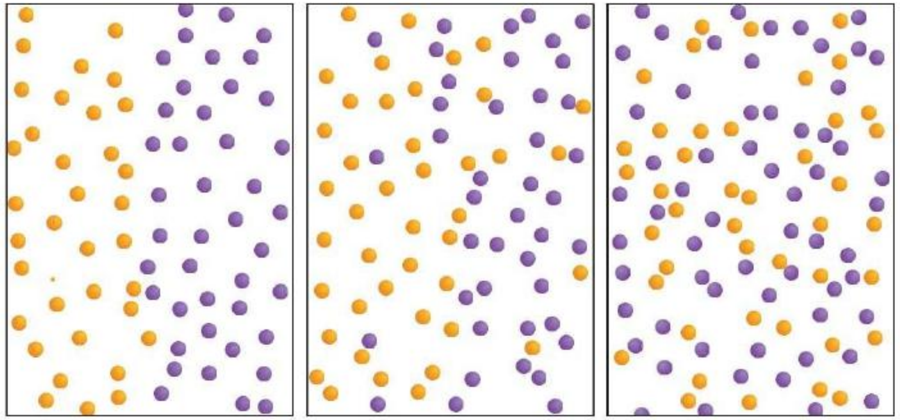
Movement and Collisions In the Lab *Wait For It*, the food coloring moved when the water in the beaker appeared to be completely still. How did this happen? Water particles, like the particles in all liquids, constantly bump and flow past each other in **random motion**—movement in all directions and at different speeds. The movement and collisions of the water particles push the food coloring particles around, causing the coloring to spread out, or diffuse. **Diffusion** is the movement of particles from an area of higher concentration to an area of lower concentration. Diffusion does not happen instantly. Particles diffuse until the concentration is the same throughout the container. When the concentration of food coloring is the same throughout the container, the liquid is one color.

Take a look at the figure below. Notice that as you move from left to right, the particles become more diffuse.



What determines how much energy particles have?

You know that a rolling ball has energy because it is moving. Particles also move, so they also must have energy. Remember, energy is the ability to cause change. Is there a relationship between how fast a particle moves and the amount of energy it has? Let's investigate!

INVESTIGATION

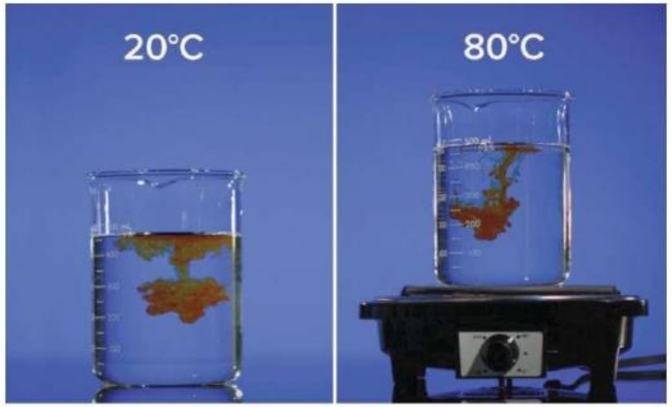
Ready, Set, Collide

GO ONLINE Watch the video *Dye Race* to investigate how adding energy affects particle movement. Record your observations below.

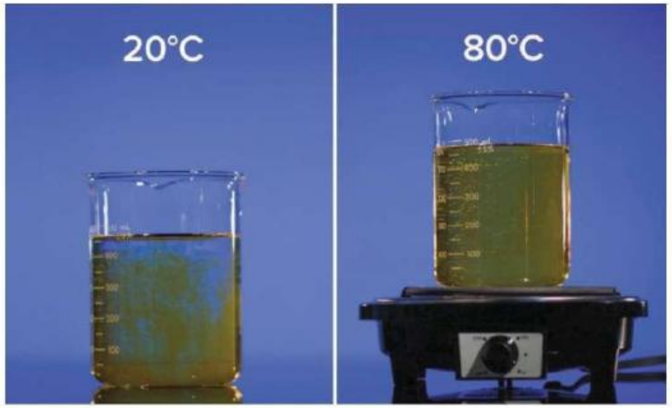
Students should record their observations. They should notice that dye in the beaker at the higher temperature diffuses more quickly than dye in the beaker at the cooler temperature.

Use your observations from the video to draw conclusions about the figure below. What can you conclude about how adding energy to the liquid on the right will affect the speed of the particles?

Answers may vary. Sample answer: The dye diffused faster in the beaker at the higher temperature. So, the more energy that is added, the faster the particles move. If the particles are moving at a faster speed, they will collide more often and cause the dye particles to diffuse faster around the beaker.



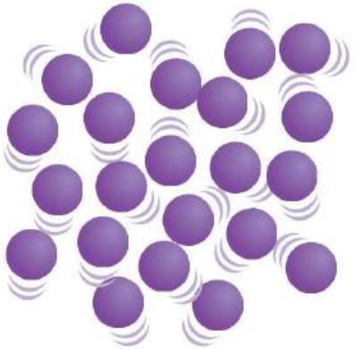
Movement and Energy Scientists use diffusion to observe how fast the particles of a substance are moving. The faster the substance diffuses, the faster the particles are moving. In the figure below, energy was added from the hot plate to the water and dye particles on the right. This added energy increased the motion energy, also called **kinetic energy,** of the particles. As the kinetic energy of the particles increased, the speed of the particles increased. The faster particles move, the more kinetic energy they have.

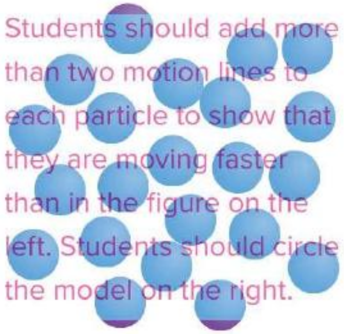


How to Model Movement Motion lines are used to model particle movement in a still image. Since particles travel at different speeds, they need to be represented by different numbers of motion lines. The more motion lines, the faster the particle is moving.

THREE-DIMENSIONAL THINKING

Add motion lines to the liquid particles **model** on the right to show they are moving faster than the liquid particles on the left. Circle the model that has more kinetic **energy.**

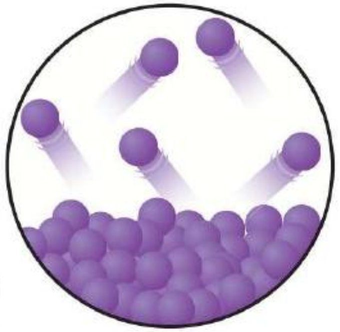




Students should add more than two motion lines to each particle to show that they are moving faster than in the figure on the left. Students should circle the model on the right.

Read a Scientific Text

HISTORY Connection The earliest modern accounts of **thermodynamics**—the study of heat—can be traced back to the late 1700s through the early 1800s. One of the contributions to thermodynamics was by James Prescott Joule, an English physicist. His ideas on the particle motion of matter were often ridiculed by his peers, but they have continued to withstand the test of time. His contributions to science are recognized by naming the unit for energy the joule (J). The passage below is an excerpt from a lecture Joule gave in 1847.



CLOSE READING

Inspect

Read the passage from *On Matter, Living Force, and Heat.*

Find Evidence

Reread the paragraph. Underline the evidence Joule gives for the existence of the motion of particles.

Make Connections

Communicate With your partner, discuss if Joule's evidence would be enough to convince you of the motion of particles. What other evidence have you learned that Joule could have included in his argument?

PRIMARY SOURCE

On Matter, Living Force, and Heat

...It will perhaps appear to some of you something strange that a body apparently quiescent should in reality be the seat of motions of great rapidity; but you will observe that the bodies themselves, considered as wholes, are not supposed to be in motion. The constituent particles, or atoms of the bodies, are supposed to be in motion, without producing a gross motion of the whole mass. These particles, or atoms, being far too small to be seen even by the help of the most powerful microscopes, it is no wonder that we cannot observe their motion. There is therefore reason to suppose that the particles of all bodies, their constituent atoms, are in a state of motion almost too rapid for us to conceive, for the phenomena cannot be otherwise explained. The velocity of the atoms of water, for instance, is at least equal to a mile per second of time. If, as there is reason to think, some particles are at rest while others are in motion, the velocity of the latter will be proportionally greater. An increase of the velocity of revolution of the particles will constitute an increase of temperature, which may be distributed among the neighboring bodies by what is called conduction—that is, on the present hypothesis, by the communication of the increased motion from the particles of one body to those of another. The velocity of the particles being further increased, they will tend to fly from each other in consequence of the centrifugal force overcoming the attraction.

Source: The scientific papers of James Prescott Joule by Joule, James Prescott, 1818-1889; Physical Society (Great Britain); Scoresby, William, 1789-1857; Playfair, Lyon Playfair, Baron, 1818-1898; Kelvin, William Thomson, Baron, 1824-1907

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COLLECT EVIDENCE

Think about the wood and metal blocks. How could the two blocks have energy? Record your evidence (A) in the chart at the beginning of the lesson.

What happens to a liquid when kinetic energy changes?

There is no way to see how fast particles are moving. Could you tell if the metal or wood block had more energy? One might have felt colder than the other. Is how hot or cold something feels a way to measure how much energy an object has? Let's investigate more!

INVESTIGATION

On the Rise

GO ONLINE Watch the video *Rising Levels* to investigate how liquids behave when heated. Record your observations below.

Students should record their observations. They should notice that as the temperature of the liquid goes up, the liquid level rises or expands in the thin tube.

Explain the relationship between kinetic energy of the particles and the volume of a liquid.

As the kinetic energy (or temperature) of the particles goes up, the speed of the particles increases causing more particle collisions, which leads to increased volume. As the kinetic energy (or temperature) of the particles goes down, the speed of the particles decreases causing fewer particle collisions. In turn, the volume of the liquid decreases.

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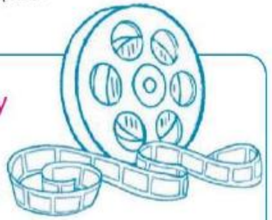

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Energy and Volume As the temperature of a material increases, its particles move faster. They collide with each other more often and push each other farther apart. The increase in volume of a material when particle motion increases is known as **thermal expansion.** The opposite can also occur. A substance can lose kinetic energy and the particles will move slower. As they move slower, they collide with each other less often, which causes the substance to take up less space. This is known as thermal contraction. **Thermal contraction** happens when particle motion decreases and causes the particles to occupy less volume.

THREE-DIMENSIONAL THINKING

On the right, sketch a diagram to **model** what the particles on the left would look like if they went through thermal expansion. Circle the model that has more kinetic **energy.**

Students should draw the particles the same size but more spread out with more motion lines to indicate a higher temperature and a larger volume. Students should circle the model on the right.

Energy and Temperature The property of thermal expansion and contraction can be used to measure temperature. **Temperature** is the measure of the average kinetic energy of the particles in a material. The temperature of a substance depends on how much kinetic energy the particles that make up the material have. The lower the kinetic energy of the particles, the lower the temperature of the substance. One way to measure the relative amount of kinetic energy or speed of the particles is by measuring how much the substance expands or contracts.

GO ONLINE for additional opportunities to explore!

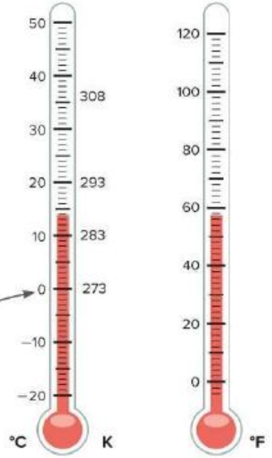
ENGINEERING Connection Investigate how thermometers use thermal contraction and thermal expansion to measure temperature.

☐ **Ask questions** to learn more about the history of thermometers after watching the **Animation** *How does a glass bulb thermometer work?*

OR

☐ **Develop a model** of a liquid thermometer using your own temperature scale in the **Lab** *Build Your Own Thermometer.*

Temperature Scales To compare temperatures you need to use the same temperature scale. A scale uses two fixed points and divides the space between the two points evenly. The Celsius scale is created with fixed points of 0°C, when water freezes, and 100°C, when water boils. Other scales include Fahrenheit and Kelvin. The Celsius scale is used by scientists worldwide. Scientists also use the Kelvin scale. The Kelvin scale was developed to predict at what temperature particles would stop all motion. This temperature is known as absolute zero at 0 K. If a material reaches 0 K, the particles in that material would not be moving and would no longer have kinetic energy. Scientists have not been able to cool any material to 0 K.



Water's freezing point on the Celsius scale, 0°C, is equal to 32 degrees Fahrenheit.

THREE-DIMENSIONAL THINKING

1. **Construct an explanation** about the relationship between average particle speed and temperature.

As particle speed increases, the temperature increases. As particle speed decreases, the temperature decreases. The relationship is proportional.

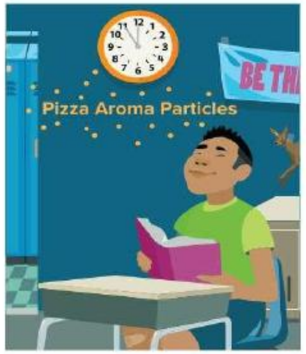
2. What conclusions can you make about kinetic **energy** and temperature?

As the temperature of a substance increases, kinetic energy increases. As the temperature of a substance decreases, kinetic energy decreases.

COLLECT EVIDENCE

How could the temperature of the wood and metal blocks be measured? Record your evidence (B) in the chart at the beginning of the lesson.

How do particles in a gas behave compared to particles in a liquid?



Think about a time when you smelled what was for lunch even though you were not near the cafeteria. The entire school did not smell the lunch at the same time. The people nearby smelled it first. The scent traveled away from the cafeteria over time. You could smell lunch because gas particles move. They move in straight lines until they collide with something, like another gas particle. These collisions change the speed and direction of the particles' movements.

INVESTIGATION

It's a Gas

GO ONLINE Watch the video *Cold Balloon* and the animation *Particle Movement in Gases* to see how particles in gases behave. Complete the graphic organizer with your observations.

When the balloon was cooled, kinetic, energy... decreased.	*When the balloon returned to room temperature, kinetic energy...* increased.
Gas particles inside the balloon... slowed down and moved closer.	*Gas particles inside the balloon...* sped up and moved farther apart.
Evidence of thermal... contraction.	*Evidence of thermal...* expansion.

Gas Particles In gases, particles move at high speeds and have high amounts of kinetic energy. Gases can expand and contract. Just like dye diffusing in a still beaker of water, being able to smell a scent over a distance is evidence for the movement of particles.

What evidence is there that particles in a solid move?

Solids, like the wood and metal you observed at the beginning of the lesson, are often described as having a definite shape. They are not fluid like liquids and gases. This means the particles in a solid do not flow past each other. Do the particles in a solid move? Let's find out!

