

Chemistry Outreach Program

**Massachusetts Institute of Technology
Cambridge, MA**

EXPERIMENTALS

IMPORTANT NOTE

The procedures in this document are intended for use only by persons with prior training in the field of chemistry. These procedures must be conducted at one's own risk. MIT and the Chemistry Outreach Program do not warrant or guarantee the safety of individuals using these procedures and hereby disclaim any liability for any injuries or damages claimed to have resulted from or related in any way to the procedures herein.

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The Oscillating Clock Reaction

In this experiment, an oscillating reaction occurs in which different states of iodine cause the accompanying color changes.

See: Shakhashiri, B. Z. *Chemical Demonstrations: A Handbook for Teachers of Chemistry*; University of Wisconsin: Madison, 1983; vol. 2, pp 248-256.

Materials

Solution A: 4.0 M H_2O_2 (all solutions must be at room temp for the demo to work!)

Solution B: 0.2 M KIO_3 , 0.077 M H_2SO_4

Solution C: 0.15 M malonic acid, 0.020M MnSO_4 , starch

250 mL erlenmeyer flask

magnetic stir bar

magnetic stirrer

sodium thiosulfate (solid; for quench)

Procedure

This reaction is very straightforward to run, but not to explain. Simply pour equal amounts of solutions A, B, and C sequentially into an Erlenmeyer flask containing a magnetic stir bar. The resulting mixture should turn amber or tan, then a deep blue or purple, and continue to oscillate between these colors. The explanation for this reaction is rather complicated; see the above reference for more details. A simple explanation is that iodine in the solution is oscillating between an ionic form (I^- , the clear solution), a free state (I_2 , the amber color), and a starch complex (the blue color). The H_2O_2 in the first solution drives the reaction.

Spiel

Before you start, ask the students what the white object in the flask is. Someone will invariably say chalk. Then explain the magnetic stirrer, and how some reactions take a very long time. Ask the students how long they think the reaction will run. Some will say forever, but at the end of the show you can let them see that it indeed will stop, when all of the peroxide is used up. This is an example of a limiting reagent. The blue starch complex will be familiar to anyone who goes camping and uses iodine to purify the water, then cooks pasta in it!

Safety/Disposal

Do not get any of the solutions on your skin. It's best to run this reaction at the beginning of the show and then put it off to the side to let it finish reacting. This helps with the sodium thiosulfate quench, which involves **slowly** adding solid $\text{Na}_2\text{S}_2\text{O}_3$ to the reaction mixture until no blue color remains. The addition of $\text{Na}_2\text{S}_2\text{O}_3$ is very exothermic and is less so with less H_2O_2 . The longer you wait before quenching the reaction, the easier it is to quench quickly. Once the reaction mixture is colorless, the solution can be safely poured down the drain.

Tollens' Test for Reducing Sugars

In this experiment, you will silver-plate the inside of an Erlenmeyer flask by reducing silver(I) to silver metal with dextrose, a reducing sugar.

See: Summerlin, L. R.; Ealy, J. L., Jr. *Chemical Demonstrations*; American Chemical Society: Washington, D. C., 1988; p 91.

Materials

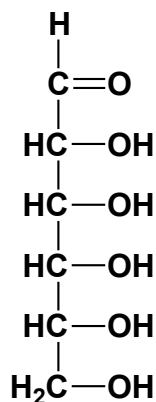
silver nitrate (4 g, brown glass vial)
dextrose (8 g, clear glass vial)
conc. ammonium hydroxide (~ 10mL, small plastic bottle)
deionized water
125 mL erlenmeyer flask
brand new 125mL erlenmeyer flask
pasteur pipet with bulb
crystallizing dish (filled with hot water)

