Demonstrations for the Materials Science Classroom

Introduction:
Material science is the study of the five classes of material: metals, ceramics/glasses, polymers, semiconductors, and composites, and their applicable properties. It is an exceedingly important subject because every field must deal with the properties of materials, whether or not it is a conscious involvement. Materials science is an interdisciplinary field that explores the properties of matter and applies this information to many areas of science and engineering. It often encompasses elements of chemistry and physics as well as several areas of engineering such as electrical, mechanical, chemical, civil, and aeronautical.

Materials have been investigated to discover their capabilities. The promotion of the field of material science has allowed engineers to design structures such as bridges that will not fail under normal circumstances, razors made with ceramics so the edge lasts longer—making it less painful to shave, and even the creation of computers through a knowledge and understanding of semiconductors.

This demonstration book has been developed to help teachers introduce materials science in high school science and engineering classes. WikiBooks provides a good introduction to the field of Materials Science - https://en.wikibooks.org/wiki/Materials_Science/Introduction. Another good overview is provided by Pacific Northwest National Lab - https://workbasedlearning.pnnl.gov/teachers/pdfs/mst_intro08.pdf. Also see Wikipedia Materails Science: https://en.wikipedia.org/wiki/Materials_science. Overview videos are posted on the Internet and could be assigned as homework to students to introduce the topic.

Table of Contents

Below is a list of supplies and equipment that would be needed to create a Materials Science Kit to perform all of the demonstrations. You may also only purchase supplies needed for demonstrations you plan to include in your teaching.

Hardware/Home Depot/Lowes Shopping List

- Rubber hose large enough to fit over Pyrex tube
- Tin solder (95% tin and 5% antimony)
- Nuts and bolts
- Propane torch
- O-rings (obtained from any hardware store)
- Two sheets of Plexiglas cut to 12 x 14 ½ inch pieces (each sheet approximately 5cm in thickness; can be purchased from Home Depot)
- 4 pieces of Simpson Strongtie **(**Strongtie.com**)** 12 inches in length (purchased at Home Depot)
- Nuts, bolts (1 inch in length and small enough to fit through holes of the Strongtie), and washers – 4 for each bolt
- Concrete nails ~ 60mm in length
- Plain carpenter nails ~ 80 mm in length
- Screws
- Agrosoke
- Copper rod, (or pipe) 1/4" diameter, about 18" long (Obtain from plumber or metal shop)
- 10 – 12 gauge copper wire
- 75 or 100 watt bulb
- Light bulb socket mounted on wooden block
- Electrical cord and plug
- Gator clips
- Tubes of different materials, e.g., copper, stainless steel, and PVC plastic. Tubes should have an inner diameter slightly larger than the magnet.
- Some type of fibrous insulation (can be purchased at hardware store – ask for insulation used by plumbers)

Discount Store List

- Ball point pens (retractable recommended)
- 9" Aluminum Baking pan
- Hand operated pressure bulb (turkey baster bulb works good)
- Raquetball
- BB's
- One or more containers ("egg") of formable putty (Silly putty, Nutty Putty)
- One or more clay extrusion presses (made by Play-Doh®)
- Different size rubber bands
- Piece of pyrex glass (cookware)
- Piece of soda-lime glass (any type of bottle glass)

Specialty Items:

- Pyrex Glass Tube (10-12mm diameter can be purchased from local glass store)
- 2 plates of glass (any size; purchase from glass store, hardware or junkyard)
- Soft soda glass rod (chemistry supply; online sources.)
- Pane of tempered glass from local glass/window store or junkyard)
- Strips of ordinary window glass, either single or double strength approximately 1 x

5 cm
- Glass rods
- Liquid Nitrogen (from local supplier)
- Steel Piano Wire (from local music store)
- Memory wire (Nitinol available online)
- A piece of drill rod steel, 1/16" in diameter, 18" long. "Drill rod", which is = 0.9% C, can be obtained from most metal shops or possibly welding shops. (Very large bobby pins are also suitable for this experiment.)
- Superconductivity kit (online sources)
- Fe-Nd-B permanent magnets of various sizes (Forcefield Magnets; Science suppliers such as Edmund Scientific; price varies depending on size and number ordered). Large cow magnets (made of Cobalt-Samarium) also work reasonably well although the effect is reduced. These can be obtained also online.
- Two polarizing sheets (Science suppliers)
- Thick (1/41, at least) plates of copper, aluminum, plastic. (Obtain from a metal working shop or salvageyard.)

Materials you should have or can get your hands on:

- Power drill and bit
- Screwdriver
- Pliers
- Tape measure or meter stick
- Small vise
- Hammer
- File
- Low power heat source (hair dryer)
- Beaker or graduated cylinder
- Tongs
- Tall graduated cylinder
- Force scale
- 2 Petri Dishes
- Overhead projector
- Carbon tetrachloride
- Iodine
- Copper chloride
- Variac (variable transformer)
- pencil
- Corn oil
- Karo syrup
- Overhead or some type of projection system like Hover Cam)
- Concentrated nitric acid
- A probe or small chemical spatula
- 2 liter plastic soda bottles
- A pop/soda can with no dents at all

1. Materials Science Introduction

Objective: To illustrate how temperature affects brittleness of materials.

Materials:

- Raquetball (obtained from any athletic or department store)
- O-rings (obtained from any hardware store)
- Liquid Nitrogen (obtain from local supplier)
- Stainless bowl or wide mouth dewar
- Safety glasses
- Insulated gloves
- Tongs

Background: Space Shuttle Challenger was NASA's second Space Shuttle orbiter to be put into service, after Columbia. Its maiden voyage was on April 4, 1983 and it made eight further round trips to low earth orbit before breaking up 73 seconds after the launch of its tenth mission, on January 28, 1986 killing all 7 crewmembers. The Space Shuttle Challenger accident occurred resulted due to the failure of an O-ring seal in the aft (lower) segments of the right solid rocket booster (SRB). The O-rings had hardened due to the below freezing temperature at time of launch which caused the O-ring not to seal properly. The seal failure caused a flame leak from the SRB that impinged upon the adjacent external propellant tank and aft SRN connecting strut. Within seconds the flame caused structural failure of the external tank, and the orbiter broke up abruptly due to aerodynamic forces. The crew compartment and many other vehicle fragments were eventually recovered from the ocean floor. Source: http://en.wikipedia.org/
Further information:

- https://www.britannica.com/event/Challenger-disaster
- https://www.thinkreliability.com/case_studies/root-cause-analysis-challenger-explosion/
- https://www.nationalgeographic.com.au/space/5-myths-of-challenger-shuttle-disaster-debunked.aspx

Links to YouTube videos of liquid nitrogen and ball demos:

- https://www.youtube.com/watch?v=fkps6Lo8gpo
- https://www.youtube.com/watch?v=sExTvR-LBOU

Safety: Liquid nitrogen is extremely cold: 196°C or -321°F. Do not handle it without insulated gloves and safety glasses. Do not directly reach into liquid nitrogen to place the ball or retrieve it. Direct contact with liquid nitrogen exposure can cause damage.