INVESTIGATION

Still Solid

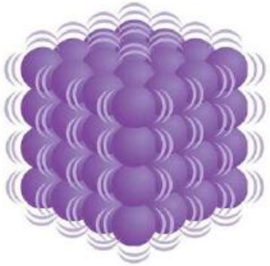
GO ONLINE Watch the video *Metal Ring* to observe how particles in a solid behave when heated. Complete the graphic organizer with your observations.

When the metal ball was heated, kinetic energy... increased.	When the metal ball returned to room temperature, kinetic energy... decreased.
Solid particles inside the metal ball... vibrated faster and moved slightly apart.	Solid particles inside the metal ball... slowed down and moved back to their original locations.
Evidence of thermal... expansion.	Evidence of thermal... contraction.

Based on what you saw in the *Metal Ring* video, how do you think you could model the particles in a solid?

Answers may vary. Sample answer: You could model the particles really close to each other, but not really moving. You would still need to show that the particles move apart from each other.

Solid Particles The particles in a solid do not have the same freedom to move around like liquid and gas particles. In a solid, the particles vibrate back and forth in place. Since solid particles only vibrate, they have low amounts of kinetic energy. Expansion and contraction in solids does occur. However, it is less noticeable because the particles are holding each other in place.



COLLECT EVIDENCE

How could models of the particles in the wood and metal blocks show why one felt colder than the other? Record your evidence (C) in the chart at the beginning of the lesson.

How does the total amount of a substance affect its energy?

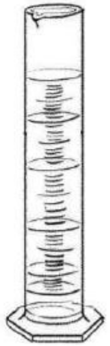
You have learned that particles have kinetic energy due to motion. Kinetic energy can be measured by comparing temperatures of substances. Kinetic energy is just one part of the total energy that a substance contains. In this lab you will add different amounts of water at different temperatures to the same amount of room temperature water. How do you think this will affect the kinetic energy of the water? Let's see what happens.

LAB In Hot Water

Safety

Materials

- beakers (4)
- room temperature water
- 30°C water
- 50°C water
- thermometers (2)
- graduated cylinder
- balance
- stopwatch



Procedure

1. Read and complete a lab safety form.

Predict the relative temperatures of the two beakers. Each beaker contains 200 g of room temperature water. 100 g of 30°C water is added to Beaker A. 20 g of 30°C water is added to Beaker B. Record your predictions of the temperatures after the water is added by entering >, =, or < on the line below.

Student predictions will vary.

2. Test your prediction. Label one beaker A and one beaker B. Fill each beaker with 200 g of room temperature water. Measure the temperature of the water in each beaker and record the measurements in the Data and Observations section on the next page.
3. Measure 100 g of 30°C water. Add to beaker A. Measure the temperature of the water after 1 min. Record your measurement.
4. Measure 20 g of 30°C water. Add to beaker B. Measure the temperature of the water after 1 min. Record your measurement.
5. Make another prediction. Again each beaker starts with 200 g of room temperature water. 100 g of 30°C water is added to beaker C. 20 g of 50°C water is added to beaker D. Predict the relative temperatures of the two beakers. Record your predictions of the temperatures after the water is added by entering >, =, or < on the line below.

Student predictions will vary.

7. Test your prediction from the previous page. Fill each beaker with 200 g of room temperature water. Measure and record the temperature of the water in each beaker in the Data and Observations section below.
8. Measure 100 g of 30°C water. Add to beaker C. Measure the temperature of the water after 1 min. Record your measurement.
9. Measure 20 g of 50°C water. Add to beaker D. Measure the temperature of the water after 1 min. Record your measurement.
10. Follow your teacher's instructions for proper cleanup.

Data and Observations

	Beaker A	Beaker B	Beaker C	Beaker D
Initial Temperature of 200 g Water				
	100 g of 30°C Water Added	20 g of 30°C Water Added	100 g of 30°C Water Added	20 g of 50°C Water Added
Final Temperature 1 min After Additional Water Added				

Analyze and Conclude

11. Return to your predictions. Develop an explanation for any similarities or differences between your predictions and the results.

Answers may vary. Student explanations should be based on their observations and the data they recorded while completing the lab.

Analyze and Conclude, continued

12. What claim can you make about the relationship between mass and energy? Use reasoning to explain how the evidence supports your claim.

Answers may vary. Sample answer: The greater the mass of a substance, the more energy the substance has. A substance with greater mass has a greater number of particles. The more particles that are present, the greater the energy of that substance.

THREE-DIMENSIONAL THINKING

A student left their half-full water bottle out in the Sun all day and would like to cool it down. They could add cool tap water to fill up their water bottle or they could add a small amount of cold water from the refrigerator. Present an **argument** on which option you would recommend. Support your recommendation with **evidence.**

Answers may vary. Sample answer: The student should use the cool tap water. The water from the refrigerator will have a lower temperature than the water from the tap. But, the tap water has a greater mass. In the lab I observed that a larger mass will cause a greater change in the temperature.

Energy and Mass Two substances have the same average kinetic energy by being at the same temperature. When one substance has more particles, that substance has more energy. For example, there are five times as many water particles in 100 grams of water than in 20 grams of water. If the temperatures of the two water samples are the same, the sample with more mass will contain more total energy. The more particles present, the more total energy present in a substance.

COLLECT EVIDENCE

How do the masses of the wood and metal blocks affect how much energy they have? Record your evidence (D) in the chart at the beginning of the lesson.

A Closer Look: Thermal Expansion in Solids

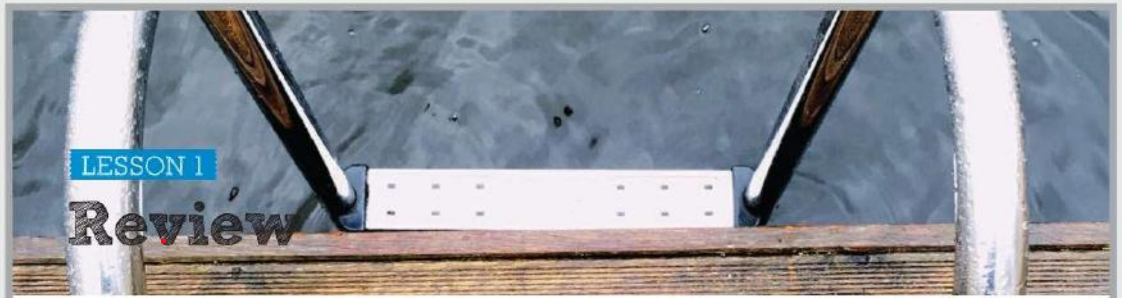
The changes to particles at the unobservable level lead to changes you can see. You learned that thermal expansion occurs in gases, liquids, and solids. Scientists have used their knowledge of thermal expansion to create thermometers. Hot air balloons are able to float because of thermal expansion. Are there any negative effects to thermal expansion?

Yes, thermal expansion can have negative effects. Two common areas where engineers take steps to guard against thermal expansion are bridges and sidewalks. Look at the photo of the Golden Gate Bridge above. What looks like a metal grate near the bottom of the inset photo is an expansion joint. This joint allows for the metal to expand during high temperatures and for the metal to contract when it is cooler.

In the photo on the right, a construction worker is adding expansion joints to concrete. Sidewalks, roads, and parking lots made of concrete are places where the effects of thermal expansion and contraction can be observed. Cracked concrete is a place where thermal expansion has occurred.

It's Your Turn

ENGINEERING Connection When engineers build new bridges, how do they know how far the joint must be able to move? What criteria and constraints drive their decision? How do climate, natural resources, and economic conditions affect the solution? Research this scenario or another question that you have about thermal expansion. Create a digital presentation to share your findings.



LESSON 1

Review

Summarize It!

1. **Relate** kinetic energy to the speed of particles.

No speed → no kinetic energy
Greater mass → greater kinetic energy
Greater speed → greater kinetic energy

Model each statement above. Model the first statement as solid particles, the second statement as liquid particles, and the last statement as gas particles.

The first model should be a solid with no speed. There should not be any motion lines to indicate that the solid is in motion. The second model should be a liquid, and the particles should be farther apart than in the solid. There should be motion lines on the liquid particles to indicate that when more particles are present and moving, the more kinetic energy a substance has. The third model should be a gas with more motion lines than the liquid indicating that the gas particles are moving at a high speed.

Three-Dimensional Thinking

Some students want to demonstrate thermal expansion. They devise the following method: A large black balloon is taken to a shady area and filled with cool air. The balloon is then taken to a bright, sunny location. After a short time, the balloon begins to expand.

3. What explanation does this investigation verify?
   - **A** A balloon filled with cool air will rise into the atmosphere.
   - [✓ **B**] As particles gain energy, the material takes up more space.
   - **C** The air inside the balloon lost energy.
   - **D** The sunlight caused the air in the balloon to contract.

Examine the model below. The particles are undergoing a change in energy.

4. Which statement best describes what is taking place in the images?
   - **A** The kinetic energy of the particles on the right is the greatest of the three images of particles.
   - [✓ **B**] The particles in the middle have more kinetic energy than the particles on the right.
   - **C** The particles in the middle have less space between them than the particles on the left, which means they have more kinetic energy.
   - **D** Energy was added to the particles on the left to give them more energy than the particles in the middle.

Real-World Connection

5. **Justify** Valdez notices that a wooden door in his house is difficult to open in the summer, but not in the winter. Valdez explains to Tony that the temperature of the door changes throughout the year. Tony says there is no way to measure the temperature of a solid because solids do not have a lot of thermal expansion. Valdez disagrees. Develop an argument supporting or opposing Tony's claim. Support your argument with at least two pieces of evidence.

Solids do expand, but at a smaller rate than liquids or gases. Expansion joints are built because solids expand. You can measure the temperature of a solid by using a thermometer.

6. **Synthesize** Wade could tell it was the night before trash pickup. The garbage can stank! What was it about summer that made the trash smell so bad, but the odor wasn't as bad during the winter months? Construct an explanation that details the role particle energy plays in smell.

In the summer, the temperatures are high. A high temperature means particles have more kinetic energy and move faster so they diffuse quickly. You smell the garbage because the smell diffuses faster than at cool temperatures.

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Still have questions?
Go online to check your understanding about the particles that make up matter.

REVISIT SCIENCE PROBES Do you still agree with the statement you chose at the beginning of the lesson? Return to the Science Probe at the beginning of the lesson. Explain why you agree or disagree with that statement now.

EXPLAIN THE PHENOMENON

Revisit your claim about why some materials feel colder than others. Review the evidence you collected. Explain how your evidence supports your claim.

START PLANNING

STEM Module Project Engineering Challenge

Now that you've learned how the motion of particles affects a substance, go to your Module Project to determine the criteria your device will have to meet. Keep in mind that your device will need to heat water without using open flames.

PAGE KEELEY SCIENCE PROBES

LESSON 2 LAUNCH

What's the Difference?

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Five friends were talking about the differences among solids, liquids, and gases. They each agreed that the differences have to do with the particles in each type of matter. However, they disagreed about which differences determine whether the matter is a solid, liquid, or gas. This is what they said:

Gwyneth: I think it has to do with the number of particles.
George: I think it has to do with the shape of the particles.
Hoda: I think it has to do with the size of the particles.
Natalie: I think it has to do with the movement of the particles.
William: I think it has to do with how hard or soft the particles are.

With whom do you agree most? ______________ Explain why you agree with that friend.

You will revisit your response to the Science Probe at the end of the lesson.

LESSON 2

States of Matter

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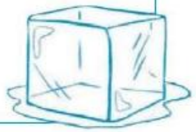
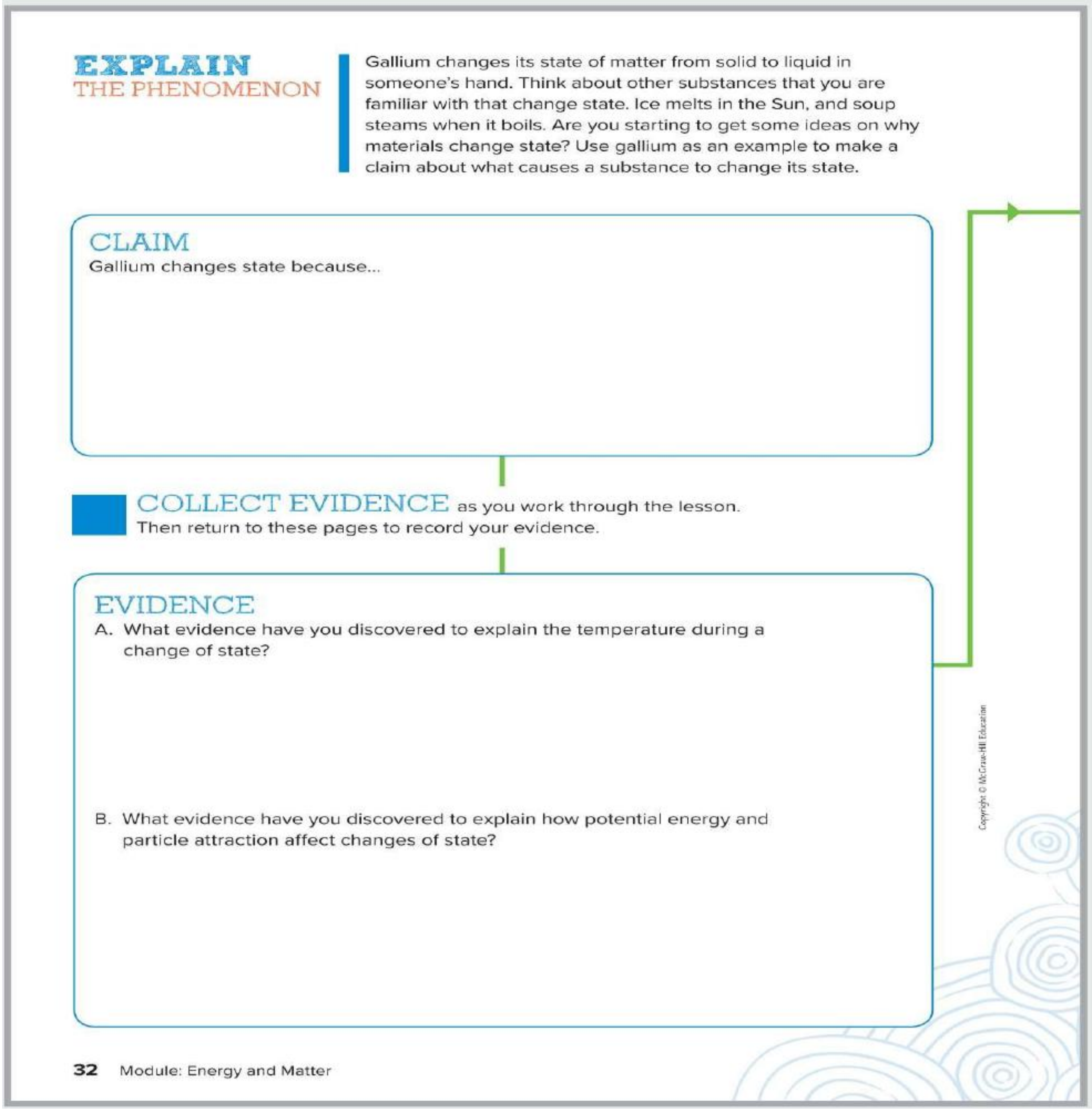
ENCOUNTER THE PHENOMENON | Why does gallium change states in this person's hand?

