
Heat & Mass Transfer Demonstrations

A Resource for K-12 Science and Engineering Teachers

A Resource for Science Fair Project Ideas

Prepared by the Heat & Mass Transfer Class (ChE 376) at Brigham Young University

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Contact: Dr. Brad Bundy, Assist. Professor, Chemical Eng. Dept., BYU, bundy@byu.edu

Warning: These demonstrations involve substances and materials when in use have the potential to cause injury and burns. For example electricity should be used appropriately . Equipment and Hot materials such as light bulbs, hot water, hand warmers, electric fans should be used with appropriate protective equipment and according to manufacturer's specifications.

Magic Grow-Go!!

5 Minute Demonstration that explains how diffusion works by showing diffusion of water into a polymer based expanding toy

Resources Required

1. Estimated Demonstration Time: 5 minutes
2. List of Materials and Estimated Cost: Fluids (tap water, deionized distilled water, etc.), jars/beakers, expanding water toys
3. Total Project Preparation Wait Time: 72 hours (the toys need plenty of time to reach their full size in water (approximately 72 hours); this makes for the best demonstration).

Safety Precautions

1. The expanding water toys were prepared and presented in sealed-off mason jars that the children could look at but not actually touch.
2. To avoid using electrical implements at the Engineering fair itself, all heating (i.e. slow soaking in a crock pot) of the magic grow toys was done at home
3. Although growing the toys in solutions other than water might have contributed a unique contrast to the project, it was deemed too potentially hazardous (from exposure to skin, ingestion, etc.) and we decided to stick with just pure water (some of the previous candidates for other solutions included methanol and oil).
4. Although most participants in the engineering fair were middle school age or older, care must also be taken to make sure the children don't try to ingest the expanding toys that we were giving out as part of our demonstration.

Preparation Instructions

1) Obtain the Necessary Materials

- Expanding water toys, available online or at the local dollar store
- Distilled deionized water, available at most grocery stores
- Tap water (from the tap)
- Any other fluids to experiment in
- Transparent jars (i.e. beakers, mason jars) to put toys and water in

2) Prepare Handout and Practice the Demonstration

- Prepare the poster and discuss as a group how to best display the information
- Discuss as a group the main ideas we want to distill in the minds of the young
- Briefly decide which mass transfer ideas to emphasize
- Most important idea: Mass transfer in the form of diffusion is resulting in expanding water toys

3) Prepare toys by putting them in different types of fluids at least 72 hours before demo

- Put toys in different types of fluid, if final product is necessary in presentation
- Alternatively, let participants put toys in themselves, and let them see the difference day to day

Demonstration Instructions

1. Have test expanding water toys already prepared in different fluids (tap water and deionized distilled) so that the attendants can see first-hand the growth due to diffusion.
2. Give an adequate explanation of how the concentration gradient allows for water to diffuse into the rubber medium.
3. Note and explain how the expanding water toys grow at different rates depending on the fluid the toy was placed in.
3. Have magic grow toys available to give away to kids so they may do their own diffusion experiments after the fair.

Potential Discussion Questions

1. What is mass diffusion and how does it relate to the way the toys increase in size when placed in water?
2. What is a polymer and how do the characteristics of polymers affect the way expanding toys work?
3. How could polymers that absorb water be of practical use?
4. Why might the purity of the water have such a pronounced effect upon the maximum possible size of the toys? (They grow many times larger in deionized water vs. tap water)
5. Why would heat or matter want to diffuse from areas of high concentration to areas of low concentration? (Statistical mechanics)

Fun Facts and Resources



Magic Grow toys can grow up to 200 times their original size under the right conditions!
The toys grow larger in deionized water than in regular tap water.
If you put the toys in water that is too hot, they will explode (nonviolently).

The original polymer used for these expanding toys was patented by Dow Chemical.

Mass Transfer in Celery and Flowers

5-minute demonstration using dye to demonstrate mass diffusion in plants. Diffusion is important in understanding many organic processes, such as cell regulation and diffusion of oxygen into our bodies. It is also important in understanding rates of some chemical reactions..

Resources Required

- 1) Estimated Time: 5 minutes for the demonstration, and 10 minutes preparation 10-12 hours prior to demonstration.
- 2) Materials and Estimated Cost:
 - a. Cups (\$4)
 - b. Water (free)
 - c. Food coloring/dye (\$5)
 - d. Celery (\$1.50)
 - e. White flowers (varies with flower type and season)
- 3) Total Project Time
 - a. 10-12 hours from start to finish, however most time is just waiting for the dye to diffuse.

Safety Precautions

- 1) Dye will stain clothes and surfaces.
- 2) Precaution should be taken when cutting celery.

Preparation Instructions

- 1) Obtain the necessary materials
 - a. Cups, food coloring, celery, and flowers can be acquired at any grocery store.
- 2) Prepare celery and flowers at least 10-12 hours prior to demonstration.
 - a. Prepare first cup at 12 hours, and others at 2 hour increments after the initial cup.
 - b. Prepare the cup by placing the celery and/or flower stem into water-dye mixture.
 - c. Prepare another cup with half the food coloring drops at the same time as the initial cup.
 - d. Label cups, indicating how long they have been soaking.

Demonstration Instructions

- 1) Put out cups onto a table, allow children to examine the celery and flowers.
- 2) Point out differences in the flowers based upon soaking time, and concentration of dye in the water.

