SAM Teachers Guide
Phase Change

Overview

Students review the atomic arrangements for each state of matter, following trajectories of individual atoms to observe their motion. Students observe and manipulate differences in attractions among atoms in each state. Then students experiment with adding energy to effect a change in state. They finish by exploring the more complex phenomena of latent heat and evaporative cooling.

Learning Objectives

Students will be able to:

- Give example of phase changes that occur every day and how they affect the world around us.
- Describe what the phases of matter (solid, liquid, and gas) look like at the atomic level.
- Explain how the forces of attraction are what keep atoms in a particular phase at a specific temperature.
- Explain how the input of energy into a system affects the state of matter.
- Describe how both latent heat and evaporative cooling play a role in changes of phase.

Possible Student Pre/Misconceptions

- Phase changes are chemical reactions.
- Particles in the solid state of matter do not move.
- Phase is inherent to a particular material.
- All solids have the same characteristics. (The same is true for liquids and gases.)

Models to Highlight and Possible Discussion Questions

After completion of Part 1 of the activity:

Models to Highlight:

- Page 2 – Atomic Motion in Gases
    - Highlight the speed and randomness of the atoms' motion as well as the relatively infrequent number of interactions.
- Page 3 – Atomic Motion in Liquids
    - Highlight the ability of the atoms to slide past each other, but also how their shape is indefinite while their volume is definite.
- Page 4 – Atomic Motion in Solids
    - Highlight the definite shape and volume of the atoms in a solid and how vibration in place is the observable motion. Note: Atoms in a solid do move, but cannot change position at a given temperature.

    - Pages 2-4: Discuss how atoms exchange kinetic energy (KE) during collisions and how that exchange affects the speed of the molecules. Observe the attractions between the molecules and how that relates to the movement.
- Link to other SAM activities: **Intermolecular Attractions**. Attractions between atoms affect phase. Atoms are attracted to each other at close distances.

Possible Discussion Questions:

- Have students compare and contrast the atomic models of the gas, liquid, and solid phases (found on pages 2, 3 and 4, respectively). What is similar and different in terms of the speed, randomness, and number of interactions experienced in the three phases?

After completion of Part 2 of the activity:

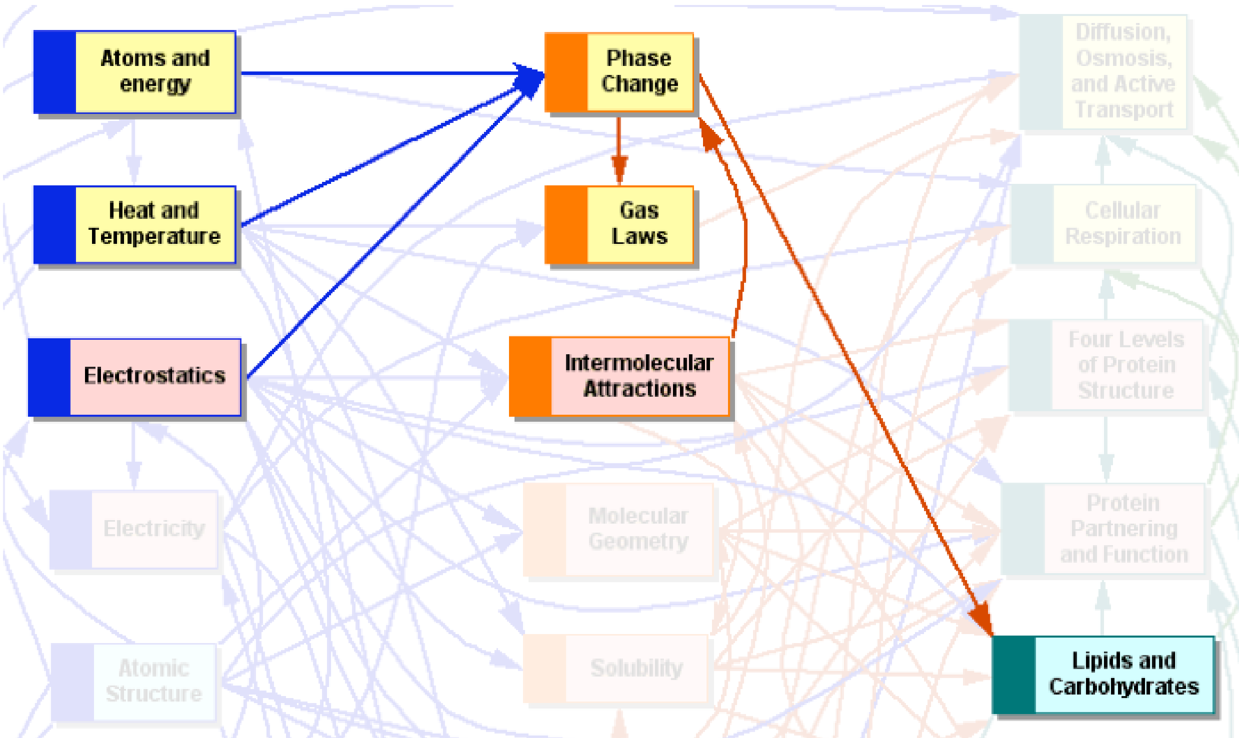
Models to Highlight:

