SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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National Science Education Standard—Physical Science
Conservation of Energy and the Increase in Disorder
Everything tends to become less organized and less orderly over time. Thus, in all energy transfer, the overall effect is that the energy is spread out uniformly. Examples are the transfer of energy from hotter to cooler objects by conduction, radiation, or convection, and the warming of our surroundings when we burn fuels.

Teacher Materials

Learning Sequence Item:

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Heat and the Second Law of Thermodynamics

March 1996
Adapted by: Brett Pyle and Paul Mirel

Heat, the Transfer of Thermal Energy, and the Second Law of Thermodynamics. At this level, students should be able to measure temperatures, know the definition of the calorie, do simple calorimetry experiments, and make other simple measurements associated with heat transfer. The concepts of radiation, convection, and conduction should be understood in qualitative ways. Even through students will have learned the definition of work and are able to calculate work done in units of joules,they should not convert calories to joules at this level. (The practice of using joules for heat obscures the fundamental discoveries of the relationship between work and heat, beginning with the qualitative observations of Rumford in drilling cannon and culminating with the quantitative measurements by Joule. This fundamental and important relationship is lost from most science textbooks as a consequence of the compulsion of writers and publishers to use SI units exclusively.) Students should understand chemical energy and changes in matter. They should be able to determine the caloric value of an energy source (like sugar). (Physics, A Framework for High School Science Education, p. 31.)

Contents

This micro-unit was adapted by **Brett Pyle** (Grady Middle School, Houston), and
Paul Mirel (Georgetown Day School, Washington, D.C.)

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Learning Sequence

Heat, the Transfer of Thermal Energy, and the Second Law of Thermodynamics. At this level, students should be able to measure temperatures, know the definition of the calorie, do simple calorimetry experiments, and make other simple measurements associated with heat transfer. The concepts of radiation, convection, and conduction should be understood in qualitative ways. Even through students will have learned the definition of work and are able to calculate work done in units of joules,they should not convert calories to joules at this level. (The practice of using joules for heat obscures the fundamental discoveries of the relationship between work and heat, beginning with the qualitative observations of Rumford in drilling cannon and culminating with the quantitative measurements by Joule. This fundamental and important relationship is lost from most science textbooks as a consequence of the compulsion of writers and publishers to use SI units exclusively.) Students should understand chemical energy and changes in matter. They should be able to determine the caloric value of an energy source (like sugar). (Physics, A Framework for High School Science Education, p. 31.)

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
Be Specific **Activity 1**	Steamulous and Response **Activity 12**	Evaporation Cooling **Assessments 3, 4, 5**	Benjamin, Count of Rumford's Inquiry Concerning the Source of the Heat Excited by Friction **Reading 1**
What Has More Heat? **Activity 2**	Heat from Friction **Assessment 1**	Heat from Friction **Assessment 6**	An Account of James Watt and the Steam Engine **Reading 2**
The Iron Bar **Activity 3**	Refrigeration **Assessments 2, 8**	Heat/Density of Air **Assessment 7**	
Conduct Yourself Accordingly **Activity 4**		Refrigeration **Assessment 8**	
A Hunka, Hunka, Burnin' Cup **Activity 5**			
The Chimney Effect **Activity 6**			
Thank You, Fans! **Activity 7**			
Basking in the Glow **Activity 8**			
The Amazing Straw **Activity 9**			
Beats Me! **Activity 10**			
Drop Zone **Activity 11**			
Heat from Friction **Assessments 1, 6**			
Refrigeration **Assessments 2, 8**			
Evaporation Cooling **Assessments 3, 4, 5**			
Heat/Density of Air **Assessment 7**			

Suggested Sequence of Events

Event #1

Lab Activity

1. Be Specific (45 minutes)

Alternative or Additional Experiments

2. What Has More Heat? (45 minutes)

Event #2

Lab Activity

3. The Iron Bar (30 minutes)

Alternative or Additional Experiments

4. Conduct Yourself Accordingly (20 minutes)
5. A Hunka, Hunka, Burnin' Cup (45 minutes)

Event #3

Lab Activity

6. The Chimney Effect (30 minutes)

Alternative or Additional Experiments

7. Thank You, Fans! (30 minutes)

Event #4

Lab Activity

8. Basking in the Glow (30 minutes)

Alternative or Additional Experiments

9. The Amazing Straw (30 minutes)

Event #5

Lab Activity

10. Beats Me! (20 minutes)

Alternative or Additional Experiments

11. Drop Zone (30 minutes)

Event #6

Lab Activity

12. Steamulous and Response (30 minutes)

Event #7

Readings from Science as Inquiry, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science

The following readings are included with the Student Materials:

Reading 1 Benjamin, Count of Rumford's Inquiry Concerning the Source of the Heat Excited by Friction
Reading 2 An Account of James Watt and the Steam Engine

Suggested additional readings:

Doherty, P., "Counting Calories." *Exploring Magazine* (Vol. 14, No. 4, 1990).
Rathjen, D., "Watt's a Joule?" *Exploring Magazine* (Vol. 18, No. 43, 1994) pp. 4–8.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay reponses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Science as Inquiry

Be Specific

To experimentally define the calorie and the specific heat of a substance.

