What Do You Think?

You know that materials can exist as solids, liquids, or gases. Each state of matter has its own characteristics.

- **Draw three circles. In the first circle draw what you think particles of material look like in the solid state. In the next circle draw the particles of the same material as a liquid. In the final circle illustrate the same material as a gas.**

Record your ideas in your Active Chemistry log. Be prepared to discuss your responses with your small group and the class.

Investigate

Part A: The Heating Curve of Water

1. Put on your safety goggles and apron. Half-fill a 250-mL beaker with crushed ice.

2. Set up your equipment as shown in the diagram. The hot-plate dial should be in the off position. When you clamp the thermometer into place, be sure that the bulb is in the center of the ice and is not touching the bottom of the beaker.
Activity 2 States of Matter: Solid, Liquid, and Gas

3. Observe the thermometer closely until it appears to have reached its lowest reading.
   a) Prepare a data table similar to the one shown below. Record the minimum temperature at time 0 min.

4. Turn on the hot plate. Use a medium-low setting, or one suggested by your teacher.

5. Gently stir the ice and water mixture with a stirring rod.
   a) Record the temperature every minute.

6. Continue to record the temperature until the water has been at a full boil for 5 min.

7. Turn off the hot plate. When the water has cooled discard it. Return all equipment as directed and clean up your station.

8. Use your data to answer the following:
   a) What was the temperature at which all the ice had melted?
   b) What was the boiling point of the water?
   c) Plot a graph of the data with time along the x-axis and temperature on the y-axis. You may wish to use a microcomputer or a calculator to plot your graph.
   d) Describe your graph. Consider: What is happening at the various points along the graph? Heat energy is being continually transferred to the system by the hot plate. At which point is the heat energy causing the temperature to increase? What is the heat energy doing if it is not acting to raise the temperature of the water?

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Temperature (°C)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part B: Making Particles Shake

1. Your teacher will assemble or have you assemble a small booklet with many blank pages.

2. Use only the right-hand pages of the booklet. At the very bottom right of the last page of the booklet draw a dot. To make the dot appear to move from the top left to the bottom right at a constant speed, draw another dot on the previous page slightly to the left and up. Continue this until you reach the first page of the booklet. Now as you flip through the booklet from the front to the back, the dot will appear to move. The smaller the movements from one page to the next, the smoother the animation effect will appear.

3. Matter can be in a solid state, a liquid state, or a gaseous state. Each state of matter has its own typical motion of particles. The physical properties of each state are a result of how the particles move relative to one another. Use animation to model the movement of particles in each state of matter. Consider using different colors to keep track of the particles.

   a) In a solid the particles stay in the same position but vibrate. Use your flipbook to model the movement of particles in a solid.

   b) In a liquid the particles are about the same distance apart as in the solid, but they can move more freely. Use animation to model a liquid.

4. Gas particles are very, very far apart and they move very quickly.

a) What problems would you have to make a flipbook for gases?

Part C: Volume Changes

1. Draw up a water plug about 1 cm long in a 30-cm long glass tube. Set the glass tubing into a test tube, as shown in the diagram below.

   a) Observe and describe the movement, if any, of the water plug.

2. Place the test tube into a beaker of warm water.

   a) Record your observations in your Active Chemistry log.

   b) How does the warm water affect the volume of the air in the test tube? What evidence did you observe that suggested a volume change?

   c) The warm water was a source of heat energy. What effect did this heat energy have on the volume of air?
3. Place the test tube into a beaker of ice water.
   a) Record your observations in your *Active Chemistry* log.

4. In physics you’ve learned that for the drop of water to stay in place, the forces must be equal and opposite. The force of gravity pulling down on the water plug must be equal to the upward force of the gas.

   When the air in the test tube was heated, the upward force on the water plug must have increased, because the water rose in the tube. Since no additional air molecules were added, the molecules must have moved faster as a result of the additional heat. As the temperature of the air increased, the molecules of air increased their speed and therefore applied a greater force to the drop of water. Once the drop of water rose high enough, the larger volume and fewer air molecules hitting the drop per second compensated for the increased speed of the molecules. The forces of gravity and pressure were equal once again.

   a) Pressure is force per area. What happened to the pressure on each wall of the test tube as you heated up the air (gas)?

   b) Draw a box with a moveable piston, as shown in the diagram at right.

   c) Use animation to show what would happen to the piston if the temperature of the gas inside the cylinder and below the piston were increased.