Potential Discussion Questions

- 1) Why does the dye go from the water in the cup to the petals of the flower?
- 2) How do you think you could dye a rose multiple different colors?
- 3) Why do we get sick if we drink too much salt water?

Fun Facts and Resources

- 1) Plant cell diffusion <http://www.gardenguides.com/135773-plant-cells-diffusion.html>
- 2) "Large redwoods move hundreds of gallons of water daily along their trunks from roots to crown. This water transpires into the atmosphere through the trees' foliage. Powered by the leaves' diffusion of water, water-to-water molecular bonds in the trees' sapwood drags the moisture upwards." <http://www.nps.gov/redw/naturescience/about-the-trees.htm>
- 3) Another link to plant cell diffusion, this one goes into much greater detail. <http://lifeofplant.blogspot.com/2011/03/osmosis-simple-diffusion-and.html>

Mass Diffusion: The Science of Smell

5 Minute Demonstration that explores how mass diffuses through solids. This is demonstrated by placing concentrated air freshener in different containers (glass, plastic, paper) and seeing how strongly we can smell the air freshener through the different barriers.

Resources Required

1. Estimated Preparation Time: 30 minutes
2. List of Materials and Estimated Cost.
 - Popcorn
 - Air Freshener
 - Plastic cups
 - Paper bags
 - Glass container
 - Cost: \$30
3. Demonstration Time: 5 minutes

Safety Precautions

1. Prevent any ingestion of toxic materials
2. Prevent any glass or other potentially sharp materials from falling

Preparation Instructions

1. Obtain 3 air fresheners.
2. Obtain a paper, plastic and glass container of approximately the same thickness.
3. Place an air freshener in each of the 3 containers. Allow to sit for 15 minutes.
4. Fill plastic cups with popcorn.

Demonstration Instructions

Mass Transfer

1. Have the students smell each of the containers.
2. See how strongly they can smell the air freshener through the different barriers. Through the paper, the air freshener can be easily detected, while they can hardly smell it at all through the glass.
3. Explain that this was a function of how well the air freshener molecules can diffuse through the solid barrier, aka Mass Transfer! This concept is important in engineering when designing vessels to house various chemical species.

Smell

1. Have the students smell the cups of popcorn.
2. Explain that every molecule species has a unique chemical and physical makeup, thus, when a pizza molecule goes in our nose, our brain recognizes from the molecules unique size and shape that it is pizza, and not a dog, or popcorn.

Potential Discussion Questions

1. Why can we smell better through some materials than others?
2. How does our nose know what we are smelling?

Fun Facts and Resources

- Diffusion through a membrane is affected by the type of membrane or barrier.
- Airborne air freshener molecules can diffuse better through certain plastics than paper bags. We hypothesized that a paper bag would undergo more diffusion than a plastic bag. However, when we tested our prediction, we found that the air freshener in the plastic bag had a stronger smell (more diffusion) than the paper bag. Only by double wrapping the air freshener in plastic were we able to have the plastic bag diffuse less of the air freshener.
- The brain detects smell by inhaling airborne molecules and detecting their size and shape.
- <http://www.tsbvi.edu/seehear/summer05/smell.htm>

Meltdown

This demonstration shows the difference between diffusion and convection in regards to both heat and mass transfer principles. Examples of diffusion are everywhere around us, from ice melting in a cup of water to oxygen getting from our blood to our cells. In industrial processes, forced convection (i.e. mixing in a continuous stirred-tank reactor) is essential in order to make a process happen quickly enough to make it economically viable.

Resources Required

1. Estimated Time: 20 min the day before to mix food coloring in water, put water in ice cube trays, and put them in the freezer. The demonstration can be 3-5 minutes depending on the depth of explanation desired for the audience.
2. Total cost: \$10-\$15 (Cost of possible water container and cooler not included)
3. Materials:
 - a. 3-4 transparent jugs (containers) for holding water (\$3)
 - b. 2 or more ice cube trays depending on number of student participants (\$2)
 - c. At least 1 container of food coloring (\$1)
 - d. Spoons (\$1.50)
 - e. Water container for repeated demonstrations (if needed and available)
 - f. Cooler to keep ice cubes
 - g. Lemonade powder (\$4)
 - h. Cups for participants to drink mixed lemonade (\$3)

Safety Precautions

1. Make sure water is potable
2. Food dye may stain, so handle with care to prevent clothing damage
3. Sanitation—make sure no foreign objects get into lemonade

Preparation Instructions

1. Add approximately 15-20 drops of food coloring to a jug of water, or until the food coloring is very concentrated
2. Pour the colored water into ice trays and freeze into cubes
3. Prepare as much lemonade as is desired for the demonstration and serve into two transparent cups/jugs
4. Fill up one additional transparent cups/jugs with hot water and another one with cold water

Demonstration Instructions

1. Add a colored ice cube to the hot water cup/jug and another one to the cold water jug
2. Observe how the hot water rapidly melts the colored ice cube and allows the food coloring to diffuse much faster through the water

- a. Mass diffusivity is higher in a liquid (water) than a solid (ice cube)
- b. The hot water melts the ice and facilitates mass transfer
- c. Food coloring transfer is much more slower in the cold water jug because it has to diffuse through the solid first, which is not melting as quickly

Now to show the effects of forced convection mass transfer:

3. Add a colored ice cube into each of the cups/jugs of lemonade
4. Have two volunteers stir the lemonade until the food coloring is transferred throughout the cup/jugs
 - a. The volunteer who stirred the fastest will accomplish this sooner because the mass convection coefficient is a function of the velocity of the lemonade
5. Serve the lemonade and enjoy!