Materials:

Per lab group:
500 mL beaker
thermometer
timer
single-element electric immersion heater
water
antifreeze

Procedure:

Have students measure between 250 and 400 mL of water and pour it into beakers. Each lab group should select a different amount of water. Students then place the thermometer in the water and record the starting temperature. They should place the immersion heater in the water and turn it on for three minutes. At the end of this time, they should record the temperature of the water and turn the heater off. They should then multiply the mass of the water times the change in the temperature. Have them empty out the water, refill the beaker with a different amount, and repeat the experiment, making sure the immersion heater has had time to completely cool.

Have the students again multiply the mass of the water times the change in the temperature. They should compare the products of mass and change in temperature for the two amounts of water and see that they are the same (within experimental error). Have the students compare their data with other groups. During discussion lead the students to the definition of the calorie as the amount of heat required to raise 1 g of water 1°C. Ask them to determine how many calories of heat the immersion heater produced during their experiments.

The above procedure serves as a calibration of the immersion heater. Students can use the caloric output of the heater to determine the specific heat of other substances. They should recognize that the specific heat of water is 1 cal/g °C based on the definition of the calorie. The formula for calculating the specific heat of any substance is:

$$\text{specific heat} = \frac{\text{quantity of heat absorbed (calories)}}{\text{mass (grams)} \times \text{change in temperature (°C)}}$$

Students should use the data to determine that the specific heat for water is 1.0 cal/g °C. Next have the students repeat the experiment using antifreeze. They should collect the data in the same manner as before, using the same immersion heater and heating for the same amount of time. In this way, they know how many calories the heater will produce in three minutes. By measuring the mass of the antifreeze and its change in temperature, they can calculate its specific heat.

Background:

Every substance has a characteristic specific heat that is unique to that substance. Since the calorie is defined as the amount of heat required to raise 1 g of water 1 ºC, then its specific heat is by definition 1 cal/g °C. This means that it takes 1 calorie of heat to raise 1 gram of water 1 degree Celsius. Also, if 1 calorie of heat is removed from 1 gram of water, its temperature will drop 1 °C.

After measuring the specific heat of antifreeze and determining that it is less than water, students may wonder why it is used in a car instead of pure water. Normally auto manufacturers recommend a 50-50 mixture. The specific heat of the 50-50 mixture is about 0.8 cal/g °C. Therefore it is not as good a coolant as pure water. However, mixing in antifreeze lowers the freezing point below 0 °C. If the water in your coolant system freezes it will expand and crack the engine block or radiator. In addition, the coolant's temperature rises as it absorbs heat from the engine. If the temperature of the coolant reaches its boiling point, then the system boils over. The addition of antifreeze also raises the boiling point above the 100 °C of pure water. This allows the system to continue cooling at temperatures above 100°C.

Further Variations:

The students could experimentally determine the specific heat of a 50-50 mixture of water and antifreeze before going into the discussion of a car's cooling system.

Adapted by B. Pyle (Grady Middle School, Houston) from:
Robinson, P.G. *Conceptual Physics: The High School Physics Program Laboratory Manual*. Menlo Park, Calif.: Addison-Wesley Publishing Company, 1992.

an alternative/extension activity for Event 1

Teacher Sheet

Science as Inquiry

What Has More Heat?

Students will measure and compare the specific heat of two metals.

Materials:

Per lab group:
~100 g aluminum
~100 g copper (tubing)
calorimeter (see teacher background)
thermometer
water
500 mL beaker
hot plate
tongs

Procedure:

Have students find the mass of the aluminum and copper and then place them in the beaker and cover with water. They should then bring the water to a boil. While waiting for the water to boil, students should fill the calorimeter with 100 mL of water and record an initial water temperature. They should then remove the aluminum from the boiling water, place it in the calorimeter, and wait until the temperature stops rising. Have them record this temperature as the ending temperature. They should then empty the calorimeter, replace it with cold water, and repeat the above process with the copper.

After the data are collected, students should calculate the specific heat of each metal. The formula used for this is:

$$\text{specific heat of metal} = \frac{(\text{mass of water})\ (\text{specific heat of water})\ (\Delta T \text{ of water})}{(\text{mass of metal})\ (\Delta T \text{ of metal})}$$

Background:

If you have calorimeters already constructed (or purchased) use those. If you do not, a simple calorimeter can be constructed by nesting two large styrofoam cups and placing a tightly sealed lid on the top cup. A hole should be placed in the lid into which a thermometer is inserted.