Procedure

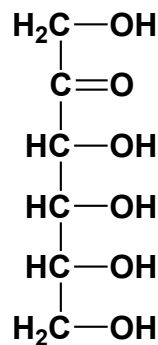
Dissolve the sugar in 20 mL water in the 125 mL erlenmeyer flask. Warm the flask in the hot water to speed up the process. Meanwhile, dissolve the silver nitrate in 70 mL water in the **brand new** 125 mL erlenmeyer flask. Then, while swirling the flask, add ammonium hydroxide to the solution using the pipette. A brown precipitate will appear and then disappear as you add more ammonium hydroxide. Titrate to the point where it disappears then add a few more drops. Pour the dextrose solution into the silver nitrate solution and swirl the contents. Place in the dish of hot water and allow it to sit undisturbed for at least 10 minutes. Usually, you can go on to the next demo then come back and examine the flask later. Pour the solution down the drain and rinse the flask well with water before passing it around the class.

Spiel

Talk about ions. Mention silverware, and ask why the silver nitrate dissolves in water while silverware does not. This silver-plating process was used to make some of the first mirrors. When you are emptying the flask, act like you are going to pour out the silver, and be surprised when it does not come out. When nothing happens initially, ask whether the test was positive or negative. Then explain that some reactions are slower than others, and chemists need to be patient. Ask for names of some common sugars. This reaction was originally developed as a test for sugars, to distinguish an aldose from a ketose. In this demo, we use dextrose as the reducing sugar (aldose). It is found in foods. Fructose is a common sugar found in soft drinks; it is sweeter than dextrose. Fructose is a ketose.



Dextrose



Fructose

A positive test indicates an aldose, or reducing sugar.



Mention that the amount of silver is very small, and not worth much money (sometimes students try to scrape it out, and it makes the flask look ugly). You can let the teacher keep the flask as a souvenir.

Safety/Disposal

If the silver nitrate/ammonium hydroxide solution sits for a few days, it forms silver nitride. These crystals explode when jarred or touched. Make up the solution fresh each time and rinse waste down the drain with copious amounts of water. Silver nitrate is poisonous by ingestion, and it stains your skin brown, so wear gloves. Ammonia is caustic and could burn skin and nasal passages. The fumes are very strong, so try to keep the bottle capped as often as possible during use.

Acid-Base Indicator from Cabbage Extract

In this demonstration, you extract a natural acid-base indicator from red cabbage and use it to test whether common household items are acids or bases.

Materials

4-5 leaves of fresh red cabbage
tap water
500 mL denatured alcohol
blender
funnel
cheesecloth or paper towel
large beaker
8-10 clear plastic cups
1M aqueous HCl
1M aqueous NaOH
any of the following: vinegar, ammonia, baking soda, lemon juice, milk of magnesia, powdered laundry detergent, tonic water, aspirin, anything else that would work

Procedure

Tear up the cabbage and load it into the blender. Add the alcohol and water, and puree. Strain the mixture to remove the solids using the cheesecloth and the funnel, collecting the extract in the large beaker. Dilute the extract with water. Pour the purple solution into the plastic cups, filling each about 2 cm full. Show first the color changes of the extract when a known acid (HCl) and a known base (sodium hydroxide) are added.

Spiel

You will need to adjust your explanation depending on the level of the class; sometimes the students haven't learned about acids and bases yet. You can discuss the extraction of useful chemical compounds (drugs (taxol), dyes, fragrances) from natural sources. First ask if anyone knows any acids. Usually someone says HCl, so test that first. Then ask for bases. This is a little more difficult. Test the NaOH next. Talk about control experiments. Then ask the class for predictions as you test the household items (ask them if it will be an acid, base, or neutral!). Some of the color changes are really impressive. Some students may be familiar with pH test paper or phenolphthalein. Discuss the properties of acids and bases. Also, you can talk about neutralization reactions, for example, by comparing the results of mixing sodium bicarbonate and milk of magnesia (active ingredient: $\text{Mg}(\text{OH})_2$) with 1M HCl. In the reaction of baking soda with HCl, carbon dioxide evolves vigorously, whereas with milk of magnesia, no CO_2 is formed. At the end, you can mix one of the acidic solutions with a basic one to try to get it back to purple.