- Page 5 – Forces Between Atoms Determine Phase
    - After students have played with the slider that adjusts the forces between atoms, discuss how force is related to state. Brainstorm how the addition of energy to interrupt those forces may play a role in changing phase.
    - **Note: Students have trouble with the question on the page. Ask students what is solid at room temperature? Does this mean it has strong attractions or weaker attractions? Use this as another opportunity to connect to van der Waals attractions and to ask about boiling point.
- Page 6 – Phase Change by Energy Input
    - Link to other SAM activities: **Atoms and Energy**. Review the idea of energy input in an isolated system vs. open system and how energy may impact phase change.
- Page 7 – Latent Heat Model
    - Discuss connections to input of heat and energy as related to phase changes. (Link to other SAM activities: **Heat and Temperature** and **Atoms and Energy**.)
    - Look at kinetic energy representation. Which has a lot of KE? Can you tell if it is hot or cold? Why are there lots of colors? Relate it to average KE.
- Page 8 – Evaporative Cooling – A More Realistic Model
    - Have students brainstorm where they have seen this phenomena in everyday life.

Possible Discussion Questions:

- Show an ideal heating curve and compare to the heating curve in the model.
- Brainstorm examples of how changing the energy of a system is necessary for a phase change. Use this to connect back to other SAM activities.
- Why can the temperature of a system be defined as the average kinetic energy? What is the effect of water molecules evaporating on the system left behind? Why?
- **Demonstration/Laboratory Ideas:** Show examples of phase changes involving the input of energy. Have students explain what is happening at the atomic level. Show an example such as dry ice and have students attempt to explain what is going on given their knowledge of phase change.

Connections to Other SAM Activities



The focus of this activity is for students to explore the states of matter (solid, liquid, and gas) and the exchange of energy that occurs during transitions from state to state.

This activity builds on the conversions between kinetic and potential energy as introduced in **Atoms and Energy**. Heat energy (kinetic energy) is added to systems and causes molecules to overcome their attractions. Kinetic energy is converted into potential energy as molecules spread apart. The reverse is also true. The **Heat and Temperature** activity also supports this activity because an increase in heat energy increases temperature and causes molecules to change phase. Both **Electrostatics** and **Intermolecular Attractions** deal with the forces at work within molecules that allow both solids and liquids to exist.

This activity supports the **Gas Laws** activity because students must understand how gases behave at the molecular level as compared to other states of matter. In **Lipids and Carbohydrates** students explore the biolipid membrane, which exists as a fluid-like solid. The membrane must be fluid enough to allow molecules to pass through, proteins to be inserted, and vesicles to be absorbed. However, it must also have solid characteristics to give a molecule its structure.

Activity Answer Guide

Page 1:

1. List three more everyday examples of phase change.

Answers will vary:
- An ice cube melting that was left sitting on the countertop.
- Water boiling and evaporating into water vapor (steam) when heated on the stove.
- A tray of liquid water freezing into ice cubes when placed in the freezer.
- Condensation of water vapor in the atmosphere into liquid rain.

Page 2:

1. Describe the motion of atoms and molecules in a gas.

The motion of atoms and molecules in a gas is random. They move in a straight line until they collide with other atoms or molecules in the gas or with the walls of the container. When close to other gas molecules there is a slight attraction, which shows a slight drag on the molecule. This is slight and may not be observed in the model.

2. How are the behavior and arrangements of gas molecules similar to and different from soccer players running in the field?

Answers will vary: The arrangement of gas molecules is similar to soccer players running on a field because the molecules are spread out. There is a great deal of space between them. It is different because the gas molecules are moving randomly and colliding into one another. The motion of soccer players would be more directed with a purpose and a plan.

