Chapter 17: Thermochemistry

17.1 The Flow of Energy – Heat and Work

Energy Transformations

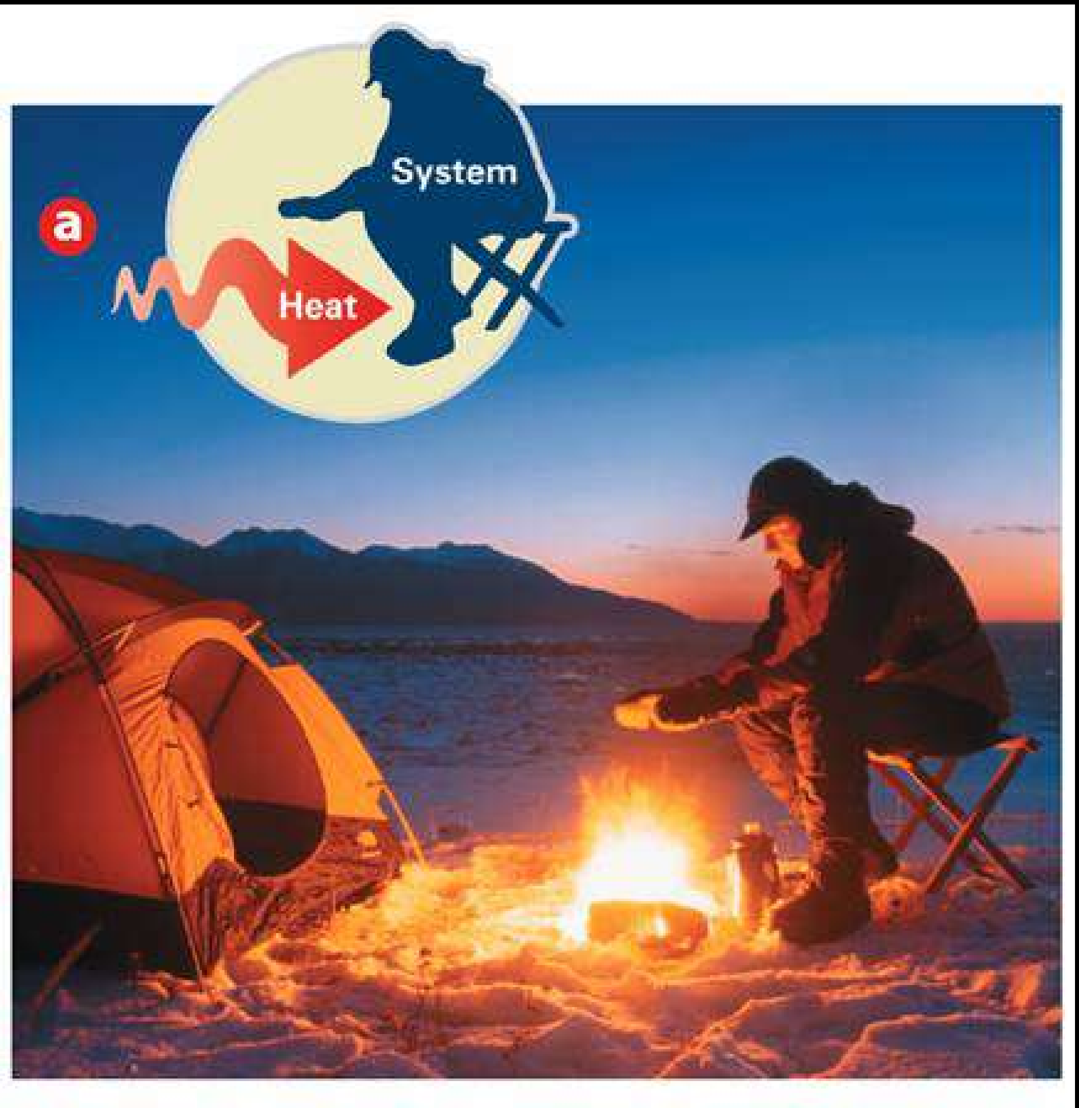
- **Heat**, *q*, - energy that transfers from one object to another because of a temperature difference
  - Flows from warmer to cooler

Energy Transformations

- **Thermochemistry** - study of energy changes that occur during chemical reactions and changes in state.
- Energy stored in the chemical bonds of a substance is called **chemical potential energy.**

