Heat: An Agent of Change

Expansion and Contraction

TEACHER GUIDE

BACKGROUND INFORMATION

This lesson includes a series of short teacher demonstrations or student activities that allow students to investigate the expansion of materials on the addition of heat. It addresses the major concept that increasing molecular motion (adding heat) causes most substances to expand, while decreasing molecular motion causes most substances to contract. Choose those activities or demonstrations that will work best for getting this concept across to your students.

Water is an important exception to the general rule that heated materials expand and needs to be mentioned as such. (However, this applies only from 0^{o} C to 4^{o} C. This explains why ice floats; it is less dense than cold water.) Like the spacecraft design engineers, we are most interested in solids, particularly metals. The Genesis engineers must select materials for the spacecraft that are most appropriate for the thermal conditions they will encounter. In the vacuum of outer space, with no atmosphere to moderate them, representative temperatures on the sun-facing side of the spacecraft are expected to reach approximately 200^{o} C, while the side facing away from the sun, only about 2 feet away, will be at temperatures of approximately 20^{o} C.

This difference is caused by properties of the spacecraft materials, which absorb the sun's radiation and heat up much more readily than they emit the heat back to space. Design engineers for Genesis must control this temperature difference. They do so by putting a multi-layer insulation (MLI) on the front of the craft. While many layers act to reduce heat transfer from the front of the MLI down to the craft, a special layer contains reflective material to send the sun's rays away from the craft, preventing absorption in the first place.

STANDARDS ADDRESSED

Grades 5-8, Physical Science
Transfer of energy

Grades 9-12, Physical Science
Conservation of energy and the increase in disorder

PROCEDURE

Begin with a short class discussion. Remind students of their simulation activity in "Atoms and Molecules in Motion."

Ask:

1. Why does heat energy cause substances to expand?

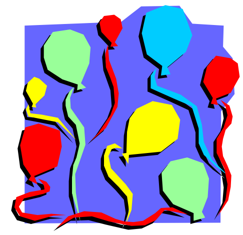
Students should respond that increased activity or motion from added heat energy requires more room.

2. What would have been the effect of the increased molecular motion if our open, marked-off area had been enclosed, such as a small room with no door and flexible rubber walls like a balloon? What if it had fragile glass walls? Heavy-duty steel walls?" You are working up to the question, "Does every substance expand or contract due to increased or decreased molecular motion at the same rate or in the same manner?"

Choose one or more of the following seven activities to use in your class.

1. Balloons in a Sunny Window or Out in the Cold

Background Information



A balloon can serve as a handy, flexible-sized container for a sample of air or other gas. Balloons will change in size in response to changes in temperature, according to the simplified gas law PV=kT, where P is the pressure of the gas, V is its volume, k is a constant multiplier to make the units turn out correct, and T is the temperature of the sample of gas. P, V, and T are the variables in this equation and in our experiment. In our experimental design, we are keeping the pressure constant, because the balloons are all expanding against air pressure, which can be assumed to be the same whether over the teacher's desk, in the refrigerator in the teacher's lounge, or outside on the playground in the sun.

You can see from the algebra that there is a direct relationship between volume and temperature. When the temperature increases, the volume increases, as long as the pressure remains the same. When the temperature decreases, the volume decreases proportionately. The elasticity of the balloon allows the sample of gas inside to change its volume without appreciable changes in pressure.

Prior to this activity, students should understand the need to keep all variables, except those being studied, constant during an experiment.

Materials Needed

2 dark-colored balloons for each lab group
Access to a warm place (over a radiator or out in the sunshine)
Access to a cold place (refrigerator or out in the snow)
Measuring equipment: string, rulers, measuring tapes, thermometers

Procedure

Students in their lab groups will need to decide on a procedure for ensuring that the two balloons are initially inflated identically. You may ask students to record the initial dimensions of their balloons.

One balloon of each pair should be left in a room temperature setting. The other should be put in a colder (in a refrigerator or snow bank) or hotter (in a sunny place or over a radiator) setting.

You may want students to measure and record the temperatures of each setting.

After the balloons have time to be affected by the temperature, students should again determine whether or not they are identical in size.

As a class, share results and discuss possible reasons for any differences found.

This is an experiment that is easily repeated at home. Involving family and friends can be very energizing for middle school students. Encourage your students to duplicate or extend in-class work at home as often as possible. You may want to send home a sealed bag containing two identical balloons, a short sheet of directions, and a paper for collecting data.