Procedure:

1. Introduce the topic of Materials Science.

2. Carefully pour some liquid nitrogen into bowl or dewar.
3. While talking, bounce a racquetball.
4. Show an O-ring and begin talking about what happened to the Space Shuttle Challenger in 1986.
5. While discussing the shuttle incident, use the tongs to place the racquetball in liquid nitrogen and allow it to site for ~20 seconds. Remove the ball with tongs and then throw it at the floor or wall.
6. This is a good way to get the attention of the students. Briefly explain what happened on the shuttle and how it relates to the brittle fracture of the ball.

2. Classifying Materials

Objective: To have students identify the differences that exist between various types of materials.

Materials:
Gather a variety of different examples of materials using household, school, and /or junkyards to create your collection.

Background: In chemistry, a metal (Greek: *metallon*) is an element that readily forms ions (cations) and has metallic bonds. Metals are sometimes described as a lattice of positive ions (cations) surrounded by a cloud of delocalized electrons. The metals are one of the three groups of elements as distinguished by their ionization and bonding properties, along with the metalloids and nonmetals. Examples are copper, zinc, silver, gold, lead, aluminum.

Intermetallic is the short summarizing designation for such intermetallic phases and compounds, i.e. chemical compounds between two or more metals with crystal structures which differ from those of the constituent metals. They have an ordered crystal structure. In a mechanical context, such compounds often offer a compromise between ceramic and metallic properties when hardness and/or resistance to high temperatures is important enough to sacrifice some toughness and ease of processing[1]. They can also display desirable magnetic, superconducting and chemical properties, due to their strong internal order and mixed (metallic and covalent/ionic) bonding, respectively. Examples: shape memory alloys such as nitinol; dental amalgams.

Polymer is a term used to describe a very large molecule consisting of structural units and repeating units connected by covalent bonds. The term is derived from the Greek words: *polys* meaning many, and *meros* meaning parts.[2] The key feature that distinguishes polymers from other molecules is the repetition of many identical, similar, or complementary molecular subunits in these chains. These subunits, called monomers, are small molecules of low to moderate molecular weight, which are linked to each other during chemical reaction called polymerization. Examples of natural polymers: silk, proteins, DNA. Examples of synthetic polymers: polyester, nylon, Teflon.

Composite materials (or composites for short) are engineered materials made from two or more constituent materials that remain separate and distinct on a macroscopic level while forming a single component. Nanocomposite materials are created by introducing nanoparticles into a macroscopic sample material. The nanomaterials tend to dramatically add to the electrical, thermal, and mechanical properties of the original materials. Examples of composites: composite wood, fiberglass, reinforced concrete. Carbon nanotubes are an examples of nanoparticles added to materials to improve electrical conductivity and strength.

Procedure:

1. Give students samples of different materials which you would find in a workshop, classroom, garage, etc.
2. Ask the students to assess the hardness of the materials on the Mohs Scale and classify each into polymers, metals, and so forth. The purpose is that the students begin to understand the differences that exist between various materials.

There are a few tricks that you can perform:

1. A steel and a stainless steel sample look the same, but given a magnet, they are all puzzled about whether or not the stainless is a steel or not.

2. A lump of rubber can cause confusion with the hardness test. Try leaving a scratch on the surface of this!!! Does this make it the hardest? This gets them thinking about hardness as a measure of plasticity. Also, aluminum and an Al alloy look similar. It is a platform for informal debate and discussion.

References:

Information from http://en.wikipedia.org/

1. https://en.wikipedia.org/wiki/Intermetallic
2. https://en.wikipedia.org/wiki/Polymer

Resources:

- Information in general came from: http://en.wikipedia.org/
- Intermetallic: https://www.slideshare.net/N.Prakasan/intermetallics; http://what-when-how.com/materialsparts-and-finishes/intermetallic-compounds/
- Nanocomposites: https://en.wikipedia.org/wiki/Nanocomposite
- Composites: https://en.wikipedia.org/wiki/Composite; https://en.wikipedia.org/wiki/Composite
- Mohs scale: https://en.wikipedia.org/wiki/Mohs_scale_of_mineral_hardness; https://www.nps.gov/articles/mohs-hardness-scale.htm

3. Ball Point Pen

Objective: To identify materials that make up a ball point pen and explain why these materials meet the functional requirements that allow the pens to operate.

Materials:

- Ball point pen – retractable preferred
    - Enough for each pair of students in class

Procedure:

1. Distribute pens.
2. Have everyone disassemble the pen (remind them they will be in trouble if they cannot reassemble the pen).
3. From the collection of parts, have students consider each part, identify the functional requirements of that part, identify the material, and explain why the material meets those functional requirements (Note: Using the Socratic question-based instructional style works really well).
4. Key components are:
    a. spring – high elastic limit – spring steel wire
    b. cams inside cap – slippery acetal plastic
    c. ink reservoir – inert relative to ink – brass or polyethylene
    d. ball – hard, round, accurately sized, controlled roughness surface and corrosion resistant
        – Tungsten carbide
5. Proceed to tell the class that the carbide (at $100 per pound) is a bargain, compared to harden steel (at $1 per pound). This is because the carbide is much more corrosion resistant (for those who chew their pens), and the amount of material in a ball is so minute that the cost of the material is negligible, compared to the cost of the manufacturing process.

4. Point Defect Board

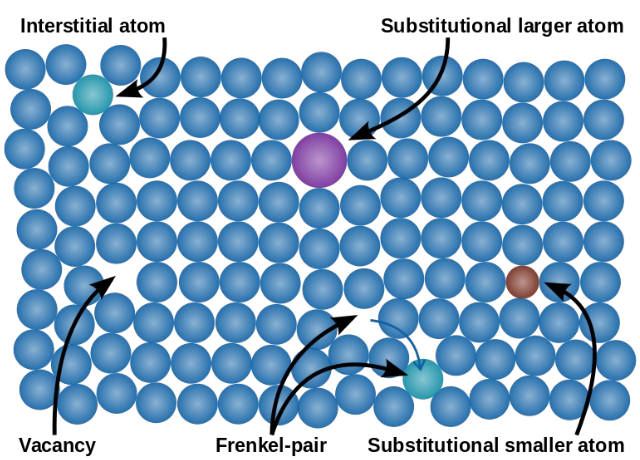
Objective: To demonstrate the formation of point defects in materials.