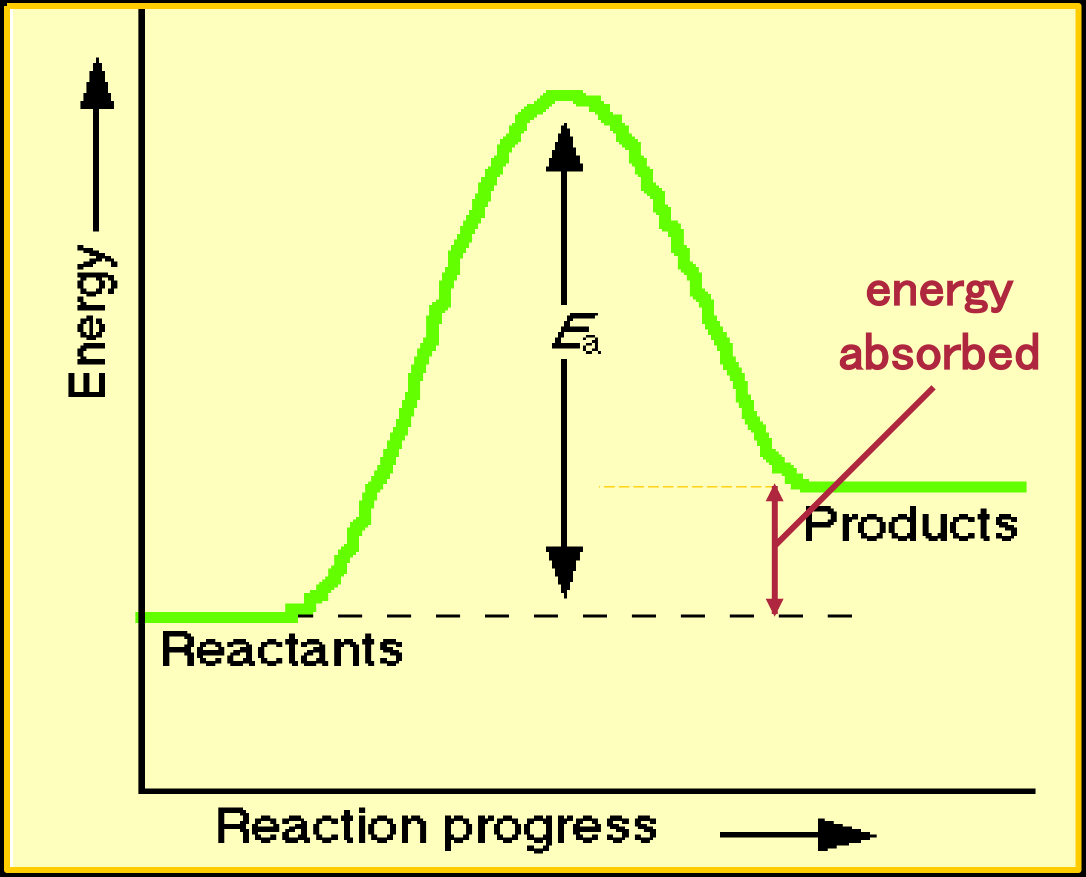
Exothermic and Endothermic Processes

- **System** - part of the universe on which you focus your attention
- **Surroundings** - everything else in the universe.
- **Law of conservation of energy** - in any chemical or physical process, energy is neither created nor destroyed.