Page 3:

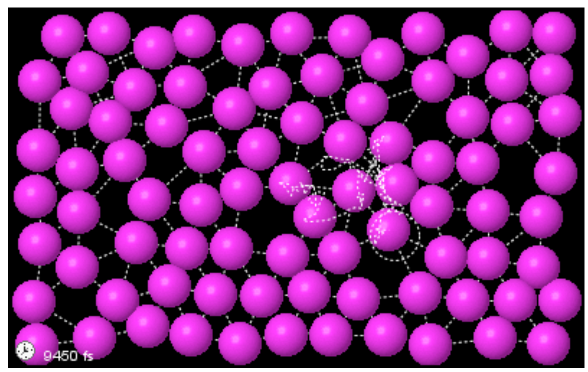
1. Record the average number of dashed lines there are per atom of each liquid.

The average number of dashed lines there are per atom is about 3. Many atoms have only two, while others have 4.

2. Observe the motion of the atom or molecule that was randomly selected. Describe the movement of that atom/molecule compared to the atoms around it.

The atoms and molecules are bumping into each other and jiggling around, occasionally moving past one another. They appear to move slower than the gas molecules. There are, however, more interactions between the atoms and molecules in a liquid as compared to gas.

3. How far do the atoms in a liquid appear to travel? Press the "Randomly pick an atom and show its trajectory" button, take a snapshot and place a snapshot image that you think best answers this question in the box below.



Sample snapshot: the trajectory shows that the atom moves by other atoms, but stays in the same general area of the model.

4. How does the motion of folks at an outdoor rally resemble a liquid?

The motion of folks at an outdoor rally resembles a liquid because the atoms (or molecules) are closer together. They have the ability to move around, but are much more likely to bump into one another in the process.

Page 4:

1. Stop the model and estimate how many dashed lines there are on average for individual atoms inside the solid (not along the edge). Write down the number for each model below.

Solid 1 – 4 interactions (as seen in the ball and stick representation). Solid 2 – 3 (as seen in the ball and stick representation).

2. How would you describe the movement and arrangement of atoms and molecules in a solid?

The arrangement of atoms and molecules in a solid is more definite than that in a liquid or gas. There is the possibility for motion (such as vibrating or jiggling), but the atoms do not change or move position past other atoms as they can in the liquid or gaseous phase.

3. Molecules of gas are so far apart that the intermolecular attractions are pretty insignificant on the random thermal motion of the gas particles. Describe the role of intermolecular forces for solids and liquids.

At the edges, there are fewer interactions than in the interior of a solid. There are not other atoms surrounding on all sides, which reduces the number of interactions.

4. How does the motion of atoms and molecules in a solid resemble people in a movie theater?

The motion of atoms and molecules in a solid resembles people in a movie theater because they have the ability to move or wiggle a small amount, but are restricted by their seat and the people that are surrounding them on all sides.

Page 5:

1. Based on what you observed in the model, choose the items in the list below that you think have weak forces between atoms. Assume all these items are at 300K.

(d) (g) (h)

2. Based on what you observed in the model above, choose the items in the list below that you think have strong forces between atoms. Assume all these items are at 300K.

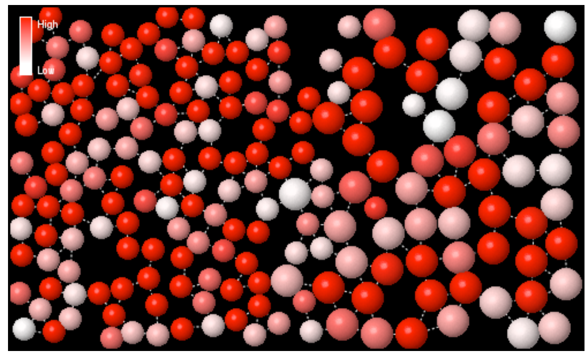
(b) (c) (e) (j)

Page 6:

1. What do you think caused the temperature of the larger atoms that are originally in the right part of the model to rise?

When the wall is withdrawn, the kinetic energy of the larger atoms on the right begins to rise. The collisions of the smaller atoms (that have higher kinetic energy) with the larger atoms cause an exchange of energy and a rise in temperature. The collisions increase energy of the larger atoms.