Potential Discussion Questions

1. Why does the food coloring diffuse faster in the hot water container than in the cold water container?
2. How does the stirring speed affect the how fast the food coloring is transferred? Why?
3. What is faster diffusion or forced convection?
4. Is it easier for the food coloring to transfer through the ice cubes or through the water?

Fun Facts and Resources

1. Earthworms breathe through their skin by diffusion
2. Cells take in oxygen and expel CO_2 by diffusion. This CO_2 is then taken by blood to our lungs where it is expelled by diffusion.
3. Convection ovens cook more quickly and evenly because of a fan inside which causes heat convection
4. <http://www.sas.upenn.edu/~glauren/earthworm.html>
<http://www.livestrong.com/article/111974-lungs-work-breathe/>

Carbonated, Not Stirred

5 Minute Demonstration on Mass Transfer from Gas Phase into Liquid Solution

Resources Required

1. Estimated Time: 5 minutes of demonstration, 10 minutes of preparation, about 2 hours waiting time with occasional stirring
2. List of Materials and Estimated Cost:
 - 4 gallons of drinking water (free)
 - 5 pounds of sugar (\$3.00)
 - 6 pounds dry ice (\$10.00)
 - 1 bottle root beer extract (\$6.00)

Containers and other equipment:

- 5 gallon beverage cooler
- Stirring utensils (long handled spoon)
- Cups to sample the root beer
- Glass beaker/bowl, 1 L

Safety Precautions

1. Dry ice is extremely cold; do not handle dry ice with bare skin because of possible cold burns
2. Dry ice gives off gas – do not store in sealed or pressurized container!
3. Dry ice gives off carbon dioxide – use only in a well ventilated environment to avoid asphyxiation hazard.

Preparation Instructions

1) Obtain the Necessary Materials

All ingredients can be obtained at a typical grocery store.

2) Prepare Demonstration

Setup the demonstration as instructed below 30 minutes to an hour in advance. Be sure to save some dry ice to demonstrate outside of the cooler where the root beer is being made.

Demonstration Instructions

1. Directions for your root beer will vary by extract brand, so be sure to verify sugar and water quantities with the packaging.
2. Dissolve the sugar and extract in 2 gallons of water inside cooler. Slowly add 5lbs crushed dry ice. Once the initial bubbling has slowed, add remaining water.
3. Allow to "brew" for at least 30 minutes to ensure carbonation.
4. Fill glass beaker or bowl with water and add small pieces of remaining dry ice to demonstrate concept.

Potential Discussion Questions

1. How does carbon dioxide become mixed with the water?
2. What other things dissolve in water?
3. What are some examples of mass transfer going on in this room?

Fun Facts and Resources

What is happening here? Carbon dioxide is sublimating, or changing from a solid (dry ice) to a gas. Heat is transferring to from the water to the dry ice to provide the energy to change phases. Once the carbon dioxide has vaporized, it bubbles through the water in the container. As the bubbles travel through the water, carbon dioxide diffuses into the water, creating enough dissolved gas to create a carbonated beverage. You will undoubtedly notice the white fog that forms on top of the water and rolls down the outside of your container. This is actually water vapor that has transferred into the carbon dioxide bubbles. Carbon dioxide itself is colorless.



Dry ice in water. The white fog is actually water vapor.

Image source: <http://commons.wikimedia.org/wiki/File:DryIceSublimation.JPG>

Diffusion of CO₂ with Soda!

5 Minute Demonstration that ... teaches the scientific principle of diffusion. It demonstrates the diffusion of carbon dioxide gas through the liquid and the solid. You can also use this experiment to demonstrate how diffusion changes with temperature and the material. For instance, carbon dioxide travels more quickly through plastic bottles than through aluminum cans. The soda industry has used this principle to make their drinks fizzy but it has many other industrial applications as well. Diffusion is used extensively in creating chemical products and in pharmacokinetics (the movement of medicine through the body).....

Resources Required

1. Estimated Time: Depending on the project...
 - a. For simple diffusion of CO₂ through the soda:
 - i. 2 hours to get materials and get set up, 5 min demonstration.
 - b. For diffusion of CO₂ through the soda bottles to determine shelf life (optional):
 - i. 6-12 months (optional).

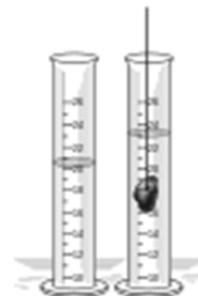
2. List of Materials and Estimated Cost.

- a. Materials
 - i. Lots of bottles of different types of sodas
 - ii. Mentos
 - iii. Graduated cylinders (shown to the right)
 - iv. Cups

If doing simple diffusion also needed are:

- v. Agitation device (hand mixer)
- vi. Large mixing bowl

- b. Estimated Cost (We anticipated 300 students)
 - i. Soda= \$.88/bottle. We purchased 20 bottles for a total of \$17.60
 - ii. Cups (very small cup for samples)= \$3.00/150 cups
 - iii. Mentos= \$3.00/pack
Total cost=\$26.60



http://commons.wikimedia.org/wiki/File:Measuring_cylindertrue_colour.png

Safety Precautions

1. This experiment has **minimal** safety hazards.
2. Spills and messes are likely to occur but no special cleanup procedures are required.
3. There is a small possibility of injury from pressure-related accidents so eyewear may be recommended.
4. Make sure not to add mentos directly to soda bottle or you might have soda all over you and everyone else watching the demonstration.

