How Fast Does Water Warm as Ice Melts?

Purpose

To have students graph the temperature of an ice-water slurry as it is heated and discover the existence of another transition plateau

Overview

Students become aware of their preconceptions by considering how hot they could heat ice water. They then test their preconceived ideas by heating an ice-water slurry and measuring its temperature. Until all the ice melts, students find that the temperature remains constant, nearly 0 degrees Celsius. They graph the data and try to make sense of the temperature plateau. Finally, the students explain what changes of state mean at the molecular level.

Key Concepts

- The temperature of ice water can rise only after all the ice has melted.
- The slope of a graph line in this activity shows the rate of temperature change.
- Temperature measures the average vibrational energy of a particle or group of particles.
- As the water in Activity 1 boiled and the ice in Activity 2 melted, the particles used the energy from the heat source to gain the extra kinetic energy required to change state. As a result, the temperature during these transitions never changed.

Context for This Activity

Mars has such low atmospheric pressure that ice at the surface would sublimate away. In this activity, students investigate the process of melting and what is involved when water changes from a solid to a liquid under everyday conditions. In Activity 5, they will take a closer look at pressure's role in maintaining ice.

Skills

- *Predicting* the outcome of an experiment
- *Writing* a procedure to test a prediction
- *Controlling* variables
- *Conducting* an experiment
- *Collecting*, *recording*, and *graphing* data
- *Drawing* conclusions and *communicating* them to others

Common Misconceptions

- The temperature of ice-water will rise as soon as heat is applied.
- Ice melts as a result of high water temperatures.
- A temperature plateau means that something is malfunctioning.

Materials

Heat source, beaker or flask, ice-water slurry, thermometer, ring stand or tripod, ring clamps, thermometer clamp, stirring rod, wire gauze (burners only), dishpan, graph paper, goggles, appropriate safety equipment (see pages 5 and 19).

Preparation

- Plan how to present the initial problem and the best way to develop a procedure.
- Set out the necessary equipment for each group. Clamp thermometers to ring stands.
- Discuss safety procedures related to heat sources, thermometers, glassware, and hot water.

Time: 2 class periods

Background

Activity 2 exposes students to yet another transition plateau—the one in which ice melts and becomes liquid water (Figure 2.1). The explanation of the ice-liquid transition plateau is much the same as the explanation of the liquid-vapor transition plateau in Activity 1. As heat is added to an ice-water slurry, the ice consumes 80 calories per gram. The ice will absorb all the heat available in order to melt. When the ice melts, it becomes water at 0 degrees Celsius, so the water remains at 0 degrees Celsius until all the ice has melted.

What is amazing is that on Mars, the ice-liquid transition plateau occurs at virtually the same temperature as the liquid-vapor transition plateau! How do the two plateaus, which are separated by about 100 degrees Celsius at sea level on Earth, end up being the same line on Mars? By the end of the module, you and your students will not only have an answer to this question, but you will understand enough about the intriguing story of water on Mars to be able to ask the same kinds of questions being asked by planetary scientists. You and your students will also learn how to use the data and images returned by NASA's missions to Mars to answer those questions (Figure 2.2).

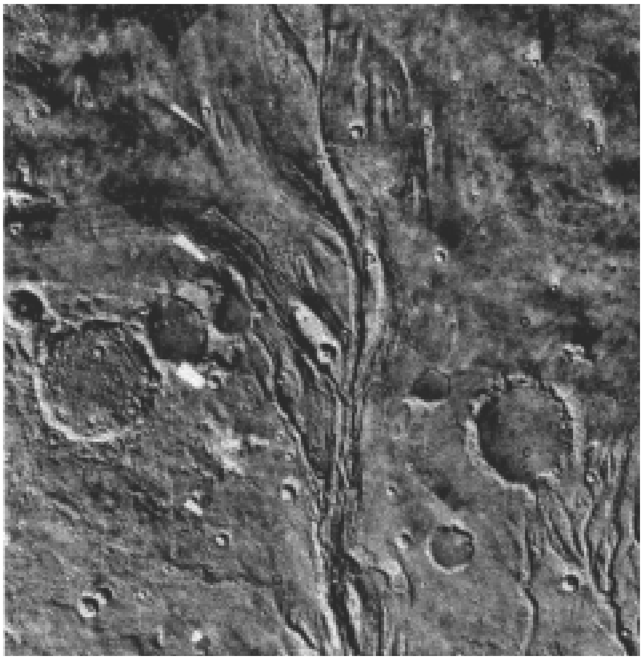

Figure 2.2. A Viking image of the channels between the Lunae Planum and the Chryse Planitia.