When the students use the above formula to calculate the specific heat of each metal, explain the formula's meaning. The specific heat of a substance is defined as:

$$\text{specific heat} = \frac{\text{quantity of heat absorbed (calories)}}{\text{mass (grams) X change in temperature } (^{\circ}\text{C})}$$

So by manipulating the above formula:

quantity of heat absorbed (calories) = (specific heat of the substance) (mass of substance) (ΔT of substance)

The amount of heat gained by a substance must equal the amount of heat lost by the substance it is in contact with. Thus:

(specific heat of metal) (mass of metal) (ΔT of metal) = (specific heat of water) (mass of water) (ΔT of water)

To find the specific heat of the metal tested, manipulate this formula so that:

$$\text{specific heat of metal} = \frac{(\text{mass of water})\ (\text{specific heat of water})\ (\Delta T \text{ of water})}{(\text{mass of metal})\ (\Delta T \text{ of metal})}$$

For reference purposes a table of specific heat is included here for common elements and substances.

Substance	Specific Heat (cal/g°C)
water (liquid)	1.00
aluminum	0.21
concrete	0.16
copper	0.092
silver	0.056
lead	0.038

Further Variations:

The substances used can be varied depending on availability. It would be best to choose substances of widely differing specific heats to avoid confusion due to experimental error.

Adapted by B. Pyle (Grady Middle School, Houston) from:
Rodecker, S.B. and Quon-Warner, M. *Laboratory Experiments and Activities in Physical Science.* San Diego: Spectrum Publications, 1992.

Science as Inquiry

The Iron Bar

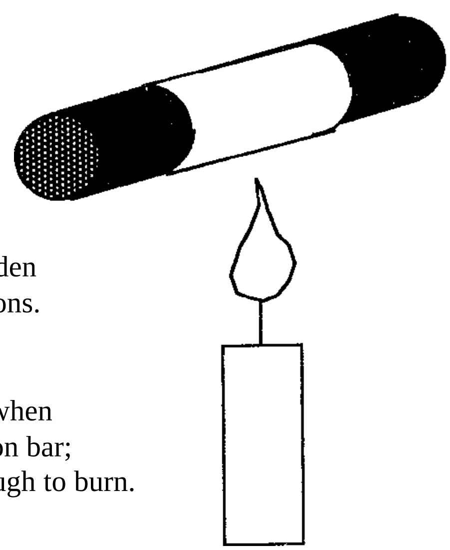
Students observe the effects of conduction.

Materials:

Per lab group:
one iron bar
one piece of wood dowel, same dimension as iron bar
sheet of paper
flame source

Procedure:

Cut the sheet of paper into pieces that will wrap around the iron bar tightly with little overlap. Have students wrap one piece around the bar and tape in place. They should then predict what will happen when they hold the paper-wrapped bar over a flame. Have them hold it as shown in the figure and record their observations.



Next have the students repeat the experiment with a wooden dowel rod of the same dimensions and record their observations.

Background:

Due to conduction, the paper will not immediately burn when wrapped around the iron bar. The heat is transferred to the iron bar; therefore, the temperature of the paper does not get high enough to burn. Paper must reach a temperature of 233 ^{o}C before it will burn.

Further Variations:

If iron bars are not available, iron bar magnets may be used. Be aware that the magnetic properties of the iron magnets may be weakened by the heating process. The use of magnets may also confuse the students in their attempt to understand what is happening. Any metal rods will work—steel, aluminum, etc.

Adapted by B. Pyle (Grady Middle School, Houston) from:
Hewitt, P., *Conceptual Physics (7th College Ed.).* Glenview: Scott, Foresman and Co., 1993.

an alternative/extension activity for Event 2

Teacher Sheet

Science as Inquiry

Conduct Yourself Accordingly

Students investigate the movement of heat energy by conduction.

Materials:

Per lab group:
candle or Bunsen burner
large paper clip
magic marker
ruler

Procedure:

Have students light the candle or Bunsen burner and place a finger about 6 cm to the side of the flame. Have them hold the finger there and note whether or not it gets hot. Then have them bend a paper clip so that it is straight. Have them mark the paper clip 6 cm from one end. They should then hold the clip at the mark and place the other end into the flame. *Tell the students to remove it and drop it if it becomes uncomfortable.* Discuss with them any observations that they may have. When discussing the movement of heat, be sure to examine whether any matter moved in order to get the heat from the flame to their finger.

Background:

The process of conduction involves the movement of heat energy through a material. The heat energy on one end of an object will cause the kinetic energy of the molecules on that end to increase and move more rapidly. As these molecules “bump” into neighboring molecules, the energy is transferred down the object to the cooler end. In the case of metals, electrons within the metal transfer energy by moving readily throughout the solid from the heated to the cooler end.

In general, objects that are made up of densely packed molecules conduct heat energy more readily than substances with loosely packed molecules (i.e., air and other gases), which do not transfer this energy as well because there are fewer molecules to “bump” into.

You may wish to have a pot holder or beaker for the students to drop hot objects on or in so that lab tables are not damaged.

Further Variations:

Students could try this experiment with a variety of materials to test which materials are better conductors of heat. Caution must be used when selecting materials to avoid objects that will catch on fire or melt. Other objects to try could include glass, aluminum foil, or wood dowel. If using a dowel choose a fairly thick piece. It may catch fire but the students should observe that the end that they are holding will not get hot even at the point when the end in the flame catches fire.

