LESSON 2

Changes of State

As outdoor temperatures rise, icebergs may start to melt.

By the end of this lesson . . .

you will be able to model and explain how a change in thermal energy can influence a change of state.

Go online to view the digital version of the Hands-On Lab for this lesson and to download additional lab resources.

CAN YOU EXPLAIN IT?

What could cause a piece of metal to melt in a person's hand?

Gallium is a soft silvery metal. This photo shows gallium in both a solid and a liquid form. At room temperature, you can cut gallium with a knife.

1. Think about some times you have seen a substance melting. What explanation can you suggest for how the gallium could melt in someone's hand?

EVIDENCE NOTEBOOK As you explore the lesson, gather evidence to help explain how a piece of metal could melt in someone's hand.

Analyzing How Energy Influences a Change of State

Changes of State

All matter can exist in three common states—solid, liquid, and gas—and can change from one state to another. The process by which matter changes from one state to another is called a **change of state**. A change of state is a physical change, so the identity of a substance is the same in whatever state it is in. For example, water is still water whether in an ice cube or after the ice melts into liquid water.

During a change of state, matter is neither created nor destroyed. The same number of particles make up a substance before and after a change of state.

Explore ONLINE!

A professional glassworker creates a vase by changing the shape of the glass.

2. Discuss Together with a partner, determine the change of state that is shown in the photo. What observations led to your conclusion?

3. Think about what takes place when glass changes from a liquid to a solid. Circle the correct words to make each sentence true.

Liquid glass and solid glass have the same / different chemical identity.

Liquid glass and solid glass have the same / different physical properties.

Hands-On Lab

Investigate a Change of State

You will predict ways in which you can make a change of state happen more quickly as an ice cube melts. You will plan and carry out an investigation to test your predictions.

MATERIALS

- 4 small ice cubes, same size
- clear plastic cups
- paper towels

Procedure

STEP 1 Work with a partner or small group to list ways that you might make an ice cube melt faster than it would melt if you left it sitting in a cup on your desk. You may only use items in your classroom.

STEP 2 For your investigation, choose three of the methods your group discussed. Write each method in the table.

STEP 3 Gather the ice cubes. Place one ice cube in a cup on your desk. Use the methods you chose in Step 1 to melt the other three ice cubes.

STEP 4 Observe the ice cubes until one of them melts completely.

STEP 5 Record your observations in the table.

What did you do?	What were the results?
Ice cube in a cup, on desk	

Analysis

STEP 6 Circle the best word to complete each sentence.

In this activity, heat was added / removed to make the ice cube melt faster.

The ice cube that received the most / least heat melted fastest.

The heat provided energy / matter that caused the ice to melt.

STEP 7 Describe two actions that are different from what you did in this activity that might make the ice melt more quickly. Explain your reasoning.

EVIDENCE NOTEBOOK

4. How does energy relate to the question of how a piece of metal might melt in someone's hand? Record your evidence.

Identify a Change of State

5. This glass of ice water shows two changes of state happening:

- The solid ice in the glass is melting to form liquid water.
- Water vapor in the air is changing to liquid water on the surface of the glass.

Write gaining or losing to complete each sentence.

The ice is melting in the glass because it is _____ energy as it changes from solid to liquid.

Water drops form on the surface of the glass because water vapor is _____ energy as it changes from gas to liquid.

Modeling Addition of Thermal Energy to a Substance

Energy Gain and Change of State

A flame adds energy to the water in this flask. As a result, the water temperature increases.

Each particle in a substance is moving in some way, so each particle has *kinetic energy*. **Thermal energy** is the total kinetic energy of all the particles in a substance. Adding thermal energy to a substance increases its kinetic energy. This increase in kinetic energy means the particles move faster. *Temperature* is a measure of the average kinetic energy of the particles.