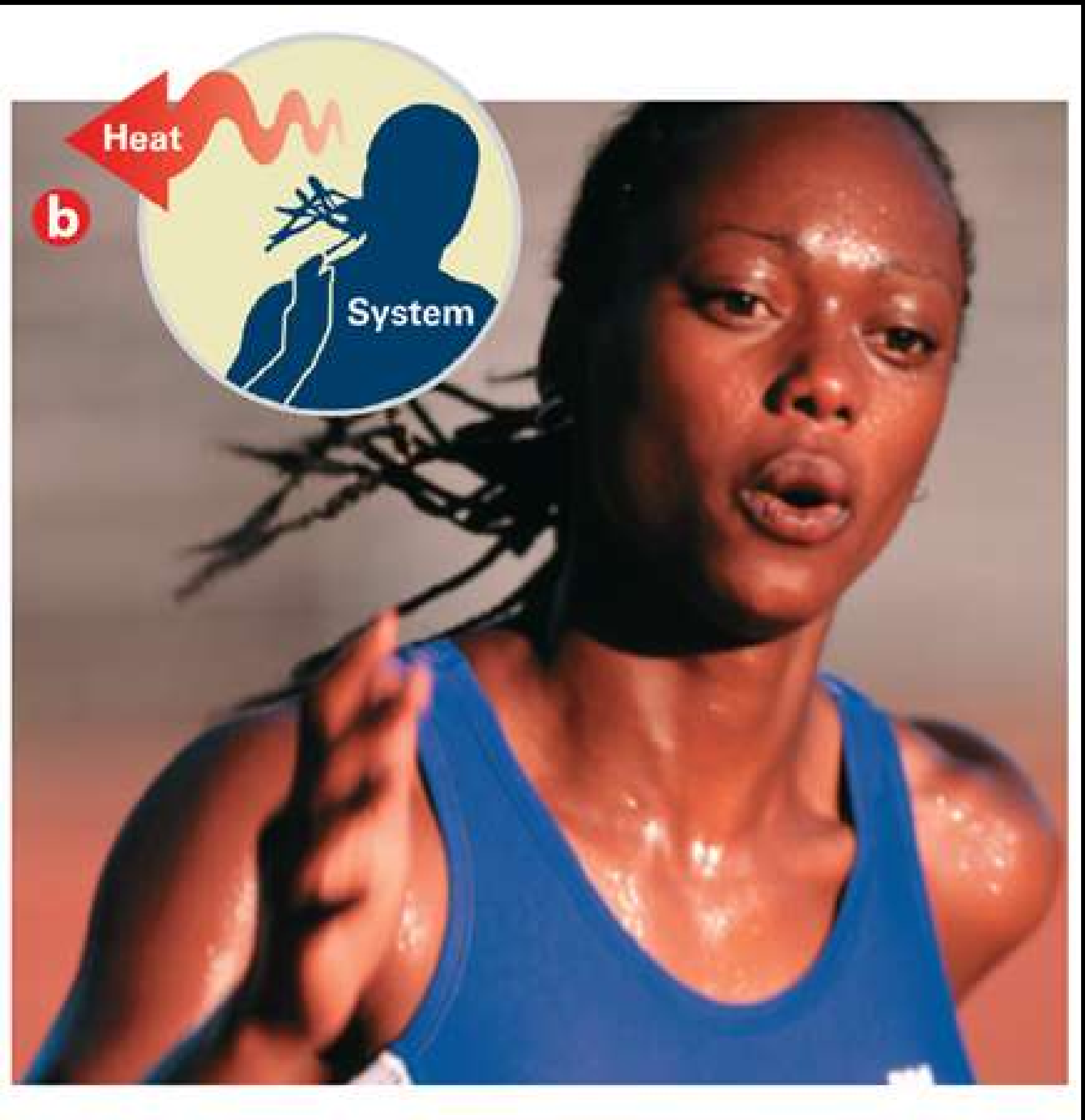


- An **endothermic process** is one that absorbs heat from the surroundings.