Adapted by B. Pyle (Grady Middle School, Houston) from**:**

Jewett, John W., Jr., *Physics Begins with an M: Mysteries, Magic, and Myth.* Needham Heights: Mass.: Allyn and Bacon, 1994.

Kardos, Thomas, *Physical Science Labs Kit.* West Nyack, N.Y.: The Center for Applied Research in Education, 1991.

an alternative/extension activity for Event 2

Teacher Sheet

Science as Inquiry

A Hunka, Hunka Burnin' Cup

Students will investigate the effects of heat conduction.

Materials:

Per lab group:
candle or Bunsen burner
paper cup
water
metal strainer
paper scraps
insulated metal tongs

Procedure:

First have students fill the paper cup halfway with water. Ask them to predict what will happen when they place the cup over an open flame. Then have them hold it with the tongs over the flame and observe the results. They should continue to hold the cup over the flame until the water boils. Have them remove the cup once the water begins boiling. Next have the students put a few scraps of paper inside the metal strainer and predict what will happen when they place the strainer over the flame. They should place the strainer over the flame, holding it there for several seconds, and record their observations.

Background:

In both of the above cases the paper will not catch on fire. In the first case the heat from the flame is transferred to the water by conduction through the paper. The heat is then dissipated by the evaporation of the water. The paper will not reach a temperature high enough to burn until all the water has evaporated.

In the second case the metal of the strainer conducts heat away, preventing the paper from reaching a temperature high enough to burn.

For questions 4 and 5 on the student sheet: The nail is a much better conductor than the potato and so will conduct heat to the center of the potato, helping the inside of the potato to heat up more quickly and thus cook faster. Bridges will freeze before roadways because the roadways overlie the ground, which conducts heat from the warmer earth to the water on the surface of the road. The bridge has cold air under it, and so does not have the advantage of the warm earth. For a complete discussion of additional considerations see Jewett, 1994, page 194.

Further Variations:

You may wish to allow the students to let all of the water boil out of their cup to see that the cup will not ignite until the water is gone. As a safety precaution, the students should have a can to drop the cup into once it ignites. You may also wish to have the students measure the time it takes for the paper to ignite in the strainer and compare that to the time it takes to ignite paper alone in the open flame.

Adapted by B. Pyle (Grady Middle School, Houston) from:
Jewett, John W., Jr., *Physics Begins with an M: Mysteries, Magic, and Myth*. Needham Heights: Allyn and Bacon, 1994.

Science as Inquiry

The Chimney Effect

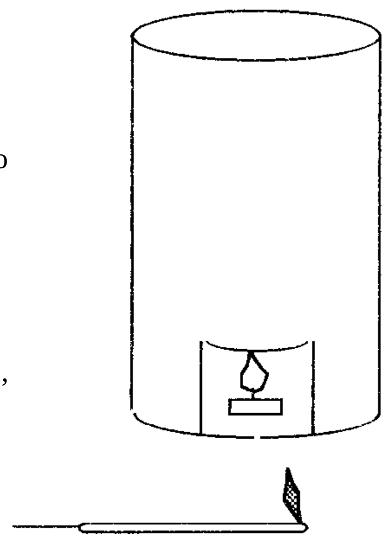
Students observe convection in air.

Materials:

Per lab group:
oatmeal box or large cardboard tube
aluminum foil
candle
stick of incense

Procedure:

Have the students cut the bottom out of an oatmeal box and then cut a 8 cm square at the bottom. Have them line the inside with aluminum foil and place a candle inside (see figure). They should light the candle and let it burn for 20–30 seconds. They should then light a stick of incense, holding it near the opening to observe the smoke pattern. Have them vary the distance of the incense stick from the opening and observe the results.



Background:

As the air in the box becomes heated from the candle, it becomes less dense and rises. As the warm air rises from the box, cooler room air flows in through the bottom opening to take its place. This air is, in turn, heated by the candle and rises. This process sets up a continuous flow of air through the box, which can be observed using the incense.

Further Variations:

Students could vary the dimensions of the container and the area of the opening. They could map the extent of the air flow using the incense and determine how far away from the container the incense can be placed and still have the smoke flow through it.

Adapted by B. Pyle (Grady Middle School, Houston) from:
Van Cleave, J. *Teaching the Fun of Physics.* New York: Prentice Hall, 1985.

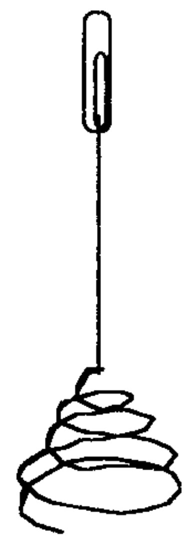
an alternative/extension activity for Event 3

Teacher Sheet

Science as Inquiry

Thank You, Fans!

Students observe the effects of convection currents in air.