6. Explain what is happening to the movement and kinetic energy of the water particles shown in the photo.

Change of State: Solid to Liquid

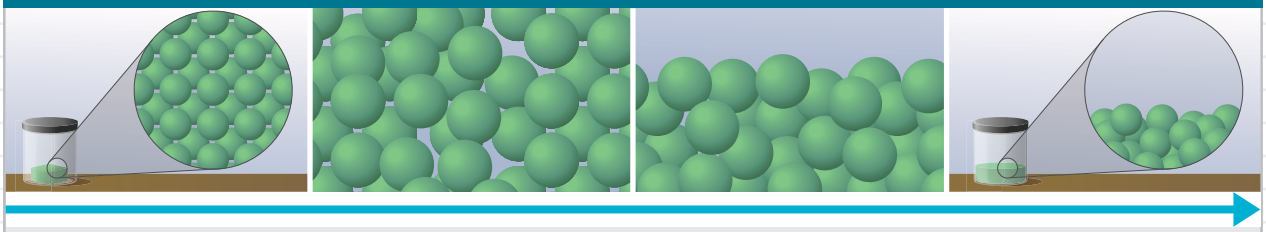
Adding enough thermal energy to a substance can cause a change of state to occur. The change of state from a solid to a liquid is called *melting*. When energy is added to an ice cube, the ice particles speed up as energy is absorbed. When the particles move fast enough, the solid ice melts and becomes liquid water. The temperature at which melting begins is called the *melting point*. Every substance has a specific melting point. This melting point will always be the same for that substance under the same conditions no matter the amount of the substance. The temperature at which ice melts and becomes liquid water is 0 °C at sea level.

Change of State: Liquid to Gas

If enough energy is added to a liquid, the liquid will turn into a gas. A change of state from a liquid to a gas is called *evaporation*. Water in a gas state is called *water vapor*. Adding thermal energy to liquid water particles causes them to speed up. When they speed up enough, the particles change to the gas state, forming bubbles. The liquid water turns to water vapor. This process is called *boiling*. Boiling and evaporation both involve the same change of state: liquid to gas. The difference is the location of the change. Evaporation takes place at the surface of the liquid and can occur over a wide range of temperatures. Boiling occurs throughout the entire liquid and takes place at a specific temperature. All substances have their own *boiling point*, the temperature at which the substance begins to boil. The boiling point of water is 100 °C.

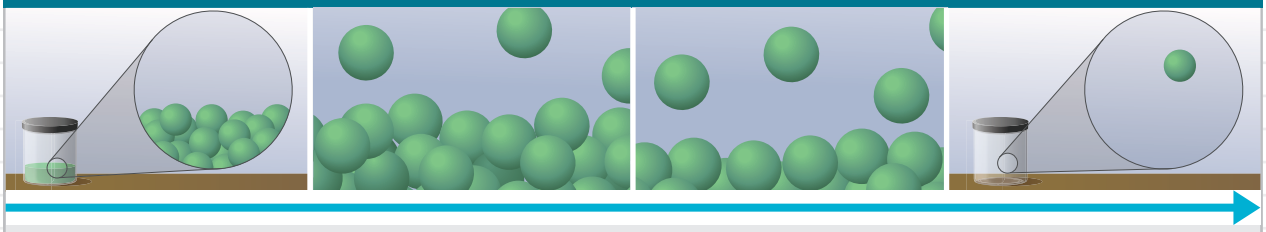
7. Write melting, evaporation, or boiling to label each photo.

Change of State From Solid to Liquid



The particles of a solid vibrate in place, held together by forces of attraction. Particles in a liquid remain close, but they have more kinetic energy that allows them more freedom of movement.

Change of State From Liquid to Gas



The particles in a gas have enough energy to overcome attractive forces, so they move about freely.

8. Describe the relationship between thermal energy and change of state. Write solid, liquid, or gas to complete each sentence.

If enough thermal energy is added to a liquid, it will change to a _____.

If enough thermal energy is added to a _____, it will change to a liquid.

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Particle Motion Increases

The particles of a solid are held together by strong forces of attraction. As a result, a solid has a definite shape. As thermal energy is added to a solid, the kinetic energy of its particles increases. The particles vibrate faster until they can move more freely, slide around each other, and form a liquid. This freedom of movement allows a liquid to flow and take the shape of its container.

When thermal energy is added to the liquid, its particle movement increases until the particles have enough energy to overcome the attractive forces. They completely break away from each other and form a gas. The movement of the gas particles not only allows the gas to take the shape of its container, but the gas particles will also move about and fill the entire space within its container.

