastic cup, small 100-beaker, test tube
- **Optional:** a mineral-oil based ferrofluid with 400Gauss saturation magnetization (teachersource.com FF-200)

Procedure:
Mix the corn oil and iron fillings in a plastic cup, Make a mixture that allows the fillings to be suspended (with a consistency as thick as maple syrup). (The exact amount is not critical) Apply a magnet to the side of the beaker and notice that the fluid acts like a solid. Drag the magnetic along the side walls to demonstrate the fluid is controlled by the magnet. Pour some of the mixture into a Petri dish and place a strong magnet underneath and notice the spikes that appear. (If they don't appear, use a stronger magnet).

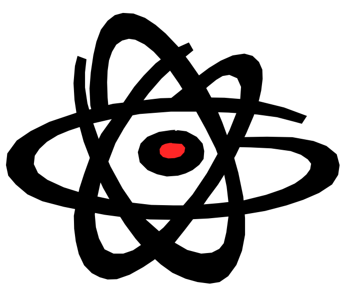
Explanation:
When the iron filing suspension is exposed to a magnetic field, the particles align in such a way that the mixture acts like a solid. When the magnet is removed the filings return to a random state and become liquid again. The resulting effect depends on the viscosity of the liquid and the strength of the applied field. Possible applications include: liquid o-rings (bearings) or car brakes.

Hazard:
Ferrofluids cause terrible stains!!

Reference:

- *Daniel J. Klingenberg, The Amateur Scientist, Scientific American, October, 1993 p112*
- *Ellis, et. al, Teaching General Chemistry, American Chemical Society, 1993, p 37*

Optical Properties



Polarizing Sugar (How sweet it is)

Objective: To demonstrate birefringence, dispersion, and polarization effects of a transparent material.

Keywords: optical properties, polarization

Materials:

- Karo syrup or sugar syrup
- Two polarizing sheets (Edmund Scientific)
- Overhead projector
- Petri dish

Procedure:

Place a polarized sheet on the surface of the overhead projector. Set the syrup-filled Petri dish on top of the sheet. Rotate the second polarizing sheet over the surface of the Petri dish.

Explanation:

When light passes through Karo Syrup the optical properties of the sugar molecules cause the light rays to rotate. The amount of rotation depends on the thickness of the syrup layer through which the light passes.

Reference

http://www.eng.iastate.edu/techknow/Lesson.Plans/engineering/AmesLabMSE/DemoBeginning.htm

Calcite Crystal (Seeing Double)

Objective: To demonstrate birefringence (double refraction) and polarization effects of a transparent material.

Keywords: birefringence, optical properties

Materials:

- Calcite crystal (Edmund Scientific)
- Two polarizing sheets (Edmund Scientific)
- Overhead sheet
- overhead projector

Procedure:

Put up an overhead with a small black dot on it or perhaps a single typed letter. Place the calcite on the overhead. Two spots are seen due to the splitting of the light.

Rotate the crystal. The dot produced by the extraordinary ray is "fake" i.e. if the calcite crystal is rotated, that spot will move while the real spot remains stationary.

Place a Polaroid sheet over the crystal. Rotate the sheet and make each spot disappear.

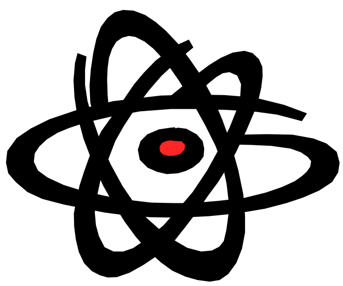
Explanation:

As unpolarized light passes through calcite the anisotropic optical properties of the material cause the light to split into two rays—the ordinary and extraordinary rays. This is because the velocity of light is different in these two directions. As such, parallel but displaced beams of polarized light emerge from the material.

