# States of Matter

**Strand** Phases of Matter and Kinetic Molecular Theory

**Topic** Investigating kinetic theory

**Primary SOL** CH.4 The student will investigate and understand that chemical quantities are based on molar relationships. Key concepts include

a) Avogadro's principle and molar volume;
b) stoichiometric relationships;
c) solution concentrations;
d) acid/base theory; strong electrolytes, weak electrolytes, and nonelectrolytes; dissociation and ionization; pH and pOH; and the titration process.

CH.5 The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include

a) pressure, temperature, and volume;
b) partial pressure and gas laws;
c) vapor pressure;
d) phase changes;
e) molar heats of fusion and vaporization;
f) specific heat capacity;
g) colligative properties.

**Related SOL** CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include

a) designated laboratory techniques;
b) safe use of chemicals and equipment;
c) proper response to emergency situations;
e) accurate recording, organization, and analysis of data through repeated trials;
g) mathematical manipulations including SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, and dimensional analysis;
h) use of appropriate technology including computers, graphing calculators, and probeware for gathering data, communicating results, and using simulations to model concepts.

**Background Information**

From their previous science courses, students should already be familiar with the three basic states of matter and their physical descriptions. The goal of this activity is to connect this knowledge with a deeper understanding of why these physical descriptions are valid, based on the orientation and movement of particles in each state.

The activity will focus on providing a visual model of particle motion and the role that energy plays. Students should gain the understanding that there is a direct relationship between temperature and molecular motion and that relative molecular motions determine physical state.

Students should also be able to explain the energy changes that cause changes of state. If it has not already been covered, these changes should be discussed in the context of endothermic and exothermic changes. Basic calorimetry calculations will be used in determining heat content and change.

**Materials**

- Large, empty pretzel jar, one-fourth filled with 1-inch white Styrofoam balls and two or three colored Styrofoam balls
- Ice cube with temperature probe frozen inside
- Colored pencils or markers
- Temperature probes
- 250-mL beakers
- Hot plates
- Balances
- Calorimeters (a double Styrofoam cup will work)
- Ice cubes
- Picture-hanging wire or other strong, thin wire
- Vacuum pump
- Attached worksheets Heating Curve for Water and Phase Diagram

**Vocabulary**

*calorimetry, conductivity, endothermic, exothermic, kinetic energy, particle motion*

**Student/Teacher Actions (what students and teachers should be doing to facilitate learning)**

*Introduction*

1. Explain the Kinetic-Molecular Theory (KMT). Ask students to define *temperature* and *pressure,* using the KMT. Explain that *hot* and *cold* are relative terms and have very little meaning in chemistry. Model this by asking students to touch the metal on their chair or desk with one hand and touch the wood with the other hand. Ask them which is colder. Point out that both substances have been in the same room together for a long time, and ask if they would have the same temperature if measured with a thermometer.
2. Explain why one substance feels cold and the other feels warmer even though they are actually at the same temperature. Bring in the idea of conductivity and metal versus nonmetal.
3. Remind students that all objects in the room and the air in the room are at the same temperature, unless there is an obvious reason for them to be at a different temperature—e.g., in direct sun, by a heat or AC register. Ask students whether the air particles are moving at the same speed as the desk molecules.
4. Use their answers to explain what Kinetic Energy is and the differences in particle motion of solids, liquids, and gases at the same temperature. Ask a student to take the pretzel jar with Styrofoam balls and model the behavior of particles in solids, showing the balls vibrate

but not move place to place. Have another student model the movement of particles in liquids (a little place-to-place movement of the balls), and another, the behavior of particles in gases (great place-to-place movement). During this process, reinforce how the motion and orientation of particles relates to the physical description of each state of matter.

