Chapter 18: Reaction Rates and Equilibrium

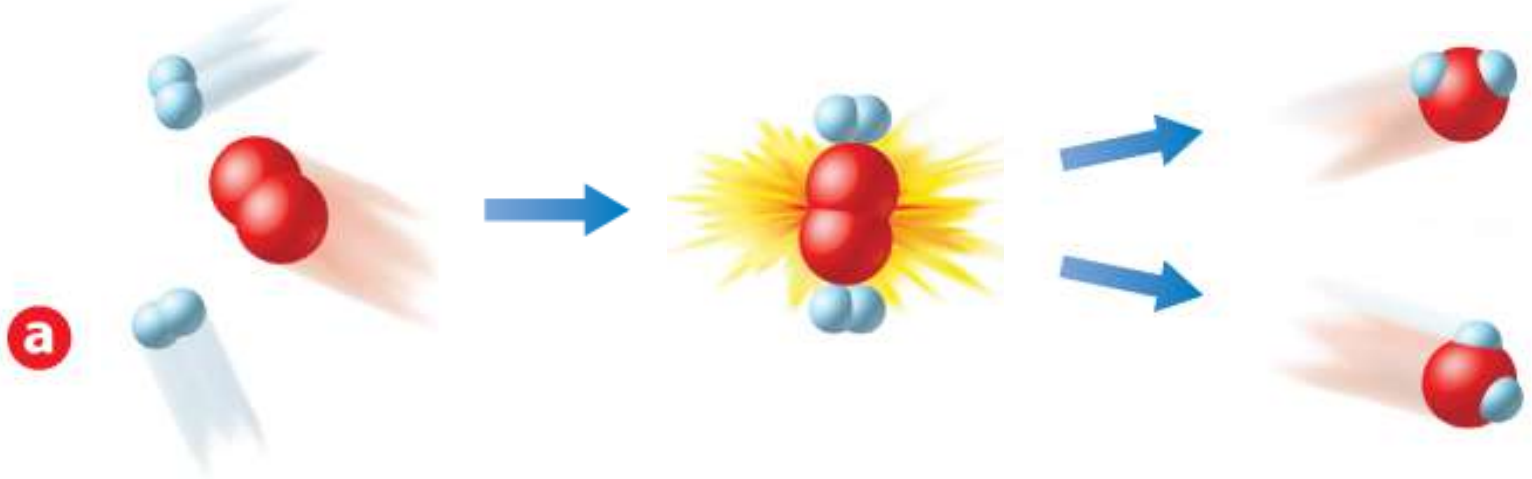
18.1 Rates of Reaction

Collision Theory

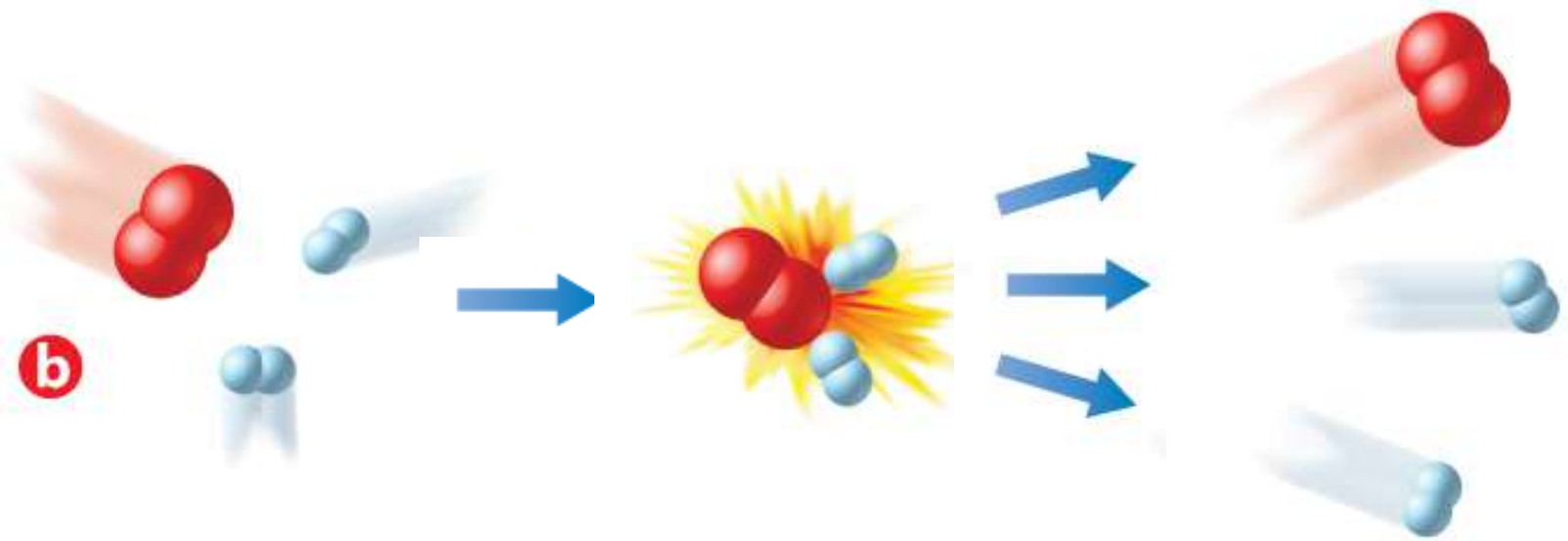
- According to **collision theory**, atoms, ions, and molecules can react to form products when they collide with one another, provided that the colliding particles have enough kinetic energy.