**Part D: “Special” Ice**

1. Your teacher will place a small piece of dry ice (solid carbon dioxide) in an empty beaker.
   a) Record your observations in your *Active Chemistry* log.

   b) Is heat energy being transferred to or away from the dry ice by the surrounding air?

   c) What change of state is taking place?
CHANGES OF STATE

All matter is made up of tiny particles. Different materials are made of different kinds of particles. These particles are always moving, and there are spaces between them. The more energy the particles have, the faster they move. There are also attractive forces among the particles. The closer the particles are together, the greater are the attractive forces.

Temperature

You get an intuitive sense of temperature by how hot or cold something feels to your skin. Your body is at 37°C (98.6°F). When something with a higher temperature comes in contact with your skin, you know that it is “hot.” When something with a lower temperature comes in contact with your skin, you know that it is “cold.” As you observed in the activity, when the temperature of air increased, the drop of water lifted. This drop of water could be a crude thermometer. As the drop rises, you know that the temperature of the air is higher. Liquids like alcohol and mercury expand when they get hot and are used for the thermometers with which you are most familiar.

The movement of the water drop gives you an insight into another interpretation of temperature. The air molecules inside the tube were moving faster as the temperature of the air increased. The temperature of the air is a measure of the speed of the molecules. In physics, you learned that kinetic energy is related to speed. Kinetic energy is equal to one-half the mass times the square of the speed of the particles (KE = \( \frac{1}{2}mv^2 \)). Observing the behavior of many gases, scientists have concluded that temperature is a measure of the average kinetic energy of the molecules.

Melting and Boiling Points

In this activity you started with a beaker of crushed ice that was at a temperature less than 0°C. As you heated the ice it did not initially melt, but the temperature of the ice began to rise. As the temperature of any solid increases, the average kinetic energy (energy of motion) of the particles of the material increases.
This motion is mainly a vibration-type motion where the molecules vibrate around a fixed location. As heat energy continued to be transferred, the temperature of the ice increased until it reached 0°C. This is called the normal melting point of water. It is the temperature at which water changes from a solid to a liquid state at 1 atm (atmospheric pressure at sea level). It is also the normal freezing point of water, when water changes from a liquid to a solid at 1 atm. Each material has its own characteristic normal melting/freezing point.

The temperature then remained at 0°C as the solid water changed to a liquid. Since the temperature remained constant, the average kinetic energy did not change. All the heat energy that was transferred caused a phase change during which the molecules of water were rearranging or decomposing. There was a change in the potential energy. If there is a change in kinetic energy you will see a change in temperature and if there is a change in potential energy, the temperature will remain constant while heat energy is transferred to a material.

When all of the water had melted at 0°C, the temperature of the liquid water increased until it reached 100°C. This is called the normal boiling point of water at 1 atm.

**Chem Words**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal melting point</td>
<td>the characteristic temperature, at 1 atm, at which a material changes from a solid state to its liquid state.</td>
</tr>
<tr>
<td>normal freezing point</td>
<td>the characteristic temperature, at 1 atm, at which a material changes from a liquid state to its solid state.</td>
</tr>
<tr>
<td>potential energy</td>
<td>stored energy of the material as a result of its position in an electric, magnetic, or gravitational field.</td>
</tr>
<tr>
<td>normal boiling point</td>
<td>the temperature at which the vapor pressure of the pure liquid equals 1 atm.</td>
</tr>
</tbody>
</table>
If the atmospheric pressure is less than 1 atm, then the water will boil at less than 100°C and is just called the boiling point of the liquid. For example, on Mt. Rainier in Washington State, at an altitude of about 4393 m (14,411 ft), the atmospheric pressure is much less than 1 atm, and you would find that water boils at a lower temperature.

When the water arrived at the boiling point, you again noted that the temperature remained the same, even though heat energy was still being transferred to the water. The temperature would remain the same until all of the liquid is vaporized. Then, with additional heat energy, the temperature would again increase and the gas molecules of water would have greater average kinetic energy.