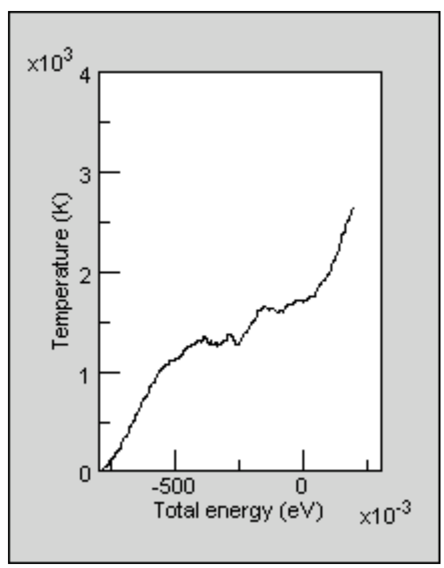
2. Place here a snapshot of the model after the wall has been withdrawn that shows the larger atoms are in liquid state.



As the wall is withdrawn and the temperature rises, the cooler solid enters the liquid state as is shown by a more irregular arrangement of the molecules.

Page 7:

1. Please fill in the snapshot of the line graph you have taken after the simulation stops:



Sample snapshot of graph after latent heat simulation has finished running.

2. Describe what was happening in the model when the temperature stopped rising (in the middle of the simulation). Describe the state of the molecules throughout this time.

As seen on the graph, the temperature stopped rising in the middle of the simulation. At that point in time, the change in phase occurred. The temperature stopped rising because all of the energy entering the system at that time was involved in overcoming attractive forces to change the state of matter rather than causing a rise in temperature.

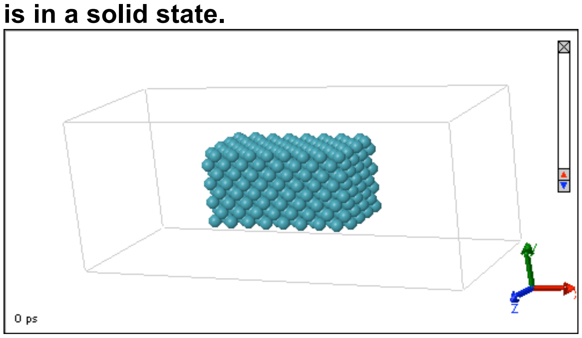
Page 8:

1. What do you think caused the system to cool down when evaporation happens in the second model, based on the reasoning from the first model?

When evaporation happens, the highest energy molecules are leaving the system as a gas. As seen in the model above, the highest energy molecules are moving at the highest speeds to reach the escape region. The molecules that are left behind have a lower average kinetic energy and, therefore, the temperature of the system is lower.

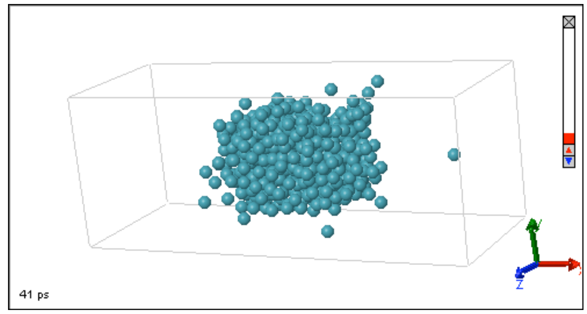
Page 9:

1. Fill in a snapshot image of xenon when it is in a solid state.



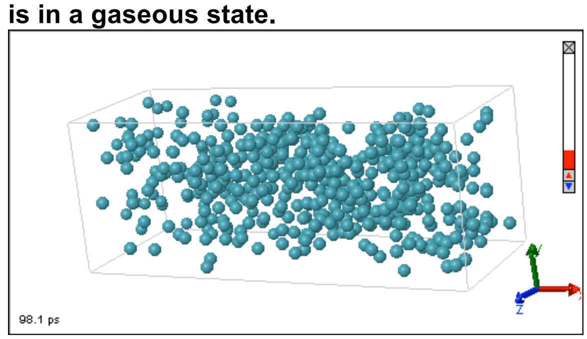
Solid state

2. Fill in a snapshot image of xenon when it is in a liquid state.



Liquid state

3. Fill in a snapshot image of xenon when it is in a gaseous state.



Gas state

4. When water cools from 2° to –2°, what happens to the motion of the molecules? (c)

5. Suppose you are small enough to sit on a molecule. Describe what you see if you were sitting on a molecule in a gas, and that gas turned into a liquid.

While riding a gas molecule, I would expect to run into other molecules randomly and fairly infrequently. If that gas were condensing into a liquid, I would expect to start slowing down and to be more tightly surrounded by other molecules. We would still be able to slide past each other, but would have much less freedom than as a gas.

6. On a microscopic scale atoms look just about as crowded in a liquid as in a solid. What are some molecular level ways you can think of to decide whether a substance is a solid or a liquid?