GO ONLINE
Watch the video *Metal: Gallium* to see this phenomenon in action.

After watching the video and observing how the metal gallium acts, record your observations in the space below.

Students should record their observations here. Students should include the metal melting in the hand in the image and the spoon melting in the video. The students may think that the metal was cold before coming to room temperature or that the water warmed the metal.





EXPLAIN
THE PHENOMENON

Gallium changes its state of matter from solid to liquid in someone's hand. Think about other substances that you are familiar with that change state. Ice melts in the Sun, and soup steams when it boils. Are you starting to get some ideas on why materials change state? Use gallium as an example to make a claim about what causes a substance to change its state.

CLAIM
Gallium changes state because...

COLLECT EVIDENCE
as you work through the lesson. Then return to these pages to record your evidence.

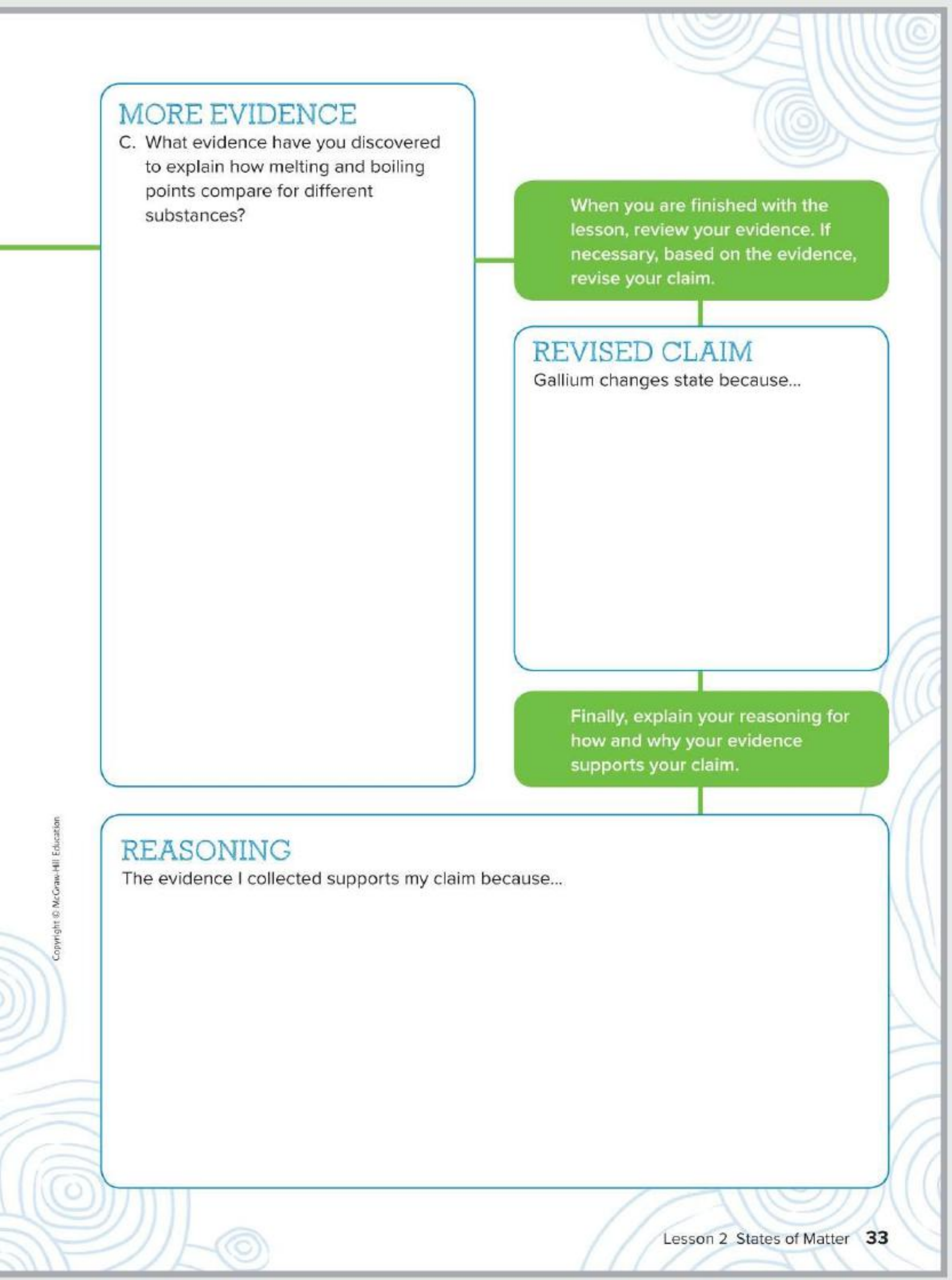
EVIDENCE
A. What evidence have you discovered to explain the temperature during a change of state?

B. What evidence have you discovered to explain how potential energy and particle attraction affect changes of state?

investigate.

A. When gallium melts, the temperature stays the same while it is melting. The graph I made of temperature while ice melted stayed around 0°C while there was ice present.

B. As gallium melts, it must absorb energy so that particles overcome attractions. The particles move more freely and have greater potential energy in the liquid than in the solid. I saw this happen in the simulation as we heated a solid and melted it.



MORE EVIDENCE

C. What evidence have you discovered to explain how melting and boiling points compare for different substances?

When you are finished with the lesson, review your evidence. If necessary, based on the evidence, revise your claim.

REVISED CLAIM

Gallium changes state because...

Finally, explain your reasoning for how and why your evidence supports your claim.

REASONING

The evidence I collected supports my claim because...

C. Different substances melt at different temperatures because the particle attractions differ. We concluded from the graph showing the heating curves of three substances that they changed states at different temperatures because the attractions holding the particles together differed. The attractions between gallium particles are stronger than between water particles, so gallium melts at a higher temperature than ice.

REVISED CLAIM

Have students review the evidence they collected. Students should have recorded evidence that supports their claim. If students found evidence that contradicts their claim, their claim is likely incorrect. Encourage students to use the evidence they recorded to revise their claim.

Students' answers will vary, but should include references to particle attractions, potential energy, and energy absorption. Sample answer: Gallium changes state because at the right temperature, energy that it absorbs overcomes particle attractions. The potential energy of the particles increases.

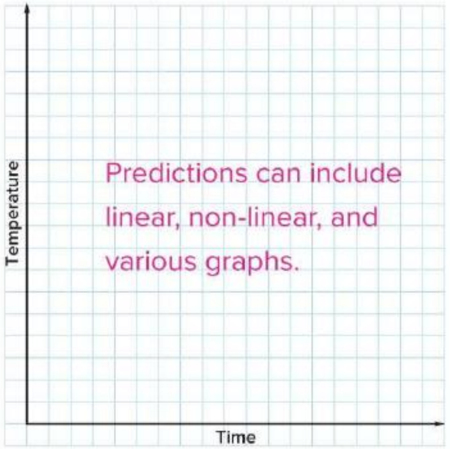
What happens to temperature during a change of state?

When the gallium was first picked up, it was at room temperature. Your body temperature is much higher than room temperature. What happens when the gallium is warmed by your hand?

Want more information?
Go online to read more about energy and states of matter.

LAB Phase Changes

When energy is added to a solid, such as ice, the energy increases the speed of the particles by increasing the kinetic energy of the particles. Ice eventually melts to liquid water when heated. On the graph below, draw a line to predict what will happen to the temperature of ice as it melts.



Predictions can include linear, non-linear, and various graphs.

Safety

Materials

crushed ice
beaker
thermometer
stopwatch
stirring rod
hot mitts
hot plate

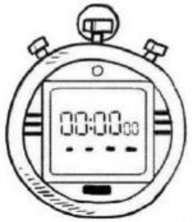
Sjoerd van der Wal/Getty Images

Procedure

1. Read and complete a lab safety form.
2. In the Data and Observations section below, create a data table to record the temperature of the ice and your observations every 30 seconds.
3. Fill the beaker ¾ full of crushed ice.
4. Record the temperature of the ice.
5. Set the beaker on a hot plate. Turn on the hot plate to medium-high.
6. Hold the beaker with a hot mitt. Use the stirring rod to stir the ice before you record the temperature.
7. Record the temperature every 30 seconds until the temperature reaches 50°C. Record your observations. Be sure to include which states of matter are present.
8. When the temperature reaches 50°C, turn off the hot plate.
9. Follow your teacher's instructions for proper cleanup.

Data and Observations

Students should have observed a constant 0°C temperature until all the ice has melted. Once the ice has melted, the temperature will rise at a steady rate until 50°C.



Analyze and Conclude

10. Analyze the data overall. Explain any patterns that you notice.

Answers may vary. As the ice was melting, the temperature remained at 0°C. Once the ice completely melted, the temperature steadily rose to 50°C.

11. Explain what you measured, and how you measured it.

Answers may vary. Students measured the temperature, or average kinetic energy, of the particles. This was measured with a thermometer.

12. How did you determine which units to use, and why?

Answers may vary. Students measured the temperature with a thermometer that gives measurements in units of degrees Celsius. These units are a standard unit of measure that is consistent for all substances at standard pressure.

13. **MATH Connection** Determine the mean temperature for when any ice was present. What might this number represent?

Answers may vary. The mean temperature when the ice was present is close to 0°C. The temperature 0°C represents the melting point of water. The added energy goes into melting the ice.

14. **MATH Connection** Determine the mean absolute deviation for when any ice was present. How can the mean deviation be improved?

Answers will vary based on student's data. Improvement can result from stirring thoroughly before each measurement.

Changes Between Solids and Liquids When the temperature of the ice reached 0°C, the solid ice began to change to a liquid. While a substance is melting or freezing, the temperature remains constant until the change of state, or phase change, is complete. The point at which a substance changes between a solid and a liquid is referred to as the melting point or the freezing point. The melting point and the freezing point are always the same for a given substance.

When the ice changed to a liquid, the temperature remained constant. What do you think happens when water changes to a gas?

FOLDABLES

Go to the Foldables® library to make a Foldable® that will help you take notes while reading this lesson.

INVESTIGATION

Next Phase

Another group of students continued the experiment to see if this pattern was the same when a liquid changes to a gas. The students examined the temperature of a beaker on a hot plate starting at 50°C and continuing until the water was boiling. Their data and observations are recorded in the table below.

Time (min)	Temperature (°C)	Observations
0:00	50.8	Liquid
0:30	60.5	Liquid
1:00	67.0	Liquid
1:30	74.4	Liquid
2:00	81.5	Liquid
2:30	88.0	Liquid
3:00	93.3	Liquid + bubbles at bottom of beaker
3:30	100.3	Liquid + boiling
4:00	100.9	Liquid + boiling
4:30	101.0	Liquid + boiling
5:00	101.1	Liquid + boiling
5:30	100.7	Liquid + boiling
6:00	100.9	Liquid + boiling
6:30	101.0	Liquid + boiling
7:00	100.9	Liquid + boiling

MATH Connection

1. Plot the temperature and time data from the Lab *Phase Changes* and the Investigation *Next Phase* on the grid below. Plot temperature on the vertical axis and time on the horizontal axis. Label the axes and add a title.
2. For each data set, draw a line that goes through the points.
3. Label the data with the states of matter that were present.

4. Identify any patterns and trends. Is this a linear relationship?

Answers may vary. Sample answer: Temperature rises when only the liquid is present. Temperature stays constant when water is boiling, and also when the ice is melting. This is not a linear relationship.

5. Develop a claim supported by evidence and reasoning on what is occurring when only a liquid is present.

Answers may vary. Sample answers: the particles are moving faster and faster. Energy is being added to the water.

6. What explanation can you make about when two states of matter are present at the same time based on the evidence?

Answers may vary. Sample answer: The energy is going into changing the state of matter.

7. If you continued to heat the water after it turned into a gas, what do you think would happen to the temperature? Explain your answer.

Answers may vary. Sample answer: The temperature would rise as the gas continued to gain energy.

8. The glass is melting in the furnace. Explain why the temperature of the glass is not rising.

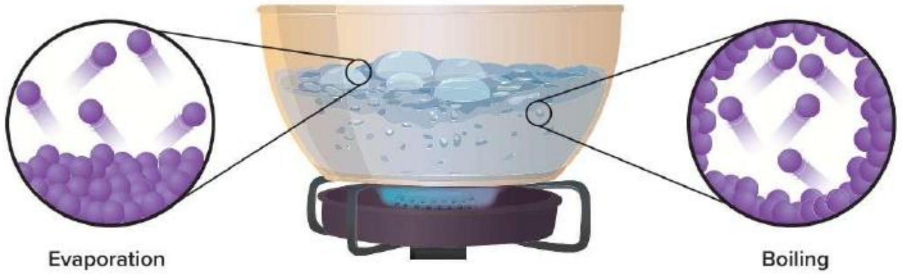
Answers may vary. Sample answer: The glass is changing from a solid to a liquid. The glass is at its melting point, so added energy is going into changing the state of matter.

Changes Between Gases and Liquids When the temperature of a gas becomes low enough, the gas changes to a liquid. The change of state from a gas to a liquid is **condensation.**

Water condenses on grass overnight

EARTH SCIENCE Connection Changes between states of matter drive the water cycle. Water changes from a liquid on the ground into a gas and enters the atmosphere. When the water vapor in the atmosphere undergoes condensation, it forms clouds. The overnight condensation of water vapor often causes dew to form on blades of grass.

Vaporization The opposite of condensation is **vaporization,** the change in state from a liquid to a gas. There are two ways that vaporization occurs, boiling and evaporation.



Evaporation	Boiling
Vaporization that occurs on the surface of a liquid is called evaporation. Evaporation can occur during boiling and at lower temperatures. A small amount of room-temperature water in a glass, for example, evaporates in a few days without ever reaching the boiling point temperature.	Vaporization that occurs within a liquid is called boiling. Boiling does not occur until a liquid is heated to its boiling point, the point where a substance changes from a liquid to a gas. Once the boiling point is reached, the continued addition of energy vaporizes the liquid. Bubbles form within a liquid as it boils.

The boiling point and the condensation point are the same for a given substance. Whether a liquid is changing to a gas or a gas is changing to a liquid, a substance will always change phases at the same temperature. While a substance is boiling or condensing, the temperature remains constant until the phase change is complete.

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THREE-DIMENSIONAL THINKING

Using your understanding about the **patterns** between vaporization and condensation, **explain** why the boiling point and the condensation point are the same temperature.

The boiling point is the temperature at which a liquid changes to a gas. The condensation point is the temperature at which a gas changes to a liquid. These changes happen at the same temperature. This is because of the pattern that exists in particle energy being lost or gained to change state.