Safety/Disposal

Be careful with the HCl and NaOH solutions. The test solutions can go down the drain. It is important to rinse out the cups very well before using them for the next demonstration or else you may be surprised by the colors you're getting! Throw the cabbage pulp in a wastebasket.

Synthesis of Nylon 610

In this first of three polymer experiments, you will make synthetic nylon (a polymer) by combining the two parent monomers, a bis-acid chloride and a bis-amine.

Materials

10 mL hexamethylene diamine solution (0.5 M, in water, with NaOH added)
10 mL sebacoyl chloride solution (0.25 M, in hexane)
100 mL beaker
tweezers
wire winding apparatus
nylon waste container

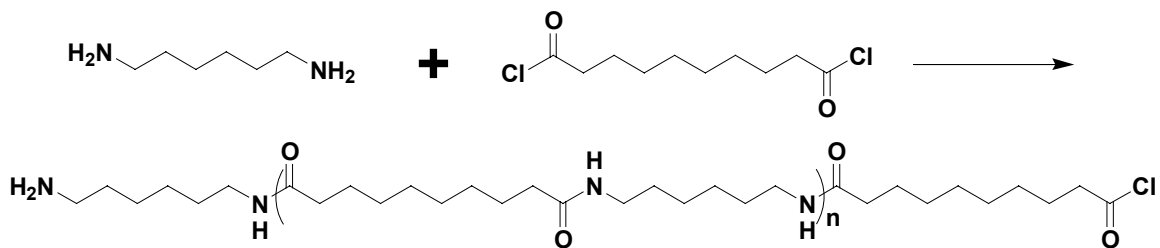
Procedure

Pour approximately 25 mL of the aqueous, basic hexamethylene diamine solution into the beakers. Very carefully, layer an equal volume of the sebacoyl chloride solution over the aqueous layer by tilting the beaker and pouring down the side. Do not stir or mix. The interface where the nylon forms will be clearly visible between the two phases. Using the tweezers, grasp the polymer film in the center of the beaker and draw it out, being careful not to let the nylon strand touch the side of the beaker. The strand can now be rapidly wound on the wire apparatus to give a rather large amount of nylon thread. The remaining monomers can be mixed using the tweezers to form a nylon blob.

Spiel

Ask for a definition of a polymer. Stress the idea of a straight chain of repeating monomer units held together by chemical bonds. Ask for natural (wool, hair, rubber, silk) and synthetic (polyester, Teflon, polystyrene, polycarbonate) examples, emphasizing the prevalence of polymers in everyday life. Discuss the effect of varying monomers to obtain different polymer properties: nylon and proteins, for example, use the same amide linkage, but contain different monomers. Conversely, when the same monomers are bonded differently, polymers having contrasting properties can result. The polysaccharides are a good example: cellulose (cotton, wood) has beta glucoside links, while starch has alpha glucoside links. You can also compare condensation polymers (such as nylon and polyester) with addition polymers (polyethylene, polystyrene, PVC, Teflon).

In this demo, a condensation polymerization takes place, as the acid chloride functionalities on both ends of the sebacoyl chloride each react with an amine to form an amide linkage.



Safety/Disposal

Wear gloves. During the mixing of the two solutions, HCl is generated and is often seen in the beaker as a vapor above the liquids. Rinse the nylon with water very well before letting anyone touch it. Put all waste from this reaction in the nylon waste container; do not put anything from this demo down the drain. Be sure to wash out the beaker well and do not leave any nylon residue on the sides because it will cause problems the next time you do this demo.

Slime!

Here is a quick, safe, and easy demonstration in which borate cross-linked poly(vinyl alcohol) gel is prepared from a water-soluble polymer, poly(vinyl alcohol).

See: J. Chem. Ed. 63, 1986, 57-61 and J. Chem. Ed. 70, 1993, 893.