Do the Math

Analyze Temperature During a Change of State

Think about warming a solid piece of ice. The ice gains energy and its temperature rises. The rise in temperature causes the ice to melt and eventually boil. This is true for ice just as it is true for any substance. What would the graph of temperature change over time look like?

You might have thought that the temperature would steadily increase as energy is added to a substance at a constant rate. However, that is not the case. The graph actually shows two time periods where the temperature does not change even though energy is being added. The first corresponds to the temperature at which the solid is changing to a liquid, or melting. The second shows the temperature at which the substance changes to a gas, or evaporates. The horizontal lines indicate that, during that time, energy transferred to the particles goes into changing the state of the substance, not into raising its temperature.

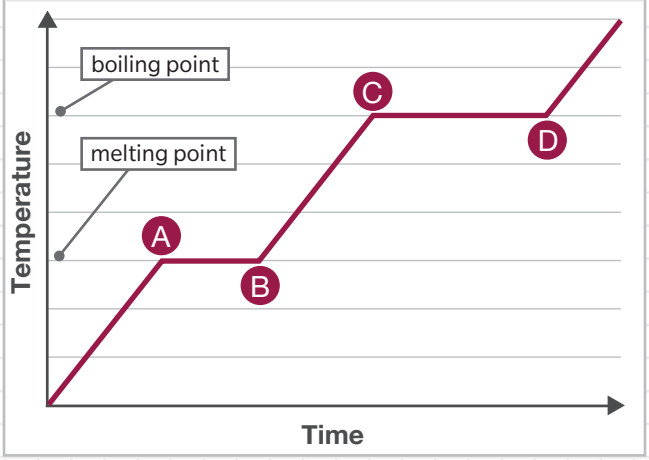
9. Which statements correctly describe what is happening during the two flat-line periods in the graph? Circle all that apply.

- **A.** Between points A and B, the solid substance is changing to a liquid.
- **B.** Between points A and B, the substance is losing energy.
- **C.** Between points C and D, the liquid substance is changing to a gas.
- **D.** Between points C and D, the substance is gaining energy.

10. You are warming a pot of ice. Explain what happens to the temperature when the water reaches its melting point and boiling point.

Changing the State of a Substance

This graph shows how the temperature of a substance changes as thermal energy is added at a constant rate.



EVIDENCE NOTEBOOK

11. How might melting point and a change in the kinetic energy of particles help to explain why a piece of metal could melt in someone's hand? Record your evidence.

Classify and Explain a Change of State

Snow is made up of frozen water molecules in the form of ice. As the temperature warms up, the snow begins to melt and runs off as liquid water.

12. What changes might occur as sunlight shines on snow? Circle all that apply.

- **A.** Liquid water that forms as the snow melts will flow downhill.
- **B.** The snow will get warmer and change into a large chunk of ice.
- **C.** The snow quickly warms up and may begin to boil.
- **D.** The temperature of the snow will slowly increase.

13. Engineer It Some towns depend on water from snow that falls high up in the mountains, melts, and flows down the mountain. Some years, spring comes early and the snow begins to melt earlier than usual. What are some problems of early water run-off down the mountain that engineers might be asked to solve? What criteria and constraints might need to be considered for concerns such as materials, space, and cost?

Modeling Removal of Thermal Energy from a Substance

Energy Loss and Change of State

You now know that when enough energy is added to a substance, it can change state. But what happens when a substance loses energy? Think about what happens when you put water in a freezer. The temperature of the liquid water is warmer than the temperature inside the freezer. As a result, heat from the water is lost to the freezer. When this happens, the water particles slow down. When enough energy is lost, the attractive forces between the particles hold the particles in a regular pattern and the particles can only vibrate in place. The liquid water changes to solid ice.

Explore ONLINE!

In the winter, ice forms on this lake. The ice starts to form on the water closest to shore.

Over the course of the winter, the lake continues to freeze. Ice forms to almost entirely cover the lake.

14. The photos show the process of a lake freezing in the winter. Why does the lake water change to ice in the winter? Include the gain or loss of energy in your explanation.