Preparation Instructions

1) Obtain the Necessary Materials

You can find the supplies at any grocery store.

2) Prepare Handout and Practice the Demonstration

If you have young kids or there are kids in the neighborhood they make for great audiences.

3) Preparation of the Materials

Take half of your already purchased soda and make it flat. This can be done by shaking, blending it, boiling it, or simply leaving it out with the cap off. Also take the mentos and cut them in half so that they can demonstrate how much CO₂ is left in the soda.

Demonstration Instructions

1. For our demonstration of mentos and soda (which unknown to most will work with any soda, diet sodas happen to have slightly more carbonation out of the bottle) we filled two graduated cylinders, one with flat soda and the other with carbonated soda. When pouring the soda in it helps to tilt the graduated cylinder so that the soda does not splash quite so much at the bottom and it retains more carbonation for the demo. Also do not fill the cylinder more than half way with soda, about a third full is good. Otherwise the fizz may come out over the top. Then at the same time drop in each a half piece of mentos that has been cut and slit. It will not "blow up" but most of the carbonation in the soda will be released and make the level of bubbles in the cylinder rise. A fun and very simple demo.
2. You can also have the kids taste a sample of the flat soda versus the carbonated soda. Then they can tell you which was has had mass diffusion of CO₂

Potential Discussion Questions

1. How long do you think it takes for soda to go flat with the lid already opened?
2. Do you think it is possible for soda to go flat when the lid hasn't been opened?
3. Is it possible for carbon dioxide to diffuse through plastic?
4. Can you think of any other ways gas diffuses through different materials?

Fun Facts and Resources

1. The first carbonated drink was produced in 1767.
2. The first carbonated water factory was built in Budapest, Hungary.
3. To find out more about diffusivity through various materials, research Fick's Law of Diffusion. This equation is what governs how quickly different materials will diffuse through one another. The diffusion coefficient (D_{AB}) is what changes for individual materials.

Convection Cyclones

Demonstrate free thermal convection in a simple and fun way! Show how warm air rises with a paper spiral and a conventional toaster. This is how certain types of space heaters are able to heat up an entire room.

Resources Required

1. Estimated Demo Time: 5 min (Preparation Time: 1 hour)
2. List of Materials and Estimated Cost.
 - Toaster: \$12.00
 - Scissors: \$2.00
 - Tape: \$1.00
 - Bottle Caps: \$0.50 each
 - Sharpened Pencil: \$0.50
 - Paper: \$0.50
 - Retort Stand: \$15.00
 - Clamp: \$3.00 each

Safety Precautions

1. Use caution as surface of toaster gets hot.
2. Don't let paper spirals fall into the toaster (Use some kind of mesh barrier, such as a wire mesh, positioned between the spirals and the toaster such that the mesh barrier isn't too hot, but prevents the spirals from falling into the toaster)
3. Handle scissors with care.

Preparation Instructions

1) Obtain the Necessary Materials

You can find most of these materials around the house or in a local store. If you want large amounts of bottle caps, they can be bought online by various wholesale sellers.

2) Prepare Handout and Practice the Demonstration

Prepare a handout that teaches the basic principles of free heat convection. Use examples such as a space heater, a campfire or a hot air balloon.

3) Set up Demonstration

Plug in toaster, set up retort stands, and attach clamps and pencils. Make a small indentation in the center of the inside of the bottle caps. Either have pre-cut spirals prepared or have spiral designs and scissors ready for students.

Demonstration Instructions

1. Cut spiral design out of paper

2. Tape center of spiral to top of bottle cap
3. Place bottle cap on top of sharpened pencil in the indentation
4. Turn on toaster
5. Wait for spiral to begin spinning

Potential Discussion Questions

1. Does free convection happen in outer space? (No, there are no air molecules in outer space)
2. What other example of convection can you think of? (Cumulonimbus clouds, ocean currents, heat from a campfire)

Fun Facts and Resources

1. Convection is the driving force for the earth's tectonic plates.
2. Cyclone demonstration with Bill Nye:
[http://teachertube.com/viewVideo.php?video_id=186395&title=Bill Nye heat 2](http://teachertube.com/viewVideo.php?video_id=186395&title=Bill+Nye+heat+2)
3. Have you ever been to the beach and felt the "sea breeze" that comes off of the ocean? This happens because of convection!
4. <http://ei.lehigh.edu/learners/energy/wind1.html>

Floating Lanterns

5 Minute Demonstration that described why heating up air would cause a lantern to float and why a constant heat source is needed

Resources Required

1. Estimated Time: 8 hours per group member
2. List of Materials and Estimated Cost.
 - Tissue paper-\$2 for 5 sheets, total \$10
 - Glue-\$2
 - Scissors-\$3
 - Heat Gun
 - Popsicle sticks-bag of 50 for \$2
 - Candy-\$10
3. Total Project Time: 40 hours

Safety Precautions

1. Heat gun, avoid exposure to the skin or flammable material.
2. Tape down cord to avoid tripping.
3. Scissors, adult supervision at all times to make sure children did not cut themselves.

Preparation Instructions

1) Obtain the Necessary Materials

1) You can find at any local supermarket the tissue paper (\$2 for 5 sheets in the gift wrapping section), glue (\$2), scissors (\$3), popsicle sticks (bag of 50 for \$2) and candy. Heat guns can be found at Home Depot we had one so we did not have to buy one.