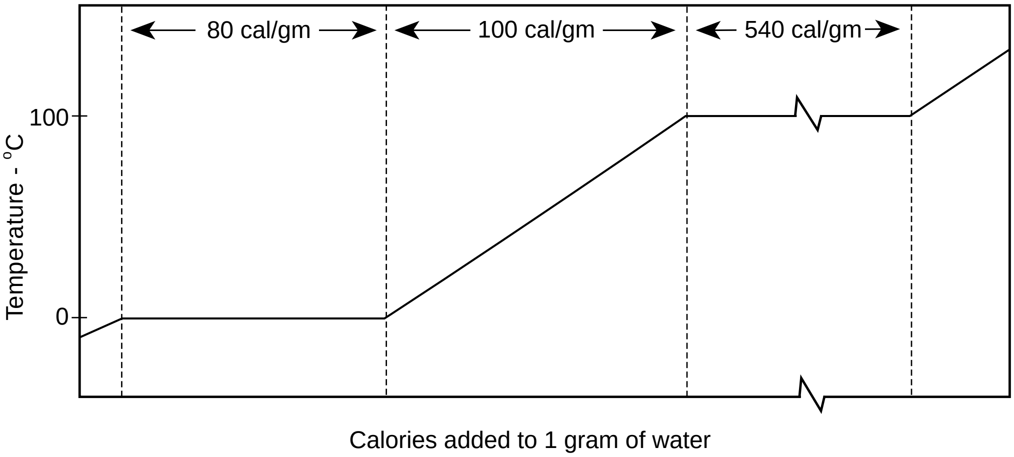

Figure 2.1. The heating curve of water shows how temperature changes as heat is added or subtracted.

Preassessment

(a) *Students Take a Position and Become Aware of Their Preconceptions:* Ask students:

- What will happen when you heat ice water?
- How hot can ice water get if given unlimited time and heating equipment?

(b) *Students Expose Their Beliefs:* Have each student write down his or her prediction, sign his or her name, and hand it in to the teacher.

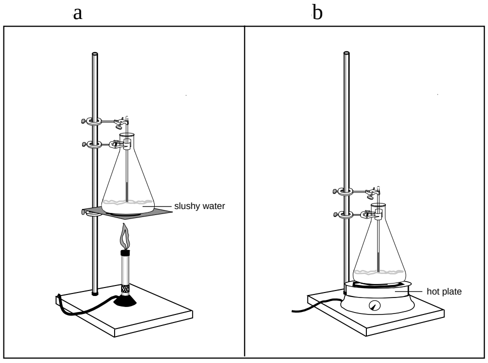

Figure 2.3. The activity set up with (a) a hot plate and (b) a burner.

Procedure to Test Students' Preconceived Ideas

1. Present the problem, "How hot can you heat ice water?" and as a class discuss how to control variables such as the amount of water, the number of burners, the height of the rings, etc.

2. Have students set up the equipment for the activity (see Figure 2.3):

   - Place crushed ice in a beaker up to the 150-milliliter line
   - Make an ice-water slurry by adding enough water to the beaker or flask to bring the ice-water mixture to the 150-milliliter line
   - Alternatively, prepare a large dishpan with the ice-water slurry and have students obtain 150 milliliters of it
   - If using a Bunsen or alcohol burner, adjust the lower ring to fit the burner properly and set a wire gauze on the lower ring
   - Place the beaker containing the slurry on the wire gauze or on the hot plate (turned off)
   - Attach the thermometer above the beaker with a clamp, string, or pipe cleaner
   - Adjust the thermometer so that the thermometer bulb is completely submerged and just above the bottom of the beaker (It should *not* touch the bottom of the beaker.)

3. Have students record the beginning temperature of the ice-water mixture.

   The temperature should be close to 0 degrees Celsius.

4. After you check each group's setup, have students either light their burners or switch on their hot plates.

5. Using a stirring rod (NOT the thermometer), have students stir and record the temperature of the ice-water mixture every 15 seconds until the water temperature reaches 25 degrees Celsius.

   Stirring is important because pockets of warm water can collect before all the ice has melted. This procedural mistake can give misleading results that take time to explain and might cause already disbelieving students to discount their observations.

   Their Activity 1 graph started at about 20 degrees Celsius. If this graph ends at 25 degrees Celsius, the graphs from the two activities can be joined to show the relationship between the two plateaus. If time permits, have students gather a continuous set of ice-to-water-to-vapor data by continuing to heat their water to boiling.

6. Have students graph their data.

   Have students use the same intervals they used for their Activity 1 graph. The graphs may be two or three papers long. If students use several sheets of paper to make their graphs, have them trim the edges and make one continuous graph.

7. Have each student make sense of the observations in his or her own way.

   This step is vital in helping students resolve any conflicts between their preconceptions and observations. By making sense of the observations, students are forced to confront their earlier thinking and to accommodate a new concept.

8. Have students share their conclusions in their groups.

9. Conduct a discussion centered on having students explain changes of state in molecular terms based on the graphs generated in Activities 1 and 2.

   Some possible ways to discuss change of state include (a) reviewing the kinetic theory and having students act out what is happening at the molecular level; (b) using flow diagrams to show how energy enters and leaves the system; (c) inventing analogies related to changes that occur after overcoming a resistance; (d) challenging students' understanding with questions similar to Analysis Questions 10–15 below.

Questions to Probe Students' Observations

1. What is the general shape of your graph? How does it compare to the shape of your neighbor's graph?

2. At what temperature did the ice in your beaker melt? How does it compare to the melting temperature of the ice in your neighbor's beaker?

3. What did you notice happening during the time the temperature plateaued?

4. How can the temperature remain steady while the hot plate/burner is still providing heat to the ice? Where is all that energy going?

Analysis Questions

These questions pertain to both Activities 1 and 2 and probe students' assumptions and understanding of boiling and melting. They are listed after Activity 2 because students will get more out of them after having direct experience with both boiling and melting. Use these questions as the basis of a discussion, for group work, or for homework.

1. How might the temperature plateau be related to the process of water boiling?
2. How might the temperature plateau be related to the process of ice melting?
3. What does the heat from the hot plate/burner do to the water molecules?
4. What does the heat from the hot plate/burner do to the ice molecules?
5. When a molecule goes from the liquid to the vapor state, how does its energy level change? What happens to its vibrational speed?
6. When a molecule goes from the solid to the liquid state, how does its energy level change? What happens to its vibrational speed?
7. Name the states of matter involved in the boiling of water.
8. Name the states of matter involved in the melting of ice.
9. Draw a cartoon panel or sequence of pictures that shows what is happening when:
   (a) The hot plate/burner is heating the water but the water has not reached the boiling point and is not boiling
   (b) The hot plate/burner is heating the water and the water has reached the boiling point and is boiling
   (c) The hot plate/burner is heating the ice, but the ice has not fully melted
   (d) The hot plate/burner has melted the ice and is now heating liquid water
10. What would you have to do to make the boiling plateau last exactly 10 minutes? An hour?
11. What would you have to do to make the melting plateau last exactly 10 minutes? An hour?
12. How is the melting of ice similar to the boiling of water? How is it different?
13. Why does water not boil at room temperature? What stops it from turning into a vapor?
14. What shape do you get when you attach the solid-to-liquid and the liquid-to-vapor graphs together? What do these shapes tell you about when water changes state?
15. Is water the only substance whose solid-to-liquid and liquid-to-vapor graphs have this shape? How could you test this idea? What differences would you predict between the change of state graphs of water and other substances?
16. Write a paragraph comparing how you answered the preassessment questions to Activities 1 and 2 with how you would answer them now.