Additional Learning Opportunities

Encourage students to repeat the experiment at home. Ask for reports to the class the following day. Emphasize differences in techniques and similarities in results.

Try the same experiment using a freezer instead of a refrigerator.

Determine the mathematics needed in a contest to see who can create the greatest size change without breaking the balloon.

Discover whether helium-filled balloons act in similar manner.

Experiment with different colors, shapes, and composition of balloons.

2. Dancing Penny

Background Information
This demonstration is adapted from a Whelmers activity of the same name, found at www.mcrel.org/whelmers/whelm03.html. It is used here with permission.

This demonstration can be performed as a discrepant event. It is also easily performed as a student activity.

In a closed container of any gas, there is a direct relationship between temperature and pressure; as temperature increases, so does the pressure. The pressure increase is caused by the increase in motion of the gas molecules as they become warmer. The added energy from the warm hands increases the motion of the gas molecules, increasing their pressure, until they lift the coin. As some gas escapes, the coin drops back down.

Materials Needed
Penny
Empty glass soda pop bottle
Cooking oil or water

Procedure
Chilling the bottle for several minutes before presenting the demonstration will increase the effect, but is not necessary. Check ahead of time that the coin fits securely on the mouth of the bottle.

Place a few drops of water or cooking oil around the mouth of the bottle to form a seal between the coin and the lip of the bottle.

Wrap both hands around the body of the bottle. Tell students to be quiet and focus their attention on the coin.

The coin will begin to tap on the lip of the bottle. If the coin does not tap, warmed air might be escaping between the coin and the lip of the bottle. Add a few more drops of oil or water.

Elicit explanations from students. Allow them to try various methods to increase the effect. These might include rubbing their hands together to create frictional heat or chilling the bottle.

Explain that the heat from the hands was conducted through the glass of the bottle to warm up the air. Challenge students to explain why the coin moved (the warmed air expanded), and where the heat energy went (it dissipated into the surrounding air).

Additional Learning Opportunities
Manufacturers of products in aerosol cans warn consumers to keep those cans away from heat. Based on this activity, explain why this caution is valid. Use diagrams to support assertions.

3. Automatic Balloon Inflator/Deflator

Background Information
If it can, air expands when heated, becoming less dense. If it is in a rigid container, it will still attempt to expand, causing an increase in pressure in the container.

Materials Needed
Empty glass soda pop bottle
Balloon
Heat source (pan of water on a hot plate)
Cold source (pan of ice water)

Procedure
This is a classic demonstration of the expansion of trapped air when warmed and its contraction when cooled.

Show an empty glass bottle to the class. Ask what is inside it. Students will probably answer, "Nothing." Accept this answer for now.

Fit a deflated balloon securely over the mouth of the bottle. Check that there are no torn spots that could leak during the demonstration. Again ask what is in the bottle. Accept any answers.

Place the bottle in a pan of heated water. As the air inside the bottle heats up and expands, it fills the balloon, which starts to inflate.

At this point, ask again, "What is in the bottle?" Students will probably think of air at this point. Discuss that the air is getting heat from the hot water, and is expanding into the balloon.

Place the bottle into cold water. As the air cools down, the balloon will gradually deflate to its original size. If the air continues to cool below room temperature and contract, the "empty" balloon may even be sucked into the bottle!

4. Popcorn

Background Information
A raw popcorn kernel is a seed of a plant. It contains water and starch inside a tough shell or hull. Popcorn pops when it is heated because the small amount of moisture inside the unpopped kernel changes from a liquid to gas. The gaseous water vapor expands so vigorously that it explodes through the covering and blows out the starch inside.

Materials Needed
Air popper
Unpopped popcorn

Procedure
Use this as you see fit, but NEVER underestimate the power of food to help middle school students focus on information. When popping the popcorn, take appropriate safety precautions. (Does your state have a "goggle law"?) Do not allow students to forget that they are learning about heat while they are enjoying their snack.

Additional Learning Opportunities
Find out how other "popped" food products, such as Puffed Wheat, are made.
Why might old popcorn not pop as thoroughly as fresh popcorn?

5. Steam Cannon

Background Information
This demonstration is adapted from an activity of the same name, from Whelmers, Volume 1. It is used here with permission.

There are safety issues with this activity. Steam is generated in a metal pipe, which shoots a rubber stopper several feet. The stopper will shoot out with a loud pop, and it can travel up to 50 feet or more. It has enough energy to break a window. Also, hot water may spatter out the end of the pipe as well.

Practice this activity in an open area before presenting it. Observe all safety precautions.