COLLECT EVIDENCE

How does what happens to temperature as a substance changes state help explain why gallium melts in someone's hand? Record your evidence (A) in the chart at the beginning of the lesson.

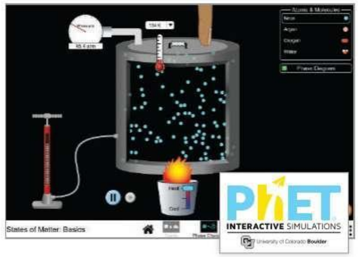
What happens to particles and energy during a change of state?

As you have observed, when the temperature rises, gallium will change state. Think about the particles in gallium. How do they move during a phase change?

INVESTIGATION

Changing Energy

GO ONLINE Explore the PhET interactive simulation *States of Matter: Basics*. Explore the simulation on your own. When you are finished, reset the simulation, and then follow the instructions below.



1. Return to the home page and go to Phase Changes tab.
2. Add energy by switching the toggle to *Heat*.

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THREE-DIMENSIONAL THINKING

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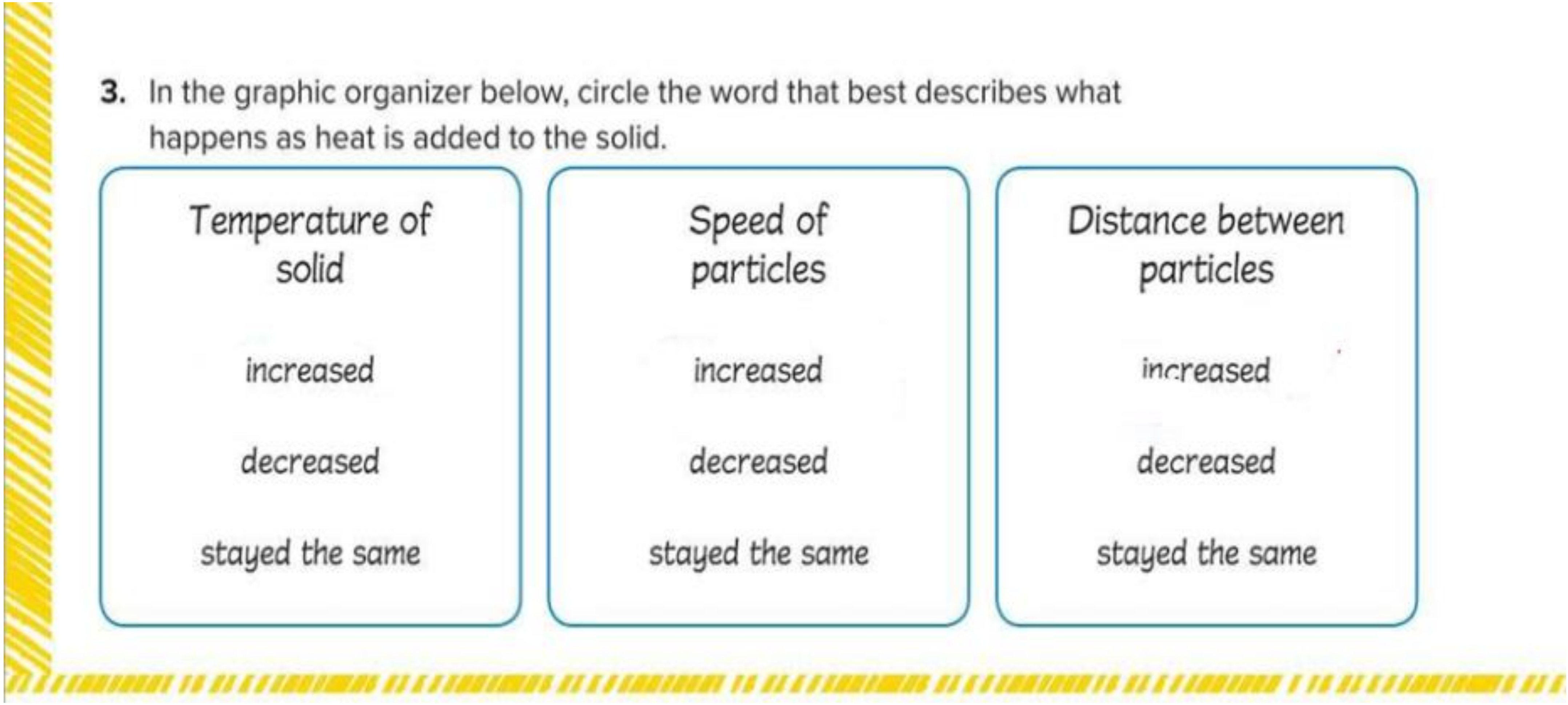
3. In the graphic organizer below, circle the word that best describes what happens as heat is added to the solid.

Temperature of solid	Speed of particles	Distance between particles
[✓ increased]	[✓ increased]	[✓ increased]
decreased	decreased	decreased
stayed the same	stayed the same	stayed the same



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decreased	decreased	decreased
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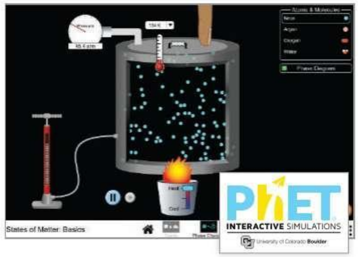

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2. Add energy by switching the toggle to *Heat*.

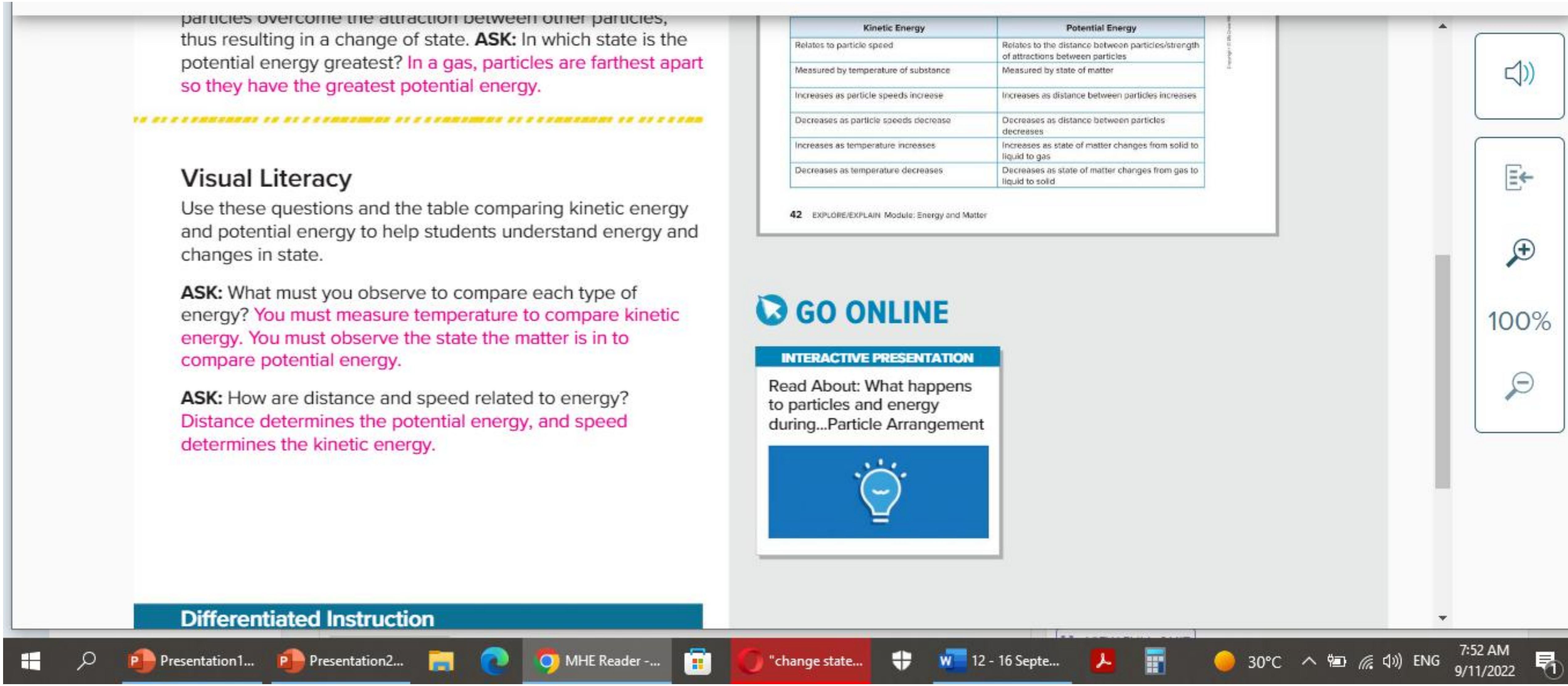
3. In the graphic organizer below, circle the word that best describes what happens as heat is added to the solid.

Temperature of solid	Speed of particles	Distance between particles
[✓ increased]	[✓ increased]	[✓ increased]
decreased	decreased	decreased
stayed the same	stayed the same	stayed the same

Particle Arrangement If energy is continually added to a substance, there reaches a point where the particles cannot go any faster without changing to another state of matter. Recall that particles in gases are fast moving and spread out from each other. In liquids, particles are closely packed but can slide past each other. In solids, the particles are closely packed and held in a rigid formation. The reason each state of matter has different shapes is because of the particle attractions in each state of matter.

Particle Attraction When energy is added and the particles cannot move any faster in the current state of matter, the energy is used to overcome the attraction between particles and causes a change of state. The additional energy increases the potential energy of the particles. **Potential energy** is stored energy due to the interactions between particles or objects. The potential energy increases as the distance between particles increases. Conversely, the potential energy decreases as the distance between the particles decreases. The particles that are farther apart have greater potential energy. The potential energy of the particles, determined by the state of matter present, contributes to the total energy of a substance.

Kinetic Energy	Potential Energy
Relates to particle speed	Relates to the distance between particles/strength of attractions between particles
Measured by temperature of substance	Measured by state of matter
Increases as particle speeds increase	Increases as distance between particles increases
Decreases as particle speeds decrease	Decreases as distance between particles decreases
Increases as temperature increases	Increases as state of matter changes from solid to liquid to gas
Decreases as temperature decreases	Decreases as state of matter changes from gas to liquid to solid



particles overcome the attraction between other particles, thus resulting in a change of state. **ASK:** In which state is the potential energy greatest? In a gas, particles are farthest apart so they have the greatest potential energy.

Visual Literacy

Use these questions and the table comparing kinetic energy and potential energy to help students understand energy and changes in state.

ASK: What must you observe to compare each type of energy? You must measure temperature to compare kinetic energy. You must observe the state the matter is in to compare potential energy.

ASK: How are distance and speed related to energy? Distance determines the potential energy, and speed determines the kinetic energy.

Differentiated Instruction

Kinetic Energy	Potential Energy
Relates to particle speed	Relates to the distance between particles/strength of attractions between particles
Measured by temperature of substance	Measured by state of matter
Increases as particle speeds increase	Increases as distance between particles increases
Decreases as particle speeds decrease	Decreases as distance between particles decreases
Increases as temperature increases	Increases as state of matter changes from solid to liquid to gas
Decreases as temperature decreases	Decreases as state of matter changes from gas to liquid to solid

GO ONLINE

INTERACTIVE PRESENTATION

Read About: What happens to particles and energy during...Particle Arrangement

THREE-DIMENSIONAL THINKING

For each example:

1. Complete the **model** of the particles.
2. Indicate how potential **energy** is changing (increasing or decreasing).
3. Indicate how the attractive forces are changing (increasing or decreasing).

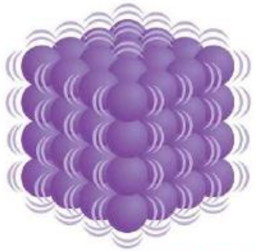
A

→ Condensing: Sketch of particles slowing down → Liquid: Sketch of particles in liquid state

Potential Energy = decreasing

Attractive Forces = increasing

B



→ Melting: Sketch of particles speeding up → Liquid: Sketch of particles in liquid state

Potential Energy = increasing

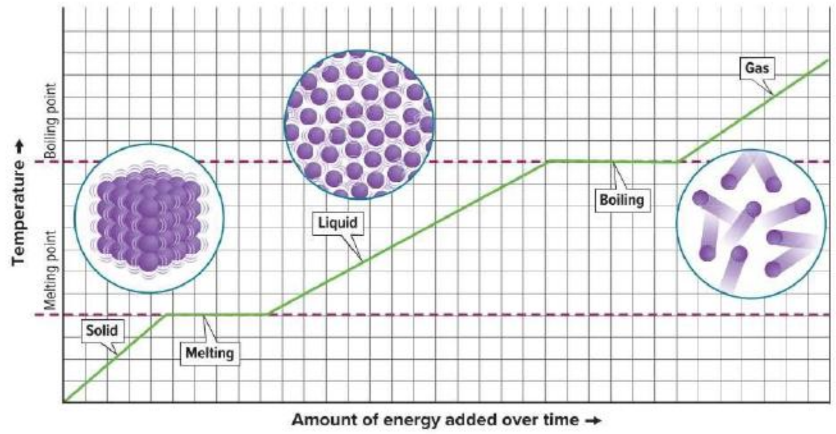
Attractive Forces = decreasing

C

→ Boiling: Sketch of particles speeding up → Gas: Sketch of particles in gas state

Potential Energy = increasing

Attractive Forces = decreasing



Heating Curves The graph above is the heating curve for water. Just as in the graphs you created, it shows what happens to temperature as energy is added to a substance. As energy is transferred to a material, temperature increases when the state of the material is not changing. The kinetic energy of the particles increases. This increases the speed of the particles.

When a substance is changing state, temperature stays the same at the melting and boiling. The potential energy of the particles increases. This increases the distance between the particles.

THREE-DIMENSIONAL THINKING

Construct an **argument** on how the existence of potential **energy** between particles supports or opposes the shape of a heating curve.

Answers may vary. Sample answer: When the state is changing, the energy is becoming potential energy. As temperature is a measure of the average kinetic energy, the temperature does not change because the average kinetic energy is not changing.

COLLECT EVIDENCE

How does the existence of potential energy and the attractions between particles help explain why gallium exists as different states of matter? Record your evidence (B) in the chart at the beginning of the lesson.