Change of State: Gas to Liquid

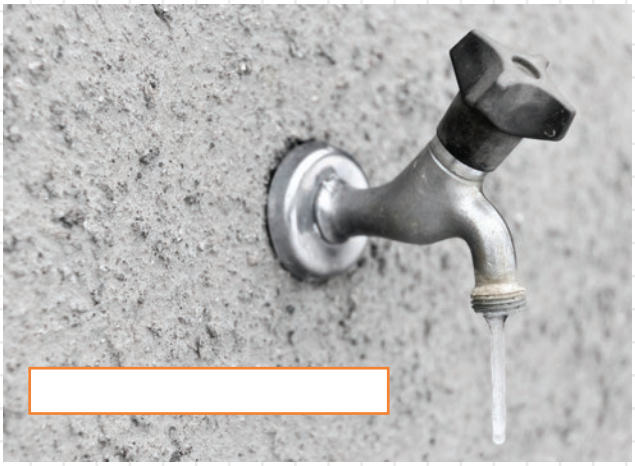
A gas changes state and becomes a liquid when the gas particles lose thermal energy. The process of a gas changing state to a liquid is called *condensation*. A common example of condensation is the picture you saw earlier of the liquid water droplets on the outside of the glass of ice water. Water vapor from the air condenses and becomes liquid water on the cold surface of the glass of ice water.

Change of State: Liquid to Solid

The process in which a liquid changes to a solid is called *freezing*. Many people might think that freezing means liquid water turning into ice. However, freezing is the term used to describe any change from a liquid state to a solid state.

Think again about water being placed in a freezer. The liquid water freezes to become solid ice. The temperature at which water freezes is its *freezing point*. The freezing point of a substance is the same as its melting point. In other words, a substance with a melting point of 20 °C will not only begin to freeze at 20 °C, but the solid substance will also begin to melt at 20 °C.

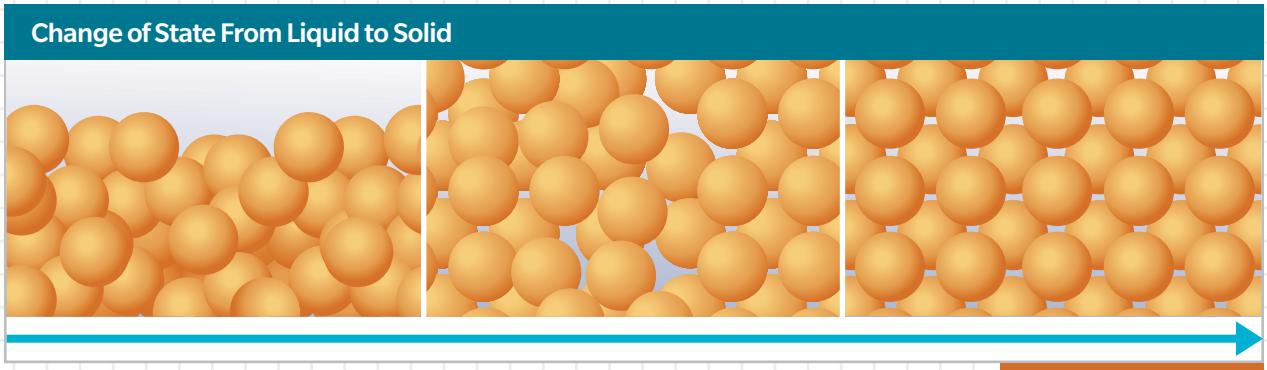
15. Write freezing or condensation to label each photo.



a dripping faucet on a cold day

a window on a cold day

your breath in cold air



Explore ONLINE!

16. Circle the correct terms to describe and explain the process being modeled above.

The process being modeled is condensation / freezing.

As the particles slow down / speed up, particle attraction forces hold them in a regular pattern.

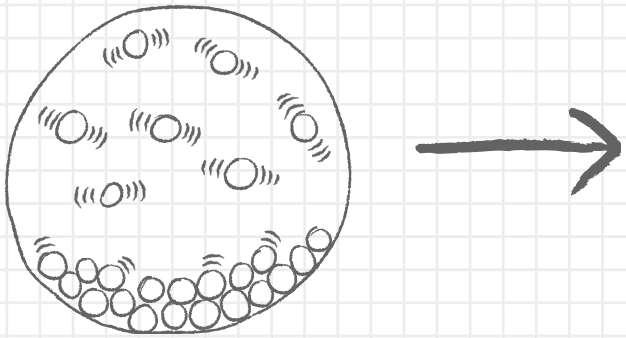
This causes the particles to lock into the fixed arrangement of a liquid / solid.