Materials:

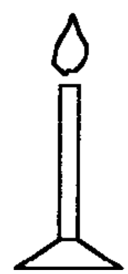
Per lab group:
paper clip
string (about 20 cm)
candle, bunsen burner, or boiling water
paper spiral (see last sheet of lab)
scissors
thermometer

Procedure:

Students should cut out the spirals that provided at the back of this lab. They should then tape the string to the middle of the spiral and tie the other end to the paper clip. After preparing the heat source (the candle, Bunsen burner, or beaker of boiling water), they should hold the paper spiral so that it is about 20 cm above the source (see figure).

Have the students record their observations and then measure the temperature of the surrounding room air and compare it to the temperature of the air where the spiral is hanging.

Background:



Warn students to be careful not to get the spiral too close to the heat source if they are using an open flame. You may want to discuss why the heated air is moving in the direction that it is.

For the student question on ceiling fans: In the summer, your ceiling fan should be running so that it is pulling air up from the ground (if it is reversible). This pulls the cooler air off of the floor and up to the ceiling where it is pushed out to the edges of the ceiling. From there it sinks back to the ground and a convection cell is set up. This helps to eliminate air temperature differences in a room. Since most of our body is not on the floor when we are sitting, standing, or even sleeping, it helps to get the cooler air into the upper part of the room.

In the winter when you have the heat on, it is best to reverse the ceiling fan so that it is blowing air downward. This pushes the hot air to the ground, where it is moved out to the edges of the room and then rises again, setting up a convection cell. Both of these methods are designed to even out the temperature between the top and bottom areas of a room, making it feel cooler in the summer and warmer in the winter.

Further Variations:

You could also demonstrate the movement of heated air by holding a stick of incense over your heat source. You have the added bonus of having a sweet smelling room at the end of the lab.

Adapted by B. Pyle (Grady Middle School, Houston) from:

Kardos, T. *Physical Science Labs Kit.* West Nyack, N.Y.: The Center for Applied Research in Education, 1991.

Teacher Sheet

Science as Inquiry

Basking in the Glow

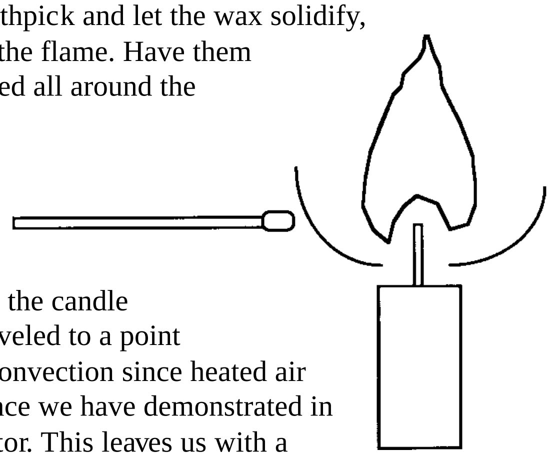
Students will observe heat transfer by radiation.

Materials:

Per lab group:
one candle
toothpick
wax shavings

Procedure:

Have students place some wax shavings on the end of the toothpick and press them so that they form a small blob on the end. Then they should bring the wax end of the toothpick close to the flame until the wax just begins to melt. They should pull back the toothpick and let the wax solidify, repeating this process around the sides and bottom of the flame. Have them make a drawing of the distance at which the wax melted all around the flame (see figure).



Background:

In this lab students must observe a heat transfer that cannot be due to conduction or convection. After they have mapped the line around the sides and below the candle flame where the wax melts, ask them how the heat traveled to a point below the flame to melt the wax. It cannot be due to convection since heated air will travel upwards. It cannot be due to conduction since we have demonstrated in an earlier lab (Activity 1) that air is actually an insulator. This leaves us with a third alternative—radiation.

Electromagnetic radiation carries energy that is absorbed by materials and can result in a rise in temperature. This radiation does not need a medium to travel through; it can pass through a vacuum. The most common form of electromagnetic radiation is light, and the absorption of heat from this type of radiation can be observed by standing in the sun or sitting by a fire.

Further Variations:

Another way to demonstrate heat transfer by radiation is to use a radiometer. The inside of a radiometer is almost completely evacuated. Therefore, the energy that makes the spinner spin can not be passed to the blades of the spinner by convection or conduction. You might also try placing a radiometer inside a vacuum pump that is located by a sunny window for even more dramatic evidence.

Adapted by B. Pyle (Grady Middle School, Houston) from:
Marson, R, *Heat*. Canby, Ore.: TOPS Learning Systems, 1990.

an alternative/extension activity for Event 4

Teacher Sheet

Science as Inquiry

The Amazing Straw

To observe heat transfer by radiation.

Materials:

Per lab group:
clear drinking straw
tape
aluminum foil
water with food coloring
candle or permanent black marker

Procedure:

Have students place a drop of colored water in the center of the straw. They should bend each end of the straw and tape closed. The ends of the straw should be airtight. Next, they should blacken one end of the straw by holding it over a candle flame (see figure), being careful not to melt the straw. A permanent black marker can also be used but may be less effective. Now they should place the straw in the sun or under a bright light and observe the movement of the colored water drop.