Endothermic Reaction

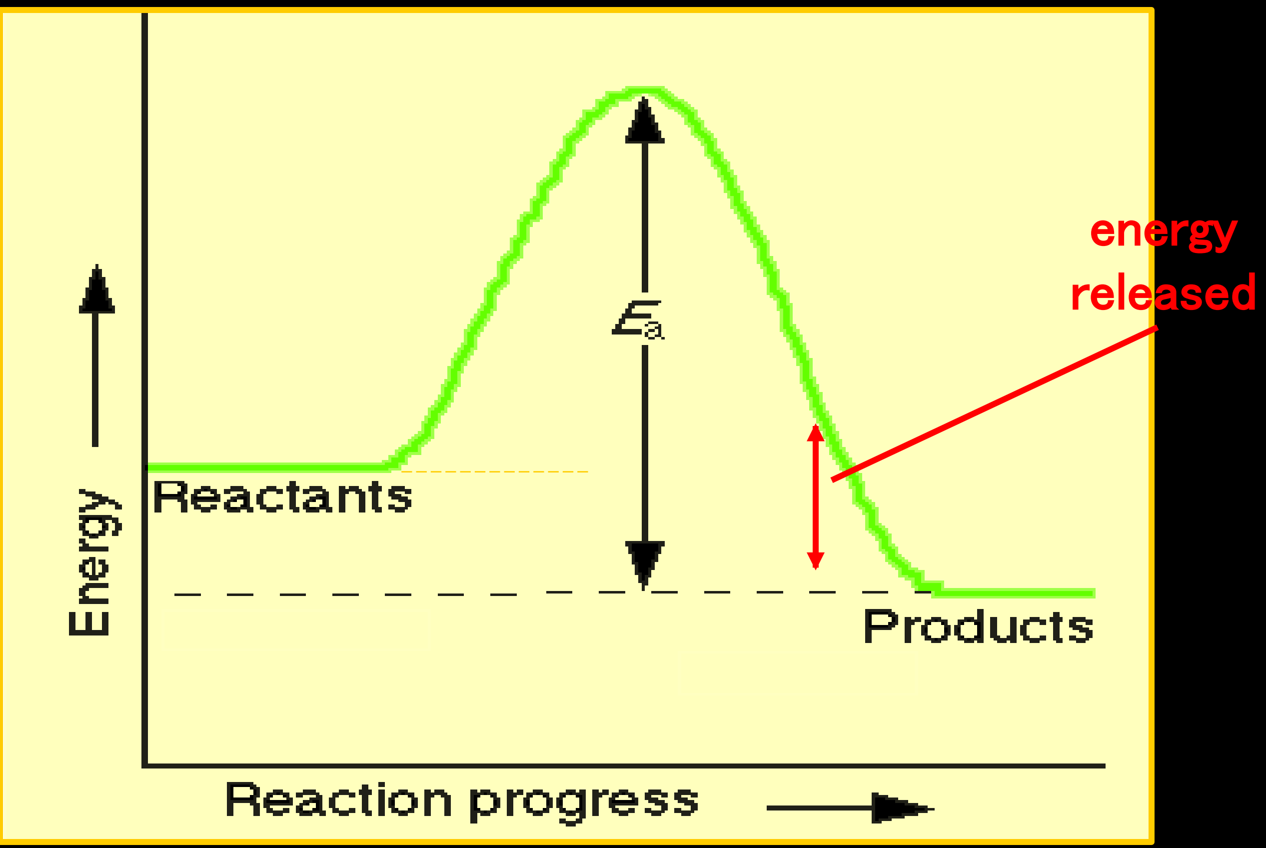


$$2Al_2O_3 + \text{energy} \rightarrow 4Al + 3O_2$$



- An **exothermic process** is one that releases heat to its surroundings.

Exothermic Reaction



$$2H_2(l) + O_2(l) \rightarrow 2H_2O(g) + \text{energy}$$

Conceptual Problem 17.1

Recognizing Exothermic and Endothermic Processes

On a sunny winter day, the snow on a rooftop begins to melt. As the melt-water drips from the roof, it refreezes into icicles. Describe the direction of heat flow as the water freezes. Is this process endothermic or exothermic?

for Conceptual Problem 17.1

1. A container of melted paraffin wax is allowed to stand at room temperature until the wax solidifies. What is the direction of heat flow as the liquid wax solidifies? Is the process exothermic or endothermic?

Units for Measuring Heat Flow

- Heat flow is measured in two common units, the calorie and the joule (1 calorie = 4.184 J)
  - The energy in food is usually expressed in Calories.

1 Calorie = 1 kilocalorie = 1000 calories

calorie-joule conversions

- 1) 60.1 cal to joules
- 2) 34.8 cal to joules
- 3) 47.3 J to cal
- 4) 28.4 J to cal

Heat Capacity and Specific Heat

- The amount of heat needed to increase the temperature of an object exactly 1°C is the **heat capacity** of that object.
  - Depends on mass and chemical composition