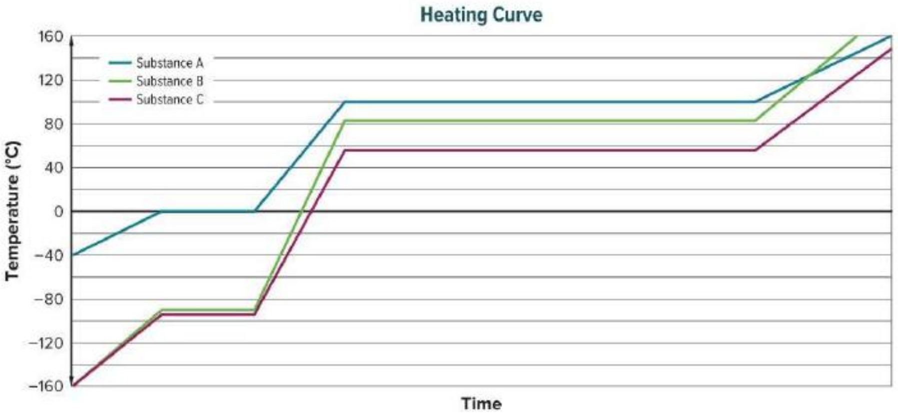
How do the melting and boiling points of different substances compare?

You know that ice melts at 0°C and liquid water boils at 100°C. Based on what you have learned so far, think about what you might expect the melting point of gallium to be.

INVESTIGATION

Turn Up the Heat

A group of students collected data using a similar procedure as the lab *Phase Changes*. They tested 100 mL of three different substances. The plot below was compiled from their data.



1. What patterns do you notice about the plot?

Answers may vary. Sample answer: All the substances change state in the same way or at the same rate. Each substance stays a single temperature as it changes state.

2. Complete the table below using the data plot.

Substance	Melting Point (°C)	Boiling Point (°C)
A	0°C	100°C
B	−90°C	85°C
C	−95°C	55°C

3. Make a claim about the melting and boiling points of different substances supported by evidence and reasoning.

Answers may vary. Sample answer: Different substances have different melting and boiling points. The particles of different substances hold together and separate at different temperatures.

4. At which temperatures are the potential energies of substances A, B, and C changing?

For substance A, the potential energy changes at 0°C and 100°C. For substance B, it changes at −90°C and 85°C. For substance C, the potential energy changes at −95°C and 55°C.

Particles and Melting Points Each substance has a unique melting and boiling point temperature. This is because the particles that make up each substance have different attractions for each other. The more attracted these particles are to each other, the more energy it takes to increase the distance between particles. This results in higher melting and boiling points. The type of particles that make up a substance affect how much energy is needed to cause a change of state. This is why different substances are in different states at the same temperature.

Water, butter, and aluminum change state at different temperatures.

COLLECT EVIDENCE

Why does gallium change from a solid to a liquid at a different temperature than ice changes to liquid water? Record your evidence (C) in the chart at the beginning of the lesson.

2. Complete the table below using the data plot.

Substance	Melting Point (°C)	Boiling Point (°C)
A	0°C	100°C
B	–90°C	85°C
C	–95°C	55°C

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Water, butter, and aluminum change state at different temperatures.

COLLECT EVIDENCE

Why does gallium change from a solid to a liquid at a different temperature than ice changes to liquid water? Record your evidence (C) in the chart at the beginning of the lesson.

What factors determine the total energy of a substance?

The particles that make up gallium are constantly in motion. This means that the gallium, even when solid, has energy. Think about what factors could change how much energy a substance has.

INVESTIGATION

Energy Factors

1. Identify which substance has the most energy. For each pair, enter >, =, <, or need more information (n.m.i.) on the line.

Substance: X
Mass: 50 g
Temperature 50°C
State: Liquid

<

Substance: X
Mass: 50 g
Temperature 100°C
State: Liquid

Substance: X
Mass: 50 g
Temperature 50°C
State: Liquid

>

Substance: X
Mass: 5 g
Temperature 50°C
State: Liquid

Substance: X
Mass: 50 g
Temperature 50°C
State: Liquid

>

Substance: X
Mass: 50 g
Temperature 50°C
State: Solid

Substance: X
Mass: 50 g
Temperature 50°C
State: Liquid

N.M.I.

Substance: Y
Mass: 50 g
Temperature 50°C
State: Liquid

2. If you marked any pair of substances "need more information", explain why.

Answers may vary. Sample answer: Without knowing more about substance X and substance Y, you cannot know which substance has more energy.

Thermal Energy The total energy of a substance depends on:

- the kinetic energy or the speed of the particles (measured by temperature),
- the potential energy or the arrangement of the particles (determined by state of matter),
- the total number of particles in the substance (measured by the mass of the substance), and
- the type of matter that makes up the substance.

Thermal energy is the total energy of a system that is dependent on the number of particles in the system, the state of the material, and the temperature. Thermal energy is not the same as temperature. Temperature is the measure of the average kinetic energy of the particles. The molten, or liquid, metal to the right is the same temperature as the metal it is flowing over. However, the liquid metal's particles have more kinetic and potential energy.

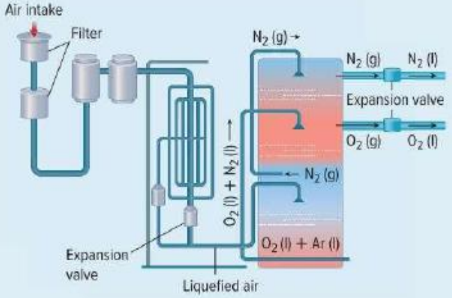
THREE-DIMENSIONAL THINKING

Explain how the particle **model** of **matter** compares to the results from the Lab *Phase Changes*.

Solid particles will speed up when energy is added. Once they reach a certain temperature (or energy level) they will try to break away from each other. In the lab, the temperature stops increasing during this time. The lab supported our particle model of matter.

A Closer Look: Fractional Distillation

ENGINEERING Connection The components of dry air are nitrogen (78 percent), oxygen (21 percent), and other gases (1 percent total). When the components are separated by differences in boiling points, the method of separation is called fractional distillation.



1. Soot and dirt are removed from air by filters.
2. In a heat exchanger, the air releases heat to the cooler surrounding fluid.
3. The cooled, compressed air passes through a nozzle into a chamber of larger diameter. As the air moves through the chamber, it cools. The temperature difference is so great that the air liquefies.
4. The liquefied air flows over several heated trays and is warmed to the boiling point of nitrogen (−195.8°C). Most of the nitrogen, with a trace of oxygen, vaporizes.
5. The liquid oxygen and remaining liquid nitrogen are collected and passed into an upper chamber for another distillation at a higher temperature.
6. After passing through more chambers, the separated gases are liquefied again and bottled as liquid nitrogen and oxygen.

Liquid oxygen and liquid nitrogen are shipped in special insulated containers at temperatures slightly lower than their boiling points.

It's Your Turn

Research and Report The last 1 percent of air is mainly argon gas. This argon is difficult to remove from the liquid oxygen with a fractional distillation process. Why might this be? Make a report of the problem and share your findings with your class.

LESSON 2

Review

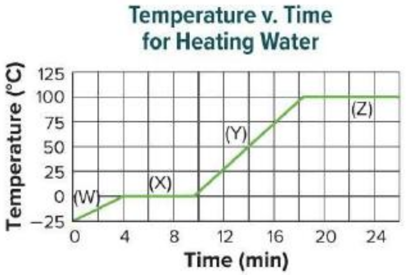
Summarize It!

1. **Organize** Create a graphic organizer that relates thermal energy, temperature, particle motion, and state of matter.

Graphic organizer should show that thermal energy is the combination of temperature, particle motion, and state of matter. The state of matter should be dependent on particle motion and temperature, and temperature being dependent on particle motion.

Three-Dimensional Thinking

The heating curve for water is shown below.



2. Analyze the heating curve. Which area or areas of the curve show a change in the potential energy of the particles?
   - **A** W
   - **B** W and X
   - **C** X and Z
   - **D** Y

3. A scientist was working with substance *Y*. Which of the following does not represent an increase in thermal energy?
   - **A** The temperature of the substance rose by 10°C.
   - **B** The volume of the substance increased by 10 mL.
   - **C** The mass of the substance increased by 10 g.
   - **D** The substance changed from a liquid into a solid.

Real-World Connection

4. **Explain** Think of a time that you noticed a change of state. Explain what happened using the terms *temperature, particle motion,* and *energy.*

Student answers will vary. Sample answer: ice melts when it is taken out of the freezer because the temperature rises, which gives the particles more and more energy. Eventually the energy is enough to break the attractive forces between particles.

5. **Compare** the amount of thermal energy required to melt a solid with the amount of thermal energy released when the same liquid becomes a solid.

The amount of energy released would be the same amount required to melt the substance. This is why the melting point and the freezing point are at the same temperature.

Still have questions?
Go online to check your understanding about thermal energy and states of matter.

REVISIT PAGE KEELEY SCIENCE PROBES

Do you still agree with the friend you chose at the beginning of the lesson? Return to the Science Probe at the beginning of the lesson. Explain why you agree or disagree with that friend now.

EXPLAIN THE PHENOMENON

Revisit your claim about how gallium changes state. Review the evidence you collected. Explain how your evidence supports your claim.

KEEP PLANNING

STEM Module Project Engineering Challenge

Now that you've learned about the role of thermal energy in changes of states of matter, go back to your Module Project to research technologies that use solar energy to heat foods. Use your research to start your own design for a device to heat water.

LESSON 3 LAUNCH

PAGE KEELEY SCIENCE PROBES

Hot Soup

Janey had a bowl of hot soup for lunch. The soup was so hot she decided to put it in the refrigerator for a few minutes to cool it. What happened to cool the soup so Janey could eat it?

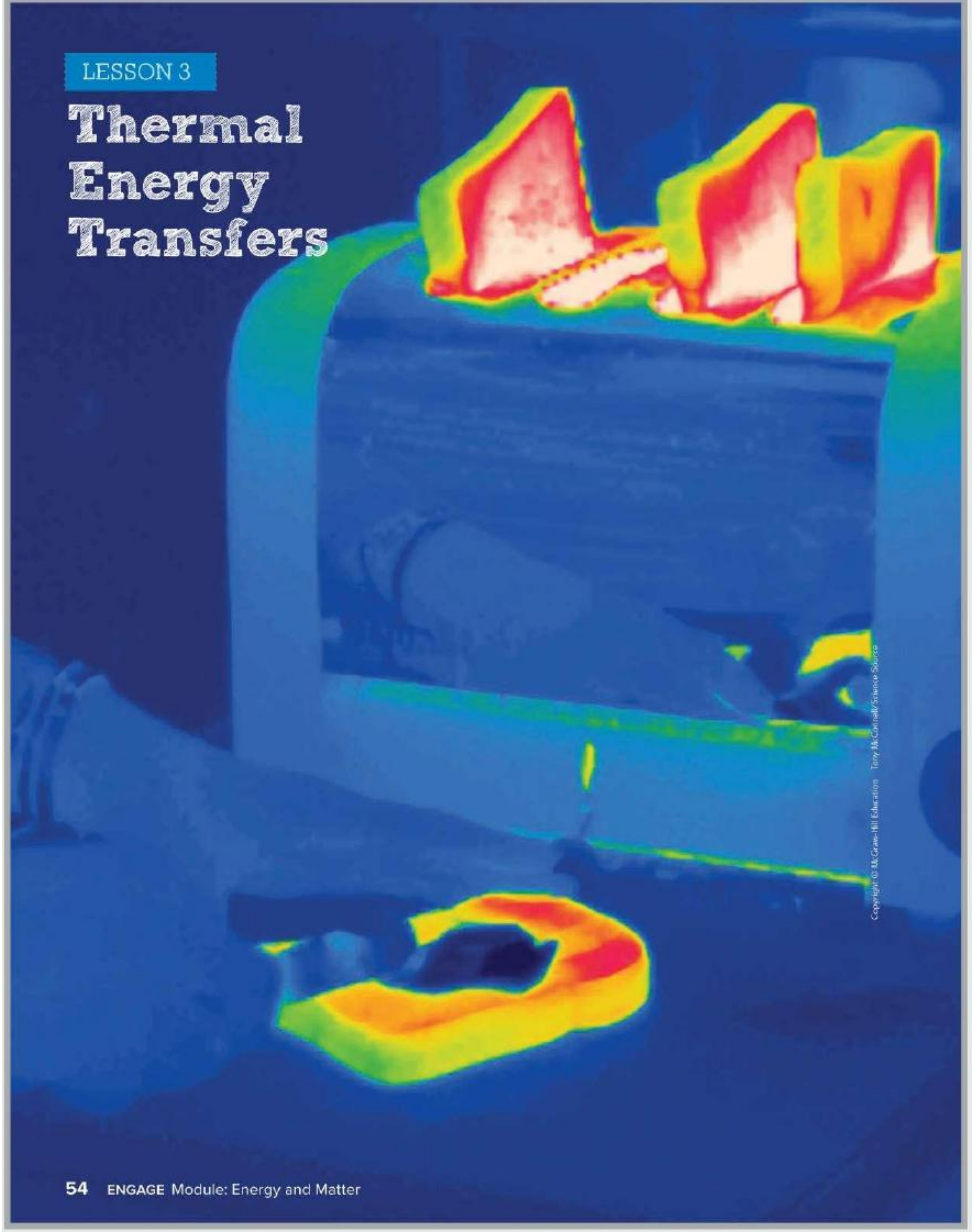
A. The heat moved from the soup to the cold air in the refrigerator.
B. The cold in the refrigerator moved into the hot soup.
C. No heat or cold moved out of or into the soup. It just cooled off.

Circle the answer that best matches your thinking. Explain your thinking. Describe what happened to cool the soup down.

You will revisit your response to the Science Probe at the end of the lesson.

LESSON 3

Thermal Energy Transfers



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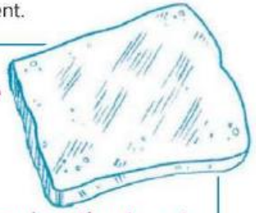
ENCOUNTER THE PHENOMENON

How does energy flow between the toast and the environment?

Watch out, that toast is hot! It must contain a lot of energy. A thermogram shows the temperature of an object by using colors. Create a model that illustrates what you think the energy of this system is when A) the toast first comes out of the toaster and B) after the toast has been left on a plate for 30 minutes. Then, explain how the two illustrations are similar and different.



Student answers may vary. Model A might indicate high levels of energy in the toast by using colors or symbols. Model B might indicate low levels of energy in the toast. Model B might show energy leaving the toast. Some similarities might be the toast is the "system" that is the focus. Differences include the energy levels of the toast.

GO ONLINE

Watch the video *Visualizing Thermal Energy* to see this phenomenon in action.

EXPLAIN
THE PHENOMENON

Now that you have thought about what happens to energy as the toast cools, are you getting some ideas about the direction of heat flow from one object to another? Using the toast as an example, make a claim about how thermal energy moves in the system between the toast and the environment.

CLAIM

Thermal energy flows from...to...

COLLECT EVIDENCE as you work through the lesson.

Then return to these pages to record your evidence.

EVIDENCE

A. What evidence have you discovered to help identify the components in a system in order to explain the direction of thermal energy transfer?

B. What evidence have you discovered to describe how radiation helps explain the direction of thermal energy transfer between the toast and the environment?

MORE EVIDENCE

C. What evidence have you discovered to describe how convection helps explain the direction of thermal energy transfer between the toast and the environment?