Demonstration Instructions

1. Cut tissue to desired shape and glued them together to create a lantern.
2. Provided example of a lantern
3. Took measurements of the time it took lanterns to fall that are heated up compared to the fall time of lanterns that are just room temperature.

Potential Discussion Questions

1. Why do you have to have a constant heat source to keep a lantern floating?

Fun Facts and Resources

1. We realized that we needed a much larger volume inside our lantern to get it to float. We also realized that the heat inside needed to reach a much higher temperature than what a blow dryer or light bulb could provide.

The Heat Transfer Race

This project demonstrates two different types of heat transfer, conduction and convection, and factors that influence the rate of that transfer. Conduction and convection heat transfer play a large role in every aspect of engineering including design, process control, and optimization.

Resources Required

1. Estimated Demonstration Time: 5 min (Preparation time: 2 hr)
2. List of Materials and Estimated Cost.
 - Cups of different material (\$5)
 - Coffee stirrers (\$1)
 - Paper bowls (\$2)
 - Coffee Pot
 - Water Cooler
 - Ice (with cooler)
 - Water
 - Prize for the winner
 - Thermocouple
 - Timer
 - Thermos, or insulated container
 - Towel
 - Napkins (\$2)

Safety Precautions

1. To prevent burns from hot water let water cool slightly in separate insulated container.
2. Clean spills with towel to avoid slipping and potential electric shock from coffee pot.

Preparation Instructions

1) Obtain the Necessary Materials

All items can be found at a local store. Many things can be found at home, or can be substituted by something found around the house.

2) Prepare Handout and Practice the Demonstration

Prepare poster and handouts if needed. Also, you can Measure temperature of water from coffee pot to ensure that it is in a reasonable temperature range (90-125 Fahrenheit). You can also do a few trial races to see how long you should time the racers to get a substantial enough temperature difference to measure.

3) Perform Demonstration

Demonstration Instructions

1. Briefly explain factors that influence heat transfer
 - a. Convection: Newton's Law of Cooling $q = hA(T_{\infty} - T)$
 - b. Conduction: Fourier's Law $q = -kA \frac{dT}{dx}$
2. Give each participant a piece of ice (of similar size and shape). Start the race and time the participants.
3. When the time is up (or one of the participants has melted the ice) stop them and determine a winner by the size of the ice left over.
4. Next, have each participant select a cup of whatever material they choose. Fill the cups with equal amounts of water.
5. Explain the rules of the race
 - a. Participants can do whatever they want to cool the water without significantly lower the volume of water (i.e. blow on the water, stir, blow through the straw, stick finger in it, etc)
 - b. Do not drink the water
 - c. When the time is up. Each person sets the cup down and the temperature is measured
6. Determine a winner
7. Ask participants what action had the largest affect on temperature/heat transfer.

Potential Discussion Questions

1. What are some examples of convection heat transfer?
2. How can you tell that heat is transferring?
3. If something feels cold, is heat flowing into your skin, or out of it?
4. How can you increase the heat transfer rate? (see Newton's Law of Cooling, and Fourier's Law)

Fun Facts and Resources

The coolant system in your car uses convection and conduction heat transfer to cool the engine. Convection transfer cools the coolant fluid though the radiator by convection heat transfer. The fluid is then run through the engine transferring heat through a mix of convection and conduction heat transfer.

When you put on a wind breaker it helps eliminate convection heat transfer to help keep you warm.

Helpful Websites for Pictures:

<http://en.wikipedia.org/wiki/Boiling>
<http://commons.wikimedia.org/wiki/File:Ice.JPG>

Popsicle Science

5 Minute Demonstration that explains conduction and the differences between conduction in wood and metal relating to industry processes of heating and cooling

Resources Required

1. Estimated Time: 5 minutes preparation, 4 hours freezing time, 5 minute demonstration
2. List of Materials and Estimated Cost.
 - Metal stick (<\$1)
 - Small cup (<\$1)
 - Popsicle (cost varies with number of participants, about \$5 for 40 people)
 - Water
 - Cooler or Freezer
 - (Optional) Lamp (used as a heating source)
3. Estimated Cost: \$35 (for 300 people)

Safety Precautions

1. Do not run with the popsicles
2. Do not consume homemade popsicles made with unsanitary metal sticks
3. Wash hands before passing out popsicles
4. Exercise care with melted popsicles (slipping hazard), keep towel close at hand
5. Do not have too much fun

Preparation Instructions

1) Obtain the Necessary Materials

Buy some popsicles and small paper cups at your local store. You can find metal sticks at home depot. Long iron nails may be used but ensure pointed ends have been blunted.

2) Prepare Water Popsicles with metal handles

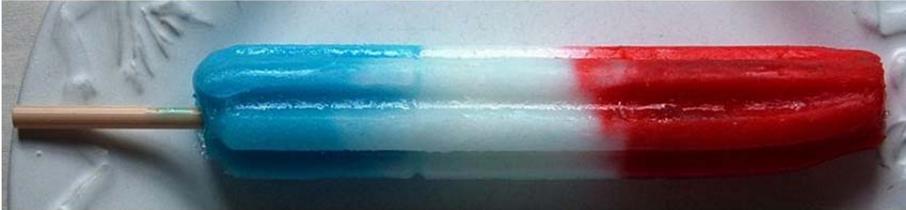
Fill the small cups with water and put the metal sticks in them so they will act as a handle after the water has frozen.