Water changes phase, from liquid to gas, when its molecules are given sufficient heat energy. Heat energy increases the motion of the water molecules. As more heat energy is transferred from the pipe to the air and steam, the molecules push on the rubber stopper with enough force to overcome friction between the pipe and the stopper.

The First Law of Thermodynamics states that heat energy is conserved. In the case of the steam cannon, the energy transferred to the cork is dissipated into the surrounding air and whatever it hits, raising the temperature of both. If the stopper hits a wall, the temperature of the wall is increased slightly. The energy of motion is not lost.

Materials Needed
6” metal pipe in 1/2” or 3/4” diameter with one end threaded
Threaded pipe cap
Thread compound or sealing tape
Ring stand and clamp, or large pliers
Water
#2 solid rubber stopper
Propane torch

Attach the threaded pipe cap at one end of the pipe. Leave the other end open. Use thread compound or sealing tape to create an airtight seal between the pipe and the cap.

Procedure
All safety precautions must be observed.

Mount the prepared pipe to a ring stand with a clamp, or hold the pipe with a large pair of pliers. Pour 5 ml of water into the pipe. Insert the rubber stopper into the end of the pipe. Make certain the pipe is pointed in a safe direction!

As the steam cannon is being prepared, students may predict what will happen.

Use the torch to heat the end of the pipe. Have the students observe from a safe distance. Make sure they have appropriate safety equipment. (Does your state have a “goggle law”?)

Additional Learning Opportunities
Trace the energy path from the gas in the propane tank to the motion of the stopper.

6. Ball and Ring

Background Information
At room temperature the ball passes easily through the ring (or the screw head passes through the eyebolt). Heating the ring (screw head) causes it to expand. This is shown when it no longer fits through the ring (eyebolt).

If you are a showman, this demonstration works well as a "magic" trick.

Materials Needed
Ball and ring apparatus OR metal screw and eyebolt fixed onto short wooden rods
Bunsen burner

Procedure
Use appropriate safety precautions for working with a heat source.

Show that the ball (screwhead) passes easily through the ring (eyebolt). Allow students to examine the apparatus closely.

Gently heat the ball (screwhead). Now attempt to pass it through the ring (eyebolt). Ask the students what was heated and how they know it expanded.

A more spectacular demonstration may be done by leaving the ball (screwhead) inserted through the ring (eyebolt) while heating it. Then it cannot be extracted until it cools down.

7. Rubber Bands and Scissors

Background Information
Water has been discussed as an exception to the general rule that heating an object causes it to expand. Rubber is another exception. Use this activity if you do not think it will confuse your students. They need to be aware that exceptions to the general rule do exist.

Materials Needed
Ringstand and clamp
Chain of rubber bands
Scissors
Hair dryer or other source of heat

Procedure
Hang the chain of rubber bands from the ringstand clamp. Tie the scissor handles to the rubber band chain. Position the clamp so that the dangling scissors just barely swing free of the tabletop.

Ask the students what will happen when the rubber bands are heated. Gently heat the rubber bands with hot air from the hair dryer, with students observing carefully.

Additional Learning Opportunities
Investigate other materials that could be used to hold up the scissors. Do they expand or contract with heat?

AT-HOME ACTIVITIES (optional)

Run hot water over the metal lid of a jar that seems impossible to open and report to the class what happens.

Place a well-fitting metal ring in the refrigerator for a while, then try it on for size. Report to the class what happens.

Investigate (perhaps in a cookbook or microwave oven manual) the differences among regular glass, Pyrex, and quartz glass. Report findings to the class.

ASSESSMENT OPTIONS

If your students are already accustomed to identifying dependent and independent variables in experiments, a short written answer could be used as a formative assessment.

The activities listed in any section as Additional Learning Opportunities may be used as assessments as well. They may be generalized to other situations or contexts.

RESOURCES

http://unidata.ucar.edu/staff/blynds/tmp.html
"About Temperature" was prepared for middle school math teachers taking part in Project Skymath. It includes a section titled "The Kinetic Theory".

http://www.mcrel.org/whelmers/whelm21.html
Check out the "Balloon Vacuum" activity from Whelmers.

http://scifun.chem.wisc.edu/HomeExpts/HOMEEXPTS.HTML
This set of family-oriented experiments from Professor Shakhashiri includes one on rubber bands and heat.

Jacobs, S. (1994). Whelmers, Volume 1. Wichita, KS: Jake's Attic Productions.

Myers, J. (1991). What Makes Popcorn Pop? Honesdale, PA: Boyds Mills Press, Inc.