Particle Motion Decreases

As the temperature of a substance becomes colder, its properties change. The reason is the change in particle motion. The particles in a gas have a high amount of energy and move very fast. As thermal energy decreases, particle motion slows, allowing the attractive forces between particles to pull them closer together. Gas particles will become liquid. If temperatures continue to decrease, the attraction between particles eventually overcomes the energy of their motion. Liquid particles can then lock into the fixed arrangement of a solid.

Language SmArts

17. Draw In the space below or on a piece of paper, complete the drawing to show the process of gas particles becoming a liquid. Then write a caption to describe what happens to the particle motion and energy during this change of state.



Gas particles are far apart and moving quickly above the surface of the liquid because gas particles have enough energy to overcome particle attraction.

Analyze Changes of State

Lava is liquid rock that comes out of the opening of a volcano in Earth's surface. It sometimes comes out in streams called lava flows that travel slowly downhill. The temperature of lava when it first erupts can vary between 700 °C–1,200 °C. As the lava flows, it slowly cools.

Lava Flowing Into the Ocean

As lava flows downhill, it sometimes reaches a body of water, such as the ocean. These two photos show what happens as the lava spills into the water.

18. What changes of state do you see happening in the photos?

19. What evidence do you see in the photos to support your answer?

20. When thermal energy is removed from a substance, the substance may condense or freeze. But when something loses energy, that energy is not "lost." The energy is transferred to something else. When the lava loses thermal energy as it cools, where is the energy going? Circle all that apply.

A. The thermal energy is transferred from the lava to the air.

B. The thermal energy is transferred from the lava to the ground.

C. The thermal energy is transferred from the lava to the water.

D. The thermal energy is held within the solid rock that forms.

Evaluating How Pressure Can Affect Changes of State

Pressure and Changes of State

As gas particles move freely, they collide with surfaces around them. The gas particles have kinetic energy, so their collisions with surfaces produce a force. The force created by the collisions of these particles with other materials is called **pressure**.

In the morning, this bike rider gets ready to go for a long bike ride. As part of getting ready, she is checking the tire pressure.

The bike rider finishes her ride in the afternoon. She checks the tire pressure again.

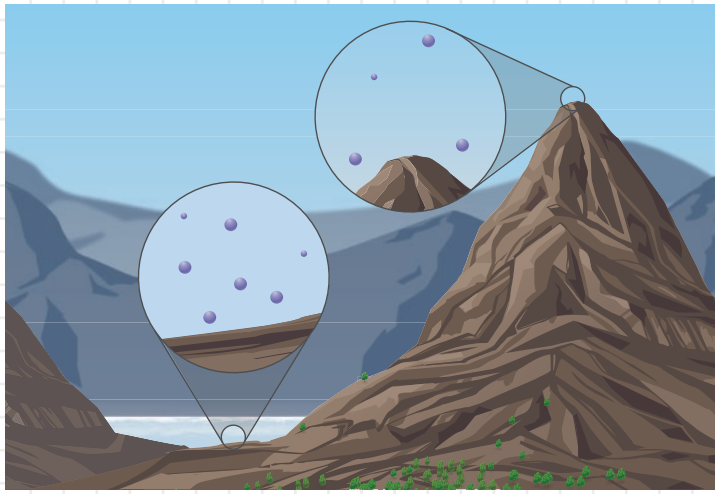
21. Use the pictures. Circle the correct word to complete each sentence.

The tire pressure changed between morning and afternoon. In the afternoon, the tire pressure was less / greater than the tire pressure in the morning. The increase in pressure is caused by a warmer / cooler temperature of the air in the tires compared to morning. As the temperature increases, the kinetic energy of the gas particles increases / decreases.

Elevation and Air Pressure

You might not think about the pressure that air puts on your body, but it is always present. Gas particles in the atmosphere exert pressure on everything, including you.

The art shows that as you move toward a higher elevation, there are not as many air particles to collide with a surface. As a result, the higher the elevation, the lower the air pressure. Air at lower elevations contains a greater number of air particles, resulting in a greater number of particle collisions with the ground and other surfaces. Therefore, lower elevations have greater air pressure.