**Heating Curve of Water**

These changes in the temperature of a material, as heat energy is transferred to it, can be summarized in a graph, similar to the one you constructed. The heating curve of water is shown in the diagram on the previous page. The length of the first horizontal section corresponds to the amount of heat energy required to make the material change from solid to liquid.
Dry ice (solid carbon dioxide) that your teacher used in the demonstration, does not have a normal melting point; instead, it has a normal sublimation point (-78.5°C at 1 atm). **Sublimation** is the process where the solid goes directly to the gaseous state. The changes of state are summarized in the diagram below.

**Checking Up**

1. What does temperature measure?
2. Describe what is happening to particles of a material when heat energy is transferred to the material and the temperature increases.
3. What happens to the temperature of a material when it is undergoing a change of state?
4. What is the difference between the normal boiling point of water, and the temperature at which water might boil?

**Reflecting on the Activity and the Challenge**

In this exercise you focused on very simple chemistry, the motions of particles in solids, liquids, and gases. You can use the techniques learned in this activity to animate more complicated chemical systems. Consider how you could illustrate a phase change, like boiling or freezing. With research you might be able to use animation to explain the chemistry you use in staging your special effect.
1. Copy and complete the following table summarizing the changes of state in your *Active Chemistry* log.

<table>
<thead>
<tr>
<th>Change of State</th>
<th>From</th>
<th>To</th>
<th>Heat (added or removed?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>boiling</td>
<td>liquid</td>
<td>gas</td>
<td>added</td>
</tr>
<tr>
<td>condensation</td>
<td>gas</td>
<td>liquid</td>
<td>removed</td>
</tr>
<tr>
<td>evaporation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>freezing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>melting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>deposition</td>
<td></td>
<td>gas</td>
<td></td>
</tr>
<tr>
<td>sublimation</td>
<td></td>
<td>solid</td>
<td></td>
</tr>
<tr>
<td>vaporization</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Copy and complete the following table in your *Active Chemistry* log.

<table>
<thead>
<tr>
<th>Definite or Indefinite?</th>
<th>Solid</th>
<th>Liquid</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>shape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>volume</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. The heating curve for water was given in the ChemTalk reading section. Create the cooling curve for water and describe each part of the curve.

4. Create a heating curve for water when you have twice the amount of water you used in the investigation. How does this heating curve compare with the original curve?

5. The melting and boiling points of three materials are given on the next page.
   a) Draw a heating curve for each material.
   b) From graphs, explain why, at room temperature (22°C), copper is solid, mercury is liquid, and oxygen is a gas.

6. When water is in a pressure cooker the pressure is greater than 1 atm. What will the boiling point of water be compared to the normal boiling point of water? What information did you use to support your answer?
Activity 2 States of Matter: Solid, Liquid, and Gas

### Preparing for the Chapter Challenge

1. Make an animation of 10 water particles changing from the solid state at 0°C to the liquid state at 0°C.

2. Animate the change of state of 10 dry-ice particles placed at room temperature.

### Inquiring Further

1. **Video animation**

   Making the leap from flipbook animation to video animation is not difficult. You will need access to a video camera that can record one frame at a time. Set the video camera so that it can record an image on a flat table or desk. To animate the process you can either record a series of drawings on paper, putting one after another on the table and taking a frame or two of each image.

   Go to the Internet and see if you can find animations on the Internet. You might find a computer helpful in making the drawings or you could investigate using animation software to make more elaborate animations.

2. **Design a thermometer**

   Use what you learned in this activity to design a thermometer that you could use to measure temperature. If your teacher approves your design, try out your thermometer.

### Table: Material Melting Point (°C) Boiling Point (°C)

<table>
<thead>
<tr>
<th>Material</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>copper</td>
<td>1083</td>
<td>2336</td>
</tr>
<tr>
<td>mercury</td>
<td>-39</td>
<td>357</td>
</tr>
<tr>
<td>oxygen</td>
<td>-218</td>
<td>-183</td>
</tr>
</tbody>
</table>

7. A certain material has a normal freezing point of 10°C and a normal boiling point of 70°C. What state is the material in at room temperature (about 22°C)? Explain your answer.

8. The normal boiling point of water is 100°C and the normal boiling point of ethanol is 78.5°C. These two liquids are soluble in each other. What technique would you use to separate these two liquids from the solution?

9. A certain material is white in the solid phase and clear (transparent) in the liquid phase. It has a normal melting point of 146°C. Which of the following materials could this be: water, sugar, or carbon dioxide? Explain your choice. (Hint: You will have to base your argument on concepts you have learned and observations made in this activity, as well as common sense.)