When you are finished with the lesson, review your evidence. If necessary, based on the evidence, revise your claim.

REVISED CLAIM

Thermal energy flows from...to...

Finally, explain your reasoning for how and why your evidence supports your claim.

REASONING

The evidence I collected supports my claim because...

Where does thermal energy go?

Have you ever forgotten about food that you had heated up in the microwave? You might have needed to heat it up again because it had become cold. The microwave increased the thermal energy of the food by increasing the temperature of the food. Why did the food become cold after you forgot about it?

Why did it become cold?

Want more information?
Go online to read more about thermal energy transfers.

LAB Transferring Temperature

Safety

Materials

small beaker	cold water
large beaker	thermometers (3)
hot water	stopwatch

Procedure

1. Read and complete a lab safety form.
2. Add 200 mL of cold water to the large beaker.
3. Add 200 mL of hot water to the small beaker.
4. Record the temperatures of the water in both beakers and of the air inside the classroom in the data table on the next page.
5. Without spilling any of the water, place the small beaker inside the large beaker.
6. Record the temperatures of the water in both beakers and the air inside the classroom. Continue recording the temperatures every minute for 5 minutes.
7. Place the beakers in an undisturbed spot overnight to use later.

Data and Observations

Time (min)	Temp. of Water in large beaker (°C)	Temp. of Water in small beaker (°C)	Temp. of Air (°C)
0			
1			
2			
3			
4			
5			

Analyze and Conclude

8. Identify any patterns in the data.

Patterns could include: the temperature of the water in the large beaker increased every minute, in the small beaker temperature decreased every minute, and the air temperature was constant.

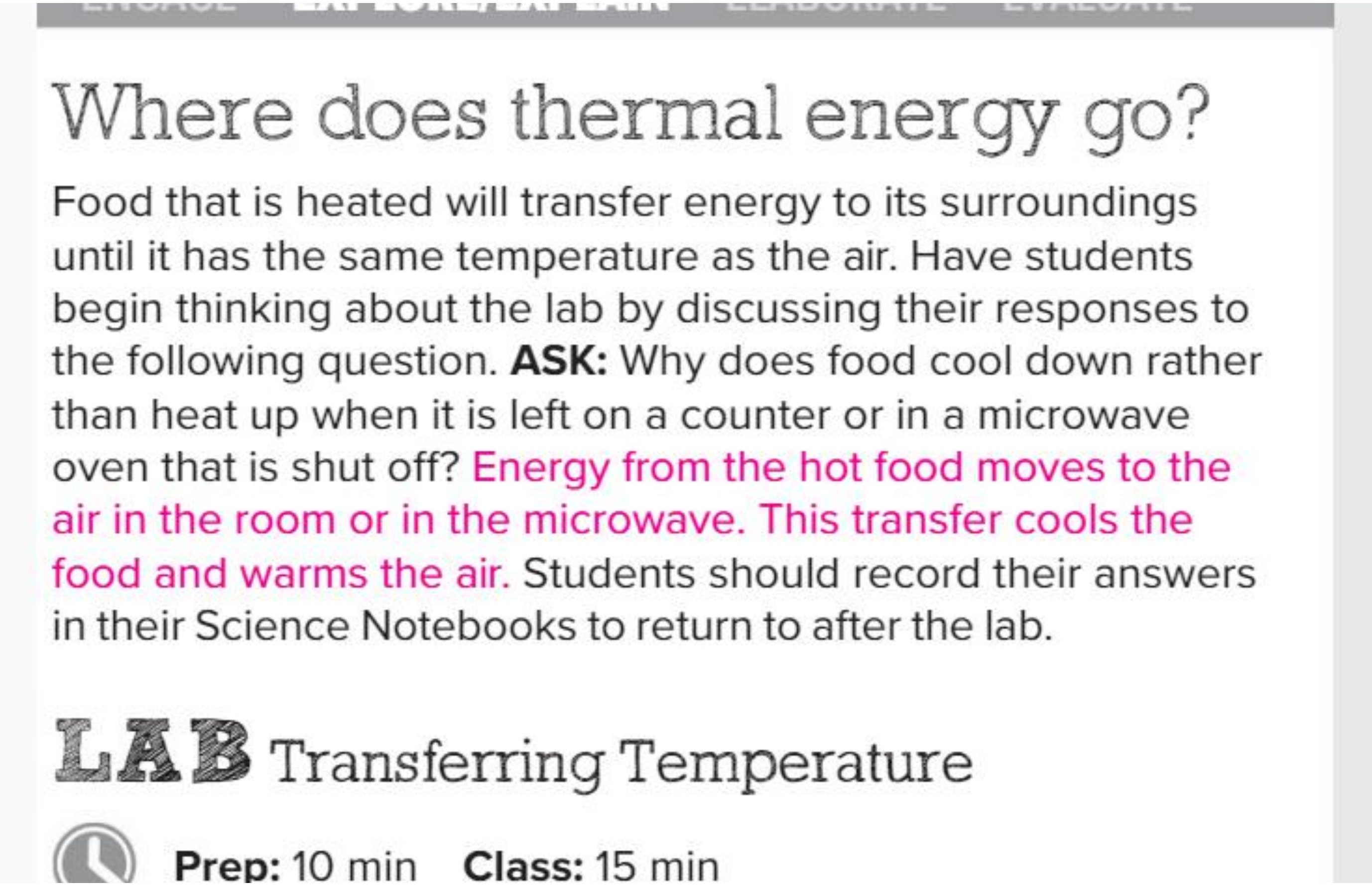
9. Why was it important to measure the temperature of the water in both beakers and the air in the classroom throughout the lab?

To see if the beakers gained thermal energy from the air inside the room. If they did, the air in the room would have gotten colder.

Systems and Energy The two beakers from the Lab *Transferring Temperature* represent a system. Systems are used to model the movement of energy. A **closed system** is a system that does not exchange matter or energy with the environment. Some situations can be thought of as closed systems, such as thermal energy transfers inside a microwave. In reality, there are no closed systems. The microwave is attached to an electrical outlet. Every physical system transfers some energy to or from its environment. An **open system** is a system that exchanges matter or energy with the environment.

The vegetables and microwave represent a system.

Objects make up the components of a system. Energy flows between the objects. The object that provides the energy for energy transfer is called the **source object.** The object that gains the energy from the energy transfer is called the **receiver object.**



Where does thermal energy go?

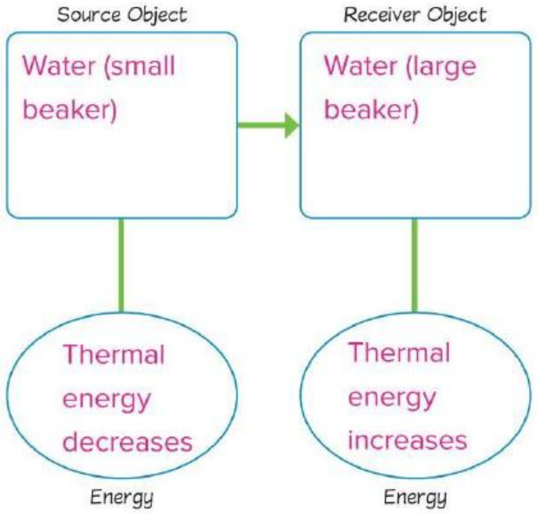
Food that is heated will transfer energy to its surroundings until it has the same temperature as the air. Have students begin thinking about the lab by discussing their responses to the following question. **ASK:** Why does food cool down rather than heat up when it is left on a counter or in a microwave oven that is shut off? Energy from the hot food moves to the air in the room or in the microwave. This transfer cools the food and warms the air. Students should record their answers in their Science Notebooks to return to after the lab.

LAB Transferring Temperature

Prep: 10 min **Class:** 15 min

THREE-DIMENSIONAL THINKING

Use the **energy** flow diagram to **model** the components of the **system** found in the Lab *Transferring Temperature*. Identify the type of energy involved and whether the energy increased or decreased.



Water (small beaker)

Water (large beaker)

Thermal energy decreases

Thermal energy increases

Direction of Thermal Energy Transfer All substances contain thermal energy. When two substances contain different amounts of thermal energy, energy can transfer between the substances. The amount of thermal energy transferred from a region of higher temperature to a region of lower temperature is **heat.** Heat can also refer to the amount of energy transferred during this process.

It is not possible to make something colder by adding "coldness" to it. A substance can only be cooled by allowing some of its energy to be transferred to a substance of a lower temperature. For example, liquid water transfers energy to the surrounding air in a freezer in order to freeze.

Where did the heat go?

THREE-DIMENSIONAL THINKING

In the figure above, the water in the ice cube tray is 10°C. It is placed in the freezer at 0°C. Add arrows to the figure to **model** the direction of **energy** transfer.

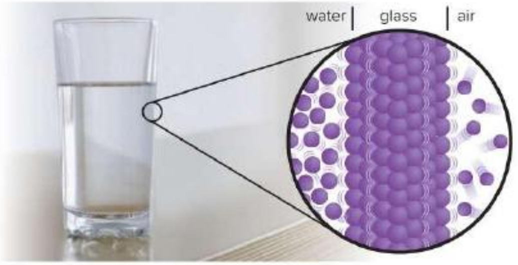
Wattanaphob Kappago/123RF

Conduction Have you ever noticed that when you place a hot piece of toast on a plate, the plate becomes warmer? Thermal energy from the toast transfers to the plate through the process of conduction. **Conduction** is the transfer of thermal energy between materials by the collisions of particles. The particles in the hot toast are in contact and so collide with the particles of the plate. This causes the particles in the plate to gain thermal energy. Conduction can occur between solids, liquids, and gases.

FOLDABLES

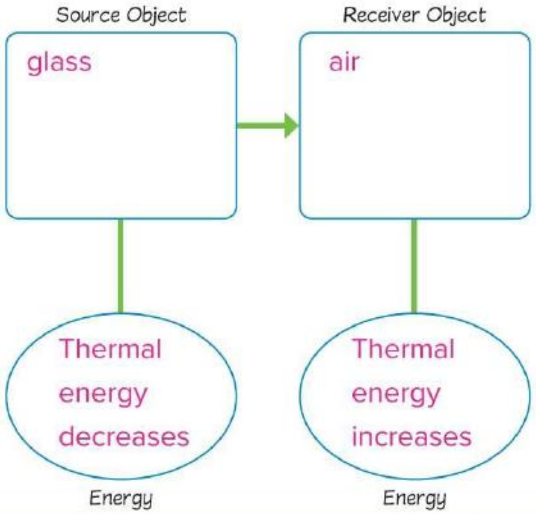
Go to the Foldables® library to make a Foldable® that will help you take notes while reading this lesson.

When particles at different temperatures collide, the particle with higher kinetic energy transfers energy to the particle with lower kinetic energy. This changes the motion of both of the particles. When the energy of a substance changes, there is always another change in energy at the same time. For example, if a particle transfers or loses kinetic energy, it will move slower. If a particle gains kinetic energy, it will move faster.



THREE-DIMENSIONAL THINKING

Look closely at the motion of the particles modeled in the image above. Use the **energy** flow diagram to **model** the components of the **system** that are transferring energy. Identify the type of energy involved and whether the energy increased or decreased.



glass

air

Thermal energy decreases

Thermal energy increases

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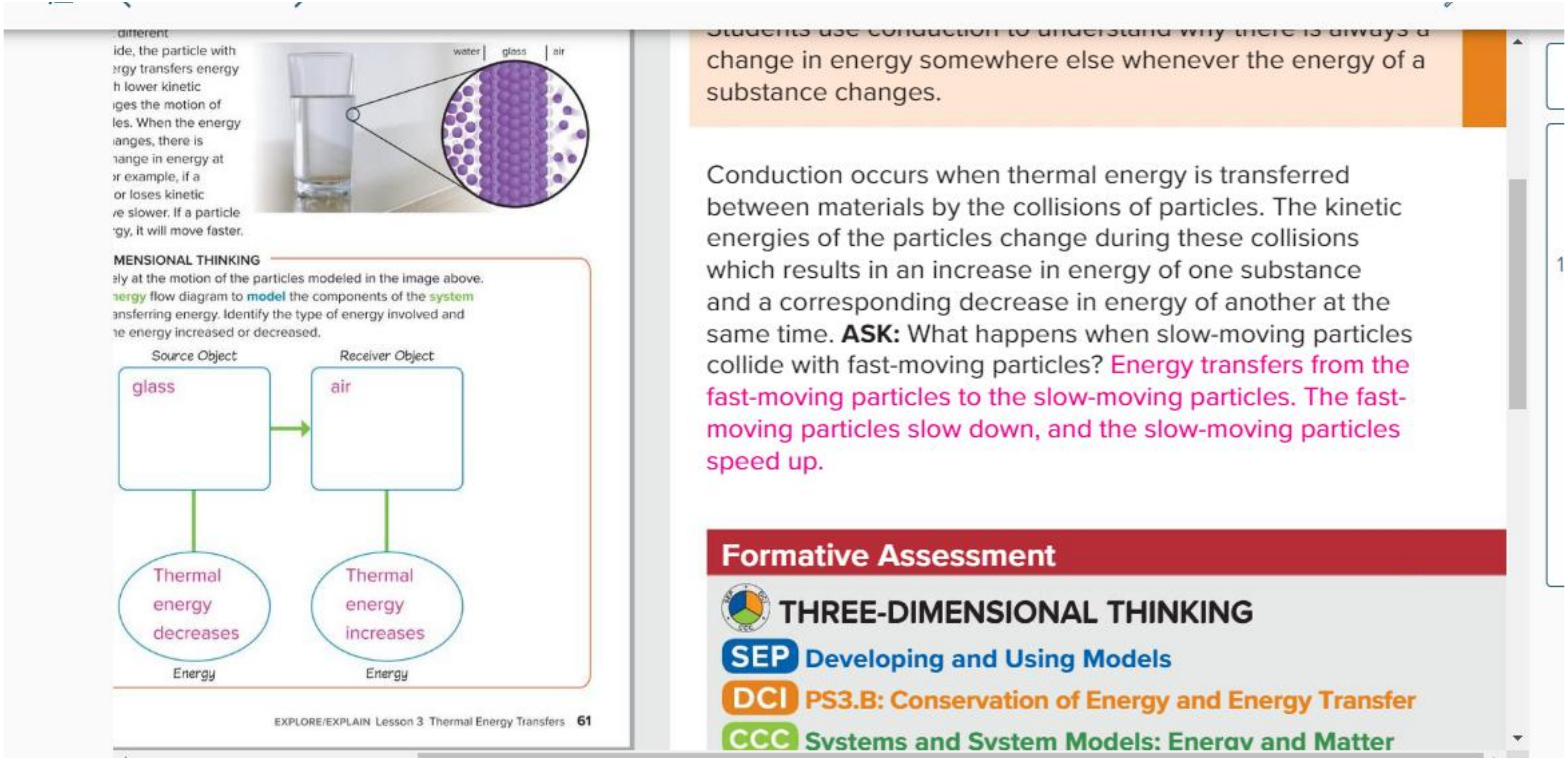

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MENSIONAL THINKING

ely at the motion of the particles modeled in the image above.
nergy flow diagram to **model** the components of the system
ansferring energy. Identify the type of energy involved and
ne energy increased or decreased.