5. Ask students the relationship between kinetic energy and changes of state. Have a student use the pretzel jar to model ice heating up to become steam and then cooling back down to become ice. Make sure he/she narrates whether energy is being put in or taken out as the phase changes are simulated. Make sure the student shows all phase changes.
6. Explain that the energy needed to change ice to steam can be measured and calculated. Demonstrate this by using an ice cube with a temperature probe frozen inside.
   - Connect the temperature probe.
   - Place the ice cube in a beaker on a hot plate, and heat.
   - Record temperature-and-time readings until the water boils.
7. While this demonstration is running, hand out the attached “Heating Curve” worksheet. Have students complete Part 1.
8. Explain the difference between heat capacity, heat of fusion, and heat of vaporization. Ask students why the temperature levels off during a phase change and where the heat that is still being added is going.
9. Show students the equation for calculating heat in a calorimeter: $H = m(\Delta T)C_p$. Make sure they understand each symbol and why it is in the equation. This is a good time to stress that heat and temperature are not the same but are directly related. Ask them why this equation cannot be used during a phase change (no $\Delta T$). Then explain how heat is calculated during a phase change, using heat of fusion and heat of vaporization.
10. Have students complete Part 2 of the “Heating Curve” worksheet.

Part 1: Determining the Heat of Fusion of Ice

*Procedure*

1. Find the mass of the empty calorimeter, and record.
2. Add about 100 mL of warm water (about 50–60°C) to the calorimeter, and record the combined mass.
3. Find and record the initial temperature of your water.
4. Obtain an ice cube from the cooler, quickly find its mass, and record.
5. Immediately add the ice to the water, and record the water temperature every 30 seconds, if using a temperature probe, or when it levels off, if using a thermometer. Be sure to note the final temperature once the ice has completely melted.
6. Clean up materials.
7. Calculate the change in temperature of the water.
8. Calculate the heat lost by the water, in joules.
9. Calculate the amount of heat the ice cube gained, and explain your answer.

10. Calculate the molar heat of fusion for the ice. (Find the moles of ice first.) Record the heat of fusion in the class data table.
11. Look up the actual molar heat of fusion, and calculate your percent error.
12. Are the class results accurate and/or precise? Why, or why not?
13. Identify two major sources of error and their effect on your outcome.

Part 2: Determining the Heat Needed to Boil Water

*Procedure*

1. Find the mass of a 250-mL beaker.
2. Pour 100 mL of ice water from an ice water bath (be sure there is no ice in your sample) into your beaker, and quickly find its mass.
3. Find and record the initial temperature of your ice water, and place the beaker on the hot plate. Heat to boiling.
4. Record the temperature when the water reaches the boiling point.
5. Turn off the hot plate, and clean up.
6. Determine the temperature change.
7. Calculate the heat gained by the water.
8. Compare this to the heat calculated in Part 2 of the "Heating Curve" worksheet for heating liquid water to boiling. Calculate your percent error.
9. Identify two major sources of error and their effect on your outcome.

*Observations and Conclusions*

1. There will be fairly large errors in determining the heat of fusion. Students should be bothered that they got more heat than they should have. Be sure to have a discussion about whether the ice started at 0° C or not. Ask students how they could figure this out and what effect it might have had on the experimentally determined value.
2. Ask students if there is another way to melt ice other than adding heat. Discuss the role of volume and pressure on physical states and phase changes. As a part of this discussion, ask students how ice skating works—i.e., how it is possible to glide so easily across the surface of a solid.
3. Demonstrate the phenomenon of melting caused by pressure by passing a thin, strong wire through an ice cube. This is easy to do if the ice cube is supported on top of a narrow bottle so that you can pull straight down. Wear gloves or wrap your hands with towels to keep the wire from cutting into them. You need to exert a good amount of pressure, so you might want a stronger student to do this. An alternative is to put lead or balance weights on each end of the wire and let it happen over time during the class period. Ask students to explain why the ice cube is still in one piece after the wire has passed through completely.

**Assessment**

- **Questions**
  - Why is Ideal Gas behavior favored at high temperatures and low pressures? Use the attached "Phase Diagram" worksheet, to explain your answer.

- Based on your answers to the worksheet, why is each region on the graph most likely to be a gas? Label the region.
- What conditions of temperature and pressure favor the solid state? Label the region.
- What do you think is the significance of the places all three curves intersect?
- Which curve represents all of the boiling points for this substance?
- Which curve represents all of the melting points for this substance?