Materials:

- Two sheets of plexiglas cut to 12 x 14 ½ inch pieces (each sheet approximately 5cm in thickness; can be purchased from hardware store)
- BB's
- 4 pieces of Simpson Strongtie 12 inches in length (purchased at Home Depot)
- Nuts, bolts, washers - 1 inch in length and small enough to fit through holes of the Strongtie. Four washers for each of the required four bolts (16 washers).
- Power drill and bit
- Screwdriver
- Pliers

Background: A point defect may be defined as an imperfection that involves a few atoms at most. Point defects occur in all classes of materials, and unifying principles govern their occurrence and behavior. The materials that will be considered may be ionic, covalent, mixed ionic/covalent, metallic, or molecular. Point defects have profound effects on the mechanical and physical properties of most engineered materials.

Information source: The Science and Design of Engineering Materials, Second Edition). James P. Schaffer, Ashok Saxena, Stephen D. Antolovich, Thomas H. Sanders Jr., and Steven B. Warner. WCB/McGraw-Hill; 2nd edition (1999)



Point defects in crystal structures: Insterstitial and substitutional atom, Vacancy, Frenkel defect. https://commons.wikimedia.org/wiki/File:Point_defects_in_crystal_structures.svg#file

Procedure:

1. To build the point defect board, begin by placing the Strongties in a square on one piece of Plexiglas.
2. Mark holes in each corner for areas to be drilled.
3. Drill holes.
4. Place drilled Plexiglas over the other piece of Plexiglas and mark holes.
5. Drill holes.
6. Next, begin assembly by pushing bolt up through one piece of Plexiglas and Strongtie making sure to use washers on both sides of the Plexiglas (in between bolt and Plexiglas and between Plexiglas and Strongtie). Each bolt will need 4 washers. Do this for all four corners.
7. With Strongties on the upper side, pour in BB's until a little over half of the area of the Plexiglas is covered.
8. Place second piece of Plexiglas over bolts, make sure to include washers, and secure down.
9. Point defect board may be placed on an overhead projector or HoverCam to demonstrate point defects to class.

Resources:

https://www.nde-ed.org/EducationResources/CommunityCollege/Materials/Structure/point_defects.htm
https://en.wikipedia.org/wiki/Crystallographic_defect

5. Cry of Tin

Objective: To introduce students to the concept of acoustic emissions.

Materials:

- Bar of tin (1 per student group). This can be made of plumbing solder that can be purchased at any hardware store. I would use solder that is 95% tin and 5% antimony. Make sure it does not have a rosin core!!
- You can also use 2 liter plastic soda bottles to illustrate acoustic emission

Background: Acoustic emissions (AE's) are the stress waves produced by the sudden internal stress redistribution of the materials caused by the changes in the internal structure. Possible causes of the internal-structure changes are crack initiation and growth, crack opening and closure, dislocation movement, twinning, and phase transformation in monolithic materials and fiber breakage and fiber-matrix de-bonding in composites. Most of the sources of AE's are damage-related; thus, the detection and monitoring of these emissions are commonly used to predict material failure.

Information from https://en.wikipedia.org/wiki/Acoustic_emission

Procedure:

1. Have students hold tin bar up to their ear and begin to bend the tin.
2. Students should here a crackling noise.
3. You can also take the 2 liter bottle and place dents in the bottle and pop them back out to illustrate acoustic emission.

6. Surface Tension of Water

Objective: To illustrate for students the magnitude of surface tension forces.

Materials:
- 2 plates of glass (size really doesn't matter; glass slides work)
- Clear glass or beaker of water
- 1 quarter or a paper clip.

Background: Surface tension results from the attraction between the molecules of the liquid, due to various intermolecular forces. In the bulk of the liquid, each molecule is pulled equally in all directions by neighboring liquid molecules, resulting in a net force of zero. At the surface of the liquid, the molecules are pulled inwards by other molecules deeper inside the liquid, but there are no liquid molecules on the outside to balance these forces. There may also be a small outward attraction caused by air molecules, but as air is much less dense than the liquid, this force is negligible. All of the molecules at the surface are therefore subject to an inward force of molecular attraction that can be balanced only by the resistance of the liquid to compression. Thus, the liquid squeezes itself together until it has the lowest surface area possible.

Information from https://en.wikipedia.org/wiki/Surface_tension

Procedure:
1. Take one piece of glass and show to class.
2. Place a second piece of glass on top of the first.
3. Carefully turn it over and watch it fall off. Be ready to grab the falling piece or have it land on a soft surface so it does not break.
4. Place a small amount of water between the two pieces of glass and repeat carefully turning it over as done in step 3. Both pieces of glass will stick together.
5. Next, take the quarter and softly place it on top of the water in the glass. Quarter should float on top of the water.

7. Glass Fibers

Objective: To illustrate how the viscosity of glass changes as a function of temperature**.**

Materials:

- Soda-lime glass rod (stirring rods)
- Torch (propane)
- Safety glasses
- Heat resistant gloves

Safety: Use caution with open flame. Wears heat resistant gloves while heating glass.

Background: Although glass is hard and solid, it is actually a very viscous liquid. The viscosity is so thick that at room temperature the liquid flow of glass is extremely slow. The "wavy" appearance of very old windows is due to the flow of glass during the manufacturing process resulting in an uneven thickness. Modern window manufacturing methods can maintain a better control over the glass flow and produce windows of uniform thickness. By heating glass to a high temperature, the viscosity can be decreased and glass fibers can be formed very easily.

Procedure:

1. Hold the two ends of the glass rod and heat the center using a laboratory torch. Depending on the length of the rod it may be necessary to wear heat resistant gloves to avoid burns.
2. The glass will become soft and turn yellow in the hot zone of the torch. Demonstrate the lowered viscosity by moving the ends of the glass rod such that the students can see that the hot glass behaves like putty.
3. As the glass becomes soft, pull the two ends apart as you remove the hot zone from the flame, forming a glass fiber.
4. The fiber can be bent a significant amount to demonstrate the elastic properties of glass.

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8. Laboratory Experiments from the Toy Store[1]

Objectives:

- To quantitatively demonstrate the concepts of elasticity, plasticity, and strain rate and temperature dependence of the mechanical properties of engineered materials.
- To qualitatively demonstrate the basics of extrusion, including material flow, strain rate dependence of defects, lubrication effects, and the making of hollow shapes by extrusion. The two parts may be two separate experiments done at different times when the respective subjects are covered.
- To demonstrate the importance of qualitative observation and the amount of information that can be gathered without quantitative measurements.

Materials:

- One or more containers (eggs) of formable putty (Silly Putty "eggs")
- One or more clay extrusion presses (made by Play-Doh)
- Ice and a bowl (can use liquid nitrogen if available)
- Low power heat source (hair dryer)

Procedure:

Part I involves allowing students to manipulate the formable putty to illustrate the definitions and concepts of the mechanical properties of materials. While the students are unwrapping the putty, the definitions of elasticity (ability of a material/object to resume its normal shape after being stretched/compressed) and plasticity (easily shaped or molded – pliable, malleable) can be reviewed.