The air at lower elevations contains more particles in a given amount of space than air at higher elevations.

Boiling Point of Water at Different Elevations		
Location	**Elevation (feet above sea level)**	**Boiling Point of Water (°C)**
San Francisco, CA	Sea level	100.0
Denver, CO	5,280	95.0
Quito, Ecuador	9,350	90.0
Mount Everest	29,029	76.5

22. Discuss Water boils at 100 °C in San Francisco, which is at sea level. But as you can see in the table, the boiling point of water varies at other locations. The higher the elevation, the lower the boiling point of water. Why would the boiling point of water decrease as elevation increases? Is pressure a factor? Work with a group to explain. Include the relationship of energy and change of state in your explanation.

Determine the Effect of Pressure on a Change of State

23. In Denver, it takes about 4 minutes to make a soft-boiled egg. At sea level, it takes about 3 minutes and 11 seconds to make a soft-boiled egg. Why does it take more time to soft-boil an egg in Denver than at sea level? Write higher or lower to complete the explanation.

Denver is at a _____ elevation than sea level, so water boils at a _____ temperature. In Denver, food must be cooked longer to make up for cooking with a _____ temperature.

Continue Your Exploration

Name: Date:

Check out the path below or go online to choose one of the other paths shown.

Careers in Science

- **Hands-On Labs**
- **Freezing Point Depression**
- **Propose Your Own Path**

Go online to choose one of these other paths.

Forensics

A scientist who analyzes evidence and presents data in a court of law is called a forensic scientist. Forensic scientists apply scientific knowledge and procedures to criminal investigations. They may analyze clues from crime scenes, accident scenes, or arson scenes. Forensic scientists are able to help solve crimes using scientific analysis.

Evidence is collected at a crime scene. Just looking at an item may not tell an investigator much. However, an expert in a crime lab can learn more from a detailed analysis of the evidence.

1. Which of the following processes would a forensic scientist use? Circle all that apply.

A. analyzing fragments to determine what they are made of

B. analyzing paint flecks to determine the color and chemical makeup

C. identifying the identity of a person based on a shoe print

D. identifying a substance that was found on a fiber

E. determining whether liquids found are the same or different

Continue Your Exploration

Analyzing the Evidence

Gas chromatography (GC) is a method used to identify certain chemicals. A tiny bit of a sample is dissolved in a liquid called the solvent. The liquid is then injected into a chamber where the sample is heated until it becomes a gas. The gas travels through a long, thin tube. The different chemicals that make up the sample travel at different rates because of their different properties. A sensor sees when a chemical passes and records the time. The scientist can identify each chemical by the amount of time it takes to pass through the gas chromatograph.

Scientists can use GC to make sure that the chemical composition of a product is correct, to identify pollutants, or to identify unknown substances in a crime scene sample.

2. Circle the statement that best describes the process that happens in the heated sample chamber of a gas chromatograph.

A. The sample melts and becomes a gas.

B. The sample boils and becomes a gas.

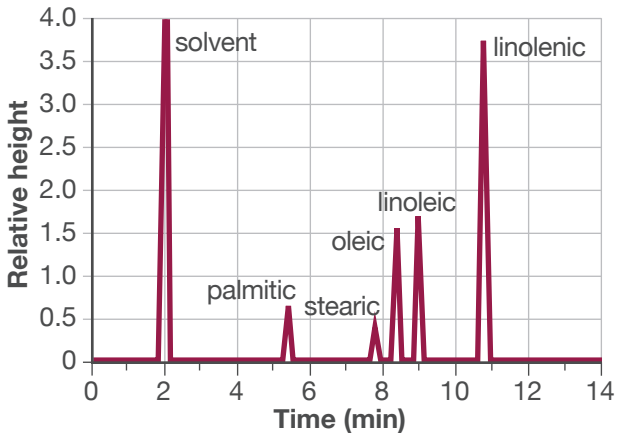
C. The sample condenses and becomes a gas.