Materials

50 mL 4% solution of poly(vinyl alcohol) in water (99-100% hydrolyzed, MW >100,000) (prepared by adding 40g PVA to 1L boiling water, and stirring until dissolved)

5-10 mL 4% sodium borate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) solution in water (with fluorescein and green food coloring added) (prepared by adding 8g sodium borate to 200mL water)

plastic cup

tongue depressor

Procedure

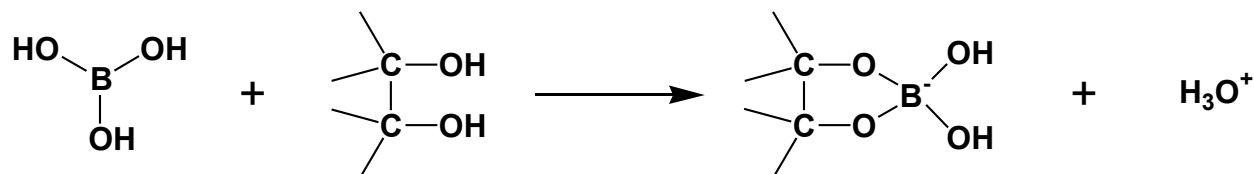
Pour approximately 50 mL of PVA solution into the cup. While rapidly stirring the solution with the tongue depressor, pour in 5-10 mL of sodium borate solution. Gelation begins almost immediately, and the consistency of the material resembles commercially available slime. Later during the light demos, you can shine UV light on your slime to make it glow.

Spiel

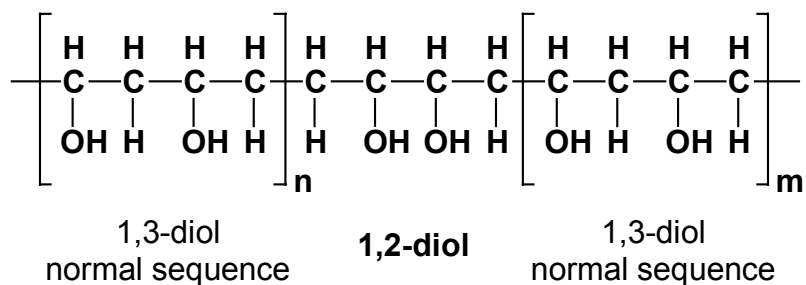
Sodium borate, or borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) is the salt of a strong base and a weak acid. In water, it hydrolyzes to form a boric acid-borate buffer, the equilibrium of which is:



Note that boric acid is so weak that it does not give up a proton, but instead, accepts hydroxide from water. At low concentrations, both boric acid and borate ion are present as the monomeric species. Boric acid/borate ion does not complex with 1,3-diols but can complex with 1,2-diols as shown:



Poly(vinyl alcohol) (PVA) is a water-soluble synthetic polymer, which has mainly 1,3-diols in its structure, but contains roughly 1-2% 1,2-diols. It is the occasional 1,2-diols that can complex with boric acid.



How does PVA interact with borate ion? Each borate can complex with two different chains of PVA, thus cross-linking the different polymer chains and making a three-dimensional network of connected chains. When the concentration of cross-linked chains is high, solvent gets immobilized within the network, and a semisolid gel is the product. Examples of networks and gels are rubber, rubber cement, Jello, fruit jellies, tofu, and yogurt. Commercial slime is the cross-linked product of guar gum and borax.

This demonstration fits in nicely after the nylon preparation, since you've already discussed polymers. You can explain that the starting material, poly(vinyl alcohol), is a polymer having long, straight chains, like pieces of spaghetti. When dissolved in water, the PVA gives a free-flowing but viscous solution. After it is cross-linked by the borax, though, the physical properties change dramatically, because the strands of PVA are now randomly linked together, with water molecules trapped within the network. If you leave the slime to dry out overnight, a thin, rigid "potato chip" is obtained.