Reference:

- *http://www.eng.iastate.edu/techknow/Lesson.Plans/engineering/ameslabmse/CalciteCrystal.htm*
- *M. A. White, Properties of Materials, Oxford University Press, p. 41*

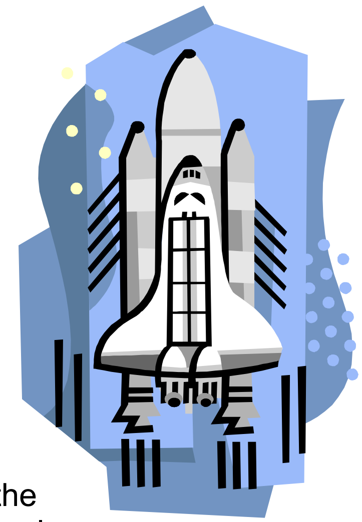
Thermal Properties



Space Shuttle Tile (Materials not too hot to handle)

Objective: To illustrate the impact of a material with a low thermal conductivity

Keywords: thermal conductivity



Materials:

- Space shuttle tile (1 in.^{2}) (spacestore.com)
- Propane torch
- Tongs

Procedure:

Hold the shuttle tile with tongs and heat it with the propane torch until it glows red hot. Set the torch aside and pick up the tile with your bare fingers. Note: Only the portions of the tile close to the region being heated are affected by the heating.

Explanation:

Imagine the heat from the torch is heat that occurs during reentry. The surface of the shuttle is bombarded by air molecules which cause friction and produce intense heat. These space tiles are made up of a ceramic of silica (SiO_2), which has a low thermal conductivity and protects the shuttle from being consumed by this heat. In silica, heat travels very slowly. When one spot is heated, it remains localized and is radiated outward and conducted through the air.

Hazard:
Extreme caution should be used in handling the torch!

Ideal Gas Law (Fun with Liquid Nitrogen)

Objective: To illustrate to interrelationship between volume and temperature in ideal gases.

Keywords: thermodynamics, ideal gas law

Materials:

- Balloon
- Liquid Nitrogen
- A wide-mouth dewar (a wide beaker in Styrofoam works too)

Procedure:

Blow up a balloon to a size that can fit the opening of the liquid nitrogen dewar. Tie off the end of the balloon and lower it into the liquid nitrogen. When you lift it out, the balloon will seem deflated, but fill back up as it warms up.

Explanation:

Think of molecules of air acting like billiard balls and colliding into each other. In an ideal gas, the volume, pressure and temperature are interrelated. Volume and pressure are directly proportional. So as the temperature lowers, the air molecules inside the balloon slow down, collide less and take less volume. As the temperature increases, the molecules move more rapidly and fill up the entire balloon volume again.

Hazard:
Liquid nitrogen is extremely cold. Do not allow it to touch your skin. It will burn initially and cause frostbite. Wear gloves when handling it.

Heat Conduction in Metals

Objective: To observe the difference in heat conduction in various metals.

Keywords: thermal conductivity

Materials:

- rods of various metals (Copper, Zinc, iron, lead, aluminum)-6" long, ¼ " diameter
- Heat source: hot water in a beaker in over a Bunsen burner
- Heat paint rated for 80ºC (omega.com #LAG-175G, $12)
- a timer (in seconds)

Procedure:
Each of the metal rods has a line of heat-sensitive paint drawn along its length. These rods are placed into the hot water. The relative conductivities are determined by the fraction of the lengths that change color.

Explanation:

All of the rods are heated in the hot water. Certain metals are good conductors of heat, while others are not as good. The metallic bonding that holds metals together is much different from the ionic or covalent bonding that holds most ceramics together. In metals the atoms are bound together by a sea of electrons that are free to move about, thus can carry energy from one area to another quite easily. In metals, heat is transferred by phonons (atomic vibrations) and electrons. The contribution of electrons exceeds those of phonons. Electrons are always in motion, however, the electrons on the hot end are moving more and carry their energy to the cold end. Thus, a net energy is transported.

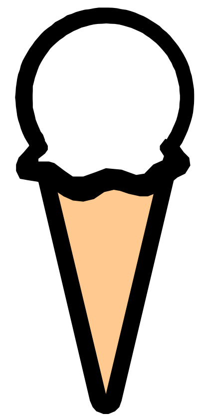
Hazard:
Be very careful with the heated surfaces.

