Heating Water: Heating Curve Demonstration

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Boiling vs. Evaporation

Make a list: differences & similarities

Write a definition for boiling and for evaporation.
Boiling – what is going on when we boil water?

Which equation best represents the process?

A. \( \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g) \)

B. \( 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(g) + \text{O}_2(g) \)

C. \( \text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{O}(l) \)

D. \( 2 \text{H}_2(g) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) \)

E. \( \text{H}_2\text{O}(l) \rightarrow 2 \text{H}(g) + \text{O}(g) \)
Boiling represents the transition from **liquid** to **gas**.

- boiling water: $\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g)$
- boiling ethanol: $\text{CH}_3\text{CH}_2\text{OH}(l) \rightarrow \text{CH}_3\text{CH}_2\text{OH}(g)$

If $\text{VP} < \text{external pressure}$, bubble collapses.

If $\text{VP} > \text{external pressure}$, boiling can occur.

The **boiling point** of a liquid is the temperature at which the vapor pressure equals the external pressure.
All substances at the same temperature have the same average kinetic energy. However, there is always a distribution of velocities, leading to a distribution of kinetic energies.

A certain fraction has enough energy to escape into the gas phase.
Evaporation Big Concept: molecules in a liquid state must have sufficient kinetic energy to overcome the intermolecular forces of attraction operating among the liquid molecules.

Strong IMFs between molecules => Force of attraction is Strong

$\text{H}_2\text{O}$
List the distinct steps involved in taking ice at -25°C to steam at 125°C.
Energy Changes Associated with Changes of State

$H_2O(s)$
(ice)

There is energy associated with each of these 5 processes.
Heating curve for water

- Temperature (°C)
- Time (minutes)

- Solid ice
- Ice melting
- Liquid water
- Water boiling
- Vapour (steam)
For example, how much energy is associated with heating one mole of H\textsubscript{2}O from -25°C to 125°C?

There are 5 steps involved in this process:
1) heating of the ice to its melting point
2) the phase change from solid to liquid
3) heating of the liquid to its boiling point
4) the phase change from liquid to gas
5) heating the gas to the final temperature

energy associated with heating:
\[ q = m \times c \times \Delta T \]

energy associated with phase changes
\[ q = (\Delta H_{\text{phase change}})(\text{number of moles}) \]
\[ q = (\text{kJ/mol})(\text{mol}) \]
The total energy is the sum of the energies for each step:

\[ q_1 + q_2 + q_3 + q_4 + q_5 = q \text{ total} \]
How much energy is associated with heating one mole of H₂O from -25°C to 125°C?

<table>
<thead>
<tr>
<th>Water</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>molar mass</td>
<td>18 g/mol</td>
</tr>
<tr>
<td>boiling point</td>
<td>100°C</td>
</tr>
<tr>
<td>Freezing point</td>
<td>0°C</td>
</tr>
<tr>
<td>Heat of vaporization</td>
<td>40.7 kJ/mol</td>
</tr>
<tr>
<td>Heat of fusion</td>
<td>6.02 kJ/mol</td>
</tr>
<tr>
<td>specific heat capacity (liquid)</td>
<td>4.18 J/g°C</td>
</tr>
<tr>
<td>specific heat capacity (gas)</td>
<td>2.01 J/g°C</td>
</tr>
<tr>
<td>specific heat capacity (solid)</td>
<td>2.09 J/g°C</td>
</tr>
</tbody>
</table>
Region 1  solid ice at -25°C to solid ice at 0.0°C

- Heating 1.00 mole of ice at −25.0 °C up to the melting point, ice at 0.0 °C
- $q = \text{mass} \times c_{\text{ice}} \times \Delta T$
  - Mass of 1.00 mole of H$_2$O = 18.0 g
  - $c_{\text{ice}} = 2.09 \text{ J/g} \cdot \text{°C}$

$q = (18.0 \text{ g})(2.09 \text{ J/g} \cdot \text{°C})[0.0\text{°C} - (-25.0\text{°C})]$

$q = 941 \text{ J}$

$q = 0.941 \text{ kJ}$
Region 2  solid ice at 0°C to liquid water at 0°C

- Melting 1.00 mole of ice at the melting point, 0.0 °C  a phase change solid -> liquid

- \[ q = n \cdot \Delta H_{\text{fus}} \]

  - \( n = 1.00 \) mole of ice
  - \( \Delta H_{\text{fus}} = 6.02 \) kJ/mol

\[ q = (1.00 \text{ mol}) \cdot (6.02 \text{ kJ/mol}) = 6.02 \text{ kJ} \]
Region 3  water at 0°C to water at 100°C

- Heating 1.00 mole of water at 0.0 °C up to the boiling point, 100.0 °C
- \( q = \text{mass} \times c_{\text{water}} \times \Delta T \)
  - mass of 1.00 mole of water = 18.0 g
  - \( c_{\text{water}} = 4.18 \text{ J/g} \cdot \text{°C} \)

\[
q = (18.0 \text{ g})(4.18 \text{ J/g} \cdot \text{°C})(100.0\text{°C}-0.0\text{°C})
\]

\[
q = 7.52 \times 10^3 \text{ J}
\]

\[
q = 7.52 \text{ kJ}
\]
Region 4  water at 100°C to steam at 100°C

- Boiling 1.00 mole of water at the boiling point, 100.0 °C (phase change)
- \( q = n \cdot \Delta H_{\text{vap}} \)
  - \( n = 1.00 \) mole of ice
  - \( \Delta H_{\text{vap}} = 40.7 \text{ kJ/mol} \)

\[ q = (1.00 \text{ mol}) \times (40.7 \text{ kJ/mol}) = 40.7 \text{ kJ} \]
Region 5  steam at 100°C to steam at 125°C

- Heating 1.00 mole of steam at 100.0 °C up to 125.0 °C
- \[ q = \text{mass} \times c_{\text{steam}} \times \Delta T \]
  mass of 1.00 mole of water = 18.0 g
  \[ c_{\text{steam}} = 2.01 \text{ J/g} \cdot \text{°C} \]
  \[ q = (18.0 \text{ g})(2.01 \text{ J/g} \cdot \text{°C})(125.0\text{°C - 100.0°C}) \]
  \[ q = 904 \text{ J} = 0.904 \text{ kJ} \]
The total energy is the sum of the energies for each step:

\[ q_1 + q_2 + q_3 + q_4 + q_5 = q_{\text{total}} \]

\[ 0.941 \text{ kJ} + 6.02 \text{ kJ} + 7.52 \text{ kJ} + 40.7 \text{ kJ} + 0.904 \text{ kJ} = 56.08 \text{ kJ} \]

**Total Energy Required**

Be careful with signs and units!
Energy Changes Associated with Changes of State

- The heat added to the system at the melting and boiling points goes into pulling the molecules farther apart from each other.
- The temperature of the substance does not rise during a phase change.
Energy Changes Associated with Changes of State

1. Ice warming
2. Ice melting to liquid
3. Liquid water warming
4. Liquid water
5. Steam warming