Activity 5

Freezing Water

GOALS
In this activity you will:
- Determine the freezing point of water.
- Show graphically what happens to the temperature as water is cooled to freezing and while it is freezing.

What Do You Think?
Fast freezing rates promote the formation of many small ice crystals. Slow freezing permits large ice crystals to form. This is important when freezing delicate foods or when making ice cream.

- What happens to the temperature of water as it freezes?

Record your ideas about this question in your *Active Chemistry* log. Be prepared to discuss your responses with your group and the class.

Investigate

Part A: Freezing Water
1. Half-fill a test tube with water. Place the test tube in a polystyrene cup containing an ice and salt mixture.
2. Measure the starting temperature of the water in the test tube.
   a) Record the starting temperature in a table in your *Active Chemistry* log.
3. Measure the temperature of the water in the test tube every 30 s as it freezes. Continue until you reach a temperature of –5ºC.
   a) Record the temperature of the water every 30 s.
   b) Note the temperature at which freezing begins.

4. Graph the temperature versus time in your Active Chemistry log. Plot time on the x-axis and temperature on the y-axis. With good planning, your lab group may be able to complete the graph as you record the data.
   Alternatively, you may use a temperature probe and software in Steps 2 and 3. In this case, the graph will be generated for you.
   a) Place a copy of the graph in your Active Chemistry log.

5. Answer the following questions in your Active Chemistry log.
   a) Describe the graph of the temperature of water as it cools and freezes. How many sections are present?
   b) The water loses heat energy the entire time it is freezing. What happened to the temperature during this time?
   c) Which section of the graph shows where the water is actually freezing? What happens to the temperature while the water is freezing?
   d) Describe the relationship between heat and temperature as water freezes.
   e) Draw three pictures showing the water molecules in the cool water, the colder water, and the frozen water.

6. From the results of the previous activity and Part A of this activity, you can see that temperature remains constant during a phase change. The temperature of a solid, liquid, or gas changes as it gains or loses heat energy. Using the graph you created as a guide, sketch a new temperature versus time graph if ice at –5ºC were heated on a hot plate until it boils.
   a) Label the portion of the graph that shows a solid, liquid, and a gas.
   b) Label the portion of the graph that shows melting, freezing, boiling, and condensing.
   c) Draw two arrows and label each arrow as exothermic or endothermic.
Part B: Heat of Fusion

In this part of the investigation, you will determine the amount of heat energy that is added to a certain quantity of ice as it melts. This is called the heat of fusion of ice.

The strategy for the experiment is to calculate the heat energy loss of the water from its initial temperature to 0°C. This will be the equivalent of the heat energy gain that was required to melt some ice. By measuring the mass of the melted ice, you can then determine the heat of fusion of ice (the energy required to melt one gram of ice).

1. Prepare a table in your Active Chemistry log similar to the one shown below to record your data.
2. Use a hot plate to heat about 200 mL of water in a beaker. When the water reaches about 80°C, turn off the hot plate.
3. Using hot pads or paper towels, measure out 150 mL of the hot water. Carefully pour the hot water into a large foam cup.
4. Fill a second foam cup about two-thirds full with ice.
5. Measure the starting temperature of the hot water in the cup.
   a) Record the starting temperature.
6. Quickly add several pieces of ice to the hot water. Stir gently. Continue adding ice as it melts. Be sure to keep ice in the hot water at all times. Continue until the temperature of the water stabilizes at 0°C.
7. When the temperature is 0°C, remove the remaining ice. Carefully measure the volume of water that is in the cup now.

<table>
<thead>
<tr>
<th>Volume of hot water before (mL)</th>
<th>Volume of cold water after (mL)</th>
<th>Volume of ice melted (mL)</th>
<th>Temp. before (°C)</th>
<th>Temp. after (°C)</th>
<th>Temp. change (°C)</th>
<th>Total heat lost (cal)</th>
<th>Heat per gram of ice (heat of fusion) (cal/g)</th>
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8. Calculate the heat of fusion using the following steps. Show all your calculations in your *Active Chemistry* log.

   a) Determine the volume of water from ice that melted.

   b) Find the temperature change of the hot to cold water.

   c) Determine how much heat the hot water lost by using the heat equation. Remember that the volume of hot water is also the mass of hot water (density of water = 1g/mL).

   \[ \Delta Q = mc\Delta T \]

   d) Since the hot water lost heat energy, the ice gained the same amount of heat energy (assuming no loss to the surroundings). This is a statement of the conservation of energy. The volume of water from melted ice is equal to the mass of ice that melted. (Recall the density of water again.) Determine the heat of fusion of ice by dividing the total heat the ice absorbed by the mass of ice that melted. The unit will be cal/g.

   \[ \text{Heat of Fusion} = \frac{\text{total heat}}{\text{mass of ice melted}} \]

9. Prepare a class data table in your *Active Chemistry* log.

   a) Record the heat of fusion of ice from the other groups.

   b) Find the average for the class.

10. You stopped the investigation when the temperature stabilized.

   a) Why do you think you stopped the investigation at this point?

   b) Would the ice continue to melt?

   c) Where would the ice be getting the heat from?