To make this experiment more quantitative, have the students mark the center of the water drop and place marks every centimeter in both directions. They can then chart the movement of the water bubble over a period of time. To increase the effect, they can wrap the nonblackened end of the straw with aluminum foil.

A discussion should follow about why the liquid is moving. The primary objective of this lab is for the students to observe that the heat cannot be getting to the air in the straw by convection or conduction and so it must be by radiation. The movement of the water due to expansion of the air in the blackened end can be related to the gas laws studied in micro-unit 9.02.

Background:

The water droplet moves because the trapped air in the blackened end of the straw is heated more than that in the nonblackened end. The temperature increase produces a volume increase, which forces the water away from the blackened end. Adding the foil produces even less heat absorption in the non-blackened end and makes the temperature difference even more extreme.

Further Variations:

Students could test wrapping the straw with various materials and observing the effects. They could graph the changes over time if the experiment was carried out quantitatively as described above. The volume increase could also be quantitatively determined by measuring the diameter of the straw. Volume = ð r^2l, where r=radius of the straw, and l = length that the water droplet moved.

Adapted by B. Pyle (Grady Middle School, Houston) from:
Edge, R.D., *String and Sticky Tape Experiments*. College Park, Md.: AAPT, 1981.

Science as Inquiry

Beats Me!

How can mechanical action be used to heat water?

Overview:

Do physical movements produce heat? This is an interesting problem for students to consider. This activity narrows this discussion to just the heating of water. The water's temperature is measured before and after the heating to see if there are any changes.

Materials:

Per lab group:
bowl
water
eggbeater
thermometer set

Procedure:

Provide room temperature water in a bowl for each group of students. Have each group measure and record the temperature of the water, and predict what will happen to the temperature of the water as they stir it. After students vigorously agitate the water for a few minutes, they measure the temperature of the water again.

Background:

This experiment is a qualitative version of Joule's experiment in which he measured the temperature rise in a known quantity of water when the water was stirred by a paddle driven by a falling weight. This experiment provides the basis for comparing caloric measurements of energy with mechanical measurements of energy.

Variations:

Any agitation method will work, to varying degrees depending on the strength of the agitation. Egg beaters work well, as do wire whips (whisks). Stirring with a spoon or fork will likely tire students before an appreciable temperature rise is obtained. Alternatively, supply students with jars (with lids), with which your students can then shake the water—but beware of flying glassware. Appropriate heat producing music may help establish a rhythm and a specific time limit.

Adapted from:
Cobb, Vicki, "Science Experiments You Can Eat," Harper & Row, 1972.

an alternative/additional activity for Event 5

Teacher Sheet

Science as Inquiry

Drop Zone

How can mechanical action be used to heat solids?

Overview:

Do physical movements produce heat in solids? Bags of pennies are dropped to see if this movement will change the temperature of the pennies.

Materials:

Per lab group:
cloth or freezer-weight plastic bags
10–20 lb of solids (pennies or lead shot—tin or copper)

Procedure:

Fill the bags about 3/4 full with pennies or shot. Leave enough space in the bag for the solids to move around on impact. Have students measure the temperature of the solids by nestling the thermometer in the midst of the solids. Then, have them close the bag(s) securely, and drop the bags to the ground. If students drop the bag 50 to 100 times from about one meter high, they should get an appreciable temperature rise. Have students measure the temperature as soon as possible after dropping the bags. Safety Note. Whenever students handle lead solids they must be reminded to keep their hands away from their eyes and mouths, and to wash their hands after class.

Background:

In an inelastic collision, as between soft metal and the hard floor, energy of motion is converted to random molecular motions, which manifest themselves as heat. This experiment demonstrates that mechanical energy can be converted to heat energy.

Variations:

Dropping the bags down a stairwell will also work, but it can be messy if the bags burst, and care must be taken not to hit anyone. Try the drop first to see if a measurable temperature rise occurs.

Suggest to the students that they measure the temperature after every 25 drops or so. Using the data from this experiment they could graph the number of drops vs. temperature rise. The graph will be linear for small changes in temperature, suggesting that heat and mechanical energy are linearly related.

Adapted from:
Public Domain by Paul Mirel, Georgetown Day School, Washington, D.C.

Science and Technology

Steamulous and Response

How can heat create mechanical action?

Overview:

Hero's engine is constructed in this activity to demonstrate that heat can produce mechanical movement. The steam due to the construction of the can and straws produces a spinning motion.