Collision Theory

- **Effective Collision**

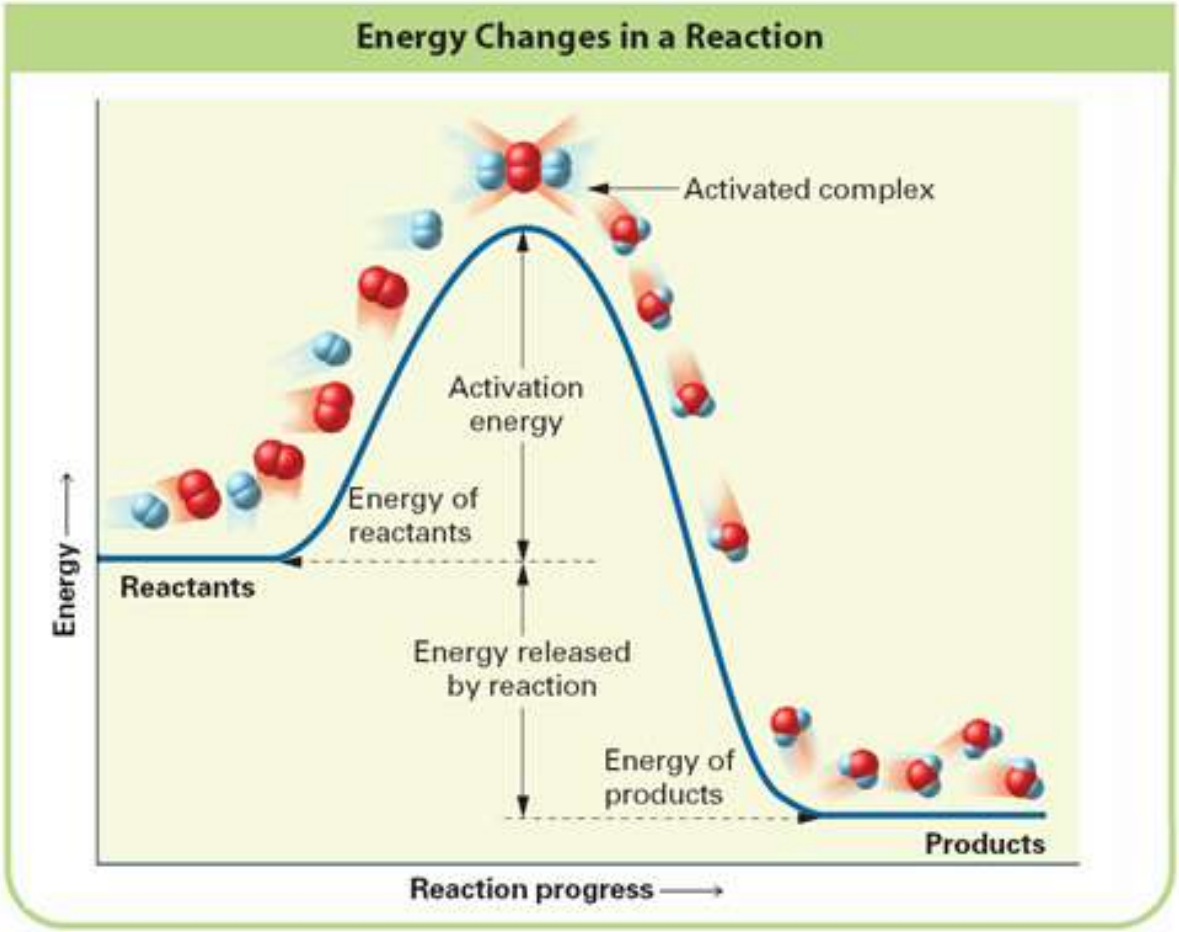


Collision Theory – Ineffective Collision



Collision Theory

- The minimum energy that colliding particles must have in order to react is called the **activation energy**.



Factors Affecting Reaction Rates

- The rate of a chemical reaction depends upon temperature, concentration, particle size, and the use of a catalyst.

Temperature

- Storing foods in a refrigerator keeps them fresh longer. Low temperatures slow microbial action.

