Heat and Thermal Energy Transfer

Strand Thermal Energy

Topic Investigating heat and thermal energy transfer

Primary SOL PS.7 The student will investigate and understand temperature scales, heat, and thermal energy transfer. Key concepts include
- b) phase change, freezing point, melting point, boiling point, vaporization, and condensation;
- c) conduction, convection, and radiation.

Related SOL PS.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which
- b) length, mass, volume, density, temperature, weight, and force are accurately measured;
- c) conversions are made among metric units, applying appropriate prefixes;
- d) triple beam and electronic balances, thermometers, metric rulers, graduated cylinders, probeware, and spring scales are used to gather data;
- f) independent and dependent variables, constants, controls, and repeated trials are identified;
- g) data tables showing the independent and dependent variables, derived quantities, and the number of trials are constructed and interpreted;
- i) frequency distributions, scatterplots, line plots, and histograms are constructed and interpreted;
- j) valid conclusions are made after analyzing data;
- k) research methods are used to investigate practical problems and questions;
- l) experimental results are presented in appropriate written form;
- n) current applications of physical science concepts are used.

PS.7 The student will investigate and understand temperature scales, heat, and thermal energy transfer. Key concepts include
- a) Celsius and Kelvin temperature scales and absolute zero;
- d) applications of thermal energy transfer.

Background Information

Thermal energy is the total internal energy of a substance and is measured in the unit calorie (c) or kilocalorie (C). A calorie refers to the amount of energy required to raise the temperature of 1 g of water 1°C. *Heat* is the transfer of thermal energy and is measured in the same unit as energy. Heat can be transferred between substances in three ways—conduction, convection, and radiation.

Conduction is the transfer of thermal energy through a series of collisions between adjacent atoms and molecules. A pot being heated on a stove is an example of conduction. The molecules from the stove are in contact with the pot, allowing the energy to be transferred. Although conduction can occur in all three states of matter, it occurs easiest in solids. *Convection* transfers thermal energy through the motion of particles. If the same pot was filled with water, convection would be responsible for transferring the energy from the heated water molecules at the bottom of the pot to the rest of the molecules in the pot. When molecules at the bottom of the pot gain thermal energy, they spread out and become less dense. Therefore, they move on top of the more densely packed molecules that are near the surface of the water, and the cooler molecules move down. As those molecules gain thermal energy, they move up and the cycle repeats itself. Convection is more likely to occur in liquids and gases, where the molecules are fluid. *Radiation* is the transfer of energy through electromagnetic waves, without needing a medium such as air or water molecules. All forms of life depend on energy transfer through radiation from the sun, heat is felt from a fire due to radiation, and fast food is kept warm under a heat lamp or infrared radiation.

Temperature is a physical property of matter and a measure of the average kinetic energy of particles in a substance. It is used to measure how hot or cold something is. Although Americans are most familiar with the Fahrenheit scale, scientists use the Celsius and Kelvin scales. The *Celsius* scale is called a centigrade scale because there are 100 degrees between the freezing (0°C) and boiling points (100°C) of water. The *Kelvin* scale is used to microscopically measure the kinetic energy of a substance. The Kelvin temperature scale was created to start at the lowest theoretical temperature possible. That temperature is called absolute zero. This is when all molecular motion stops. Therefore, the Kelvin scale starts at absolute zero or 0 K.

As thermal energy changes, the kinetic energy of molecules also changes, causing the matter to go through *phase changes*. *Boiling point* is the temperature at which matter changes from a liquid to a gas, *melting point* is the change from a solid to a liquid, and *freezing point* is the change from a liquid to a solid. A substance *vaporizes* as its energy increases and it changes from a liquid to a gas. *Condensation* occurs when a substance in the gaseous state loses energy and changes to a liquid.

Materials

- Lab report (attached)
- 16 oz to 20 oz plastic bottles—one for each group
- Ice
- Buckets or dish pans—one for each group
- Thermometers or temperature probes
- Timers
- Variety of materials to be used for insulating the bottle (e.g., Styrofoam, cloth, cardboard, cotton balls, straws, bubble wrap, aluminum foil)
- Plastic wrap
- Masking or packing tape
- A variety of cups and lids (e.g., coffee mug, cardboard cup, plastic insulated coffee cup, Styrofoam cup, glass, thin plastic cup, aluminum mug)
- Hot plate
- Small beaker
- Large glass beaker or flask
- Beaker tongs or oven mitt

Vocabulary

absolute zero, boiling point, Celsius, condensation, conduction, convection, freezing point, Kelvin, melting point, radiation, vaporization