When using gas chromatography to identify an unknown sample, a scientist first prepares a standard that contains known chemicals. The standard is analyzed to see how long it takes those chemicals to go through the gas chromatograph. By comparing the results for the unknown sample with a standard of known chemicals, the identity of the unknown sample can be determined.

A forensic scientist has been asked to examine a fiber from the scene of a fire. Gas chromatography was used to identify oil found on the fiber. The analysis of the sample is shown in the chromatogram. From the results, the scientist determined that the sample was linseed oil. Linseed oil is commonly used as paint thinner and is very flammable.

Chromatogram of the Evidence Sample

The different peaks are used to identify the solvent, substances in the sample, and their amounts.



3. How might knowing that the material on the fiber was paint thinner help an investigator solve a crime?

4. Collaborate Work with a partner to put together a brief presentation for the class about how forensic scientists use chemical analysis to help solve crimes. Use some kind of technology in your presentation to support your idea, such as presentation software, a video link, and digital photos.

Can You Explain It?

Name: **Date:**

Think back to the person holding a piece of gallium. Use what you have learned to answer the question.

What could cause a piece of metal to melt in a person's hand?

EVIDENCE NOTEBOOK

Refer to the notes in your Evidence Notebook to help you construct an explanation for what could cause a piece of metal to melt in someone's hand.

1. State your claim. Make sure your claim fully explains how the metal could melt.

2. Summarize the evidence you have gathered to support your claim and explain your reasoning.

Checkpoints

Answer the following questions to check your understanding of the lesson.

Use the photo to answer Questions 3 and 4.

3. Sweating is one way the body cools itself. Circle the statement that best explains this cooling process.

- **A.** Water condenses on the skin, adding thermal energy to the body.
- **B.** Moisture from the body evaporates from the skin, removing thermal energy from the body.

4. Which situations model a cooling process similar to sweating? Circle all that apply.

- **A.** water droplets forming on the outside of a glass of ice water
- **B.** a wet bandana around the neck of hiker
- **C.** an athlete wearing a shirt that wicks moisture away from the skin
- **D.** a hot, moist towel placed on sore muscles to soothe them

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Use the photo to answer Questions 5 and 6.

5. Which weather conditions would most likely create the fog as shown in the photo?

- **A.** rapidly cooling air that is low in water vapor
- **B.** rapidly cooling air that is high in water vapor
- **C.** rapidly warming air that is low in water vapor
- **D.** rapidly warming air that is high in water vapor

6. Clouds and fog form under similar conditions. How might air pressure at higher altitudes affect the formation of clouds? Circle your answer.

- **A.** As air rises, the reduced pressure allows the air to expand and cool until water vapor evaporates into water droplets that form the clouds.
- **B.** As air rises, the reduced pressure allows the air to expand and cool until water vapor freezes into water droplets that form the clouds.
- **C.** As air rises, the reduced pressure allows the air to expand and cool until water vapor condenses into water droplets that form the clouds.

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7. As snow slowly melts in the sunshine, what is happening to the particles of water that make up the snow? Circle all that apply.

- **A.** Particles are gaining energy.
- **B.** Particles are changing from liquid to solid.
- **C.** Particle motion is increasing.

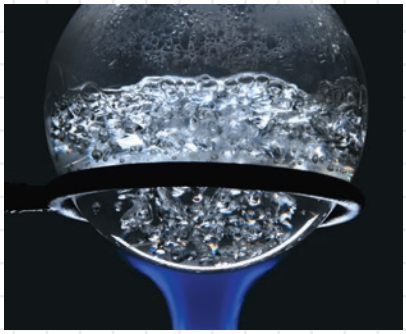
Interactive Review

Complete this section to review the main concepts of the lesson.

A change of state is the change of a substance from one physical state to another, such as from a liquid to a solid.

A. Explain whether the identity of a substance changes during a change of state. Give an example.

A change of state can occur when thermal energy is added to a substance.



B. Describe the change in motion and kinetic energy of the particles as thermal energy is added to a liquid. Which change of state might happen?

A change of state can occur when thermal energy is removed from a substance.

C. Describe the change in motion and kinetic energy of the particles as thermal energy is removed from a liquid. Which change of state might happen?

Changes in pressure can affect changes of state.

D. Explain why liquid particles at a high pressure would need more energy to change to a gas than liquid particles at a low pressure.