Increasing temperature increases reaction rate

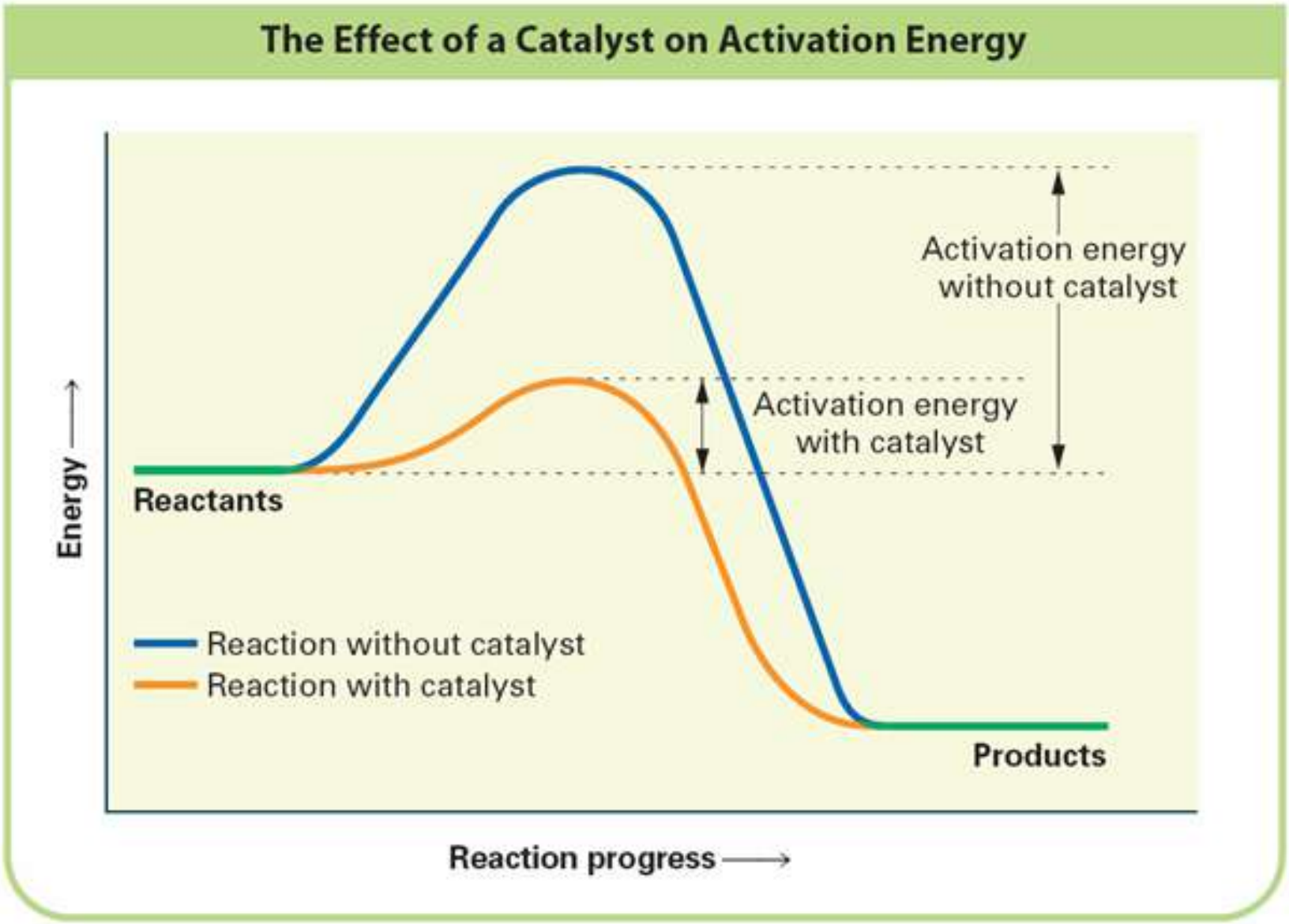
Concentration

- Increasing concentration increases the reaction rate

Particle Size

- A smaller particle size (greater surface area) increases the reaction rate

⑩Catalysts


The Effect of a Catalyst on Activation Energy
Activation energy without catalyst
Activation energy with catalyst
Energy
Reactants
Reaction without catalyst
Reaction with catalyst
Products
Reaction progress

Catalysts

- Increase the reaction rate by lowering the activation energy

- An **inhibitor** is a substance that interferes with the action of a catalyst. Antioxidants and antimicrobials used in drying fruits and preserving fruit juices slow the action of microbes and limit contact with air.

18.1 Section Quiz.

- 1. In a chemical reaction, the energy of reactants is always

  a) greater than the energy of the products.

  b) more than the activation energy.

  c) less than the activation energy.

  d) less than the energy of the products.

18.1 Section Quiz.

- 2. An increase in which one of the following will NOT increase the reaction rate?

  a) temperature

  b) concentration of reactants

  c) total mass of reactants

  d) surface area of reactants

18.1 Section Quiz.

- 4. A catalyst works because it

  a) lowers the activation energy.

  b) increases the temperature.

  c) is permanently changed in a reaction.

  d) supplies energy to a reaction.