1. The students may form the putty into a smooth ball and bounce the ball on a rigid surface from a height of about 10cm and note the general height of the rebound and the lack of permanent deformation. The amount of deformation can be quantified by using the measuring stick.
2. The ball may then be placed in the bowl of ice (or liquid nitrogen) and cooled. Notice that the ball flattens on the bottom illustrating creep. While cold, the putty can be reformed into a ball and bounced again from the same 10cm height. The amount of rebound should be noted. The rebound height will be higher than when warm indicating an increase in hardness with decreasing temperature.
3. Next, form the putty into a cylinder. The students pull the putty slowly lengthwise and note the extensive plastic deformation (Fig. 1). This is a graphic demonstration of the concept of ductility.
4. Reform the cylinder and quickly pull it apart. This should result in some plastic deformation and a sharp break. Cooling it in ice before doing this will give you better results.
5. You can also place putty in liquid nitrogen and shatter with a hammer illustrating the temperature dependence of deformation.

Part II of this experiment involves the use of a clay extrusion press such as the Play-Doh Fun Factory.

1. Using one of the dies, have a student slowly extrude a shape. A second shape should be extruded using a much greater speed. The first shape should have a smooth surface and the second should be irregular due to speed cracking, a common extrusion problem. A little bit of water can be placed on the inside and outside part of the die to demonstrate how lubrication helps to counteract the speed cracking effect.
2. Next, two experiments may be performed to demonstrate material movement. In the first, two colors of clay are placed side-by-side with the intersection parallel to the extrusion axis. Extruding through a single-hole die shows that the two colors maintain their respective position. Placing the two colors so that the intersection is perpendicular to the extrusion axis and extruding demonstrates that the back color moves faster and moves inside the front color. The extruded shape can then be cut to show the extent of the movement. The amount of each color in a cross section varies along the length of the extrusion. Similar movement can also be demonstrated using the multi-small hole (spaghetti) die.

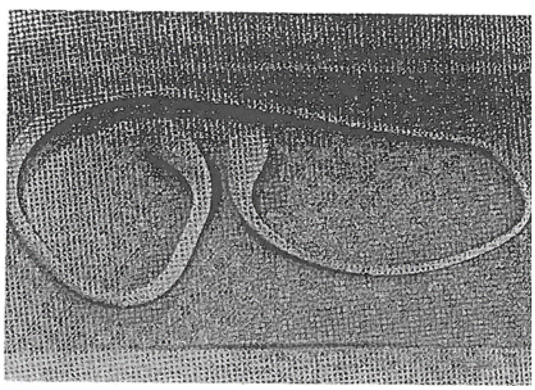

Figure 1 Deformed putty which underwent a large amount of ductile plastic deformation

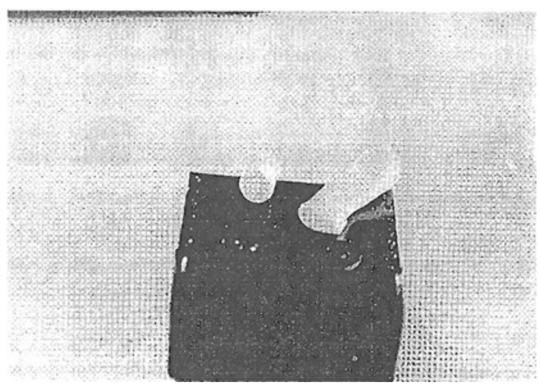

Figure 2 The fracture surface of the putty after brittle, high-rate deformation.

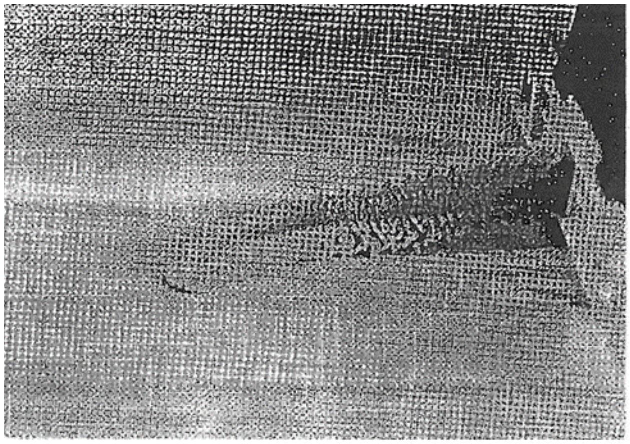

Figure 3 Rectangular shape extruded at slow then fast rates showing the transition to speed cracking.

[1] Information provided by: *Laboratory Experiments from the Toy Store*
by
H.T. McClelland
Department of Manufacturing and Industrial Technology
Arizona State University

9. Rubber Band Stress-Strain Curve

Objective: To illustrate the relationship between the stress-strain curve of a material and behavior of the material.

Materials:

- Different size rubber bands
- Board with nail
- Force scale
- Tape measure or meter stick
- Ice
- Liquid nitrogen
- Bowl/container for liquid nitrogen (to place rubber bands in)
- Safety glasses
- Insulated gloves
- Forceps

Safety: Liquid nitrogen is extremely cold: -196 degrees Celsius, or -321 degrees Fahrenheit. Caution should be used with it as is can burn skin when in contact. Do not handle without insulated gloves. Wear safety glasses or a face shield when transferring liquid nitrogen. Treat liquid nitrogen and any object cooled with liquid nitrogen with respect.

Background: A stress-strain curve characterizes the behavior of the material being tested. It is most often plotted using engineering stress and strain measures, because the reference length and cross-sectional area are easily measured. Stress-strain curves generated from tensile test results help engineers gain insight into the *constitutive relationship* between stress and strain for a particular material. The constitutive relationship can be thought of as providing an answer to the following question: Given a strain history for a specimen, what is the state of stress? As we shall see, even for the simplest of materials, this relationship can be very complicated.
Information from:

- Strength of materials: https://en.wikipedia.org/wiki/Strength_of_materials
- Stress-strain analysis: https://en.wikipedia.org/wiki/Stress%E2%80%93strain_analysis
- Constitutive relationship: https://en.wikipedia.org/wiki/Constitutive_equation

Procedure:

1. Use a small force scale to measure force. Measure elongation of the rubber bands on the board first at room temperature.
2. Chill rubber band (ice) and repeat step 1.
3. Put rubber band in liquid nitrogen and repeat.
4. Repeat steps 1-3 for each of the rubber bands.
5. Graph data on board or paper.
6. Discuss results with class.

10.Solubility and Immiscibility

Objective: To illustrate the difference between solubility and immiscibility.

Materials:

- 2 Petri Dishes
- Overhead projector or Hover Cam
- Water
- Carbon tetrachloride (CCl_4)
- Iodine
- Copper chloride
- Safety glasses
- Protective gloves
- Droppers or pipets

Background: Solubility is the amount of a solute that will dissolve in a specific solvent under given conditions. The dissolved substance is called the solute and the dissolving fluid (usually present in excess) is called the solvent, which together form a solution. The process of dissolving is called solvation, or hydration if the solvent is water.