- **Journal/Writing Prompts**
  - Write about a molecule of a specified substance as it travels a heating and/or cooling curve. Narrate what happens to the molecule's behavior (movement and orientation) and energy. The phase changes should be accurate to the substance specified.

**Extensions and Connections (for all students)**

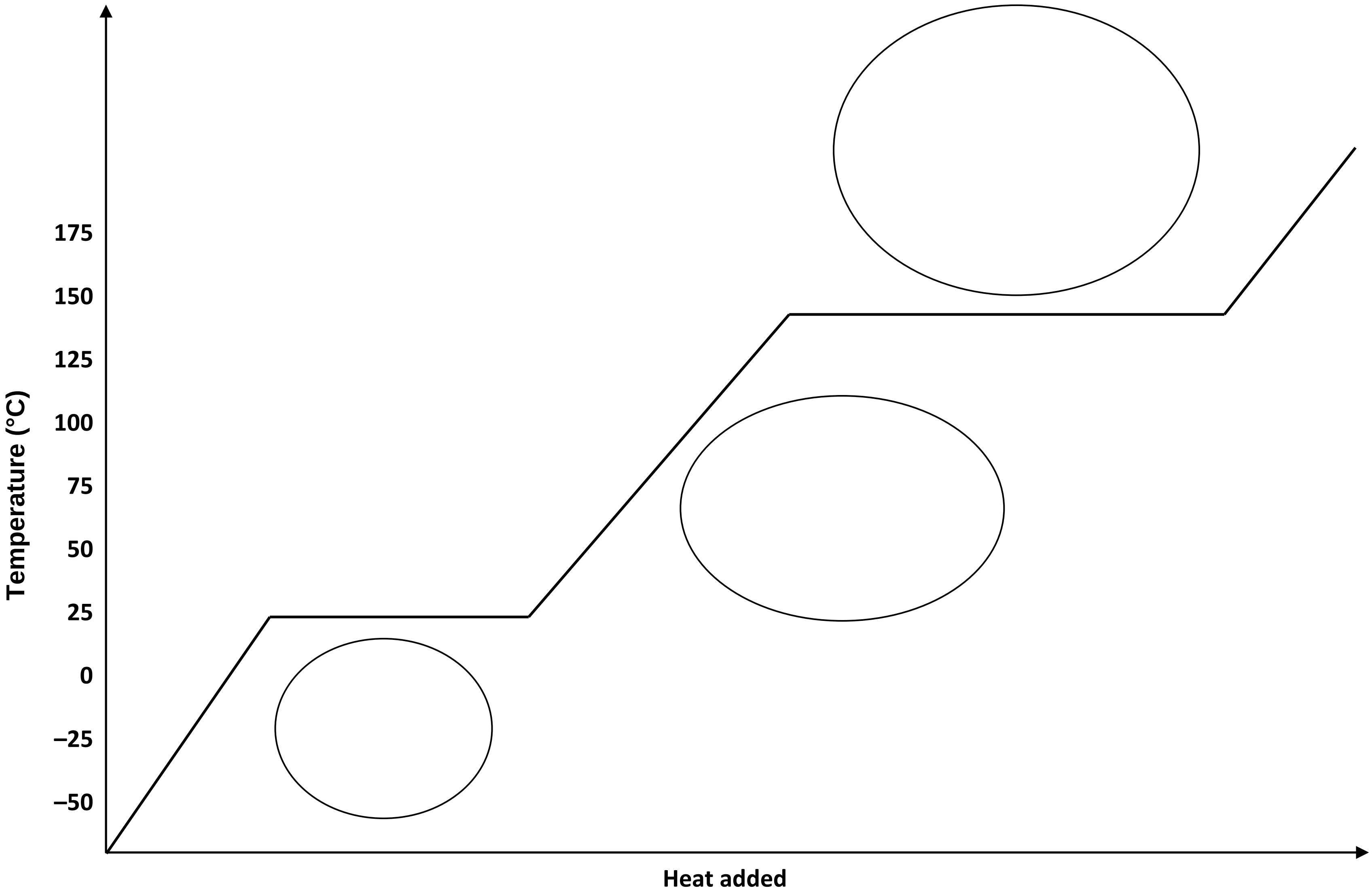
- Have students design an investigation into a phase change, perhaps including colligative properties. Encourage them to keep it simple and small in focus. The idea is for students to identify variables and constants and to test out a hypothesis. Some examples are listed below. Remember, it is not that important that they get an answer to their question or that the question is based in valid science; it can be useful to let them test some common myths. This should be about the process and being able to explain why things work or do not work. Possible investigations might include the following:
  - Does salt water freeze and/or boil faster than pure water?
  - Does cold water freeze faster than hot water?
  - Does the amount/type of solute affect the boiling point?
  - Does alcohol boil at the same temperature as water?
  - Does the rate of melting depend more on mass or more on surface area?