Reference:

- *L. B. Spinney, A textbook of Physics, Macmillan Company. p230*
- *Meiners (editor), Physics demonstration experiments, The Ronald Press, 1970 p 758*
- *M. A. Omar, Elementary Solid State Physics, Addison-Wesley, 1975, p 158*

Liquid Nitrogen Ice Cream

Objective: Who cares? It's ice cream…OK, OK. To observe the effect of temperature on the state of different materials



Keywords: crystallization, phase change

Materials:
- 5 liters of liquid nitrogen
- 1 quart heavy cream
- 1.5 cups sugar
- 2 cups milk
- 2 teaspoons vanilla
- Large bowl
- Wooden spoon
- Serving utensils: Styrofoam cups, spoons, lots of Napkins
- **Optional:** for chocolate: 1 cup cocoa powder; for a creamy version: 1-4oz. container of egg beaters; or any favorite additive, such as Oreos, fruit preservatives, or candy pieces.

Procedure: In a large bowl, add the contents and mix with a wooden spoon (or other sort of material that won't break when cooled to very low temperatures). Add one to two liters of liquid nitrogen and stir vigorously. When the cream has thickened and begins to lose its shiny appearance, add your additives and more liquid nitrogen, if necessary. Continue to stir until the nitrogen has evaporated (i.e. the fog has disappeared). From here just keep adding the LN2 until the ice cream is of the desired consistency. Serve immediately. Enjoy!

Explanation: Liquid nitrogen is quite cold (77K), at room temperature it changes phase from liquid to gas. As the liquid nitrogen warms up, it exchanges energy with its environment (the ice cream mixture). As they equilibrate, the ice cream freezes.

During the freezing process, atoms lose kinetic energy and move less rapidly. This causes ice crystals to form in the ice cream mixture. However, the growth of these crystals is impeded by stirring. Stirring disrupts the crystallization process and allows new nucleation sites to continually appear. This prevents the ice cream from becoming hard and grainy (i.e. composed of large ice crystals).

Hazard: Liquid nitrogen is extremely cold. Do not allow it to touch your skin. It will burn initially and cause frostbite. Wear gloves when handling it.

Reference:

- *http://www.strangematterexhibit.com/demonstrations.html*
- *Jearl Walker, Scientific American Magazine, The Physics of Grandmother's Peerless Homemade Ice Cream, April 1984*

Corrosion

Corrosion (A rusty nail)

Objective To illustrate the principles of corrosion and passivation in steel

Equipment:

- A piece of steel. (Drill rod has 0.9% carbon, available in most metal shops)
- Concentrated nitric acid
- Beakers
- Water
- A probe or small chemical spatula
- Tongs

Procedure:

Caution: Perform this experiment in a hood. Place a small piece of the steel drill rod in a beaker. Pour concentrated nitric acid slowly into the beaker. The strong oxidizing environment of the nitric acid will cause a very adherent oxide or rust to form very quickly and protect the metal from further corrosion. Dilute the acid by pouring water into the beaker. Pour the water in very slowly so as not to disturb the (invisible) oxide layer on the steel. Using the spatula or a probe, scratch the surface of the steel. The scratch will expose unprotected metal to the weak acid and corrosion will begin. Corrosion will be very rapid and will generate a large amount of heat and colored, noxious fumes. Remove the steel from the diluted acid solution and rinse to stop the reaction.

Background:

All metals oxidize or rust, which is a form of corrosion. For many metals the rust layer is so thin it is transparent and so adherent that it protects the metal from rusting further. This oxide layer coats aluminum, which is the reason why aluminum beverage cans do not rust. Here, the oxide serves as a protective layer. However, for steels this oxide layer or rust does not protect the surface, but destroys it.