The chemistry term ***miscible*** refers to the property of various liquids that allows them to be mixed together. By contrast, substances are said to be ***immiscible*** if they cannot be mixed together, e.g., oil and water.
Information from:
https://en.wikipedia.org/wiki/Solubility;
https://en.wikipedia.org/wiki/Miscibility

Safety: Carbon tetrachloride is a possible carcinogen and should be used with extreme caution. It may be fatal if inhaled, absorbed through the skin or swallowed. It may cause eye, skin, and respiratory tract irritation if you come in contact with it. Use only in a well ventilated area and preferably in hood.

Procedure:

1. Take two petri dishes and place them on an overhead/Hover Cam.
2. Place enough water to cover the bottom of each petri dish.
3. Using a dropper, place a pool of carbon tetrachloride in the center of the water of both petri dishes.
4. In one of the petri dishes, place drops of iodine in the pool of carbon tetrachloride and in the surrounding water. You should see the iodine dissolve in the CCl_4 but not in the surrounding water.
5. In the other dish, place some copper chloride in the carbon tetrachloride and surrounding water. You should see that the $CuCl_2$ does not dissolve in the pool of CCl_4 but does in the surrounding water.

11.Heat Treating Piano Wire

Objective: To illustrate the effects of thermal expansion and phase transformations on steel piano wire.

Materials:

- Steel piano wire (enough to cover length of board)
- Wood Board (1-2 feet in length)
- Metal screws
- Some type of weight (a key may be used)
- Variac (variable transformer)
- Weight

Background: Heat Treatment is a group of manufacturing techniques used to alter the hardness and toughness of a material. The most common application is metallurgical. Heat treatments are also used in the manufacture of many other materials, such as glass. The techniques include annealing, case hardening, induction hardening, precipitation strengthening, tempering and quenching. Steels can be heat treated to make them harder or softer. Different steels respond differently to heat treatment depending on the carbon content.

Information from https://en.wikipedia.org/wiki/Heat_treating

Procedure:

1. Insert the screws on each end of the board leaving enough room to string wire.
2. String steel piano wire between the two metal screws on a board 1 – 2 ft wide.
3. Suspend the small weight in the center of the wire.
4. Connect a small variac to the screws and do the heat treatments (heating and cooling) using the variac.
5. By watching the suspended weight, students can see thermal expansion, but more interesting are the phase transformations on heating and cooling.

12. Heat Treating Nails

Objective: To illustrate the effects of heat treatment on steel.

Materials:

- Concrete nails ~60mm in length
- Plain carpenter nails ~80mm in length
- Propane torch
- Beaker of water
- Small vise
- Hammer
- Pliers
- File
- Safety glasses
- Insulated gloves

Background: Heat Treatment is a group of manufacturing techniques used to alter the hardness and toughness of a material. The most common application is metallurgical. Heat treatments are also used in the manufacture of many other materials, such as glass. The techniques include annealing, case hardening, induction hardening, precipitation strengthening, tempering and quenching. Steels can be heat treated to make them harder or softer. Different steels respond differently to heat treatment depending on its carbon content. The concrete nails contain about 0.6% carbon and they can be austenitized, quenched, and tempered rather nicely. The carpenter nail contains less than 0.1% carbon and it cannot be hardened.

Austenitization means to heat iron, iron-based metal, steel to a temperature at which it changes crystal structure from ferrite to austenite. The more open structure of the austenite is then able to absorb carbon from the iron-carbides in carbon steel.[1]

Information from:
Heat treating: https://en.wikipedia.org/wiki/Heat_treating
Austenitization: https://en.wikipedia.org/wiki/Austenite#Austenitization [1]
Martensite: https://en.wikipedia.org/wiki/Martensite

Safety: Use caution when using an open flame. Handle hot metal with tongs.

Procedure:

1. Using a concrete nail, demonstrate to the students that the nail can be filed. Make a mark on the nail about 20 mm from the tip with the file.
2. Grasp the nail with the pliers and heat in the flame of the propane torch to

austenitize the nail. The nail should turn a bright orange color, approximately 850 degrees Celsius for austenitizing.

3. Quench the nail in water by placing it in the beaker of water immediately.
4. Quenching will cause the steel to transform to martensite but it also causes tiny flakes of iron oxide to be thrown from the surface of the nail. The flakes are readily visible inside the beaker.
5. When quenched to martensite, the nail is very brittle.
6. Clamp the nail about 25 mm from the tip into the vise, and pound the head with a hammer.
7. ***Be careful to swing the hammer so that the flying fragment will move away from the class.***
8. The nail should fracture with no bending.
9. Be sure to demonstrate to the class how the nail cannot be filed now.
10. Reheat the broken end (the part remaining in the vise) until you can see just a hint of red. This will temper the nail making it soft enough to bend at a 90 degree angle. Heat again with the hammer to illustrate how it will not fracture once it's been tempered.
11. Repeat same process with carpenter nail. It cannot be hardened.

13. Water Absorbing Polymer

Objective: To help students understand the various properties of polymers.

Materials:
- Agrosoke® (purchased from Lowe's)
- 1 gallon of water
- Large clear container to hold water

Background: Agrosoke® Root Watering Crystals were made specifically for improving plant growth with reduced water requirements. It is a synthetic anioinic polymer. The crystals make growing plants easier and are designed to be compatible with fertilizers and plant growth aids. These are root watering crystals that save water and can be used for both indoors and outdoor plants. When wet, Agrosoke® crystals turn into a gel and create "mini reservoirs of water" around the root systems of plants. The plant's roots will pull this water from the gel as needed. Agrosoke® crystals have strong structual stability, which enables them to reduce compaction so they will hold up under pressure instead of breaking into smaller particles.

There are many products on the market in the "water gel" category of materials. These commonly are sodium polyacrylate which is a type of super-absorbing polymer. A good description of these and another demo can be found at: https://www.cmu.edu/gelfand/education/k12-teachers/polymers/polymer-and-absorption/super-absorb-powder.html. There are also numerous YouTube videos demonstrating the polymer and water: https://www.youtube.com/results?search_query=sodium+polyacrylate+mixed+with+water

Information from: http://agrosoke.com.tripod.com/id3.htm

Procedure:
1. Scoop 3 tablespoons of agrosoke® and place into a large clear container.
2. Pour 1 gallon of water into container.
3. Observe and discuss what happens.

14. Buckling Breakdown

Objective: To illustrate the principle of "buckling breakdown" where a material is subjected to a stress it was not designed to withstand.