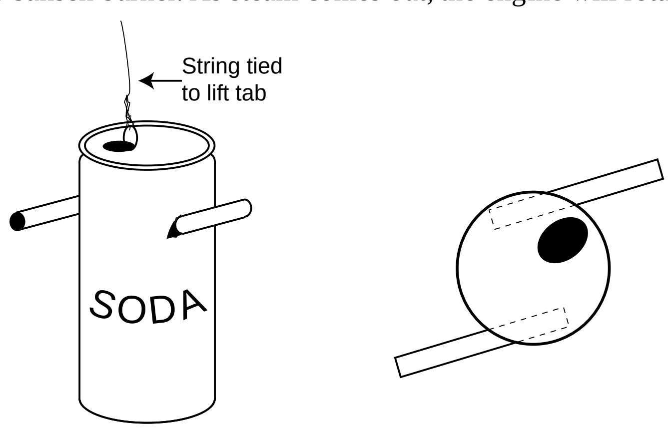
Materials:

Per lab group:

ring stand
clamps
bunsen burner
Hero's Engine
- empty soda can
- 2 plastic straws
- string
- duct tape
- scissors

Procedure:

Construct Hero's Engines (see figure). Punch holes in opposite sides of the soda can with scissors. Place the two straws in the holes and tape securely in place. Tie a piece of string to the lift tab on the soda can and tie the string to the ring stand (to support the engine at a suitable height for the burner). Have students hang the engine so it is relatively free to rotate. They should add a moderate amount of water to the Hero's engine, using enough water so that the water won't boil away immediately, but not so much that scalding hot water comes out of the jets. Then they seal the engine with tape and heat the water to boiling with the bunsen burner. As steam comes out, the engine will rotate.



Finished Hero's Engine, excluding tape over pop top and straw entry points

Top view, showing straw placement

Background:

The Hero's engine is the precursor to all modern engines. As steam exits the jets (holes at the ends of the straws) the impulse applied to the steam accelerates the steam. Since an equal but opposite impulse is applied to the jets themselves, and the direction of the impulse is applied roughly perpendicular to the diameter of the engine, the resulting torque makes the engine spin. As the engine spins, it twists the string. Energy is then stored in the torsion of the string and in the increase in height of the engine as the twisted string gets shorter.

Variations:

When connected to a spool, the engine can be used to pull up on small weights, thus demonstrating the conversion of heat to gravitational potential energy.

Adapted from:
Public domain by Paul Mirel, Georgetown Day School, Washington, D.C.

Science as Inquiry/
Science and Technology

Heat from Friction

Item

When an automobile moves down the street, the tires heat up. The faster it moves, the hotter the tires get (up to a maximum temperature).

Why does this happen and where is the heat coming from? Give as detailed an explanation as you can.

Answer;

Friction! A superior student might be able to discuss molecular motion as molecules pushing on one another and so causing some to move faster, hence heating. A really top one (?? later grades) may be able to talk about organized motion in one direction (wheel or tire rotation) becoming disorganized, random motion of molecules in the air (and rubber) in the tire—conversion of organized translational motion (kinetic energy of body) into disorganized (kinetic energy of molecules). The faster the car moves, the more motion change occurs per unit time, so more energy is distributed as heat per given time. The tire heats up to a higher temperature until the cooling rate from radiation, conduction to outside air, etc., equals the heating rate and equilibrium is reached.

Science as Inquiry/
Science and Technology

Refrigeration

Item

Joe thinks that when a refrigerator cools food, the energy is removed from the food but stays stored in the cooling system inside the refrigerator. Jane thinks that the energy must go somewhere outside the refrigerator.

Who is right and why?

Answer:

Jane is more correct, since if the refrigerator kept all of the energy that was removed from food, then it would eventually all be at the same (warmer) temperature. It cannot be a closed system. So energy must be transferred to the surroundings for the inside to be able to ‘remove’ energy from warm food.

Science as Inquiry/
Science in Personal
and Social Perspectives

Evaporation Cooling

Item

Long before the invention of air conditioners, people used fans in hot weather to help feel cooler.

Marcia claims that fans only make you feel cooler, it's just psychological—you sense the air moving across your skin.

Louis says that fanning really does help to cool you—your skin temperature does go down.

Who is right? Accepting that the fan does move air rapidly across your skin, can you explain how the science of this movement does or does not cool the skin surface?

Answer:

The cooling is real. It happens because of evaporation of surface moisture (sweat) into the moving air. As the liquid changes to gas, energy is absorbed from the surface, leaving the surface cooler.

Science as Inquiry/
Science in Personal
and Social Perspectives

Evaporation Cooling

Item

Long before the invention of air conditioners, people used fans in hot weather to help feel cooler. Using a fan to cool yourself is more effective when which of the following conditions are met?

1. The humidity is very low in the air.
2. The humidity is very high in the air.
3. You have just taken a shower and your hair is still wet.
4. You have dried your body and hair very thoroughly.

A. 1 and 3 only
B. 1 and 4 only
C. 2 and 3 only
D. 2 and 4 only

Justification:

Explain the physical principles involved in your choice of answer.

Answer:

A. Only objects with surface moisture will be cooled. The fast moving air helps the moisture evaporate. Evaporation will be faster if the humidity is low—the water content of the air can be easily increased. Evaporation cools because energy is taken up by the vibrating liquid molecules, which are breaking apart and becoming more freely moving gas molecules.