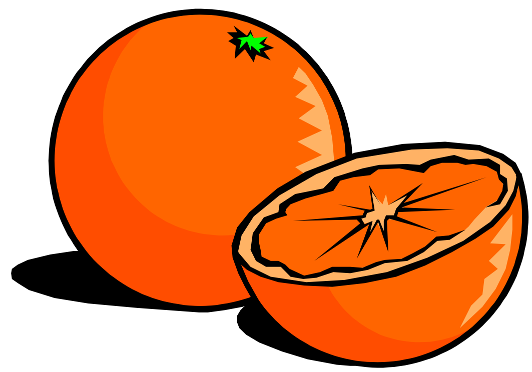
Reference:

- *http://www.eng.iastate.edu/techknow/Lesson.Plans/engineering/AmesLabMSE/DemoBeginning.htm*

Orange Batteries (Edible Galvanic Cells)

Objective: To observe the generation of electricity from chemical reactions (electrochemistry)

Keywords: electrochemistry, galvanic cells, oxidation and reduction, corrosion



Materials:

- Oranges
- A knife for cutting oranges
- multimeter (or microammeters)
- wires leads with alligator clips
- Several different metals: pennies, aluminum foil, nickels, nails

Procedure:

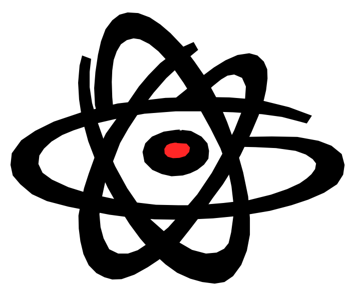
Roll the oranges with your hand to release the juices inside. Cut the orange into quarters and insert a pair of dissimilar metal electrodes into one the orange quarters. Connect the electrodes to the multimeter and determine the current. Make these measurements for several metal pairs and note which pair produces the most current.

Clean-up: Wash the orange juice off of electrodes. Examine the metals and see if they look cleaner and eat the used oranges.

Explanation:

Electrochemical cells generate electric current by converting chemical energy (the tendency to give up electrons in chemical reactions) into electrical energy (the energy of moving electrons). The acid in the orange (or electrolyte) reacts differently with each of the two metals (electrodes) depending on their electrochemical potential. In this galvanic cell, one of the metals gains a positive electric charge, while the other gains a negative charge. These charges create current, which will flow if the battery circuit is complete.

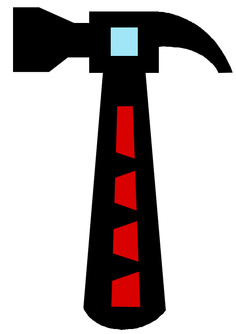
Polymers



Glass-Transition Temperature (Smash a rubber hose)

Objective: To illustrate how polymers properties can change with temperature

Keywords: glass transition temperature, polymers



Materials:

- Rubber hose (Tygon tubing: sargentwelch.com #WLS-73653-C)
- Liquid nitrogen
- Hammer
- Safety glasses.

Procedure:
Draw attention to how flexible the rubber hose is. Dip the rubber hose into liquid nitrogen for about a minute. Remove it from the liquid nitrogen and smash it with hammer. The rubber hose is now glassy and shatters like conventional glass. Pass the shatter hose around and notice the fracture pattern is similar to a brittle material. Allow the hose the warm up to room temperature and show how the properties have recovered.

Variation 1: The rubber hose can be replaced with flowers. They too shatter like glass when cooled. The fracture patterns are compelling because they resemble glass but as they warm up are delicate once again.

Variation 2: Place a steel rod in the rubber hose and dip in liquid nitrogen. Remove the metal rod and support the two ends of the hose. The hose will start to sag as it warms up.

Explanation:
Rubber is made of long spaghetti-like chains of carbon atoms that are all tangled together. Between the chains is a weak Van der Waals bond. At room temperature, these chains are able to slide by each other. At low temperatures, a type of cross-linking occurs, which is comprised of stiff covalent bonds. At higher temperature these bonds melt and the rubber softens again.

Hazard:
Liquid nitrogen is extremely cold. Do not allow it to touch your skin. It will burn initially and cause frostbite. Wear gloves when handling it.