3) Freeze the Popsicles

Put the cups with water and metal sticks in a freezer and wait 4 hours while the water freezes. Keep all popsicles in a cooler or freezer until immediately prior to the demonstration.

Demonstration Instructions

1. Remove both the homemade and store bought popsicles from the freezer or cooler and have your audience touch both the wooden and metal popsicle sticks. Observe which one feels colder.
2. Now heat up each stick either by holding the sticks in your hands or by heating them next to an incandescent lamp.
3. Observe whether the ice popsicle on a metal stick or the real popsicle on a wood stick melts faster.



http://commons.wikimedia.org/wiki/File:Bomb_pop.JPG

Potential Discussion Questions

1. Which material passes heat best? Why do some materials transfer heat faster than others?
2. What are common everyday situations in which conduction can be observed?
3. Why does holding a lit match not burn your hand?
4. Why are electric stoves made from metal?

Fun Facts and Resources

Heat moving through a solid is called conduction and all materials have a different ability to move heat. This is called thermal conductivity, and is represented by the variable k ($\text{W m}^{-1} \text{K}^{-1}$).

Some common thermal conductivities include $k = .1 \text{ W m}^{-1} \text{K}^{-1}$ for wood, $k = 16 \text{ W m}^{-1} \text{K}^{-1}$ for stainless steel and $k = 1\text{-}3 \text{ W m}^{-1} \text{K}^{-1}$ for rock.

A more complete list of k values can be found at http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

A video that visually explains conduction in different materials can be found at www.youtube.com/watch?v=wV7gzckegdU

Hot, Hot Hands

5 Minute Demonstration that explains two fundamental heat transfer principles:

Radiation and Conduction.

Resources Required

1. Estimated Demonstration Time: 3-4 minutes (preparation time = 2.5 hrs)
2. List of Materials and Estimated Cost.
 - Thermal paper (40 sheets)- \$32.00 after shipping and handling
 - Insulator (any type of glove)-free to \$5.00

Safety Precautions

1. The students CANNOT ingest the paper.

Preparation Instructions

1) Obtain the Necessary Materials

The thermal paper can be purchased online. We bought 40 sheets for \$32.00 after shipping and handling. For the insulator, you can be as creative as you'd like. We used a simple glove; other ideas are a blanket, aluminum foil or regular paper.

2) Prepare Handout and Practice the Demonstration

If you have young kids or there are kids in the neighborhood they make for great audiences. The key features of the demonstration are to help the kids understand both radiation and conduction, and get them excited about science and specifically heat transfer. A set of effective questions is important to a meaningful learning experience, so consider what questions to ask during the demonstration. Base your questions off the age group you will be presenting to. A few of the questions we asked are listed below.

3) Prepare small sheets of thermal paper to give the students

We used a small paper cutter, and cut the thermal paper into 1" squares to give the students after they experienced the "Hot, Hot Hands" demonstration. Giving them these pieces of paper has a dual purpose: they will continue to think about the principles of heat transfer they learned in the demonstration, and they will show their friends and family, and might have the opportunity to explain the principles themselves! Again, the purpose of this demonstration is to help the students think and be excited about science.

Demonstration Instructions

1. Two things will make the demonstration a success: effective questions and excitement on your part. The following will be representative of how our group demonstrated this project, however feel free to modify the demonstration to what would be most effective for the students (an alternate idea will be presented at the end).
 - Have each student take a large sheet of the thermal paper, and put their hand on it. Help them understand that this paper is heat sensitive, meaning it reacts when exposed to heat. Be sure to tell them not to take their hand off the paper until you say they can.
 - Ask the question: “What is radiation?” Allow the students adequate time to think about the answer, and then help guide them with the poster if they do not have an answer. Maybe offer some examples of radiation to help them understand.
 - Ask the question: “What is conduction?” Again allow the students adequate time to think about an answer, and use the poster as necessary along with some examples.
 - After you feel they have enough understanding of these two heat transfer principles, teach them about radiation from and conduction through our bodies. Maybe ask some probing questions to make sure they understand that their bodies are constantly radiating heat. Furthermore, help them understand that conduction heat transfer occurs through their body to other surfaces they come into contact with.
 - Draw their attention to the sheet of paper that their hand is touching, and ask them to remove their hand and observe the change in the paper. Ask a follow up question: “Why did this happen?”
 - After the excitement about the color change has come to a controllable level, use the glove to help the students understand insulation. We asked specifically: “Why do gloves keep your hands warm?”
 - Give the students the small pre-cut pieces of thermal paper, and invite them to demonstrate the principles they learned to their family and friends.

Note: Alternative use of glove: have each student put a glove on one hand, and have them place both hands on the thermal paper at the beginning of the demonstration. Then teach them about insulation after they notice the hand with the glove didn't cause a color change in the paper.

Potential Discussion Questions

The questions from the demonstration are listed below:

- What is radiation?
- What is conduction?
- Questions to ensure students' understanding of radiation and conduction
- After students remove their hand from the thermal paper: why did the paper change color?
- Why do gloves keep your hands warm?

Note: The last question is the application question, and is relatively simple; you may want to adjust the application question to the level of difficulty that matches your students understanding.