Source Object	Receiver Object
glass	air
Thermal energy decreases	Thermal energy increases
Energy	Energy

Students use conduction to understand why there is always a change in energy somewhere else whenever the energy of a substance changes.

Conduction occurs when thermal energy is transferred between materials by the collisions of particles. The kinetic energies of the particles change during these collisions which results in an increase in energy of one substance and a corresponding decrease in energy of another at the same time. **ASK:** What happens when slow-moving particles collide with fast-moving particles? Energy transfers from the fast-moving particles to the slow-moving particles. The fast-moving particles slow down, and the slow-moving particles speed up.

Formative Assessment

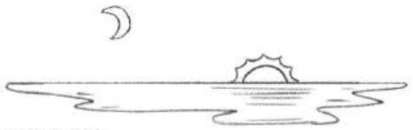
THREE-DIMENSIONAL THINKING

SEP Developing and Using Models

DCI PS3.B: Conservation of Energy and Energy Transfer

CCC Systems and System Models: Energy and Matter

LAB Transferring Temperature Over Time



Safety

Materials

undisturbed beakers (from the *Transferring Temperature* lab)
thermometers (3)

Procedure

1. Read and complete a lab safety form.
2. Retrieve the beakers from where they were left overnight.
3. Record the temperature of the water in the two beakers and the air in the classroom in the Data and Observations section.
4. Follow your teacher's instructions for proper cleanup.

Data and Observations

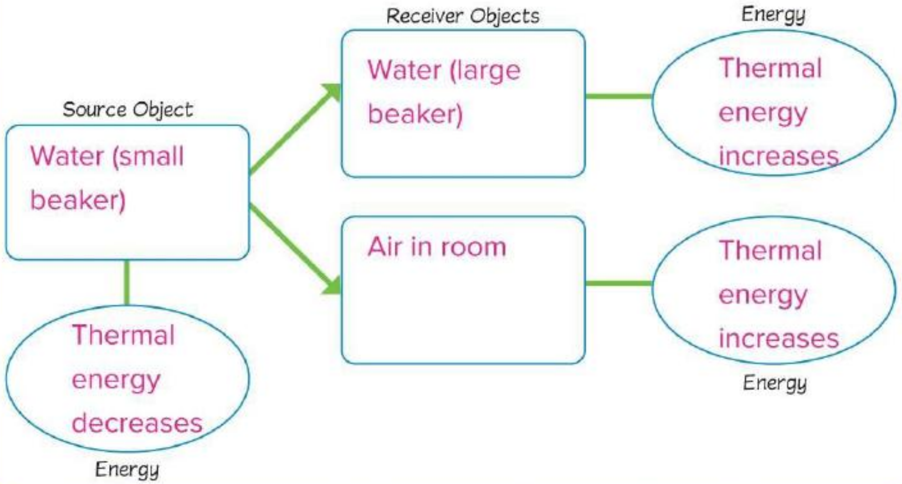
Students should record the temperature of water in each of the beakers and the temperature of the room.

Analyze and Conclude

5. What happened to the temperature of the water in the beakers?
They became the same temperature.

6. How are the components of the system in this lab similar to or different from those in the previous lab?
The air in the room was more significant because everything became the same temperature as the air.

7. Complete the energy flow diagram to identify the components of the open system, the type of energy involved, and whether the energy increased or decreased.



Thermal Equilibrium When the temperatures of materials that are in contact are the same, the materials are said to be in **thermal equilibrium.** After the materials reach thermal equilibrium, the particles that make up the water, the beaker, and the air continue to collide with each other. The particles transfer kinetic energy back and forth, but the average kinetic energy of all the particles remains the same.

COLLECT EVIDENCE

How does identifying the components in a system help explain the direction of thermal energy transfer between the toast and the environment? Record your evidence (A) in the chart at the beginning of the lesson.

How does thermal energy transfer when objects are not in contact?

How does a toaster heat the toast? If you have ever taken a look at the inside of a toaster you might have noticed that the heating coils never touch the bread. If the coils do not come into contact with the toast, then the toast cannot be heated by conduction. How else can thermal energy be transferred?

LAB Lights On

Safety

Materials

lamp
thermometers (2)
stopwatch

Procedure

1. Read and complete a lab safety form.
2. Record the air temperature with two thermometers in the Data and Observations section below.
3. Place one thermometer about 10 cm under a lamp. Place the other thermometer away from the lamp.
4. Record the temperature of each thermometer every 30 sec for 2 min. Record your observations below.
5. Follow your teacher's instructions for proper cleanup.

Data and Observations

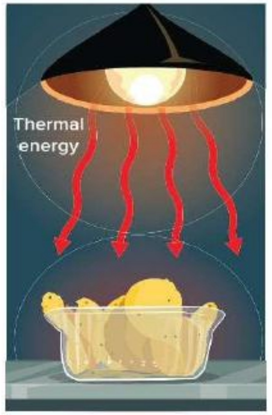
Students should create their own data table to record the temperatures of the air under the lamp and the air away from the lamp.

Analyze and Conclude

6. What happened to the temperatures of the two thermometers?

The thermometer under the lamp showed an increase in temperature. The thermometer away from the lamp showed no change.

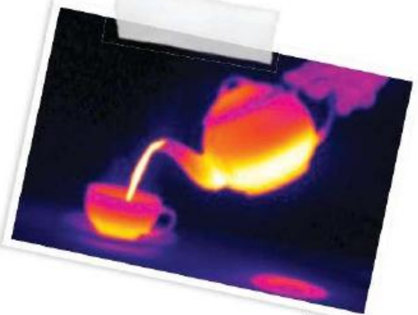
Radiation Another process that transfers energy is radiation. **Radiation** is the transfer of thermal energy from one material to another by electromagnetic waves. All matter, including the Sun, fire, and even you, transfers thermal energy by radiation. Warm objects emit more radiation than cold objects do.



A thermogram, like the one shown below and at the beginning of the lesson, is an image created by a technology that measures the radiation given off by objects. The thermogram below shows hot water pouring from a teapot into a cup. Objects giving off more radiation are shown in white, reds, and yellows, while cooler objects are shown with blues, purples, and black.

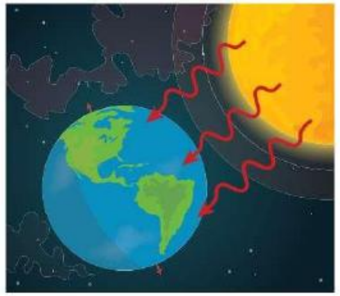
THREE-DIMENSIONAL THINKING
In the thermogram on the right, how do conduction and radiation **explain** the **energy** transfers occurring?

Conduction happened between the teapot and the table leaving behind a spot of high thermal energy when it was picked up. Radiation is happening on all objects.



What's happening here?

EARTH SCIENCE Connection Thermal energy from the Sun can only travel to Earth by radiation. This is because space is a vacuum—a space that contains little or no matter. Since there is little matter in space, thermal energy cannot transfer by conduction, which requires objects to be in contact. Radiation is the method of thermal energy transfer in space. However, radiation also can transfer thermal energy through solids such as rocks, liquids like the ocean, and gases in the atmosphere.



COLLECT EVIDENCE

How does radiation help explain the direction of thermal energy transfer between the toast and the environment? Record your evidence (B) in the chart at the beginning of the lesson.

How else does thermal energy transfer in liquids and gases?

Have you ever heard the saying "hot air rises"? If you hold your hand over the top of a toaster, it is warmer than if you hold your hand near the side. Why is that, and how does it relate to how thermal energy transfers?

INVESTIGATION

Rising Liquids

GO ONLINE Watch the video *Groovy Lava Lamps*. Then answer the following question.

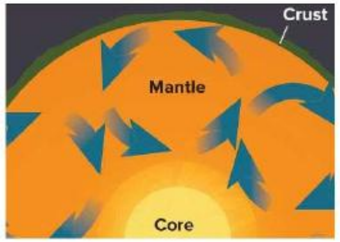
How might thermal energy transfers cause the patterns in the movement of the liquid in the lava lamp?

Students might guess that some of the liquid gained thermal energy, which made the liquid rise. When it reached the top of the lamp, it lost the thermal energy to the surroundings, so it fell back down only to rise again from gaining more thermal energy.


What patterns do you notice?

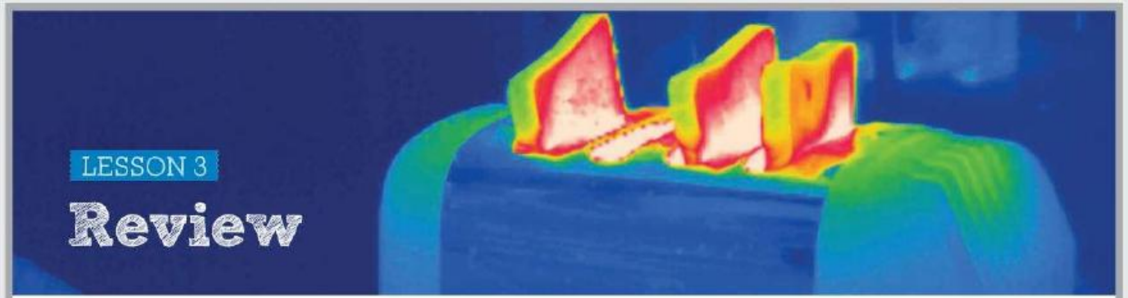
Convection Thermal energy can transfer in a third way. **Convection** is the transfer of thermal energy by the movement of particles from one part of a material to another. Convection explains why hot air rises and cooler air sinks. So as the toaster warms the air in the toaster, the air rises and moves upward into the room. Convection occurs in liquids and gases. Convection does not occur in solids because the particles in solids cannot flow.

EARTH SCIENCE Connection Convection plays an important role in the cycling of materials in Earth's systems. Convection currents circulate water in Earth's oceans and other bodies of water. Convection of thermal energy also moves air on Earth's surface and magma in Earth's interior as shown in the figure on the right.



COLLECT EVIDENCE

How does convection help explain the direction of thermal energy transfer between the toast and the environment? Record your evidence (C) in the chart at the beginning of the lesson.



LESSON 3

Review

Summarize It!

1. **Model** Many zoos provide heat lamps for their animals, such as meerkats. Create an energy flow diagram showing the transfer of thermal energy between the animals, the heat lamp, and the environment.

The energy flow diagram should indicate that the source object is the heat lamp. The receiver objects are the animals and the environment. The thermal energy of the source object decreases. The thermal energy of the receiver objects increases.

Three-Dimensional Thinking

Velinda wants to verify that thermal energy moves from warmer substances to cooler substances until all the substances attain the same temperature. She writes her experimental plan after forming her hypothesis about what will happen to the temperatures at different locations throughout the system. She develops a materials list and procedure for her investigation.

Materials	Procedure	Communication
hot plate 500-mL beaker thermometers timer piece of ice water	1. Place water and ice in the beaker. 2. Take the temperature of the water at the bottom of the beaker, the center of the beaker, and the top of the beaker. 3. Start the stopwatch and record the temperature. 4. Place the beaker with water and ice on the hot plate. Turn the hot plate to medium heat. 5. Every 2 min, record the time and temperature until the water boils. 6. Continue heating and take two more temperature readings.	Create a graph with the data. Write a report that includes the hypothesis, whether the hypothesis is supported, and a conclusion statement about thermal energy movement.

2. Which lab equipment did Velinda omit from her materials list that will ensure her personal safety as she performs her experiment?

A balance scale, candle, glass dish

B goggles, apron, heat-resistant gloves

C metal tongs, Bunsen burner, spark igniter

D vent hood, fire safety handbook, eyewash station

3. Identify the independent and dependent variables of the experiment.

A Independent: temperature; dependent: thermal energy

B Independent: thermal energy; dependent: time

C Independent: temperature; dependent: time

D Independent: time; dependent: temperature

Real-World Connection

4. Illustrate Phoebe is making fruit pops. She places the liquid in the pop molds and places them in the freezer. Phoebe is wondering how the freezer can turn the liquid pops solid. Sketch a diagram showing the flow of thermal energy through all the components in the system.

Diagrams should include the liquid fruit pop, the freezer, and the room. The flow of energy should move from the fruit pop to the freezer to the room.

Still have questions?
Go online to check your understanding about thermal energy transfers.

REVISIT

PAGE KEELEY SCIENCE PROBES

Do you still agree with the statement you chose at the beginning of the lesson? Return to the Science Probe at the beginning of the lesson. Explain why you agree or disagree with that statement now.

EXPLAIN THE PHENOMENON

Revisit your claim about the direction of thermal energy transfer between the toast and the environment. Review the evidence you collected. Explain how your evidence supports your claim.

KEEP PLANNING

STEM Module Project Engineering Challenge

Now that you've learned about thermal energy transfers, go to your Module Project to sketch your design for your cooker technology. Make sure your design meets all the criteria and constraints of the problem, including the use of an energy source other than an open flame.

PERFORMANCE EXPECTATION

LESSON 4 LAUNCH

SCIENCE PROBES

Is the cup hot?

Adita and his friends were learning about insulators and conductors in school. They all agree that metal, a conductor, will heat up more quickly than ceramic, an insulator. They have different ideas about how the materials will cool. This is what each friend said:

Adita: I think the ceramic will cool quicker than the metal.
Niabi: I think the metal will cool quicker than the ceramic.
Irene: I think they will both cool at the same rate.
Rafi: I think conductors and insulators have nothing to do with how a material cools, just how a material heats up.

Which student do you agree with the most? ____________________
Explain your ideas about conductors and insulators.

You will revisit your response to the Science Probe at the end of the lesson.

Data and Observations

Data will vary.
Sample Data Table:

Mass	20 g	40 g	60 g	80 g
Initial Temperature	20°C	20°C	20°C	20°C
Final Temperature	45°C	40°C	30°C	25°C

Analyze and Conclude

8. **MATH Connection** Find the change in temperature for each mass of water by subtracting the initial temperature from the final temperature.

Temperature changes will vary, but should be a positive number.
Final temperature – initial temperature = change in temperature

9. What patterns do you notice in the data?

As mass increases, temperature change decreases.

10. Plot the temperature and mass data for the beakers on the grid below. Plot the temperature change on the vertical axis and mass on the horizontal axis. Label the axes and add a title. Draw a line that goes through the points.

Students should notice that the points form a line pointing from top left to bottom right.

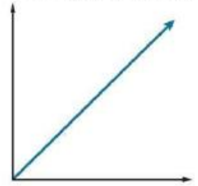
Analyze and Conclude, continued

11. Describe the relationship between the two variables.

As mass increases, the temperature change decreases.