Reference:

- *M. F. Ashby and D. R. H. Jones, Engineering Materials, Pergamon Press, 1980, p 57*

Entropy in Polymers

Objective: To explore the impact of entropy in polymers

Keywords: mechanical properties, elastomers, thermodynamics

Materials:

- a large rubber band

Procedure:

Your bottom lip can be used as a simple thermometer. Place an unstretched rubber band against your bottom lip and note its temperature. Stretch a rubber band rapidly (but don't break it) and put it against your lip again. Note the rubber band is slightly hotter.

Variation: Stretch a rubber band and hold it for a minute. Place it against your lip to note the temperature. Release the rubber band and place it against your lip again. Note the rubber band now feels cooler.

Explanation:

Rubber bands are made up of molecular chains that are highly kinked and twisted. When you stretch them, these molecular chains uncoil and align. The heat you feel is due to the heat released as the rubber chains uncoil and due to the creation of van der Waal bonds between chains (or crosslinking). Stretching a polymer aligns the chains and reduces the randomness (or entropy). Upon release of the stress, chains spring back into their random original shape. Here, crosslinked bonds are broken, which requires energy to break and causes the cooling sensation we feel.

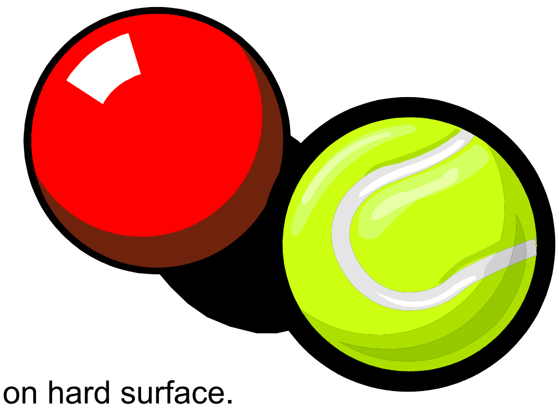
Reference:

- *Barrett, Nix, Tetelman; The principles of Engineering Materials, Prentice-Hall, 1973, 346*
- *M. Eisenstadt, Introduction to Mechanical Properties of Materials, Macmillian Company, P 89*
- *M. A. White, Properties of Materials, Oxford University Press, p. 292*

Happy/Sad Bouncing Balls (Spheres with a Disposition)

Objective: To observe the impact of structure on mechanical properties in polymers

Keywords: crosslink, rubber, coefficient of restitution



Materials:

- Choositz Decision Balls (Educational Innovations teachersource.com #SS-3)

Procedure:
Examine the two identical balls. Bounce the two balls on hard surface. One ball will bounce numerous times. The other will drop with a thud.

Explanation:
Although these balls are identical in size, color and density, they differ in their mechanical properties (bounciness). The difference lies in their chemical makeup. The "happy" (neoprene rubber) and "sad" (polynorborene rubber) have different polymeric chain architectures. Neoprene is a three-dimensional network of linear chains that are cross-linked, which prevents chains from moving passed each other. Polynorborene is made up of block co-polymers that lie in rings and are more rigid. Atoms in this molecule absorb the energy upon impact, causing it to not bounce.

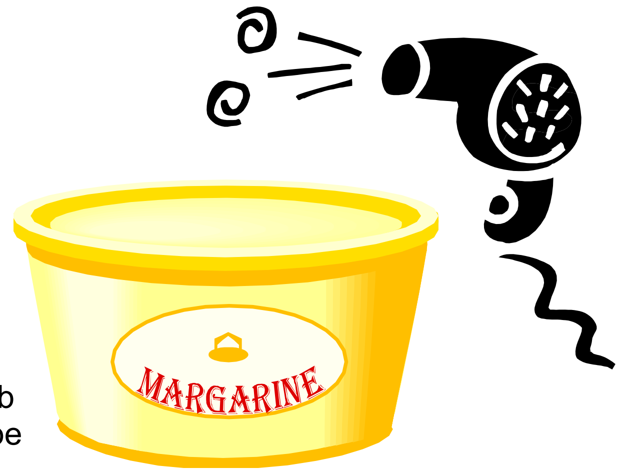
Reference:

- *M. A. White, Properties of Materials, Oxford University Press, p. 294*

Shrinking Polymers

Objective: To demonstrate the effect of processing on polymers

Keywords: polymers, processing



Materials:

- heat gun
- heat shrink tubing
- or a clean margarine tub or yogurt cup

Procedure:
Apply heat to the shrink tube or margarine tub and observe that it returns to its original shape before extrusion.