Materials:

- An empty pop/soda can with no dents on the sides
- pencil

Background: Soda pop cans are designed to withstand internal pressures. They have a low tolerance to compressive stresses applied perpendicular to the sides, i.e., they dent very easily by applying a few pounds of pressure when squeezing. The strength of the material is such that while the can may dent, it does not puncture. If a compressive stress is applied parallel to the sides, e.g. squeezing the can from the top and bottom, the can is able to withstand almost 160 pounds of force. However, the slightest force perpendicular to the sides will cause the can to collapse.

Procedure:

1. Place an undented can on the floor.
2. Have a volunteer who weighs less than 160 lbs. gently step onto the top of the can. Other persons or a chair may help the volunteer balance on the can on one foot.
3. Tap the side of the can with the pencil. The can will fail suddenly and crunch flat under the weight of the volunteer.

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15. Glass

Objective: To illustrate the mechanical properties of glass

Materials:
- Pane of tempered glass (Obtain from local hardware, glass or window store)
- Two chairs
- Safety glasses for entire class
- Pliers

Background: Tempered glass for windows is made by blowing air on the outer surfaces of the glass pane such that they cool very rapidly while the glass in the interior is still warm. When the inside glass cools it shrinks and contracts. This contraction effectively means that the inside glass "pulls" on the outside glass. In engineering terms, the outer surfaces are in compression while the inner glass is in tension. The compressive stress gives the glass pane great strength as long as the outer surface is not chipped. If the glass is chipped such that a crack reaches the interior glass that is under tension, the glass pane will shatter as the tensile forces are suddenly released.
Safety: Always use caution when working with glass. See warnings and cautions below in the procedure. Make sure students are at least ten feet from the demonstration.

Procedure:
1. Place the pane flat with the edges supported on two chairs so you have a platform 18" or so off the ground with about 12"-18" of glass unsupported between the chairs. (You may also suspend the pane on 2"x4"s placed on the ground.)
2. Slowly stand on the pane such that your entire weight is on the unsupported portion of the glass. The glass should hold up to 400 pounds easily. (**N.B.** It is extremely rare that the pane will break. If the glass does break it will break in the plane of the glass meaning that glass pieces will fly out parallel to the floor. It is best to have students remain **at least 10 feet away** and wear safety goggles while doing this demonstration.)

If you wish to demonstrate the effect of a flaw in the glass, the experiment may be continued as follows:

3. Clear everyone from the area. Wear safety glasses. (The pane of glass may be placed in a clear plastic bag if desired.)
4. Support one corner of the pane on one of the chairs or rest it on the floor. Grip the opposite corner with the pliers and squeeze to crack the glass. The pane will shatter, spreading glass over a large area. (Most of the glass will fly in the plane of the pane of glass. Make certain the pane is not pointing toward the class as the glass will fly several feet!)

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16. Fatigue

Objective: To illustrate the effects of fatigue on a metal.

Materials:

- Tin solder (obtained from hardware store) cut into 20 cm pieces
- Protractor to measure angles

Background: In materials science, fatigue is the progressive, localized, and permanent structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses that have maximum values less than (often much less than) the static yield strength of the material. The resulting stress may be below the ultimate tensile stress, or even the yield stress of the material, yet still cause catastrophic failure.[1]

Information from[1]: https://en.wikipedia.org/wiki/Fatigue_(material)
Yield stress: https://en.wikipedia.org/wiki/Yield_(engineering)
Ultimate tensile strength: https://en.wikipedia.org/wiki/Ultimate_tensile_strength

Procedure:

1. Repeatedly bend a piece of the tin solder at 30º angles until the piece breaks. Count the number of cycles it takes to break the piece and record the number.
2. Repeat at 60º angles.
3. Repeat at 90º angles.
4. Plot cycles to failure vs bend angle on the board paper.
5. Discuss results with class.

17. Memory Metal

Objective: To illustrate the shape-memory effect as a function of temperature.

Materials:

- Memory wire/nitinol (cut into 3-5inch piece)
  - Available from multiple sources including Flinn Scientific and Educational Innovations
- Hot water in a clear container such as a beaker (near boiling); can also use a hair dryer instead of water.
- Tongs/tweezers

Background: Nitinol or "memory metal" undergoes a reversible shape change as a function of temperature. The wire is formed into a specific shape at high temperature and then cooled very rapidly. At room temperature the wire can be bent into any shape but once the temperature is raised (to approximately 95-200° F depending on the particular alloy) the wire will once again form into the original shape. Orthodontists commonly use memory wire in braces and it has wide applications in medical and electronic devices.

Procedure:

1. Show the students the initial shape of the wire.
2. Deform the wire by wrapping it around your finger or twisting it. Do not tie it in a knot.
3. Using the tweezers, lower the wire into hot water. The wire will return to the original shape.

Adapted from NNCI.net *Demonstration Guide*:
https://www.nnci.net/sites/default/files/inline-files/SENIC%20Outreach%20Demo%20Guide-04-16.pdf
https://www.nnci.net/sites/default/files/inline-files/Shape%20memory%20alloys_1_2_1.pdf

A full lesson on shape memory alloys can be found at: https://www.nnci.net/node/5320

Another demo can be found at:
http://www.nisenet.org/catalog/exploring-materials-memory-metal

18. Work Hardening

Objective: To illustrate how metals get harder as you bend them.

Materials:
Copper rod, (or pipe) 1/4" diameter, about 18" long
Ring stand with clamp
Propane torch
Safety glasses
Insulated gloves

Background: How easily a metal bends, how hard a metal is, and how far a metal can be stretched before it breaks are all measures of its mechanical properties. These properties are directly related to the atomic structure of the metal. If a pure metal is heated to a high temperature and cooled it will often be very soft since the atomic structure is very uniform. If the metal is bent the atomic structure will be disturbed and the metal will get much harder.

Procedure:

1. Clamp one end of the copper rod to a ring stand. Using a propane torch (two or three are better) start heating at the far end until the tip is glowing bright red.
2. Slowly move the heat in towards the clamped end so that the red-hot hot zone moves down the length of the rod and the rod has been entirely heated. It is not necessary to keep the whole rod glowing at the same time; a hot zone 1" or so in width is fine as long as you move it down the whole length.
3. Cool the rod by placing it in a sink full of water or by spraying water over the rod. **Be careful not to burn yourself.** The bar will now be very soft, so don't bend it! You may want to lightly sand the outside to remove any oxide.
4. Hand the bar to the smallest student in the room and ask them to bend it. They should be able to do this easily. However, the rod will become very hard due to the bending.
5. Now pass the rod to another student and ask them to try and straighten it. They will find this very difficult due to the work hardening effect.
6. This demo can be repeated simply by reheating the copper rod, straightening it back out and then reheating again.
7. A coat hanger can also be used for this demo. Bend the straight section of the coat hanger to a "U", then immediately try to bend it back straight. The curve of the "U" will remain bent due to the work hardening effect in this area.