Stirling Engine

5 Minute Demonstration that that will help explain how heat can be turned into work.

Resources Required

1. Estimated Demonstration Time: 5 min (Prep Time: 3-5 hours)
2. Materials
 - 1 x M6 x 15 Machine screw (not stainless)
 - 2 x M6 x 20 Washers
 - 1 x M6 nut
 - 1 x Balloon (I used a wedding balloon)
 - 1 x 300mm piece of 1mm wire (for the con rod)
 - 1 x 200mm piece of 1.6mm wire (for the cranks)
 - 1 x Roll of Steel wire wool
 - 1 x 200mm piece of 0.45mm fishing line
 - 5 x Electrical Screw blocks / terminal blocks/ choc blocks
 - 1 x Epoxy resin
 - 1 x Tuna tin
 - 2 x Pop cans (Steel works better)
 - Desk Lamp and 100 Watt light bulb
 - Tin snips
 - Drill press
 - Leather Gloves
 - Wire cutting pliers
3. Estimated Cost ~\$25.00 (Price does not include anything below Pop cans)



Safety Precautions

1. The metal can get quite hot near your heat source; we recommend not touching the can below the tuna can.
2. When putting together, wear gloves to avoid being cut by the metal while cutting holes.
3. We recommend using 100 Watt light bulb instead of candles (to avoid open flames).
4. Ask for the assistance of an expert if you use a drill press.

Preparation Instructions

1) Obtain the Necessary Materials

You can find the all the materials at a hardware and a grocery store.

2) Construct the Engine

We used the directions found at <http://www.youtube.com/watch?v=X2qssmxA82U> and <http://www.youtube.com/watch?v=5m09CJFdERc&feature=fvwp&NR=1>. After your engine is finished, pour ice-water into the middle can, heat up the bottom can, wait, and then give the wheel a push. *Hint: For it to work, everything must be aligned properly. If you have trouble getting it to work, try to adjust the lengths of the wires so they rotate naturally.*



3) Prepare Discussion Notes and Practice the Demonstration

If you have young kids or there are kids in the neighborhood, they make for great audiences.

Demonstration Instructions

For the demonstration simply discuss how the engine works. Explain principles such as radiation and how hot air expands and increases in pressure. Show them how the moving parts work. Demonstrate and explain how the interior of the engine works with an extra pop can that includes steel wool mechanism. Consider giving a treat to students who listen intently through the whole discussion.



Potential Discussion Questions

Scientific Principles

Buoyant convection and thermodynamics: The heat source causes the air in the cylinder to expand and rise. The ice water cools the air from above and causes a cold compression. The motion caused by hot air rising and cold air falling creates a convective current within the piston and generates a rising and falling motion which pushes and pulls on the drive shaft. Thermodynamically, it is explained that it takes a small amount of work to compress a gas while it is cold, while a large amount of work is generated when expanding a gas while it is hot. This process yields positive net work, which is captured and transformed into mechanical work by the drive shaft mechanism. Remember to explain that all forms of energy can be transformed. In the case of a Stirling engine (formerly called a heat engine), energy in the form of heat is transformed into mechanical work. We also call this *useful* work because we can easily use it for many applications, such as to generate electricity, drive a car, lift something, etc.

1. Where does the energy needed to turn the wheel come from? (*Heat*)
2. What type of energy is being created here? (*Mechanical Work*)
3. Does hot air weigh more or less than cold air? (*Less; that's why it rises*)
4. What are other common forms of energy? (*Potential, Kinetic, Chemical, etc.*)
5. Can these forms of energy also be converted into mechanical work? (*Yes*)

Fun Facts and Resources

LTD Stirling Engines (Low Temperature Differential) can run off the change in temperature between your hand and ice. https://www.youtube.com/watch?v=ABKmm_aBuH0

Microwaves and Heat Transfer

5 Minute Demonstration that explains heat transfer through radiation and convection that engineers use to control process temperatures of materials.

Resources Required

1. Estimated Demonstration Time: 5 min (Preparation Time: 10-15 min)
2. List of Materials and Estimated Cost.
 - Graham Crackers
 - Chocolate
 - Marshmallows(optional)
 - napkins
 - microwave
 - fan
3. Cost: If need to buy a microwave and fan approx. 20-30 dollars for those. Then for the chocolate, marshmallows and graham crackers it is approx. fifty cents to a dollar a person depending on the quality of materials.

Safety Precautions

1. Since microwaves are the primary feature of this demonstration, basic microwave safety should be observed.
 - Don't allow metal to enter the microwave during the demonstrations
 - Don't allow small children to operate the microwave
2. Be careful while handling the chocolate and materials that come out of the microwave as they can be very hot.
3. Electric cords from the microwave and the fan should be taped down to avoid tripping.

Preparation Instructions

1) Obtain the Necessary Materials

Melting chocolate in a microwave can compromise the cleanliness of the microwave, and if you'd like, a cheap microwave (and fan if you don't have one) can be purchased at your local 2nd hand store. Chocolate, graham crackers, and napkins can be purchased at a local grocery store. If sufficient funds are available, marshmallows can be purchased and added to the experiment to make smores.

2) Prepare Handout and Practice the Demonstration

As this demonstration is geared towards younger children and teenage kids, practicing on your own children or the neighbors is a great way to get ready for your demonstration. Be sure to familiarize yourself with the time it takes to sufficiently melt the amount of chocolate you will be putting in the microwave. Also, melt the demo chocolate to be placed in front of the fan well ahead of time (1-2hrs) so that it will have time to harden before your demonstration.

3) Set-up

With a fairly wide table, place the microwave on one side and the fan on the other (at about table height). Place the pre-cooled demo chocolate and graham cracker on a napkin and tape the napkin down (the fan tends to blow it around). Keep graham crackers, chocolate, and napkins close by.