Science as Inquiry/
Science in Personal
and Social Perspectives

Evaporation Cooling

Item

Long before the invention of air conditioners, people used fans in hot weather to help feel cooler. Using a fan in a room:

A. Cools the room no matter what the conditions.
B. Cools only when the humidity is very high.
C. Cools only the people in the room.
D. Cools by moving cold air from the ceiling down to the floor.

Justification:

Explaln the scientific principles involved in your choice of answer.

Answer:

C. Only objects with surface moisture will be cooled, as the moving air helps the moisture evaporate from the surface. People perspire so they always have surface moisture.

Science as Inquiry/
Science in Personal
and Social Perspectives

Heat from Friction

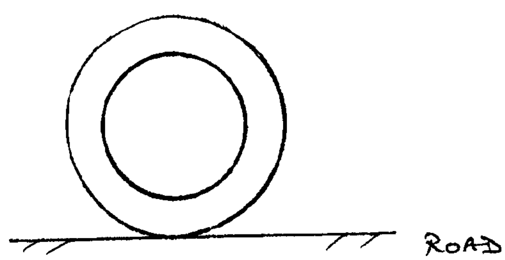
Item

In a mystery story, the detective feels the tires on a car parked in the street. "Aha!" he says, "this car was recently driven on the highway." What is the best explanation for this deduction?

A. The tires feel hot, as driving fast creates heating from friction.
B. The tires feel soft, as driving fast causes air loss from the tires.
C. The tires feel cool since driving fast causes heat loss from the tires.
D. The detective is kidding; he really cannot tell by feeling the tires if a car has just been driven.

Justification:

On the sketch of an automobile tire, add arrows to show forces on it and on the road with which it is in contact. Why might these forces cause an energy change?



Answer:

A. Friction! Forces of air molecules on the inside, plus rubber tension, balance road forces upwards, which equal forces of gravity on the vehicle downwards. The flexing of the rubber molecules in the rubber tire, because it isn't a perfect circle, probably creates most of the heating effect.

A superior student might be able to describe molecular motion as molecules pushing on one another and so causing some to move faster, hence heating. A really top one (? later grades) may be able to talk about organized motion in one direction (wheel or tire rotation) becoming disorganized random motion of molecules in the air (and rubber) in the tire —conversion of organized translational motion (kinetic energy of body) into disorganized (kinetic energy of molecules).

Science as Inquiry/
Science in Personal
and Social Perspectives

Heat/Density of Air

Item

When a volume of air near the ground level is heated, which of the following happens?

A. It expands, becomes less dense, and moves upwards.
B. It expands, becomes less dense, and moves downward toward the ground.
C. It contracts, becomes more dense, and moves upward.
D. It contracts, becomes more dense, and moves downward toward the ground.

Justification:

Explain what would happen if the air near the ground level is cooled.

Answer:

A. The particles in hot air are moving faster. They move apart to take up more space because the outside pressure (the rest of the air) remains the same. Thus they will be less dense and will rise into the cooler, more dense air surrounding them. The opposite will happen if the air volume is cooled.

Science as Inquiry/
Science and Technology/
Science in Personal
and Social Perspectives

Refrigeration

Item

Joe thinks that when a refrigerator cools food, the energy is removed from the food but stays stored in the cooling system inside the refrigerator. Jane thinks that the energy must go somewhere outside the refrigerator. What is the simplest evidence as to who is correct?

A. Joe, because the kitchen gets colder, the longer the refrigerator runs.
B. Joe, because when large amounts of food are put into the refrigerator, the ice in the ice trays starts to melt.
C. Jane, because the temperature inside the refrigerator goes up to begin with when warm food is placed inside it.
D. Jane, because the kitchen is warmer when the refrigerator is on than when it is turned off.

Justification:

Make a diagram using labeled boxes and arrows to show how heat flows from warm food that is being cooled by a refrigerator. This diagram should be consistent with your chosen answer.

Answer:

D. Jane is more correct, since if the refrigerator kept all of the energy that was removed from food, then it would eventually all be at the same (warmer) temperature. It cannot be a closed system. So energy must be transferred to the surroundings (kitchen), which is warmed by the energy from the warm food.

Science as Inquiry

Top & Bottom

Item
How will the temperature of the water at the bottom of a waterfall compare to the temperature of the water at the top of the waterfall? Explain..

Answer:

Science as Inquiry

Conversions

Item

When you rub your hands together you convert the mechanical motion of your hands to heat. What could you do to heat your hands more rapidly? What liquids do you think would make heating your hands this way more effective or less effective?

Answer:

Science as Inquiry

Power Drilling

Item

As you use a power drill, the bit often heats up. What is going on here? Why do machinists use an oil and water spray to protethe drill bit when they drill holes in metal?

Answer:

Science as Inquiry

Rug Burns

Item

Is a rug burn actually caused by heat? That is, when you slide along a carpet, is the injury more like a scrape or more like a burn from a hot object? Explain why you believe your answer to be true.

Answer: