Section 2

Changes of State

Objectives

After this lesson, students will be able to

K.2.2.1 Explain what happens to a substance during changes between solid and liquid.

K.2.2.2 Explain what happens to a substance during changes between liquid and gas.

K.2.2.3 Explain what happens to a substance during changes between solid and gas.

Target Reading Skill

Outlining Explain that using an outline format helps students organize information by main topic, subtopic, and details.

Answers

Sample outline:

Changes of State

I. Changes Between Solid and Liquid
   A. Melting
   B. Freezing
II. Changes Between Liquid and Gas
   A. Evaporation
   B. Boiling
   C. Boiling Point and Air Pressure
   D. Condensation
III. Changes Between Solid and Gas

All in One Teaching Resources

- Transparency K10

Preteach

Build Background Knowledge L2

Changing States of Water

Ask: **What happens to a puddle of water on a sunny day?** *(It dries up.)* **What happens to ice on a warm day?** *(It melts.)* **What happens to a pond in very cold temperatures?** *(It freezes.)* Encourage students to share any other experiences of water changing states. Challenge them to explain what was happening to the molecules of water.

Section 2

Changes of State

Reading Preview

Key Concepts

- What happens to a substance during changes between solid and liquid?
- What happens to a substance during changes between liquid and gas?
- What happens to a substance during changes between solid and gas?

Key Terms

- melting
- melting point
- freezing
- vaporization
- evaporation
- boiling
- boiling point
- condensation
- sublimation

Lab zone Discover Activity

What Happens When You Breathe on a Mirror?

1. Obtain a hand mirror. Clean it with a dry cloth. Describe the mirror's surface.
2. Hold the mirror about 15 cm away from your face. Try to breathe against the mirror's surface.
3. Reduce the distance until breathing on the mirror produces a visible change. Record what you observe.

Think It Over

Developing Hypotheses What did you observe when you breathed on the mirror held close to your mouth? How can you explain that observation? Why did you get different results when the mirror was at greater distances from your face?

Target Reading Skill

Outlining As you read, make an outline about changes of state. Use the red headings for the main ideas and the blue headings for the supporting ideas.

Changes in State
I. Changes Between Solid and Liquid
A. Melting
B.
II. Changes Between Liquid and Gas

Picture an ice cream cone on a hot summer day. The ice cream quickly starts to drip onto your hand. You're not surprised. You know that ice cream melts if it's not kept cold. But why does the ice cream melt?

Particles of a substance at a warmer temperature have more thermal energy than particles of that same substance at a cooler temperature. Remember from earlier that thermal energy always flows as heat from a warmer substance to a cooler substance. So, when you take ice cream outside on a hot summer day, it absorbs thermal energy from the air and your hand. The added energy changes the ice cream from a solid to a liquid.

Increased thermal energy turns an ice cream cone into a gooey mess! ▶

Lab zone Discover Activity

Skills Focus Developing hypotheses L1

Materials hand mirror, dry cloth

Time 10 minutes

Expected Outcome When held close to the face, water vapor in warm breath will condense on the mirror's cool surface, and the mirror will become clouded or fogged.

Think It Over Something clouded the surface of the mirror. Some students might explain that moisture from their warm breath condensed on the mirror's cool surface. At greater distances, the moisture in their breath dispersed in the air before reaching the mirror's surface.

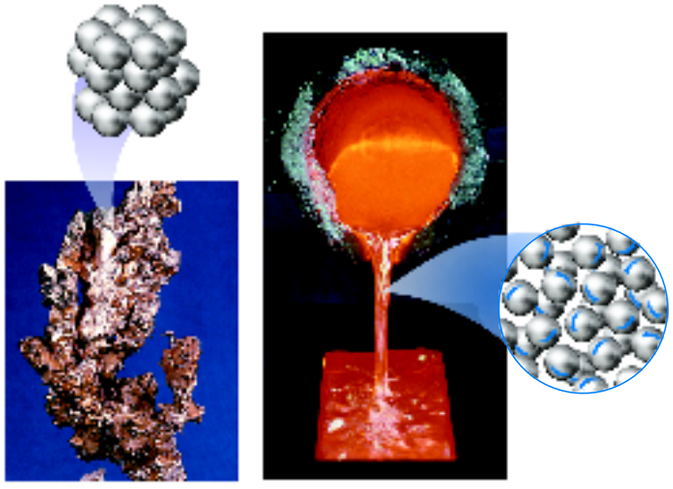


FIGURE 9
Solid to Liquid
In solid silver, atoms are in a regular, cubic pattern. Atoms in liquid (molten) silver have no regular arrangement.
Applying Concepts *How can a jewelry maker take advantage of changes in the state of silver?*

Changes Between Solid and Liquid

How does the physical state of a substance relate to its thermal energy? Particles of a liquid have more thermal energy than particles of the same substance in solid form. As a gas, the particles of this same substance have even more thermal energy. A substance changes state when its thermal energy increases or decreases sufficiently. A change from solid to liquid involves an increase in thermal energy. As you can guess, a change from liquid to solid is just the opposite: It involves a decrease in thermal energy.

Melting The change in state from a solid to a liquid is called **melting.** In most pure substances, melting occurs at a specific temperature, called the **melting point.** Because melting point is a characteristic property of a substance, chemists often compare melting points when trying to identify an unknown material. The melting point of pure water, for example, is 0°C.

What happens to the particles of a substance as it melts? Think of an ice cube taken from the freezer. The energy to melt the ice comes mostly from the air in the room. At first, the added thermal energy makes the water molecules vibrate faster, raising their temperature. **At its melting point, the particles of a solid substance are vibrating so fast that they break free from their fixed positions.** At 0°C, the temperature of the ice stops increasing. Any added energy continues to change the arrangement of the water molecules from ice crystals into liquid water. The ice melts.

Instruct

Changes Between Solid and Liquid

Teach Key Concepts L2

Melting and Freezing

Focus Tell students that particles of a substance at a warmer temperature have more thermal energy than particles of the same substance at a cooler temperature.

Teach Explain that matter changes state when thermal energy is added or removed. Ask: **How do the particles in a solid substance change when energy is added?** *(They vibrate faster.)* Diagram how the addition of energy causes particles of a solid to move faster and faster until they break free from their fixed positions. Then diagram how liquid particles move more slowly as energy is removed until they form the regular patterns of a solid.

Apply Ask: **At what point do the particles of a solid break free from their fixed positions?** *(Melting point)* **Why do different substances have different melting points?** *(They have different arrangements of particles that respond differently to added thermal energy.)* **learning modality: visual**

Independent Practice L2

All in One Teaching Resources

- Guided Reading and Study Worksheet: *Changes of State*

Student Edition on Audio CD

Differentiated Instruction

English Learners/Beginning L1
Vocabulary: Science Glossary
Pronounce the key terms *melting, freezing,* and *boiling*. Encourage students to repeat them. Define the words using pictures or motions. Suggest that students write the definitions in a glossary. They might also draw diagrams or use their primary language to help them remember meaning. **learning modality: verbal**

English Learners/Intermediate L2
Vocabulary: Science Glossary Expand on the activity at left by adding the rest of the key terms in this section. Also suggest that students write a sentence for each term in their glossaries. Model how to write the sentence using words from the text or English words they already know. Invite students to read their sentences aloud. **learning modality: verbal**

Monitor Progress L2

Oral Presentation Have students identify and describe examples of matter changing state between solid and liquid.

Answer
Figure 9 A jewelry maker can change the shape of liquid silver. The solid silver then holds the shape the jeweler has created.

Teacher Demo

Observing Melting Temperature L1

Materials large beaker, clock or stopwatch, hot plate, crushed ice or snow, stirring rod, thermometer

Time 15 minutes

Focus Ask: **What happens when thermal energy is added to a solid?** *(The solid particles move faster.)*

Teach Cover the bottom of the beaker with about 5 cm of crushed ice or snow. Insert the thermometer and carefully fill the beaker with more crushed ice or snow. Place the beaker on the hot plate and turn to medium-high heat. Stir the ice water carefully as it melts. Record temperature readings every 5 seconds until all the ice is melted. Continue heating and taking readings until the water reaches room temperature. Turn off the hot plate and remove the beaker to a heat-proof surface.

Apply Ask: **While the ice was melting, did the energy from the hot plate increase the temperature of the water?** *(No.)* **Then what happened to that energy?** *(The energy changed the arrangement of water molecules from ice crystals to liquid water.)* **learning modality: visual**

Address Misconceptions L2

Freezing Temperatures

Focus Many students may think that liquids freeze only at low temperatures.

Teach Ask: **Name solids that melt at temperatures that are higher than room temperature (about 20°C).** *(Sample answers: plastic, candle wax, chocolate, and butter)* **What happens when these materials cool from a liquid state?** *(They become solid.)*

Apply Point out that becoming a solid is the same as freezing, even when it occurs at room temperature. **learning modality: verbal**

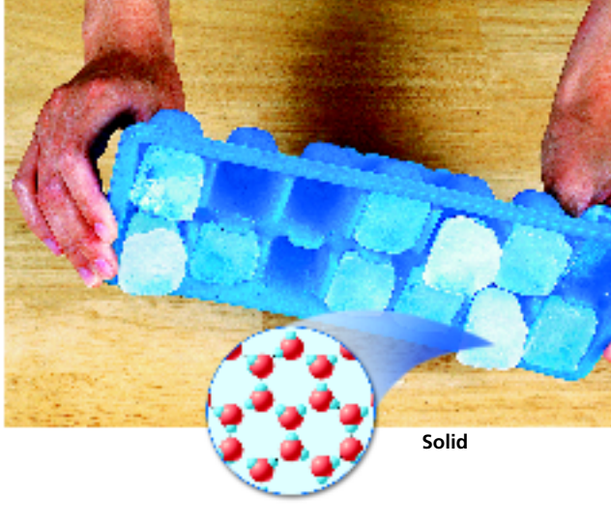


FIGURE 10
Liquid to Solid
Just a few hours in a freezer will change liquid water into a solid.

Freezing The change of state from liquid to solid is called **freezing.** It is just the reverse of melting. **At its freezing temperature, the particles of a liquid are moving so slowly that they begin to form regular patterns.**

When you put liquid water into a freezer, for example, the water loses energy to the cold air in the freezer. The water molecules move more and more slowly as they lose energy. Over time, the water becomes solid ice. When water begins to freeze, its temperature remains at 0°C until freezing is complete. The freezing point of water, 0°C, is the same as its melting point.

Reading Checkpoint What happens to the particles of a liquid as they lose more and more energy?

Try This Activity

Keeping Cool

1. Wrap the bulbs of two alcohol thermometers with equal amounts of gauze.
2. Lay the thermometers on a paper towel on a table.
3. Use a medicine dropper to put 10 drops of water on the gauze surrounding the bulb of one thermometer.
4. Using rubbing alcohol rather than water, repeat step 3 with the second thermometer.
5. Read the temperatures on the two thermometers for several minutes.

Interpreting Data Which liquid evaporates faster? Explain your answer.

Changes Between Liquid and Gas

Have you ever wondered how clouds form, or why rain falls from clouds? And why do puddles dry up after a rain shower? To answer these questions, you need to look at what happens when changes occur between the liquid and gas states.

The change from a liquid to a gas is called **vaporization** (vay puhr ih ZAY shun). **Vaporization takes place when the particles in a liquid gain enough energy to form a gas.** There are two main types of vaporization—evaporation and boiling.

Evaporation Vaporization that takes place only on the surface of a liquid is called **evaporation** (ee vap uh RAY shun). A shrinking puddle is an example. Water in the puddle gains energy from the ground, the air, or the sun. The added energy enables some of the water molecules on the surface of the puddle to escape into the air, or evaporate.

Try This Activity

Skills Focus Interpreting data L3

Materials 2 alcohol thermometers, 2 pieces of gauze, paper towel, 2 medicine droppers, water, rubbing alcohol

Time 15 minutes

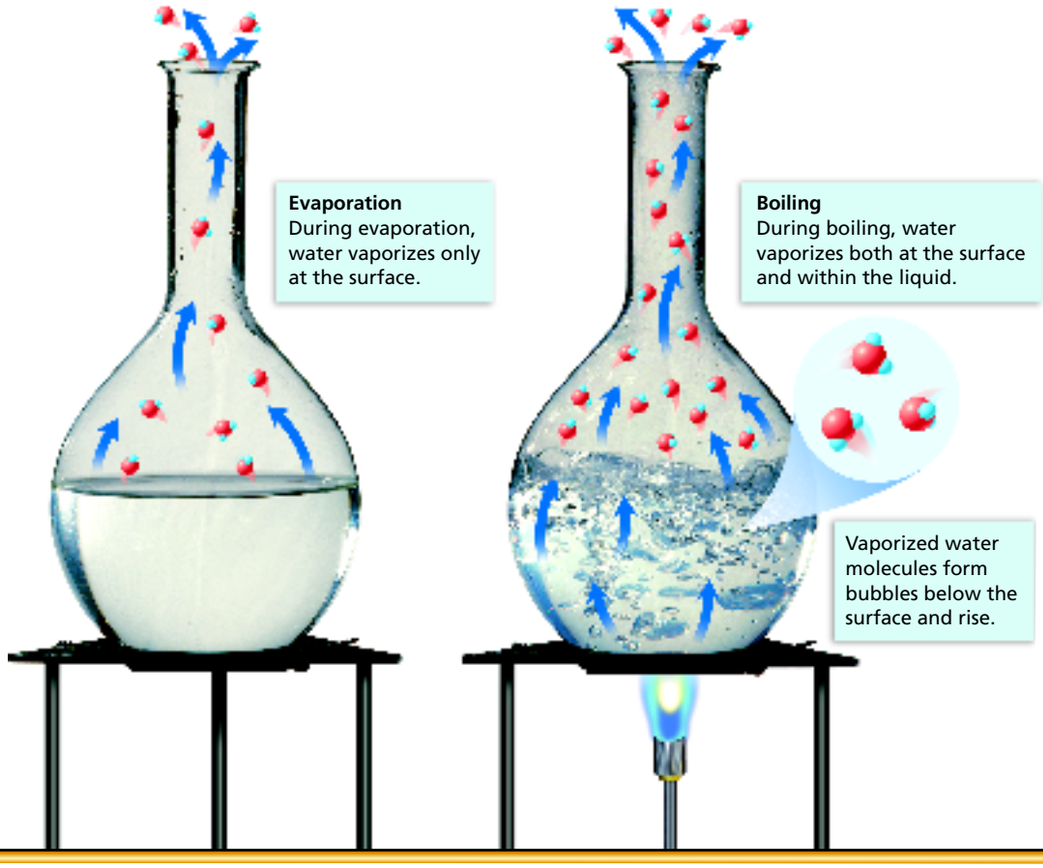
Expected Outcome The rubbing alcohol evaporates faster because it cools the thermometer more than water.

Extend Have students compare the evaporation rates of water and salt water. **learning modality: visual**

Boiling Another kind of vaporization is called boiling. **Boiling** occurs when a liquid changes to a gas below its surface as well as at the surface. You see the results of this process when the boiling liquid bubbles. The temperature at which a liquid boils is called its **boiling point.** As with melting points, chemists use boiling points to help identify an unknown substance.

Boiling Point and Air Pressure The boiling point of a substance depends on the pressure of the air above it. The lower the pressure, the less energy needed for the particles of the liquid to escape into the air. In places close to sea level, the boiling point of water is 100°C. In the mountains, however, air pressure is lower and so is water's boiling point. In Denver, Colorado, where the elevation is 1,600 meters above sea level, water boils at 95°C.

FIGURE 11
Evaporation and Boiling
Liquids can vaporize in two ways.
Interpreting Diagrams *How do these processes differ?*



Differentiated Instruction

Gifted and Talented L3
Changing the Freezing Point of Water Explain that water in the Arctic and Antarctic Oceans is colder than the normal freezing point of water (0°C). Challenge students to determine the effect of salt on the freezing point of water by designing an experiment. One way to set up the experiment is to add salt to water in a plastic container, then place a thermometer in the container, and put the containers in the freezer. Or students may fill part of an ice cube tray with water and the other part with salt water. Encourage students to carry out their experiment after you have reviewed it. **learning modality: kinesthetic**

Changes Between Liquid and Gas

Teach Key Concepts L2

Vaporization and Condensation

Focus Ask: **How are the particles of a gas different from those of a liquid?** *(Gas particles can spread far apart.)*

Teach Explain that vaporization occurs when the particles of a liquid gain enough energy to become a gas. Ask: **What do you think happens when particles in a gas lose energy?** *(A liquid can form.)*

Apply Ask: **What are some examples of vaporization?** *(Evaporating puddle, boiling water)* **Condensation?** *(Breath on mirror, clouds, a "sweating" glass)* **learning modality: visual**

All in One Teaching Resources
- Transparency K11

Lab zone Teacher Demo L1

Contrasting Evaporation and Boiling

Materials beaker, dropper, hot plate, overhead projector, water, wax pencil

Time 20 minutes

Focus Ask: **What are the two main types of vaporization?** *(Evaporation and boiling)*

Teach With the projector on, place drops of water inside a small wax circle on the overhead until the circle is almost filled. Observe the water over time. Ask: **What is happening to the water?** *(It is evaporating.)* Heat 500 mL of water in a beaker until it boils. Ask: **What is happening to the water?** *(It is boiling.)*

Apply Ask: **How do boiling and evaporation differ?** *(Only surface particles vaporize when water evaporates.)* **learning modality: visual**

Monitor Progress L2

Drawing Have students diagram evaporation and boiling.

Answers

Figure 11 Evaporation occurs only at the surface. Boiling occurs both at the surface and within the liquid.

Reading Checkpoint The particles move more and more slowly.

Math Analyzing Data

Math Skill Making and interpreting graphs

Focus Tell students that changes of state depend on temperature changes of a substance over time.

Teach Invite students to examine the graph. Point out the zigzag shape of the line. Ask: **Which variable is changing in places where the line is flat?** *(Only time)* **In places where the line moves up?** *(Both time and temperature)*

Answers

1. Temperature (°C) on the *y*-axis, time (minutes) on the *x*-axis

2. The temperature is rising from 0°C to 100°C.

3. Segment B: melting point of ice; segment D: boiling point of water

4. Change from solid to liquid; change from liquid to gas

5. Water molecules in segment E have more thermal energy because they are at a higher temperature.

All in One Teaching Resources

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Changes Between Solid and Gas

Teach Key Concepts

Sublimation

Focus Review what happens when a solid melts and a liquid evaporates.

Teach Explain that during sublimation, solids form a gas without passing through the liquid state. Ask: **When does sublimation occur?** *(When the surface particles of a solid gain enough energy to form a gas)*

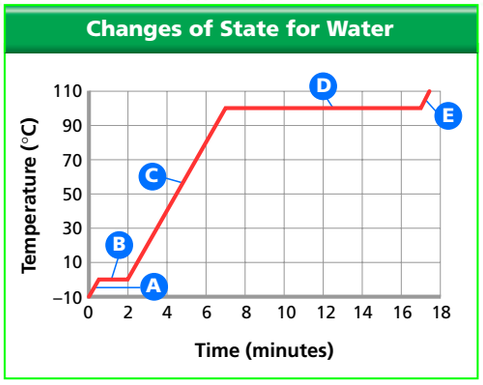
Apply Ask: **Why do ice cubes stored for a long time in the freezer get smaller?** *(The ice sublimes.)* **learning modality: verbal**

Math Analyzing Data

Temperature and Changes of State

A beaker of ice at −10°C was slowly heated to 110°C. The changes in the temperature of the water over time were recorded. The data were plotted on the graph shown here.

1. **Reading Graphs** What two variables are plotted on the graph?
2. **Reading Graphs** What is happening to the temperature of the water during segment C of the graph?
3. **Interpreting Data** What does the temperature value for segment B represent? For segment D?
4. **Drawing Conclusions** What change of state is occurring during segment B of the graph? During segment D?



5. **Inferring** In which segment, A or E, do the water molecules have more thermal energy? Explain your reasoning.

FIGURE 12
Condensation of Water
Water vapor from a hot shower contacts the cool surface of a bathroom mirror and condenses into a liquid.

Condensation The opposite of vaporization is called **condensation.** One way you can observe condensation is by breathing onto a mirror. When warm water vapor in your breath reaches the cooler surface of the mirror, the water vapor condenses into liquid droplets. **Condensation occurs when particles in a gas lose enough thermal energy to form a liquid.** For example, clouds typically form when water vapor in the atmosphere condenses into liquid droplets. When the droplets get heavy enough, they fall to the ground as rain.

You cannot see water vapor. Water vapor is a colorless gas that is impossible to see. The steam you see above a kettle of boiling water is not water vapor, and neither are clouds or fog. What you see in those cases are tiny droplets of liquid water suspended in air.

Reading Checkpoint How do clouds typically form?

Changes Between Solid and Gas

If you live where the winters are cold, you may have noticed that snow seems to disappear even when the temperature stays well below freezing. This change is the result of sublimation. **Sublimation** occurs when the surface particles of a solid gain enough energy that they form a gas. **During sublimation, particles of a solid do not pass through the liquid state as they form a gas.**

One example of sublimation occurs with dry ice. Dry ice is the common name for solid carbon dioxide. At ordinary atmospheric pressures, carbon dioxide cannot exist as a liquid. So instead of melting, solid carbon dioxide changes directly into a gas. As it changes state, the carbon dioxide absorbs thermal energy. This property helps keep materials near dry ice cold and dry. For this reason, using dry ice is a way to keep temperature low when a refrigerator is not available. When dry ice becomes a gas, it cools water vapor in the nearby air. The water vapor then condenses into a liquid, forming fog around the dry ice.

Reading Checkpoint **What physical state is skipped during the sublimation of a substance?**

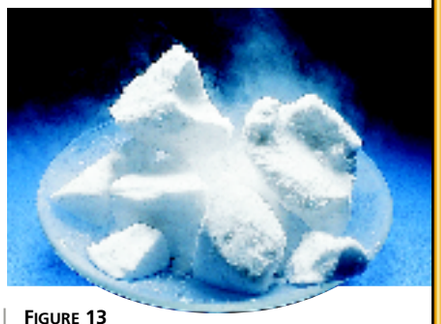


FIGURE 13
Dry Ice
When solid carbon dioxide, called "dry ice," sublimates, it changes directly into a gas. **Predicting** *If you allowed the dry ice to stand at room temperature for several hours, what would be left in the glass dish? Explain.*

Section 2 Assessment

Target Reading Skill **Outlining** Use the information in your outline about changes of state to help you answer the questions below.

Reviewing Key Concepts

1. a. **Reviewing** What happens to the particles of a solid as it becomes a liquid?
   b. **Applying Concepts** How does the thermal energy of solid water change as it melts?
   c. **Making Judgments** You are stranded in a blizzard. You need water to drink, and you're trying to stay warm. Should you melt snow and then drink it, or just eat snow? Explain.
2. a. **Describing** What is vaporization?
   b. **Comparing and Contrasting** Name the two types of vaporization. Tell how they are similar and how they differ.
   c. **Relating Cause and Effect** Why does the evaporation of sweat cool your body on a warm day?
3. a. **Identifying** What process occurs as pieces of dry ice gradually get smaller?
   b. **Interpreting Photos** What is the fog you see in the air around the dry ice in Figure 13? Why does the fog form?

Writing in Science

Using Analogies Write a short essay in which you create an analogy to describe particle motion. Compare the movements and positions of people dancing with the motions of water molecules in liquid water and in water vapor.

Monitor Progress L2

Answers

Figure 13 Nothing would be left because all the carbon dioxide would sublimate and mix with the air.

Reading Checkpoint Water vapor in the atmosphere condenses into liquid droplets.

Reading Checkpoint The liquid state

Assess

Reviewing Key Concepts

1. a. The particles break free from their fixed positions. **b.** The thermal energy increases. **c.** You should melt snow and then drink it. If you eat snow, your body must use some of its valuable energy to change the snow to a liquid.

2. a. The change from a liquid to a gas **b.** Evaporation and boiling; in both, a liquid becomes a gas. Evaporation occurs only on a liquid's surface, while boiling occurs both on the surface and below the surface. **c.** Your body supplies the thermal energy necessary to change the sweat from a liquid to a gas, causing the body to lose heat and become cooler.

3. a. Sublimation **b.** Water vapor; the water vapor in the air is cooled and condenses when dry ice sublimes.

Reteach L1

Have students diagram how particles of matter change as they change from one state to another. Ask: **What is required for matter to change from one state to another?** *(Addition or removal of thermal energy)*

Performance Assessment L2

Skills Check Have students create a concept map that describes the different changes of state. Students should also include whether thermal energy is being added or removed.

All in One Teaching Resources

- Section Summary: *Changes of State*
- Review and Reinforce: *Changes of State*
- Enrich: *Changes of State*

Lab zone Chapter Project

Keep Students on Track Have student groups write a description of how particles behave in each state of matter. Then have them decide how to model each state, using words and drawings. Groups should decide whether to create a cartoon or a skit, and then prepare a storyboard. Explain that a storyboard is made up of rough sketches with notes that outline the action of a story.

Writing in Science

Writing Mode Description

Scoring Rubric

4 Exceeds criteria; includes a highly imaginative analogy that accurately relates the particle motion of different states of matter to the movements of dancers

3 Meets criteria

2 Includes an analogy that is not quite accurate or completely developed

1 Essay is incomplete and/or contains serious errors

Lab zone Skills Lab

Melting Ice

L2

Prepare for Inquiry

Skills Objectives

After this lab, students will be able to

- predict which ice cube will melt faster.
- interpret data about temperature changes.
- infer the source of thermal energy.

Prep Time 15 minutes
Class Time 30 minutes

Advance Planning

- Make enough ice cubes for the class.
- Heat water or use warm tap water.

If using probeware, refer to the *Probeware Lab Manual*.

Safety

Review safety guidelines in Appendix A.

All in One Teaching Resources

- Lab Worksheet: *Melting Ice*

Go Online PHSchool.com
For: Data sharing
Visit: PHSchool.com
Web Code: cgd-1022

Students can go online to pool and analyze their data with students nationwide.

Guide Inquiry

Introduce the Procedure

- If using probeware, demonstrate its use.
- Emphasize the importance of recording time and temperature at the instant of total melting.

Troubleshooting the Experiment

- Remind students to keep the bulb of the thermometer completely immersed at all times.
- Have students wipe away any melted water from the ice cube before putting it in water.

Lab zone Skills Lab

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Melting Ice

Problem

How does the temperature of the surroundings affect the rate at which ice melts?

Skills Focus

predicting, interpreting data, inferring

Materials

- stopwatch or timer
- thermometer or temperature probe
- 2 plastic cups, about 200 mL each
- 2 stirring rods, preferably plastic
- ice cubes, about 2 cm on each side
- warm water, about 40°C–45°C
- water at room temperature, about 20°C–25°C

Procedure

1. Read Steps 1–8. Based on your own experience, predict which ice cube will melt faster.
2. In your notebook, make a data table like the one below.
3. Fill a cup halfway with warm water (about 40°C to 45°C). Fill a second cup to the same depth with water at room temperature.
4. Record the exact temperature of the water in each cup. If you are using a temperature probe, see your teacher for instructions.
5. Obtain two ice cubes that are as close to the same size as possible.
6. Place one ice cube in each cup. Begin timing with a stopwatch. Gently stir each cup with a stirring rod until the ice has completely melted.
7. Observe both ice cubes carefully. At the moment one of the ice cubes is completely melted, record the time and the temperature of the water in the cup.
8. Wait for the second ice cube to melt. Record its melting time and the water temperature.

Data Table

Cup	Beginning Temperature (°C)	Time to Melt (s)	Final Temperature (°C)
1			
2			

Analyze and Conclude

1. **Predicting** Was your prediction in Step 1 supported by the results of the experiment? Explain why or why not.
2. **Interpreting Data** In which cup did the water temperature change the most? Explain.
3. **Inferring** When the ice melted, its molecules gained enough energy to overcome the forces holding them together as solid ice. What is the source of that energy?
4. **Communicating** Write a paragraph describing how errors in measurement could have affected your conclusions in this experiment. Tell what you would do differently if you repeated the procedure. (*Hint*: How well were you able to time the exact moment that each ice cube completely melted?)

Design an Experiment

When a lake freezes in winter, only the top turns to ice. Design an experiment to model the melting of a frozen lake during the spring. *Obtain your teacher's permission before carrying out your investigation.* Be prepared to share your results with the class.

Expected Outcome

The ice cube in warmer water melts faster.

Analyze and Conclude

1. Sample answer: I predicted that the ice cube in warm water would melt faster, and that happened in the experiment.
2. In the cup with warm water; greater difference between initial temperature and melting point
3. The thermal energy of the water in each cup
4. Sample answer: Errors could include misreading the thermometer or not measuring the time correctly. Taking the final temperature too late will increase the time measurement.

Extend Inquiry

Design an Experiment Sample experiment: A partially frozen container of water with a layer of ice on top is exposed to a lamp (the "sun") while the other is kept in the shade. Check plans for safety.