Chapter 10 Molecular Structure: Liquids and Solids

10.6

Matter and Changes of State
Melting and Freezing

A substance

• Is **melting** while it changes from a solid to a liquid.
• Is **freezing** while it changes from a liquid to a solid.
• Such as water has a freezing (melting) point of 0°C.
Calculations Using Heat of Fusion

The heat of fusion

• Is the amount of heat released when 1 gram liquid freezes (at its freezing point).
• Is the amount of heat needed to melt 1 gram solid (at its melting point).
• For water (at 0°C) is \[ \frac{334 \text{ J}}{1 \text{ g water}} \]
The heat to freeze (or melt) a specific mass of water (or ice) is calculated using the heat of fusion.

\[
\text{Heat} = \frac{\text{g water}}{1 \text{ g water}} \times 334 \text{ J}
\]

Problem: How much heat in joules is needed to melt 15.0 g of ice?

\[
15.0 \text{ g ice} \times \frac{334 \text{ J}}{1 \text{ g ice}} = 5010 \text{ J}
\]
Learning Check

A. How many joules are needed to melt 5.00 g ice at 0°C?
   1)  335 J  2) 1670 J  3) 0 J

B. How many joules are released when 25.0 g water at 0°C freezes?
   1)  335 J  2) 0 J  3) 8350 J
Solution

A. How many calories are needed to melt 5.00 g ice at 0°C?
2) 1670 J \[ 5.00 \text{ g} \times \frac{334 \text{ J}}{1 \text{ g}} \]

B. How many calories are released when 25.0 g water at 0°C freezes?
3) 8350 J \[ 25 \text{ g} \times \frac{334 \text{ J}}{1 \text{ g}} \]
Sublimation

- Occurs when particles absorb heat to change directly from solid to a gas.
- Is typical of dry ice, which sublimes at -78°C.
- Takes place in frost-free refrigerators.
- Is used to prepare freeze-dried foods for long-term storage.
Evaporation and Condensation

Water

- **Evaporates** when molecules on the surface gain sufficient energy to form a gas.
- **Condenses** when gas molecules lose energy and form a liquid.
Boiling

At boiling,

• All the water molecules acquire enough energy to form a gas.
• Bubbles appear throughout the liquid.
Heat of Vaporization

The heat of vaporization is the amount of heat

- Absorbed to vaporize 1 g of a liquid to gas at the boiling point.
- Released when 1 g of a gas condenses to liquid at the boiling point.

Boiling Point of Water $= 100^\circ$C
Heat of Vaporization (water)
$$= \frac{2260 \text{ J}}{1 \text{ g water}}$$
Heats of Vaporization and Fusion of Particles with Strong Attractive Forces (Polar) and Weak Attractive Forces (Nonpolar)

<table>
<thead>
<tr>
<th>Nonpolar covalent</th>
<th>Polar covalent</th>
<th>Ionic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat of vaporization (J/g)</td>
<td>Heat of fusion (J/g)</td>
<td></td>
</tr>
<tr>
<td><strong>Propane</strong> C$_3$H$_8$</td>
<td>336</td>
<td>18</td>
</tr>
<tr>
<td><strong>Benzene</strong> C$_6$H$_6$</td>
<td>395</td>
<td>128</td>
</tr>
<tr>
<td><strong>Acetic acid</strong> C$_2$H$_4$O$_2$</td>
<td>390</td>
<td>192</td>
</tr>
<tr>
<td><strong>Ethanol</strong> C$_2$H$_5$OH</td>
<td>880</td>
<td>109</td>
</tr>
<tr>
<td><strong>Ammonia</strong> NH$_3$</td>
<td>1,380</td>
<td>351</td>
</tr>
<tr>
<td><strong>Water</strong> H$_2$O</td>
<td>2,260</td>
<td>334</td>
</tr>
<tr>
<td><strong>Sodium chloride</strong> NaCl</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Learning Check

How many kilojoules (kJ) are released when 50.0 g steam from a volcano condenses at 100°C?

1) 113 kJ
2) 2260 kJ
3) 113 000 kJ
Solution

How many kilocalories (kcal) are released when 50.0 g steam in a volcano condenses at 100°C?