Safety/Disposal

There are no known toxic effects produced by borax, PVA, or the gel. To be on the safe side, make sure that anyone who touches the gel washes their hands afterwards. Warn the students not to get it on their clothing and of course, not to eat it! You can throw the gel in the trash, but make sure that no students try to take it with them.

Collapsible Gel

In this final polymer demo, a crosslinked network polymer swells by absorbing 100 times its weight in water, then expels the water when the network collapses.

Materials

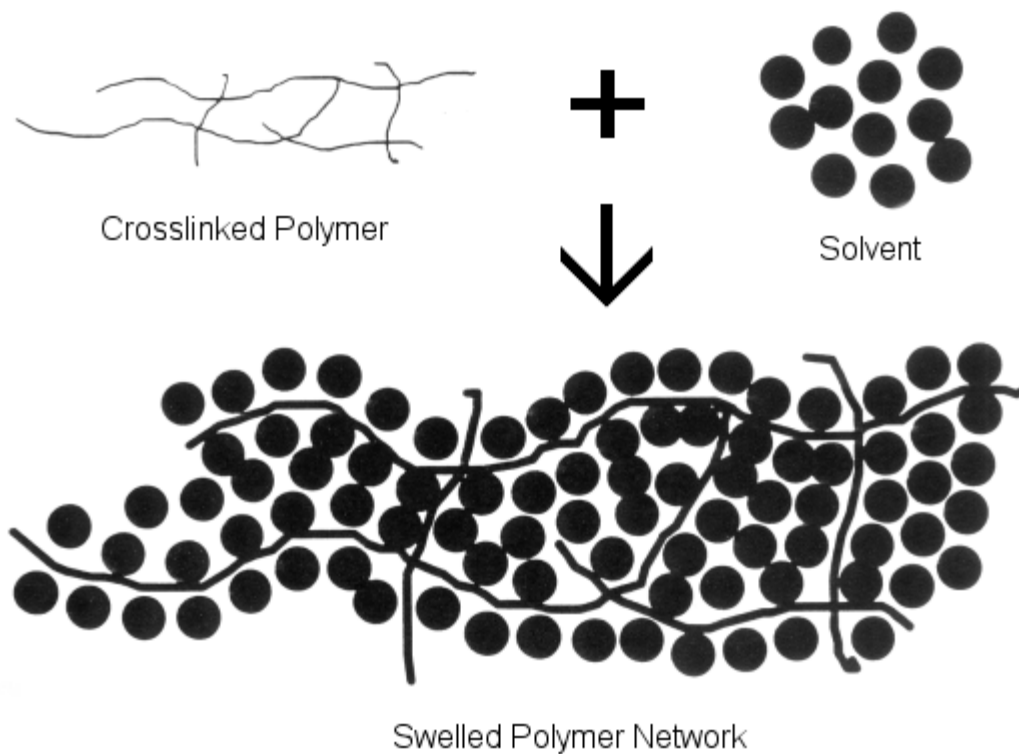
- 4 g collapsible gel powder
- 400 mL **deionized** water
- 2 g copper (II) chloride
- 2 drops yellow food coloring
- 600 mL clean beaker
- glass stirring rod

Procedure

Place 400 mL of deionized water in the beaker, and add one or two drops of yellow food coloring. Sprinkle 4 g of the collapsible gel powder into the water and stir vigorously. As you stir, the mixture should gradually start to thicken and appear “chunky”. Be patient, this usually takes a couple of minutes. When all of the water has been absorbed into the gel, show the students that it is very effective by turning the beaker upside down. (This *usually* works.) Sprinkle 2 g of CuCl_2 (the brown powder) onto the gel and stir. The gel should turn green in the region where you’ve sprinkled the powder. Keep stirring until all of the gel appears green. The “chunkiness” of the gel should immediately begin breaking up. You could have a volunteer do all of the stirring and then tell the class how it feels. Allow the beaker to stand undisturbed. As the CuCl_2 diffuses into the crosslinked network of the gel, water will begin to diffuse out and you will see a stratification in the beaker, with the yellow water moving to the top and the gel (which will now green) moving to the bottom of the beaker. Eventually, about half of the beaker will be the yellow water layer and half will be the green gel.