**Strategies for Differentiation**

- Prepare the data table prior to completing the moles activities so students can record information in an organized manner.
- Have students input information collected on a data chart template (computer). Data entry areas should be locked so students cannot add information or edit anything but the areas required by the activity.
- Have students use a digital balance to calculate mass.
- Have students use a digital thermometer or temperature probe that can be connected to a computer to record.
- Have students use a talking calculator to assist in the solving of mathematical calculations.
- Have a group of students model the behavior of particles in solids by standing in a box outlined on the floor and vibrating in place but not moving within the square. Have other students model the movement of particles in liquids (a little place-to-place movement of their bodies) and another group model the behavior of particles in gases (great place-to-place movement). During this process, reinforce how the motion and orientation of particles relates to the physical description of each state of matter.
- Have students visit an ice skating rink and discuss the melting of ice that makes gliding on ice possible.

# Heating Curve for Water

**Name:** ________________________________________ **Date:** __________________________



# Heating Curve for Water

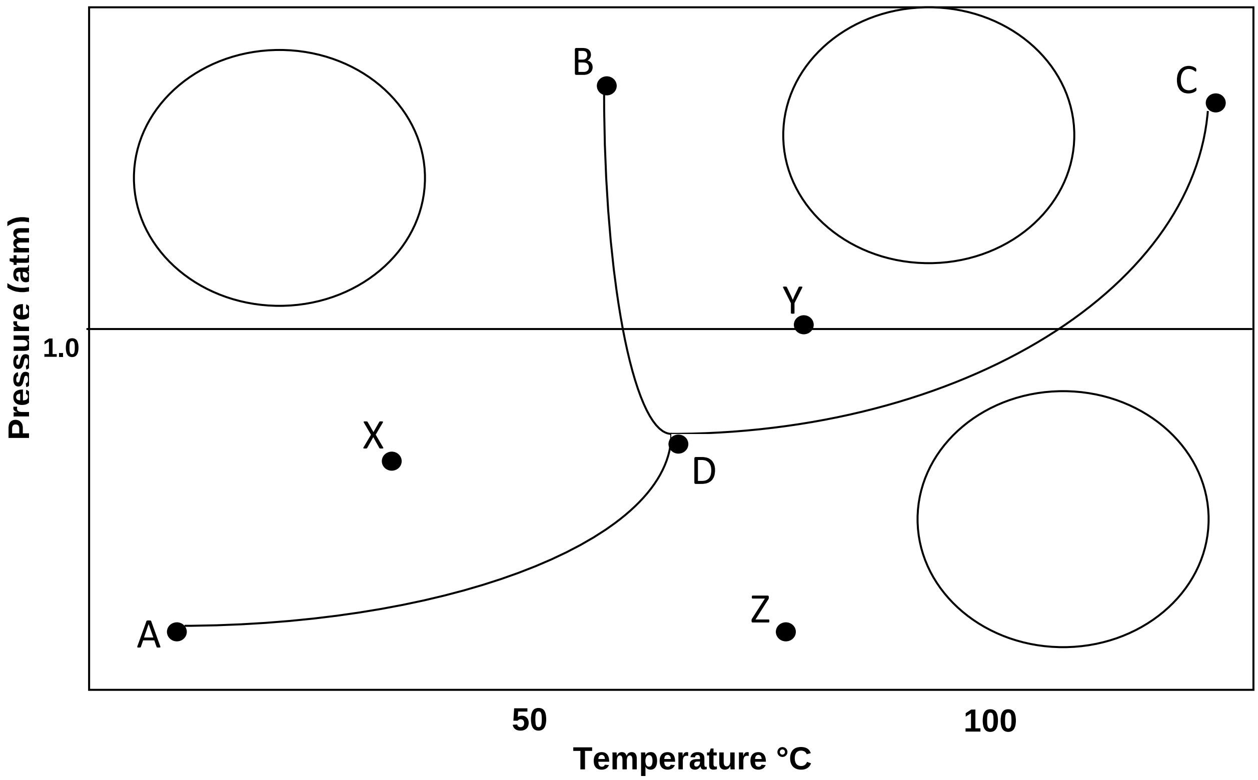
**Name:** ___________________________________________ **Date:** ___________________________