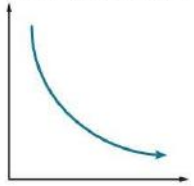
Thermal Energy Transfers and Mass Recall that mass is one of the factors that determines the amount of thermal energy in a substance. It takes more energy from the surroundings to increase the kinetic energy of the particles if there are more particles. As mass increases, the change in temperature will decrease for the same energy input. This is an inversely proportional relationship. Identifying proportional relationships provides information about different properties. For instance, knowing that change in temperature v. mass is an inversely proportional relationship would help answer a problem on whether it's faster to heat up a small pot of water or a large pot of water.

Directly Proportional



x increases, *y* increases

Inversely Proportional



x increases, *y* decreases

THREE-DIMENSIONAL THINKING

Sketch a particle **model** to explain the relationship between change in temperature and mass.

Models should show that the greater the mass of the substance the more thermal energy is needed to increase its temperature.

COLLECT EVIDENCE

How does the mass of a material in the kitchenware affect how it transfers thermal energy? Record your evidence (A) in the chart at the beginning of the lesson.

Data and Observations

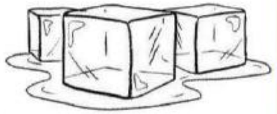
Students should record their observations and the time it takes for each ice cube to melt.

Analyze and Conclude

6. Which set-up melted the ice cube the fastest? The slowest?

Aluminum foil was the fastest, and cotton batting was the slowest.

7. How does your evidence on the amount of time it took the ice cubes to melt explain how much thermal energy each material transferred?



The aluminum foil melted the ice cube the fastest, so it transferred the most thermal energy. The cotton batting melted the ice cube the slowest, so it transferred the least amount of thermal energy. The air transferred a medium amount of thermal energy.

Materials and Energy Transfer In the Lab *Melt Down*, the aluminum foil, cotton batting, and the air in the room transfer thermal energy differently. If you could control all of the other variables, you could find out how much thermal energy each material transferred. In the next investigation, find out how a group of students discovered just how much energy was needed to heat water.

INVESTIGATION

Heat of Water

Read the passage. Use the information from the passage to answer the following questions.

Tama, Jason, and Sia wanted to determine how much energy was needed to heat water. To cut down on multiple trials, they all decided to use different masses of water but heat them all by 10°C. Tama found the energy needed to heat 10 g of water was 418 J. Jason found the energy needed to heat 30 g of water was 1254 J. Sia found the energy needed to heat 20 g of water was 836 J.

1. Organize the data into a table.

Mass	Energy
10 g	418 J
20 g	836 J
30 g	1254 J

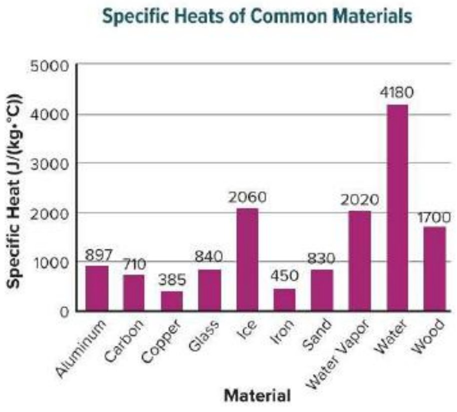
2. What patterns do you notice in the data?

As mass increased, the amount of energy increased.

3. **MATH Connection** Is there a common ratio between the data sets? Explain what you think the ratio means.

Yes the ratio is 1:41.8. This is how much energy is needed to heat each gram of water 10 degrees C.

Specific Heat The ratio that you found describes the specific heat of a substance. **Specific heat** is the amount of thermal energy required to increase the temperature of 1 kg of a material by 1°C . Every material has a specific heat. It does not take much energy to change the temperature of a material with a low specific heat compared to a material with a high specific heat. The chart below lists specific heats of various materials.



GO ONLINE for additional opportunities to explore!

Want to know more about how a material affects thermal energy transfers? Investigate how specific heat determines which materials are used for keeping us cool or warm by performing one of the following activities.

☐ **Model** how energy transference is determined by types of materials in the **PhET Interactive Simulation** *Energy Forms and Change.*

OR

☐ **Argue** the use of home insulation after reading the **Scientific Text** *Insulating the Home.*

EARTH SCIENCE Connection You may have noticed that the specific heat of water is particularly high. A large amount of energy is needed to increase the temperature of water by 1°C. This characteristic of water has many benefits. The high specific heat of water is one of the reasons why pools, lakes, and oceans stay cool in summer. It also means that areas of land that are near large lakes or an ocean generally have more moderate climates. They are cooler in the summer and warmer in the winter because it takes a lot of energy to change the temperature of the water.

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Conductors and Insulators Materials are classified into two groups based on their specific heats: conductors and insulators. A **thermal conductor** is a material through which thermal energy flows easily. The particles in a thermal conductor move easily so kinetic energy is transferred easily between particles. Metals are better thermal conductors than nonmetals. A **thermal insulator** is a material through which thermal energy does not flow easily. The particles in a thermal insulator do not move as easily so kinetic energy is not transferred easily between particles.

The handle of the pan in the figure on the right is made out of wood. Wood is a thermal insulator. The pan is made out of iron—a thermal conductor. Thermal conductors have lower specific heats than thermal insulators. This means it takes less thermal energy to increase the temperature of a thermal conductor than it takes to increase the temperature of a thermal insulator of the same mass.

THREE-DIMENSIONAL THINKING

You can bake food in either a metal pan or oven safe glass. Which would require more **energy** to heat up? Which would cool down the fastest? Explain your reasoning.

A glass dish would require more energy to heat up because it has a higher specific heat. The metal pan would cool down the fastest because it has a low specific heat.

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COLLECT EVIDENCE

How does the type of material in the kitchenware affect how it transfers thermal energy? Record your evidence (B) in the chart at the beginning of the lesson.

What other properties affect thermal energy transfer?

The materials that make up a piece of matter and the mass of that matter affect how much thermal energy transfers. Kitchenware also comes in many different shapes and colors. There are thick cast iron skillets and thin aluminum pans, tall glasses and shallow bowls. Do these factors affect how much thermal energy transfers? Let's investigate!

5. Have your teacher approve your procedures. Follow your approved procedures to compete your investigation.
6. After you complete your investigation, follow your teacher's instructions for proper cleanup.

Data and Observations

Students should construct data tables based on their procedures and needed evidence.

Analyze and Conclude

7. Construct an explanation on how the evidence you collected during the lab supported or opposed the relationship between the property and the change in temperature. Are there any alternative interpretations of the evidence?

Students should construct an explanation with a reasonable claim on how the property they chose to investigate affected thermal energy transfer or did not affect thermal energy transfer. The claim should be supported with evidence from the lab and solid reasoning.

Thermal Energy and Properties of Materials Many different properties of a substance can determine how thermal energy will transfer. Some properties include the reflectivity of a substance, the thickness of a substance, and the exposed surface area.

Reflectivity v. Absorbency	Thickness	Surface Area
Reflection is when energy carried by a wave bounces off a surface. The opposite of reflection is absorption, or the transfer of energy by a wave to a medium through which it travels. The color white reflects all radiated light energy while the color black absorbs all radiated light energy.	The thickness of a substance can determine how thermal energy is transferred. The thicker a substance, the larger the distance the thermal energy has to travel. A larger thickness could increase how long a substance takes to heat up and also delay how long it takes to cool down. Thickness relates to the mass of a substance.	Surface area is the amount of exposed, outer area of a substance. Increased surface area for a given volume increases the energy transfer between the substance and the surroundings. For example, a shallow bowl has more surface area than a deep bowl. The shallow bowl will transfer more thermal energy to the surroundings.

Many factors can affect how thermal energy is transferred between substances. The amount of energy needed to change the temperature of a matter sample by a given amount depends on the type of the matter, the size of the sample, and the environment.

THREE-DIMENSIONAL THINKING

Develop an **explanation** for which student in the image gains the most thermal **energy** from the environment.

The student in the darker colored shirt would gain more thermal energy from the environment because darker colors absorb more energy than light colors.

COLLECT EVIDENCE

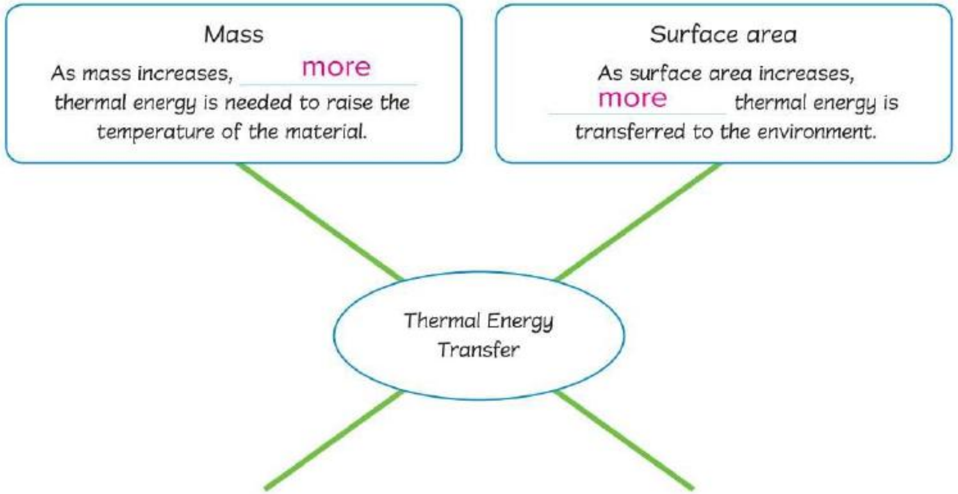
How do other properties of the kitchenware affect how it transfers thermal energy? Record your evidence (C) in the chart at the beginning of the lesson.

LESSON 4

Review

Summarize It!

1. **Organize** Complete the graphic organizer below with the properties that affect how thermal energy transfers between materials. Add any additional properties that you discovered from the lesson.



Mass

As mass increases, more thermal energy is needed to raise the temperature of the material.

Surface area

As surface area increases, more thermal energy is transferred to the environment.

Thermal Energy Transfer

Students could include absorbency, type of material, thickness, or another additional property that affects thermal energy transfer. They should include a description of each property.

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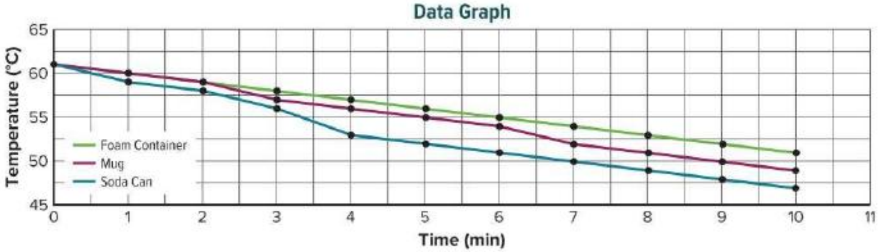
Three-Dimensional Thinking

Jake and Sonya perform a laboratory investigation to explore thermal energy transfer between different materials. They place 100 mL of hot tap water in each of these containers: a foam cup, a mug, and an empty soda can. They record the temperature of the water every minute for 10 minutes. Finally, they plot the data on a graph.



2. Which substance is the best at conducting thermal energy?
   - **A** foam container
   - **B** mug
   - **C** soda can
   - **D** None of the above are good conductors.

3. Which variable would Jake and Sonya need to keep constant to make sure it doesn't affect how the thermal energy transferred out of the three containers?
   - **A** mass of water in each container
   - **B** open surface area of each container
   - **C** color of each container
   - **D** All of the above would need to be constants.

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4. The specific heat of air is 1.0 J/g•K and the specific heat of copper is 0.4 J/g•K. Which statement describes how each material would affect the amount of thermal energy transferred?
   - **A** Air and copper transfer thermal energy the same.
   - **B** Copper transfers thermal energy the quickest.
   - **C** Air transfers thermal energy the quickest.
   - **D** Specific heat does not determine how thermal energy transfers.

Real-World Connection

Material	Specific Heat (J/(kg•°C))
Aluminum	897
Copper	385
Glass	840

5. **Argue** A kitchenware company is looking to market a new skillet. They want to be able to say that it "heats up quickly and cools down quickly". The materials they have narrowed it down to are: aluminum, copper, and glass. Develop an argument supporting or opposing the three choices based on their specific heats.

Copper would be the best choice. It has the lowest specific heat. This means it is a thermal conductor and will heat up quickly and cool down quickly.

6. **Infer** why the sauce on a hot pizza burns your mouth but the crust of the pizza does not burn your mouth.

Even though the sauce and crust have the same temperature, the pizza sauce has a high specific heat and contains more thermal energy.

Still have questions?
Go online to check your understanding about what properties affect thermal energy transfers.

REVISIT SCIENCE PROBES

Do you still agree with the student you chose at the beginning of the lesson? Return to the Science Probe at the beginning of the lesson. Explain why you agree or disagree with that student now.

EXPLAIN THE PHENOMENON

Revisit your claim about what properties affect thermal energy transfers. Review the evidence you collected. Explain how your evidence supports your claim.

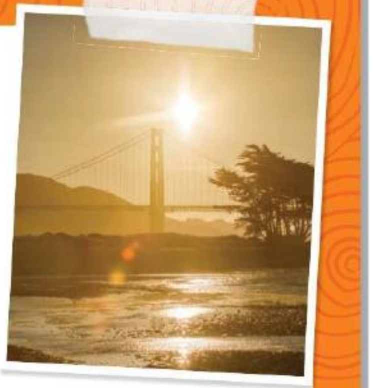
PLAN AND PRESENT

STEM Module Project Engineering Challenge

Now that you've learned thermal energy transfers, go to your Module Project to develop a plan on how to test the new cooking technologies to see which ones meet the criteria and constraints of the problem. Keep in mind that the better the design, the larger the temperature increase of the water.

STEM Module Project
Engineering Challenge

Cookin' with the Sun



You work at an engineering design company that develops alternative cooking methods. Your clients are a group of researchers preparing for a data collection trip where they will be in the field for an extended amount of time. For the last few years, their data collection site has been under drought conditions and no open flames are allowed. They have made a request for a device that will enable them to cook without using open flames.

Your goal is to design, construct, and test a device that is capable of heating a pot of water. You will present your device along with your constructed argument about the device's effectiveness to the clients.

Planning After Lesson 1

Before you begin designing your heating device, record your thoughts about the following:

- who needs this solution
- what needs must be met
- any relevant scientific issues
- any societal or environmental impacts

Answers will vary, but should include all of the bulleted points. Sample answer: Research engineers for a company that develops alternative cooking methods need this to heat food without flames. Scientific issues include identifying energy sources available out in the field and that will not run out. The solution should not harm the environment, should result in little or no pollution, and will need to be portable and compact.

Explain the importance of why all the above components must be defined.

Answers will vary. Sample answer: These things must be defined so that the solution has the best chance to be successful.