1) 113 kJ

\[
\text{50.0 g steam} \times \frac{2260 \text{ J}}{1 \text{ g steam}} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 113 \text{ kJ}
\]
Summary of Changes of State

- Sublimation
- Deposition
- Condensation
- Vaporization
- Melting
- Freezing

Heat absorbed
Heat released

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A heating curve

- Illustrates the changes of state as a solid is heated.
- Uses sloped lines to show an increase in temperature.
- Uses plateaus (flat lines) to indicate a change of state.
Learning Check

A. A flat line on a heating curve represents
   1) a temperature change
   2) a constant temperature
   3) a change of state

B. A sloped line on a heating curve represents
   1) a temperature change
   2) a constant temperature
   3) a change of state
Solution

A. A flat line on a heating curve represents
   2) a constant temperature
   3) a change of state

B. A sloped line on a heating curve represents
   1) a temperature change
Cooling Curve

A cooling curve

- Illustrates the changes of state as a gas is cooled.
- Uses sloped lines to indicate a decrease in temperature.
- Uses plateaus (flat lines) to indicate a change of state.
Use the cooling curve for water to answer each.

A. Water condenses at a temperature of
   1) 0°C  2) 50°C  3) 100°C

B. At a temperature of 0°C, liquid water
   1) freezes  2) melts  3) changes to a gas

C. At 40 °C, water is a
   1) solid  2) liquid  3) gas

D. When water freezes, heat is
   1) removed  2) added
Solution

Use the cooling curve for water to answer each.

A. Water condenses at a temperature of
   3) 100°C
B. At a temperature of 0°C, liquid water
   1) freezes
C. At 40 °C, water is a
   2) liquid
D. When water freezes, heat is
   1) removed
To reduce a fever, an infant is packed in 250. g ice. If the ice (at 0°C) melts and warms to body temperature (37.0°C), how many joules are removed?

**STEP 1** Diagram the changes.

\[ \Delta T = 37.0^\circ C - 0^\circ C = 37.0^\circ C \]

temperature increase
Combined Heat Calculations (continued.)

STEP 2  Calculate the heat to melt ice (fusion)

\[
250 \text{ g ice} \times \frac{334 \text{ J}}{1 \text{ g ice}} = 83500 \text{ J}
\]

STEP 3  Calculate the heat to warm the water from 0°C to 37.0°C

\[
250 \text{ g} \times 37.0°C \times \frac{4.184 \text{ J}}{\text{ g°C}} = 38700 \text{ J}
\]

Total: Step 2 + Step 3 = 122200 J
Learning Check

When a volcano erupts, 175 g steam at 100°C is released. How many kilojoules are lost when the steam condenses, freezes, and cools to -5°C?

1) 396 kJ
2) 529 kJ
3) 133 kJ
Solution

(2) 529 kJ  Steam condenses at 100 °C
\[
\frac{175 \text{ g} \times 2260 \frac{\text{J}}{\text{g}} \times 1 \frac{\text{kJ}}{1000 \text{J}}}{1 \text{ g} \times 1000 \text{ J}} = 396 \text{ kJ}
\]

Water cools 100°C to 0°C
\[
\frac{175 \text{ g} \times 100 \degree \text{C} \times 4.184 \frac{\text{J}}{\text{g} \degree \text{C}} \times 1 \frac{\text{kJ}}{1000 \text{ J}}}{1 \text{ g} \times 1000 \text{ J}} = 73.2 \text{ kJ}
\]

Freezes to ice at 0 °C:
\[
\frac{175 \text{ g} \times 334 \frac{\text{J}}{\text{g}} \times 1 \frac{\text{kJ}}{1000 \text{ J}}}{1 \text{ g} \times 1000 \text{ J}} = 58.5 \text{ kJ}
\]

Ice Cools 0°C to -5 °C
\[
\frac{175 \text{ g} \times 5 \degree \text{C} \times 2.03 \frac{\text{J}}{\text{g} \degree \text{C}} \times 1 \frac{\text{kJ}}{1000 \text{ J}}}{1 \text{ g} \times 1000 \text{ J}} = 1.78 \text{ kJ}
\]

529 kJ total