Heat Capacity and Specific Heat

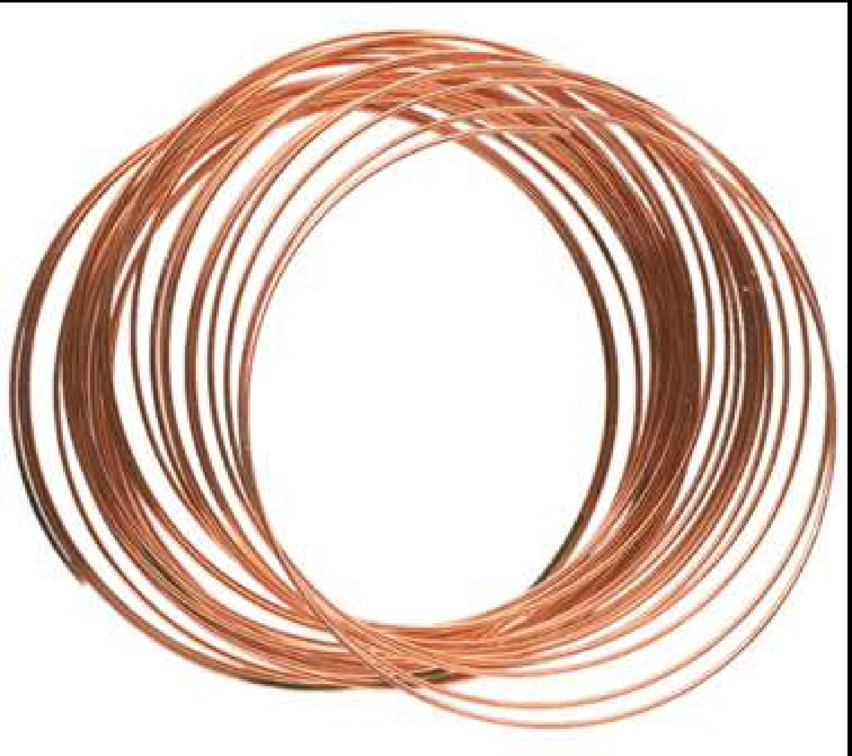
- **Specific heat** - amount of heat it takes to raise the temperature of 1 g of the substance 1°C.

$$C = \frac{q}{m \times \Delta T} = \frac{\text{heat (joules or calories)}}{\text{mass (g)} \times \text{change in temperature (°C)}}$$

Sample Problem 17.1

Calculating the Specific Heat of a Metal

The temperature of a 95.4-g piece of copper increases from 25.0°C to 48.0°C when the copper absorbs 849 J of heat. What is the specific heat of copper?



for Sample Problem 17.1

4. How much heat is required to raise the temperature of 250.0 g of mercury 52°C?

The specific heat of mercury is 0.14 J/gC.

Practice

- 1) A sample of aluminum requires 3.1 J of energy to change its temp from 19°C to 37°C. What is the mass? The specific heat of aluminum is 0.90 J/g°C.

17.1 Section Quiz.

1. The energy released when a piece of wood is burned has been stored in the wood as

   a) sunlight.

   b) heat.

   c) calories.

   d) chemical potential energy.

17.1 Section Quiz.

2. Which of the following statements about heat is false?

a) Heat is the same as temperature.

b) Heat always flows from warmer objects to cooler objects.

c) Adding heat can cause an increase in the temperature of an object.

d) Heat cannot be specifically detected by senses or instruments.

17.1 Section Quiz.

3. Choose the correct words for the spaces: In an endothermic process, the system __________ heat when heat is __________ its surroundings, so the surroundings ________________.

   a) gains, absorbed from, cool down.

   b) loses, released to, heat up.

   c) gains, absorbed from, heat up.

   d) loses, released to, cool down.

17.1 Section Quiz.

4. Which of the relationships listed below can be used to convert between the two units used to measure heat transfer?

a) 1 g = 1°C

b) 1 cal = 4.184 J

c) 1°C = 1 cal

d) 1 g = 4.184 J

17.1 Section Quiz.

5. Assuming that two samples of different materials have equal mass, the one that becomes hotter from a given amount of heat is the one that

a) has the higher specific heat capacity.

b) has the higher molecular mass.

c) has the lower specific heat capacity.

d) has the higher density.

17.2 Measuring and Expressing Enthalpy Changes

Calorimetry

- The heat content of a system at constant pressure is called the **enthalpy** (*H*) of the system.