19. Tempered Steel

Objective: To illustrate how heat can be used to "temper" a steel, making it very strong instead of brittle.

Materials:

- A piece of drill rod steel, 1/16" in diameter, 18" long. "Drill rod", which is = 0.9% C, can be obtained from most metal shops or possibly welding shops. (Very large bobby pins are also suitable for this experiment.)
- Propane torch
- Beaker of water

Background: The atomic arrangement of atoms in steel changes with temperature. At room temperature, the atoms form a cube with one atom in the center of the cube body (called body-centered cubic or BCC) but by heating steel to a high temperature this arrangement can be changed to a cube with atoms on the faces (called face- centered cubic or FCC). If the hot steel is plunged into cold water (called "quenching") the atoms do not have time to go back to the favored BCC arrangement. Instead, a complex structure results which is very brittle. If the steel is reheated slightly, the atoms move slightly and the atomic arrangement becomes very hard and tough. This reheating is called tempering and most tool steels have been quenched and tempered.

Tempering: https://en.wikipedia.org/wiki/Tempering_(metallurgy)
Cubic crystal systems: https://en.wikipedia.org/wiki/Cubic_crystal_system
Quenching: https://en.wikipedia.org/wiki/Quenching

Procedure:

1. Cut the rod in half so that you have two pieces, approximately 9" long.
2. Bend the two rods into "U" shapes.
3. Heat the curve of one "U" until it becomes bright orange using the torch. (You can hold the two ends of the "U" in your hand during heating, steel has a very low thermal conductivity so the ends will not get hot. However insulated gloves and tongs are recommended for safety.) Immediately plunge the hot section of the rod into a container of cold water. This process is called quenching. (Note: if large bobby pins are used they are often coated with a plastic resin coating which will burn off in the flame.)
4. Repeat Step 3 above with the second "U". Once this "U" has been quenched in the water, reheat it slightly in the flame. It is only necessary to get the metal warm, **DO NOT** get it so hot as to cause the color to change. This procedure is called tempering.

5. Pull the two ends of the two “U”s apart. The steel which was only quenched will very brittle. The quenched and tempered “U” will be so strong and tough in the

region of the “U” that it will be impossible to get it to bend in this region.

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20. Superconductivity Experiment

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

Materials:

- Superconductivity kit (sources below)
- Liquid nitrogen
- https://www.arborsci.com/products/economy-superconductivity-kit
- https://www.flinnsci.com/superconductivity---demonstration-kit/ap1489/
- https://www.can-superconductors.com/demonstration-kits.html

Background: A superconductive material carries an electrical current with no loss of electricity due to resistance i.e., resistivity is virtually zero below a critical temperature. Superconductive materials also repel magnetic fields. This complete ejection of magnetic field lines is termed the Meissner effect.

Information from: https://en.wikipedia.org/wiki/Superconductivity

Procedure:

1. Place the superconductor pellet in a petri dish. The petri dish can be insulated somewhat by making a depression in a large piece of styrofoam and placing the petri dish in this depression. (The kit may provide a holder.)
2. Pour in liquid nitrogen until the pellet is cold and the liquid nitrogen doesn't evaporate immediately.
3. Using plastic tweezers, place a small FeNdB magnet chip (or the magnet provided by the kit) over the top of the superconductor. The superconductor will exclude the magnetic field and the magnet will remain suspended in thin air over the pellet.

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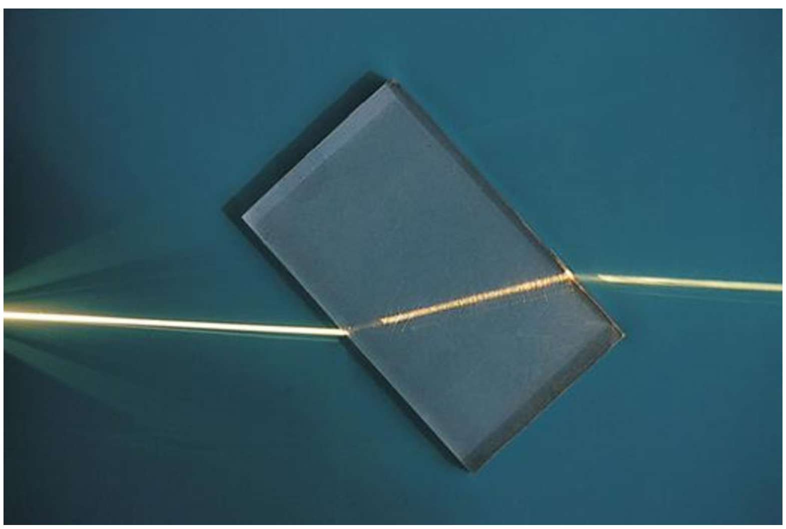
21. Index of Refraction

Objective: To demonstrate how glass and corn oil have the same index of refraction.

Materials:
- Glass rods
- Corn oil
- Beaker or graduated cylinder

Background:
The index of refraction of a material is the factor by which the phase velocity of electromagnetic radiation is slowed in that material, relative to its velocity in a vacuum.

Procedure:
1. Place glass rod into beaker or graduated cylinder.
2. Slowly pour in corn oil.
3. Glass rod should not be visible inside cylinder due to the reflectance and scattering of light at oil/glass interface which is zero.



A ray of light being refracted in a plastic block

Image source:
By ajizai - http://www.docstoc.com/docs/130534946/Chapter-7-Refractive-index, Public Domain, https://commons.wikimedia.org/w/index.php?curid=30455241

22. Karo Syrup Experiment

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

Materials:

- Karo syrup
- Two polarizing sheets (Edmund Optics)
- Overhead/ Hover Cam
- Tall graduated cylinder or clear glass/beaker
- Cardboard

Background: 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.

Procedure:

1. Place on an overhead or Hover Cam a piece of cardboard with a hole cut into it the same diameter as your graduated cylinder or beaker.
2. Place a polarized sheet on the cardboard.
3. Place the graduated cylinder over the hole in the cardboard.
4. Have a student hold the second polarized sheet over the top lens of the overhead so no light reaches the screen.
5. Pour the syrup slowly into the cylinder. Different colors of light will be visible as the thickness increases.
6. Have the student rotate the polarized sheet they are holding. Different colors will be seen at different angles.

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23. Permanent Magnets

Objective: To illustrate the magnetic properties of Neodynium or Fe-Nd-B permanent magnets and the eddy current response of nonmagnetic conductors to a strong magnetic field. Students should realize that all conductive materials are affected by magnets.

Materials:

- Fe-Nd-B permanent magnets of various sizes (various sources online such as K&J Magnets (price varies by size and number ordered). Large cow magnets (made of Cobalt-Samarium) also work reasonably well although the effect is reduced.
- Thick (1/41, at least) plates of copper (Cu), aluminum (Al), and plastic. (Obtain from a metal working shop or salvage yard.)
- Tubes of different materials, e.g., copper, stainless steel, and PVC plastic. Tubes should have an inner diameter slightly larger than the magnet nd be about 18 inches in length. (One source is a plumbing suspply.)