11. When experiments similar to the one that you have done are completed with extreme care and many, many times, chemists publish their work and arrive at a value for the heat of fusion of ice. The accepted heat of fusion of ice is 79.6 cal/g. This means that it takes 79.6 cal of heat to melt one gram of ice.

   a) How close to the accepted value was your heat of fusion of ice?

   b) How close was the class average?
Melting and Freezing

In the previous activity, you investigated boiling and condensation. Recall that boiling was also called vaporization. It is the change of state from a liquid to a gas. Condensation is the change of state from a gas to a liquid. Boiling is an endothermic change because water had to gain heat energy in order to boil. Condensation is an exothermic change.

In this activity, you investigated freezing and melting. Melting is the change from a solid to a liquid phase. Melting is also called fusion. The temperature at which this occurs for a given substance is the melting point. At the melting point there is enough kinetic energy to cause particles in the crystal structure to break free from the forces holding them together in the crystal structure. This required energy for a given mass is the heat of fusion.

Freezing is the change from a liquid to a solid phase. Freezing is also called crystallization. The temperature at which this occurs for a given substance is the freezing point. The freezing point occurs at the same temperature as the melting point. The energy lost when a substance freezes is the heat of crystallization. Fusion (melting) is endothermic and crystallization (freezing) is exothermic. The heats of fusion and crystallization are equal in magnitude, but opposite in sign.

Recall also, that changes of state are physical changes. If you apply heat to the bottom of a candle, the wax will melt. As it cools, the wax will harden again. This is an example of a physical change. In Activity 2,
you lit the wick of a candle and the atoms in the hydrocarbons in the wax rearranged as they reacted with oxygen. They underwent a combustion reaction to form carbon dioxide and water. This is a chemical change. In a physical change, no new materials are created. In this activity, when the ice melted or the water froze there was no change in the molecular structure of the water. It was still H₂O.

**Heat Energy and the Changes of State**

Changes of phase always occur with a change of heat energy. The material either gains (endothermic) or loses (exothermic) heat energy during a phase change. The amount of heat gained or lost during a phase change depends on which phase change is taking place. Although the heat content of the material changes during a phase change, the temperature does not. Since the temperature does not change, the kinetic energy of the particles that make up the material does not change either.

If continuing to add (or remove) heat energy to (or from) the material does not change its temperature, what is it doing? The particles of a solid material are held together tightly, liquids less so, and for gases, the bonding energies are negligible. The energy that is absorbed by a material during an endothermic phase change like melting is used to overcome these bonding energies between the particles. The energy that is released during an exothermic phase change like freezing is due to the formation of interactions between the particles. During melting, adding heat energy is breaking the bonds between adjoining water molecules and the solid ice is becoming liquid water.
What Do You Think Now?

At the beginning of the activity you were asked:

- What happens to the temperature of water when it freezes?

Now that you have completed this activity, how would you answer this question?

Chem Essential Questions

What does it mean?

Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your Active Chemistry log.

<table>
<thead>
<tr>
<th>MACRO</th>
<th>NANO</th>
<th>SYMBOLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>What did you observe when hot water was mixed with ice water?</td>
<td>When ice melts, the solid H₂O becomes liquid H₂O. Explain the relationship between the addition of heat to the solid ice and the change in the way the molecules move relative to one another.</td>
<td>You can represent the melting of ice, the heating of the water, and the creation of vapor with a graph to better illustrate what is happening. Draw a temperature vs. time graph for these phase changes of H₂O.</td>
</tr>
</tbody>
</table>

How do you know?

How do you know that the amount of heat required to melt a quantity of ice is 80 calories per gram of ice? Describe the experiment that can determine this heat of fusion.

Why do you believe?

Foods are frozen and then defrosted. Estimate the time to defrost a specific food from your freezer. List one food that can turn from a solid to a liquid when defrosting and one food that remains a solid after defrosting.

Why should you care?

Adding ice to a warm drink can be a part of your cooking show. How would you describe this in an entertaining way for a 10-second part of your cooking-show segment?
Reflecting on the Activity and the Challenge

You have now learned that heat energy is gained or lost as a solid, liquid, or gas changes temperature. You have also learned that during a phase change, energy is gained or lost, but the temperature remains the same. Freezing foods is an important process that is used in food preparation. It is primarily used to preserve foods but it also can be used to make special desserts and salads. Including descriptions of phase changes in your cooking segment will be informative for your audience.

1. If you put water in the freezer to make ice, would you set your freezer thermostat at zero Celsius or at a temperature below zero Celsius? Explain why.

2. Use the information on the Heating and Cooling Curve to answer the following questions:

   Compare the amount of heat needed to:
   a) melt 100 g of ice or freeze 100 g of water if both are at 0°C.
   b) change the temperature of 50 g of ice and 50 g of water by 20°C.
3. Compare the amount of heat in:
   a) water at 100°C or water vapor (steam) at 100°C.
   b) 100 g of ice and 100 g of water at 0°C.

4. Determine the amount of heat needed to melt 50 g of ice at 0°C.

5. Determine the amount of heat needed to vaporize 500 g of water at 100°C.

6. Determine the amount of heat needed to raise the temperature of 350 g of water from 20°C to 100°C.

7. How much heat must be removed from 600 g of water at 80°C to bring it down to 0°C?

8. This question will require several steps. Determine the total amount of heat needed to take 200 g of ice at –25°C to water vapor at 100°C.

9. **Preparing for the Chapter Challenge**
   Prepare a list of three instances where there are melting/freezing phase changes occurring in everyday cooking. Describe the processes as either endothermic or exothermic.