Demonstration Instructions

1. To pique the interest of the students, have bars of chocolate on display asking students to teach us how a microwave heats food.
 2. Then let the students put a bar of chocolate on a graham cracker square and heat it in the microwave for 35 seconds.
 3. While the students watch the chocolate melt, explain that radiation heat transfer is occurring as the microwaves bouncing around inside the microwave excite the bonds of certain molecules inside our food (using our arms or a video to show how the bonds vibrate and rotate).
 4. Then migrate to the discussion of convective cooling by pulling the melted chocolate out of the microwave and asking the students how they normally cool down their food when it's hot (most responses should be blow on it, stick it in the freezer, etc.).
 5. Moving over to the fan, show the students the sample of chocolate that had previously been cooled in front of the fan with the convection equation displayed. Describe how increasing the air blowing over the chocolate (h coefficient) increases the transfer of heat out of the chocolate, and how the temperature difference drives heat from the chocolate into the air.
 6. As a reward, give each of the students that listen to our demonstration one of the melted bars of chocolate on graham crackers and send them on their way to educate the world.
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Potential Discussion Questions

1. What type of heat transfer do microwaves use, and what types of waves are used to accomplish this?
2. Why does placing a fan in front of a hot object help it cool down faster?

Fun Facts and Resources

Microwaves use radiation heat transfer (in the form of microwaves) to heat up foods containing lipids, carbohydrates, and water. Microwaves cause the molecules in the food to vibrate rapidly and the energy from the molecular motion is expressed as heat. Metal objects are often dangerous to place in the microwave because the molecules in metals cannot vibrate easily, so all of the energy from the microwaves builds up as an electrical current that can be dangerous.



Vacuum Freezing

5 minute demonstration to explain latent heat transfer. In the demonstration, a vacuum is used to make a liquid boil, which actually lowers the temperature of the liquid and can lead to freezing. Many life processes use latent heat transfer as a cooling mechanism and the energy change involved in phase change is important for industry to understand.

Resources Required

1. Estimated Time: 5-10 minutes
2. List of Materials and Estimated Cost.
 - Vacuum pump- \$50-\$100 (A less effective hand vacuum pump can be purchased for about \$18)
 - 100 mL flask with a connection for rubber tube + tube - \$5
 - Stopper to seal off top of flask- \$1
 - See-through protective casing-\$10
 - 25 mL water (or ethanol if a less powerful pump is used)
3. Total Project Time: 15 minutes

Safety Precautions

1. The vacuum requires an outlet so be careful with the chord. Using a chord cover or tape it down in areas of traffic.
2. You will be using glass flasks, so handle with care. There is potential for your pump to break the flask so you should wear eyewear and encase the experiment in case of an accident.

Preparation Instructions

1) Obtain the Necessary Materials

A vacuum pump and materials for an encasing can be found at a home goods store or online. The flask and rubber tube can be purchased easiest online.

2) Practice the Demonstration

This demonstration is great for young audiences from elementary to high school age. You should practice this demonstration on your own beforehand (see instructions below). It is best to set up the vacuum and flask up on a table or desk. Place the casing over the flask with the vacuum and tubing coming out of the back of the encasing.

Demonstration Instructions

1. Attach a flask half filled with water (or ethanol) to a vacuum pump

2. To introduce the demonstrations, ask a volunteer to feel the temperature of the flask. (It should be at room temperature)
3. Begin pulling a vacuum on the flask and ask what is happening to the temperature inside the flask. Explain how latent heat transfer is causing the water to freeze
4. Allow the students to feel the flask and the obvious temperature difference
5. Apply the concept of latent heat transfer to common occurrences, etc. sweating, and explain the importance of this phenomena

Potential Discussion Questions

- 1 Why does sweating cool us down?

Sweating is the body's mechanism for keeping our body at an ideal temperature. When our body temperature rises, we excrete water or "sweat". Our body then uses heat, or "energy", from our energy reserves to evaporate the water, causing our body to return to normal conditions.

- 2 Why does decreasing pressure cause freezing?

In our demonstration, we lower the pressure, which lowers the vapor pressure, causing the water to boil. Evaporation requires energy so as the boiling continues the energy of the water decreases and causes a change in state. Additionally, freezing is based on two factors: temperature and pressure. At normal atmospheric conditions, water will freeze at 32°C which is what we are accustomed to seeing. However, when you significantly decrease the pressure, you can actually freeze water at a slightly higher temperature. We would have to dramatically decrease the pressure to see any difference in water, but the concept applies.

Fun Facts and Resources

- Latent Heat Transfer is the heat required to change the phase of a substance. Different phases have different structures. Solids have tightly-packed molecules, liquids are bound but free-flowing, and gas molecules are not bound at all. Heat is required to change the state because bonds must be loosed, broken, tightened, or made. This heat does not change the temperature of the material but is all used to cause the phase transition.
- Heat is a form of energy!
- Latent Heat Transfer is everywhere! Plants and most living organisms rely on latent heat transfer to maintain homeostasis, which is the ability of an organism to maintain a constant internal environment. This is important because slight shifts in homeostasis can make you very sick. For example 98.6°F is considered normal body temperature, but increase that just two degrees and you would be considered sick and feverish!
- <http://okfirst.mesonet.org/train/meteorology/HeatTransfer.html>
- http://www.biology4kids.com/files/systems_regulation.html