Explanation:

These plastic items were extruded or stretched from a smaller original form. With heating, these items return to these shapes. The heat supplies enough energy for the contraction to take place.

Hazard:
Be very careful with the heated surfaces.

Water Loc (Super [absorbent] Polymers)

Objective: To observe super absorption in hydrophilic cross-linked polymers

Keywords: polymers

Materials:

- Sodium Polyacrylate (sargentwelch.com, WLC94338-06)
- Paper cups
- Plastic spoons

Procedure:

Put a small amount of sodium polyacrylate into a paper cup. Add a small amount of water. This ffine white powder will turn into slush-like solid. The cup can be turn upside down and the contents will not pour out. At the end of the activity, add salt to the water absorbed sodium polycrylate to reverse the process.

Explanation:

Sodium polyacrylate $(CH_2\text{-}CH)_nCOONa$) is a sodium salt of polyacrylic acid $(CH_2\text{-}CH)_nCOOH$) and the material found in disposable baby diapers. Due to its hydrophilic nature, it is a long chained polymer that has the ablility to absorb as much as 400-800 times its mass in water and form a giant hydrogen-bonded sponge. In the dry powdered state the chains of the polymer are coiled and lined with carboxyl groups or (-COOH). When hydrated with water, the carboxyl groups dissociate into negatively charged ions, which repel each other and widened the space between polymer chains. The material continues to swell. Adding salt liquefies the gelled polymer. Salt removes the water because NaCl has an even stronger affinity for it.

Reference:

- *http://www.geocities.com/CapeCanaveral/Cockpit/8107/superabsorbe.html*
- *Prof. Thomas G. Stoebe, University of Washington, Handout.*

Silly Putty™ and GAK

Objective: To observe the influence of cross-linking in polymers and the associated mechanical properties.

Keywords: polymers, cross-linking

Materials:

- Silly putty™
- Synthesize your own with:
    - Elmer's glue
    - Borax (sodium borate)
    - Water
    - Mixing bowl
    - **optional:** food coloring

Synthesis: In one container mix 4 oz. Elmer's glue (water-soluble) with 4 oz. water, and set it aside. In another container, mix 1/2 cup of water with one teaspoon borax (which is sodium borate) and stir. Mix the two solutions and add a few drops of food coloring for effect. Mix well with a wooden stick until you have a solid mass. (Another source of sodium borate is liquid laundry starch such as Sta Flo™.)

Procedure:
Roll the GAK or Silly putty into a short tube and pull the ends slowly. See how long you can stretch it before it breaks apart. Make another short tube of the material and pull the ends apart quickly. The material resists and does not expand, but snaps apart.

Explanation:

Synthesis: Elmer's glue is a copolymer polyvinyl alcohol, PVA, a plastic made from oil. Borax is a natural mineral mined from the earth made of boron, sodium, oxygen and water. When you add water to Elmer's glue the PVA, being unstable, starts to dissolve in the water. When you add the wet borax, it is slightly acidic, and it reacts with the PVA to crosslink it. This cross-linking causes the mixture to undergo an irreversible gelation.

Mechanical: GAK is an example of a non-Newtonian fluid—a material whose viscosity increases as the shear rate increases (also know as a dilatant material). Pulling the GAK at different shear rates changes its deformation behavior. It is also a fluid, which allows it to fill the shape of the container it lies in.

Reference:

- *C. Astin et. al Physics Education,* ***37*** *(6), 2002*
- *Prof. Thomas G. Stoebe, University of Washington, Handout.*
- *MAST Polymer Experiment 3 -- http://matse1.mse.uiuc.edu/~tw/*

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