Background: Fe-Nd-B magnets have the highest energy density of all commercial magnets. They are used in a number of devices to study materials, as well as in a number of household electronic devices. The phenomenon of eddy currents is used extensively in the area of non-destructive-evaluation to determine whether small cracks invisible to the naked eye are present in metallic structures.

Procedure:

1. Place one magnet on the bottom of your hand and the other on top of your hand. Or, place the magnets along the arm of a student (top and bottom) and slowly move the magnet up the volunteer's arm as far as it will go. The larger the magnets the greater the thickness of flesh through which the field penetrates. Magnets 1/4" square should stick through the palm of a hand.
2. Flip the bottom magnet over and watch the top one flip by itself.
3. Demonstrate the principle of eddy currents by having students wave a magnet over the surface of the CU, Al, and plastic plates as near as possible without scraping the surface. Eddy currents are induced in conductors so the student will feel nothing with plastic, very strong eddy currents in Cu, since it is a good conductor, and the Al will be in between.
4. Place the magnets on the Cu, Al, and plastic plates and tilt them until the magnet starts to slide. Due to the eddy currents opposing gravity, the student will have to tilt the Cu plate to a high angle before the magnet starts to slide.
5. Drop a small magnet through the Cu tube. Instead of falling straight through, the eddy currents will oppose gravity and it may take 1-3 seconds for the magnet to fall through a tube 18" long. Allow students to look down the tube after you drop the magnet; it almost looks as if the magnet is floating down the

length of the tube.

6. Experiment with tubes and plates made from different materials making sure to have conductors and non conductors.

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24. Thermal Insulation

Objective: To illustrate thermal conductivity of fiber insulation.

Materials:
- Propane torch
- Some type of fibrous insulation board (can be purchased at hardware store – ask for insulation used by plumbers)
- Thermometer
- Tongs or forceps

Background: Heat is the internal kinetic, vibrational energy that all materials contain (except at absolute zero). Heat spontaneously flows from a high temperature region to a low temperature region, and the greatest heat flow occurs through the path of least resistance.

The proximity of a high temperature region to a low temperature region constitutes a temperature gradient. Thermal insulation maintains a thermal gradient by reducing the flow of heat across the temperature gradient.

Insulation exists in most large appliances, for example, in ovens, refrigerators, freezers, and water heaters. In some cases, the insulation serves to prevent heat loss *to* the environment. In other cases, it serves to prevent heat gain *from* the environment.

Information from https://en.wikipedia.org/wiki/Thermal_insulation

Procedure:
1. Ask for a volunteer to hold and read the thermometer.
2. Place fibrous insulation board over the thermometer being held by tongs by the volunteer (make sure correct side is up).
    a. Alternately place thermometer on a surface and cover it with the insulation board.
3. Using a propane torch, heat front surface of insulation board for as long as needed to illustrate the point that heat is not passing through the board.
4. Have student feel the front side of the insulation versus the back side.

25. Thermal Shock

Objective: To illustrate thermal expansion and thermal shock.

Materials:

- Piece of Pyrex® glass (can be purchased at discount stores as cookware)
- Piece of soda-lime glass (any type of bottle glass)
- Blowtorch or Bunsen burner
- Tongs or forceps
- Insulated gloves
- Safety glasses

Background: In physics, thermal expansion is the tendency of matter to increase in volume or pressure when heated. For liquids and solids the amount of expansion will normally vary depending on the material's coefficient of thermal expansion. When materials contract, tensile forces are created. When things expand, compressive forces are created.

Thermal shock is the name given to cracking as a result of rapid temperature change. Glass and ceramic objects are particularly vulnerable to this form of failure, due to their low toughness, low thermal conductivity, as well as their high melting point (which often leads to their use in high-temperature applications.)

Information from https://en.wikipedia.org/wiki/Thermal_shock

Safety: Use caution when quenching the glass to make sure you are not hit with any fractured glass

Procedure:

1. Heat Pyrex® and soda-lime glass with propane torch.
2. Quench each in water.
3. The Pyrex® will not fracture while the soda-lime should fracture into small pieces.

26. Corrosion and Passivation

Objective: To illustrate the principles of corrosion and passivation of steel.

Materials:

- A piece of steel. "Drill rod" which is = 0.9% **C** can be obtained from most metal shops or possibly welding shops.
- Concentrated nitric acid
- Beakers
- Water
- A probe or small chemical spatula
- Tongs

Background: All metals oxidize or rust. This is termed corrosion. For many metals the rust layer is so thin it is transparent and so adherent that it protects the metal from further rust. This is the case for aluminum and stainless steel. In some cases, the oxide builds up slowly and is only partially protective such as for silver and copper. In other cases, the rust does not protect the metal at all. This is the case for most steels.

Safety: **PERFORM THIS EXPERIMENT IN A HOOD!**

Procedure:

1. Place a small piece of the steel drill rod in a beaker.
2. 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 quickly and protect the metal from further corrosion.
3. 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.
4. Using the spatula or a probe, scratch the surface of the steel (hold rod with tongs). The scratch will expose unprotected metal to the weak acid and corrosion will begin.
5. Corrosion will be very rapid and will generate a large amount of heat and colored, noxious fumes. **Only perform this experiment in a hood!**
6. Remove the steel from the diluted acid solution and rinse with water to stop the reaction.
7. Examine the surface and discuss with students what has occurred.

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27. More Surface Effects…..Faster Explosions

Objective: The purpose of the following activities is to give you more experience with examining the effects of changing surface to volume ratios. Faster explosion looks at the effect of different surface area to volume ratios on the speed of reaction.

Safety Precaution: Do not eat or drink anything in the lab! Wear safety goggles!

Materials:

- Two empty film canisters and their lids (obtain free from Walmart film department)
- One tablet of Alka Seltzer tablet
- Pack of Mentos
- Water
- Diet Coke
- One small mortar and pestle
- Timer

Procedures:

1. Break the Alka Seltzer tablet in half as exactly as you can.
2. Put one of the halves of the Alka Seltzer tablet into the mortar bowl and crush it with the pestle until it is finely granulated.
3. Fill each film canister halfway with tap water.
4. Put the ½ of the uncrushed Alka Seltzer and theh ½ of the crushed Alka Seltzer each into a different film canister at the same time. Quickly put their lids on.
5. Record the amount of time it takes for each canister to blowits lid off.
6. Rinse the film cans and repeat 1-5 using the Coke product and mentos.

The most exciting phrase to hear in science, the one that heralds new discoveries, is not ‘Eureka!’ (I found it!), but ‘That’s funny…’

Isaac Asimov (1920 - 1992)