Using the "Heating Curve for Water" graph, complete the following:

1. In what temperature range, in °C, is water a solid? On the graph, find the circle in this temperature range, and label it "Solid." Inside this circle, draw a picture of how water *molecules* look in the solid phase.
2. In what temperature range is water a liquid? Find the circle in this temperature range, and label it "Liquid." Inside this circle, draw a picture of water *molecules* in the liquid phase.
3. In what temperature range is water a gas? Find the circle in this temperature range, and label it "Gas." Inside this circle, draw a picture of water *molecules* in the gas phase.
4. At what temperature does water melt? Find the line that corresponds to this temperature, and *above the line,* label it "Melting." Indicate whether this change is endothermic or exothermic. ___________________________
5. At what temperature does water freeze? Find the line that corresponds to this temperature, and *below the line,* label it "Freezing." Indicate whether this change is endothermic or exothermic. ____________________________________
6. At what temperature does water boil? Find the line that corresponds to this temperature, and *above the line,* label it "Boiling." Indicate whether this change is endothermic or exothermic. ____________________________
7. At what temperature does water condense (change from gas to liquid)? Find the line that corresponds to this temperature, and *below the line,* label it "Condensing." Indicate whether this change is endothermic or exothermic.
8. Use a chemistry book to look up the definition of *temperature*. What does temperature measure? ___________________________
9. Explain the relationship between temperature, motion, and position of particles inside a container. ________________________________________________________________
10. At what temperature is both the liquid and gas phase of water present inside a container? ______________
11. At what temperature is both the solid and liquid phase of water present?__________
12. Label the following equations as melting, condensing, boiling, or freezing:
    $H_2O(s) \rightarrow H_2O(l)$ ________________________
    $H_2O(l) \rightarrow H_2O(g)$ ________________________
    $H_2O(l) \rightarrow H_2O(s)$ ________________________
    $H_2O(g) \rightarrow H_2O(l)$ ________________________
    Do these equations represent a chemical or physical change?
13. Calculate the heat needed to raise 30.0 g of ice from −10°C to 0°C (heat capacity of ice = 2.03 J/g°C).
14. Calculate the heat needed to melt 30.0 g of ice (heat of fusion = 6.02 kJ/mol).
15. Calculate the heat needed to raise 30.0 g of water from 0°C to 100°C (heat capacity of water = 4.18 J/g°C).

# Phase Diagram

**Name:** ______________________________________ **Date:** __________________________




1. Inside of each circle in the diagram above, label the physical state present in that region, and draw the orientation of the particles in that state.
2. Identify the phase change represented by each of the following curves:
   DC ____________________________
   BD ____________________________
   AD ____________________________
3. What states of matter are present at point D? ______________________________ What is this point called? ___________________________________
4. Estimate the normal melting point for this substance: ____________. Estimate the normal boiling point for this substance: ____________.
5. What physical state is present at point Y? __________________________________________
6. What process occurs when you move from × to Y? __________________________________
7. What process occurs when you move from Z to Y?__________________________________
8. What process occurs when you move from Y to X?__________________________________
9. What process occurs when you move from X to Z? __________________________________
10. What is the significance of point C? What is this called? ______________________________
11. Would this substance be more dense as a solid or as a liquid? (Think about whether increasing pressure of the solid would make it melt or freeze.) ________________________ Why?