Thermochemical Equations

- A chemical equation that includes the enthalpy change is called a **thermochemical equation.**

$$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(s) + 65.2\ \text{kJ}$$

Thermochemical Equations

- The **heat of reaction** is the enthalpy change for the chemical equation exactly as it is written. If ΔH is negative, the reaction is exotherm; if it is positive the reaction is endothermic.

$$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(s) \qquad \Delta H = -65.2\ \mathrm{kJ}$$

Sample Problem 17.3

Using the Heat of Reaction to Calculate Enthalpy Change

Using the thermochemical equation in Figure 17.7b on page 515, calculate the amount of heat (in kJ) required to decompose 2.24 mol $NaHCO_3(s)$.

$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$

$\Delta H = 129\ kJ$

Practice

- The reaction for heat packs to treat sports injury is:
- $4Fe + 3O_2 \rightarrow 2Fe_2O_3$ $\Delta H = -1652$ kJ
- How much heat is released when 1.00 g of Fe is reacted?

17.2 Section Quiz.

- 1. For the reaction $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$, $\Delta H = -65.2$ kJ. This means that 65.2 kJ of heat is ______________ during the process.

  a) absorbed

  b) destroyed

  c) changed to mass

  d) released

17.2 Section Quiz.

- 2. How much heat is absorbed by 325 g of water if its temperature changes from 17.0°C to 43.5°C? The specific heat of water is 4.18 J/g°C.

  a) 2.00 kJ

  b) 3.60 kJ

  c) 36.0 kJ

  d) 360 kJ

17.2 Section Quiz.

- 3. Oxygen is necessary for releasing energy from glucose in organisms. How many kJ of heat are produced when 2.24 mol glucose reacts with an excess of oxygen?
  - $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g) + 2808\ kJ/mol$

  a) 4.66 kJ

  b) 9.31 kJ

  c) 1048 kJ

  d) 6290 kJ

17.3 Heat in Changes of State

Heats of Fusion and Solidification

- The **molar heat of fusion** (ΔH_{fus}) is the heat absorbed by one mole of a solid substance as it melts to a liquid at a constant temperature.
- The quantity of heat absorbed by a melting solid is exactly the same as the quantity of heat released when the liquid freezes.

Sample Problem 17.4

Using the Heat of Fusion in Phase-Change Calculations

How many grams of ice at 0°C will melt if 2.25 kJ of heat are added?