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

1. Draw a graph on the board, labeling the x-axis as thermal energy, and the y-axis as temperature. Place an ice cube in a beaker and ask students to identify its state of matter. Place the beaker on a hot plate and have students predict what will happen once it is heated. As the ice begins to melt, ask students if all of the ice will melt at once. Discuss melting point and explain that matter requires time and energy to undergo a phase change. Ask students if the temperature increases or decreases during a phase change. Illustrate the phase change on the graph. Once the ice cube completely melts, explain how the temperature begins to rise again, showing it on the graph. Point out the bubbles that form on the bottom of the beaker and discuss where they came from. Discuss boiling point and vaporization and add it to the graph.
2. Begin by using a hot plate to boil water in a beaker or flask. While the water is heating up, lead students in a discussion on how thermal energy is being transferred from the hot plate to the glassware and throughout the water. Have students state the chemical formula for a water molecule and identify its state of matter. Ask students to draw a diagram representing water molecules in each phase on their lab reports. After the water begins to boil, have students write the chemical formula for the steam they see. Students should identify that it is still H_2O in the form of water vapor. Turn off the hot plate.
3. Display a variety of different types of cups. Ask students which of the cups would be best to hold the hot water and why. Once they have a chance to brainstorm, explain that you want to place the hot water in the cup that will retain the temperature for the longest period of time. As a class, decide on the top three choices, then distribute the water evenly between those three cups. Using a thermometer or temperature probe, measure and record the water temperature (in °C) of each cup then allow the cups to sit for 5 minutes. After 5 minutes, recheck the temperature of water in each cup and determine which cup allowed the least amount of change in temperature. Have students draw conclusions to explain the results.
4. During the 5-minute waiting period, review how conduction and convection rely on particles to transfer energy directly. Then ask students how the water in rivers, lakes, and oceans is heated and changed into vapor. Lead students in a discussion of radiation as a means of thermal energy transfer through electromagnetic waves. Review the differences between vaporization and evaporation, explaining how radiation causes water to evaporate from the surface of bodies of water. Ask students for other examples of radiation that they see in their daily lives.
5. Explain to students that they have been selected to engineer a water bottle insulator. Athletes complain that their water gets hot too fast and they would like to have a means to keep their water cold for a longer period of time.
6. Have students work in groups of three or four to choose an insulation material from the list of materials available and conduct research. Provide graphic organizers and gather relevant

Web sites for students to review during the research process, or give students key words in order to guide their search. Have students use their research to form a hypothesis and then design and implement an experiment to test it.

7. Discuss with students possible limitations (e.g., size, mass, materials) and determine constants for all groups. Some parameters might include that all experiments should
   - result in finished products that measure a specified mass (e.g., less than 200 g)
   - result in finished products that fit into a standard-size cup holder or have a specific volume
   - use the same amount of water in the bottle and ice around the bottle
   - be conducted within the same time limit
   - allow for the same number of repeated trials
   - measure temperature in degrees Celsius.
8. Have students conduct their experiments, record observations, draw conclusions, and complete their lab reports.

Assessment

- **Questions**
  - Think about how the molecular movement of a water molecule changes when thermal energy was added. In your experiment, were you observing thermal energy moving in or out of the water bottle? Explain.
  - Add a column to your data table to report the amount of temperature change in the Kelvin scale. Given that 0° C is equal to 273 K, how would you convert and record your data from degrees Celsius to Kelvin?
  - What method(s) of thermal energy transfer (conduction, convection, or radiation) allowed the heat to escape the fastest from the water bottle? Explain.
  - In the introduction, thermal energy was applied to H_2O, demonstrating phase changes. Explain what happens when thermal energy is removed from water vapor. How would you describe the motion of the molecules and the phase changes that occur?
- **Journal/Writing Prompt**
  - Identify the three types of thermal energy transfer. List examples of each type.
- **Other**
  - Research the freezing and boiling point of another element or substance. Create a graph to illustrate its phase changes.

Extensions and Connections (for all students)

- Have students follow the written procedures of their peers to conduct their own experiments. Students should then critique the quality of the procedures.
- Have students research Daniel Fahrenheit, Anders Celsius, and William Thomson to identify their significant achievements and determine the years they published their theories. Have students create an illustration that represents all three scales.

Strategies for Differentiation

- Provide a visual example (poster) of conduction, convection, and radiation and an illustration of a thermometer showing the relationship between Kelvin, Celsius, and Fahrenheit.

- Acquire a variety of images representing various forms of thermal energy transfer. Have students sort the images into groups.
- For their experiments, predetermine the materials for each group, as well as the final product parameters in order to meet time constraints and student needs.
- Have students complete the conclusion portion of the lab through a "think-pair-share" discussion on the merits of each design presented. Each team should choose the preferred design and explain its choice.
- Have students create diagrams to demonstrate the motion of the molecules as they go through various phase changes.
- Allow time for students to explore the provided materials prior to beginning the activity.
- Provide a sample of step-by-step procedures that one might follow to create his/her design. Provide product samples from previous activities to be used as models.

Lab Report

Name: ___________________________________ **Date:** _________________________

Introduction:

Chemical formula of water: ________

Chemical formula of water vapor: _______

Diagram of molecules in each phase:

Solid **Liquid** **Gas**

Experimental Design

Problem:		
Independent Variable:		Dependent Variable:
Hypothesis:		
Constants:	Control:	
Materials:		
Procedures:	Observations:	
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

Results

1. After your group has completed testing, share your research and results with the class.
2. Design a data table to record the results from all groups.
3. On a separate sheet of paper, construct a graph to compare group results. Label each axis with the appropriate variable, including units of measure and increments.

Conclusion

1. Using your data table and graph, analyze the results and form a conclusion. Include statements to support the conclusion, based on your observations.