Spiel

When a covalent crosslinked polymer is formed, it is one molecule. An example is a bowling ball; it is one big heavy molecule! The collapsible gel is a lightly crosslinked polyelectrolyte that is the sodium salt of polyacrylic acid. Water is an excellent solvent for polyacrylic acid, but the gel is crosslinked, but rather than dissolving in the water, it swells and traps all the water inside the network. When the CuCl_2 is added, it chelates with the polyelectrolyte, changing its dimensions and forcing the expulsion of water. The mechanism of this action is not completely known. Probably the best explanation is to say that when you add the CuCl_2 , you change the interactions between the water and the network, making the water a less effective solvent. Therefore, the network does not swell as much. The process by which the water is ejected from the network is called syneresis. The gel that we use is very similar to that used in baby diapers.



Safety/Disposal

Carefully decant the water into the sink. The gel can be thrown away. It is usually best to put it in something like a paper towel or latex glove before throwing it in the trash, so you don't make a big mess. The gel should not be eaten, but is probably non-toxic.

Light and Chemistry

The idea behind this demonstration is to show that light can be generated in at least three ways, all chemical in nature and different from the way that traditional lightbulbs work.

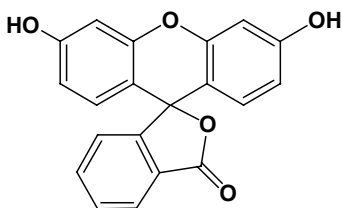
Materials

fluorescein (aqueous solution in a vial)
pasteur pipette with bulb
wide-mouth jar, filled with tap water
tonic water
glow in the dark object
glow sticks
UV lamp

Procedure/Spiel

How is light generated? The sun, incandescent lightbulbs, and hot coals all produce light using the same phenomenon: something is heated up until it glows. Halogen lights and neon signs work by exciting atoms of gas with an electric current. Three other ways to generate light, **fluorescence**, **phosphorescence**, and **chemiluminescence**, are demonstrated here.

Fluorescence. Fluorescein is the most fluorescent compound known. It is used in fitting contact lenses and in tracing groundwater, among other things.



Turn off the lights in the classroom and pull the shades if possible. Place the UV lamp over the jar of water, being careful not to shine the light in the eyes of the students. This works better if the water in the jar has had time to settle, so try not to move the jar around too much. Add a few drops of the concentrated fluorescein solution via pipette. The fluorescein glows bright green and as the drops disperse you get some pretty patterns.

What happens when a molecule fluoresces? Molecularly, it is absorption and emission of a photon. The emitted light is of a longer wavelength and lower energy than the absorbed one since the excited state usually decays to a vibrational ground state before emitting the light. Fluorescence is a very fast process, and it stops as soon as the light source is shut off.

Where can one find other fluorescent compounds? Quinine, found in tonic water, will glow blue if you pour some into a clear plastic cup and shine UV light onto it. Also, certain laundry detergents, such as Wisk, contain fluorescent additives. UV light from the sun makes your clothes glow and appear super clean! In fact, the label on the bottle often fluoresces also, presumably to catch your eye in the grocery store.

Phosphorescence. Charge up the glow in the dark object using the UV lamp and show the class the glowing object. Phosphorescent objects should be familiar to almost everybody: stick-on stars, frisbees, cereal box goodies, watch faces, posters, and so on. In contrast to fluorescence, phosphorescence is a slow process – the glowing continues even after the light source is removed. In phosphorescence, a molecule absorbs a photon and re-emits another photon as the molecule relaxes back to the ground state. Light is emitted over a long period of time because the excited molecule undergoes a transition to a different excited state, which cannot easily decay to the ground level and therefore the decay is slow.

Chemiluminescence. Usually, exothermic chemical reactions give off energy in the form of heat or infrared light. In a chemiluminescent reaction, energy is given off as visible light. The glow sticks become miniature chemical reactors when snapped and shaken. Get a volunteer and let the student break the vial inside of the glow stick. Ask why snapping it starts the reaction. You can point out that no incoming light is needed and that once the reaction has gone to completion, no further light is emitted. You can shut off the chemiluminescent reaction by freezing a glow stick in liquid nitrogen. It's more efficient but works in the same way that keeping a glow stick in the freezer does. The chemicals used in the glow stick are trade secrets.

Safety/Disposal

The water can be dumped down the drain. Let the students keep the lightsticks at the end of the show (but save them for the liquid nitrogen part later!)

The Glowing Pickle

Materials

Kosher **dill** pickle

Variac

"Pickle Box" composed of a wooden box with two nails sticking out about two inches apart. An electrical cord is attached to the heads of the nails (inside the box) using alligator clips. The cord is then plugged into the variac.

Procedure

Place a pickle on the 2 nails. Plug the cord into the variac, then turn on the variac and slowly increase the voltage flowing through the pickle (you will probably need to turn it all the way up). The pickle should begin to glow a yellow color on one end. After a few seconds, the pickle begins cooking and gives off a nasty odor.

Spiel

The yellow color is the sodium d-line. Pickles are made from cucumbers and NaCl (among other things), and the salt water solution provides a conducting path through the pickle. The NaCl also serves as a source of Na^+ ions which are reduced by the electricity to an excited state of Na^0 which relaxes down to the ground state releasing the yellow light. The Na^0 is then oxidized back to Na^+ , presumably by oxygen. This is the same color that is in sodium lamps on the Mass Pike and other places. You can talk about the different colors released by different metals. You can also mention how astronomers identify the components of stars by the colors they release.

Safety/Disposal

Throw away the fried pickle. Be careful of the nails and always turn off the variac before attaching or removing the pickle.

Temperature

This demonstration affords you a chance to play with liquid nitrogen and dry ice.

Materials

- liquid nitrogen in 4L or 10L dewar
- dry ice in styrofoam cooler
- plastic cups
- disposable latex gloves
- flowers
- raquetballs

Procedure/Spiel

Usually it helps to begin by getting the students to think about temperatures in Celsius. Ask them what room temperature is (22°). Also, you can quiz them on the boiling point (100°) and freezing point (0°) of water. Then, whip out the dry ice, which sublimates at -78.6 °C. Talk about sublimation. Throw some dry ice into a cup of water. You can also pass out small chunks of the dry ice for the students to examine. Bring out the liquid nitrogen (bp -195.8 °C). Pour some into a cup and show that it boils at room temperature. You can pour some into a glove (be careful not to freeze your partner's hands as he/she holds the glove open) and point out the effects of cooling on elasticity. Shatter the glove. You can pour some liquid nitrogen on the floor. Explain that nitrogen is the main component in the earth's atmosphere. Other things that freeze well: fresh flowers, raquetballs (used ones work better but new ones are ok). Pickles, pencils, etc. do not work well. The glow stick will completely stop glowing if immersed in liquid nitrogen (like a super-freezer!).

Safety/Disposal

Both dry ice and liquid nitrogen can cause frostbite and burns from prolonged contact with skin. When you hold the dry ice, toss it back and forth between your hands like a hot potato. If you pass it around, tell the students to do the same, and to not close their hand around it. Liquid nitrogen can be poured on the skin, as the liquid vaporizes when it nears the warm skin and so never really touches the skin. However, any jewelry (rings, watches, bracelets) that contacts the liquid nitrogen will get very cold and these items against the skin can do harm. Therefore, make sure that if you pour it on someone's hand that they have taken off their jewelry first. Do not let students take dry ice with them!