The ΔH_{fus} for water is 6.01 kJ/mol

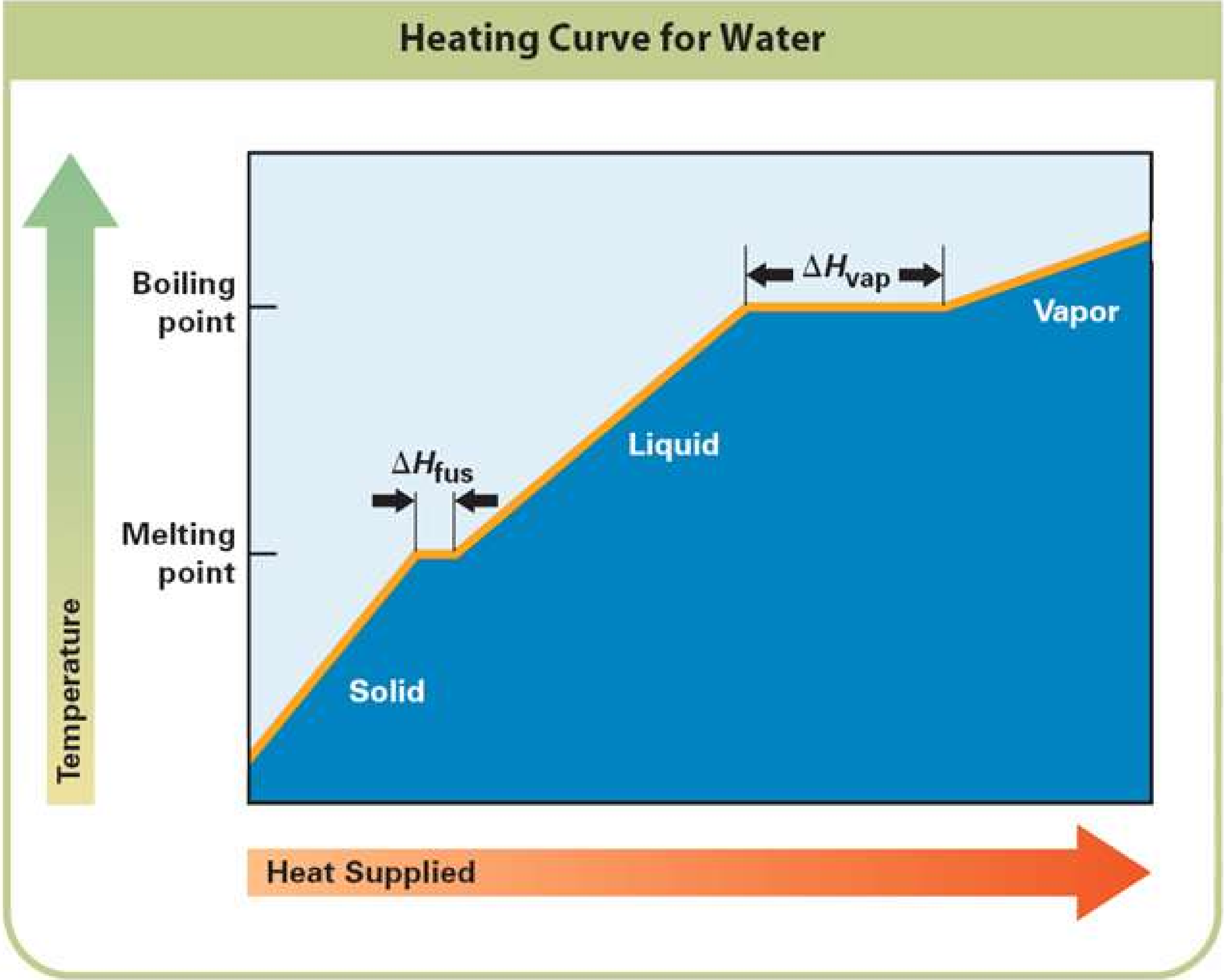
Practice

The ΔH_{fus} for water is 6.01 kJ/mol

- 1) Calculate the energy released when 15.5 g of ice freezes at 0°C.
- Calculate the energy required to melt 12.5 g of ice at 0°C and change it to water at 25°C. (Specific heat capacity is 4.18 J/g°C)

Heats of Vaporization and Condensation

- The amount of heat necessary to vaporize one mole of a given liquid is called its **molar heat of vaporization** (ΔH_{vap}).
- The quantity of heat absorbed by a vaporizing liquid is exactly the same as the quantity of heat released when the vapor condenses.


Heating Curve for Water
Boiling point
Melting point
Temperature
ΔH_{vap}
ΔH_{fus}
Vapor
Liquid
Solid
Heat Supplied

Sample Problem 17.5

Using the Heat of Vaporization in Phase-Change Calculations

How much heat (in kJ) is absorbed when 24.8 g $H_2O(l)$ at 100°C and 101.3 kPa is converted to steam at 100°C?

The ΔH_{vap} for water is 40.7 kJ/mol

Practice

- 1) Calculate the energy to melt 15 g of ice at 0°C, heat it to 100°C and vaporize it to steam at 100°C. The specific heat of water is 4.18 J/g°C. The ΔH_{fus} for water is 6.01 kJ/mol and the ΔH_{vap} for water is 40.7 kJ/mol.

17.3 Section Quiz.

1. The molar heat of condensation of a substance is the same, in magnitude, as its molar heat of

   a) formation.

   b) fusion.

   c) solidification.

   d) vaporization.

17.3 Section Quiz

2. The heat of condensation of ethanol (C_2H_5OH) is –43.5 kJ/mol. As C_2H_5OH condenses, the temperature of the surroundings

   a) stays the same.

   b) may increase or decrease.

   c) increases.

   d) decreases.

17.3 Section Quiz

3. Calculate the amount of heat absorbed to liquefy 15.0 g of methanol (CH_3OH) at its melting point. The molar heat of fusion for methanol is 3.16 kJ/mol.

   a) 1.48 kJ

   b) 47.4 kJ

   c) 1.52×10^3 kJ

   d) 4.75 kJ

17.3 Section Quiz

4. How much heat (in kJ) is released when 50 g of $NH_4NO_3(s)$, are dissolved in water? $\Delta\ s_{soln} = -25.7$ kJ/mol

a) 12.85 kJ

b) 13.1 kJ

c) 25.7 kJ

d) 1285 kJ