The molecules that make up a liquid still have the ability to move past one another easily. In a solid,the atoms and molecules that make up a solid move in place, but do not slide past each other as with the liquid.

7. When you get out of the water after swimming, you often feel cold as water evaporates off of your skin. That means you must be losing heat energy. As the water evaporates, it is changing from a liquid to a gas. Explain why the process of evaporation should use up heat from your skin.

Evaporative cooling is taking place just like in the model on page 8. The highest energy water molecules are leaving the liquid phase and become gas (evaporating). As this happens, the average temperature of the molecules left behind is reduced.

SAM HOMEWORK QUESTIONS
Phase Change

Directions: After completing the unit, answer the following questions to review.

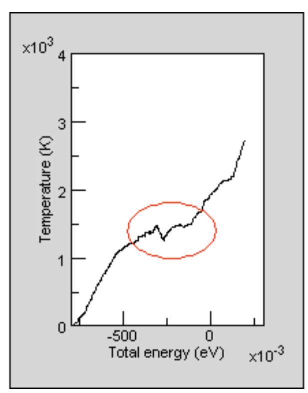
1. In the box below, draw molecules of a sample **gas**. Then, explain the motion of gases at the molecular level.

2. In the box below, draw molecules of a sample **liquid**. Then, explain the motion of liquids at the molecular level.

3. In the box below, draw molecules of a sample **solid**. Then, explain the motion of solids at the molecular level.

4. How can *increasing* the temperature change the phase of a particular material? How can *decreasing* the temperature affect the phase of a particular material?

5. Explain why a bowl of hot soup will ultimately cool to room temperature when it is left on a countertop.



6. The graph to the right shows the phase changes from a crystal to a gas. Explain what is happening at the molecular level at the part of the graph that is circled. Refer to the two axes of the graph (temperature and total energy) in your answer.

7. **Career connection:** Models that predict weather have to consider energy involved in phase changes. Why do hurricanes form over warm oceans? Where does the energy of a hurricane come from?

SAM HOMEWORK QUESTIONS
Phase Change – With Suggested Answers for Teachers
Directions: After completing the unit, answer the following questions to review.

1. In the box below, draw molecules of a sample **gas**. Then, explain the motion of gases at the molecular level.

   Gas molecules should be spread out and have a lot of space between them. Molecules move randomly and change their motion when they collide into one another or the sides of a container.

2. In the box below, draw molecules of a sample **liquid**. Then, explain the motion of liquids at the molecular level.

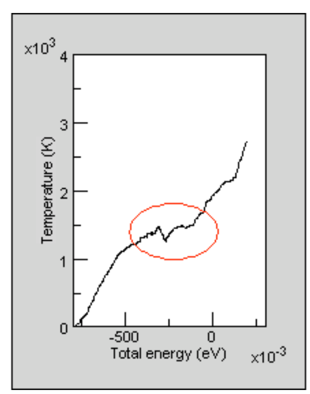
   Liquid molecules should be closer together, but able to move past one another. They can move around and slide past one another, but have a definite volume.

3. In the box below, draw molecules of a sample **solid**. Then, explain the motion of solids at the molecular level.

   Solid molecules should be locked into a definite shape and volume. The molecules can "jiggle" in their place, but cannot move freely.

4. How can *increasing* the temperature change the phase of a particular material? How can *decreasing* the temperature affect the phase of a particular material?
   Increasing the temperature increases the motion and energy of particles in any phase. This may allow the particles to overcome the attraction between them and change phase, such as from a liquid to a gas. The opposite is true of decreasing the temperature.

5. Explain why a bowl of hot soup will ultimately cool to room temperature when it is left on a countertop.
   Evaporative cooling causes the highest energy particles to leave the liquid phase and enter the gas phase. The lower energy particles are left behind, so the soup gets cooler.



6. The graph to the right shows the phase changes from a crystal to a gas. Explain what is happening at the molecular level at the part of the graph that is circled. Refer to the two axes of the graph (temperature and total energy) in your answer.
   The temperature (shown on the y-axis) stopped rising because all of the energy entering the system (shown on the x-axis) at that time was involved in overcoming attractive forces in order to change the state of matter. No rise in temperature took place at that time.

7. **Career Connection:** Warm oceans produce greater evaporation. In the process of evaporation, heat energy is used to separate liquid water into gaseous water. When the water vapor condenses back into droplets, that heat is released warming the air and causing wind currents. The heat energy of the ocean water is converted into the energy in the winds of the hurricane through phase changes.