18.2 Reversible Reactions and Equlibrium

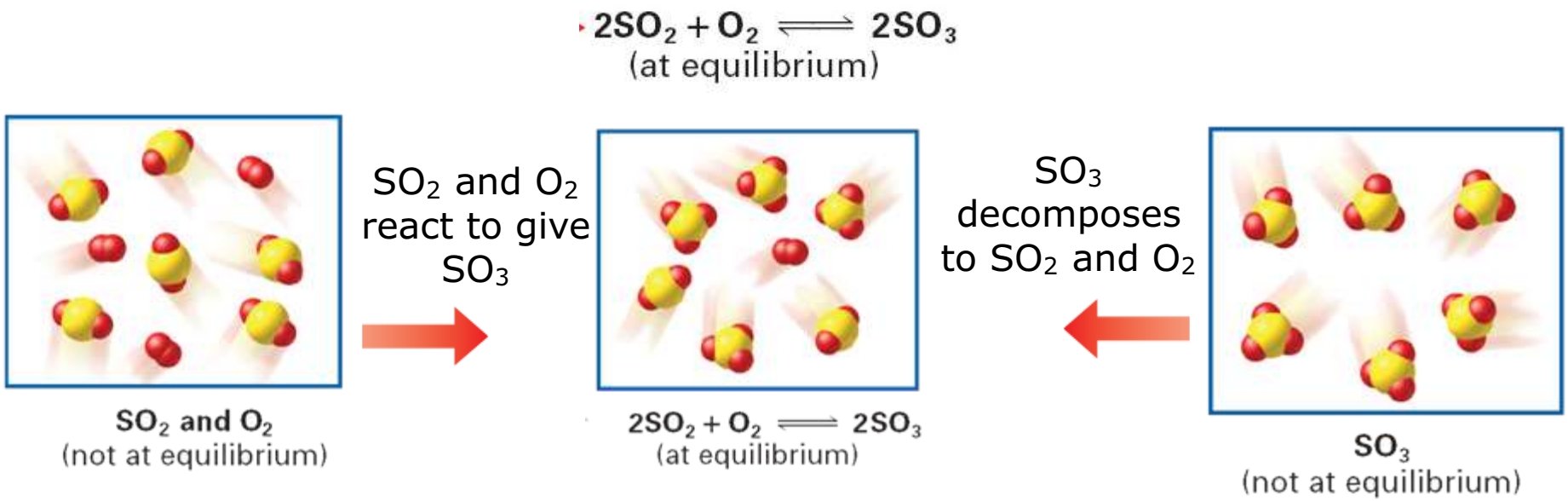
Reversible Reactions

- At chemical equilibrium, no net change occurs in the actual amounts of the components of the system.

Reversible Reactions

- A **reversible reaction** is one in which the conversion of reactants to products and the conversion of products to reactants occur simultaneously.

Reversible Reactions



At equilibrium, all three types of molecules are present.

Reversible Reactions

- When the rates of the forward and reverse reactions are equal, the reaction has reached a state of balance called **chemical equilibrium**.

Factors Affecting Equilibrium: Le Châtelier's Principle

- The French chemist Le Châtelier proposed what has come to be called **Le Châtelier's principle**: If a stress is applied to a system in dynamic equilibrium, the system changes in a way that relieves the stress.

Concentration

- If you increase the concentration of reactants, you make more products (shift right)
- If you add more product, you make more reactant (shift left)
- If you remove product, you make more product (shift right)

Temperature

- An increase in temperature shifts in the direction that absorbs heat
- Ex: in an exothermic reaction heat is a product so increases temp. forms reactants; removing heat would shift right to form products

Pressure

- An increase in pressure shifts to the side with fewer moles of gas

Conceptual Problem 18.1

Applying Le Châtelier's Principle

What effect do each of the following changes have on the equilibrium position for this reversible reaction?

$$PCl_5(g) + \text{heat} \rightleftharpoons PCl_3(g) + Cl_2(g)$$

a. addition of Cl_2

b. increase in pressure

c. removal of heat

d. removal of PCl_3 as it is formed

for Conceptual Problem 18.1

6. How is the equilibrium position of this reaction affected by the following changes?

$$C(s) + H_2O(g) + \text{heat} \rightleftharpoons CO(g) + H_2(g)$$

a. lowering the temperature

b. increasing the pressure

c. removing hydrogen

d. adding water vapor

$N_2O_{4(g)} + 58\ kJ \leftrightarrow 2NO_{2(g)}$

- Addition of heat
- Decrease in pressure
- Addition of NO_2
- Removal of N_2O_4

18.2 Section Quiz.

- 1. In a reaction at equilibrium, reactants and products
  - a) decrease in concentration.
  - b) form at equal rates.
  - c) have equal concentrations.
  - d) have stopped reacting.

18.2 Section Quiz.

- 2. In the reaction $2NO_2(g) \rightarrow 2NO(g) + O_2(g)$, increasing the pressure on the reaction would cause

  a) the amount of NO to increase.

  b) the amount of NO_2 to increase.

  c) nothing to happen.

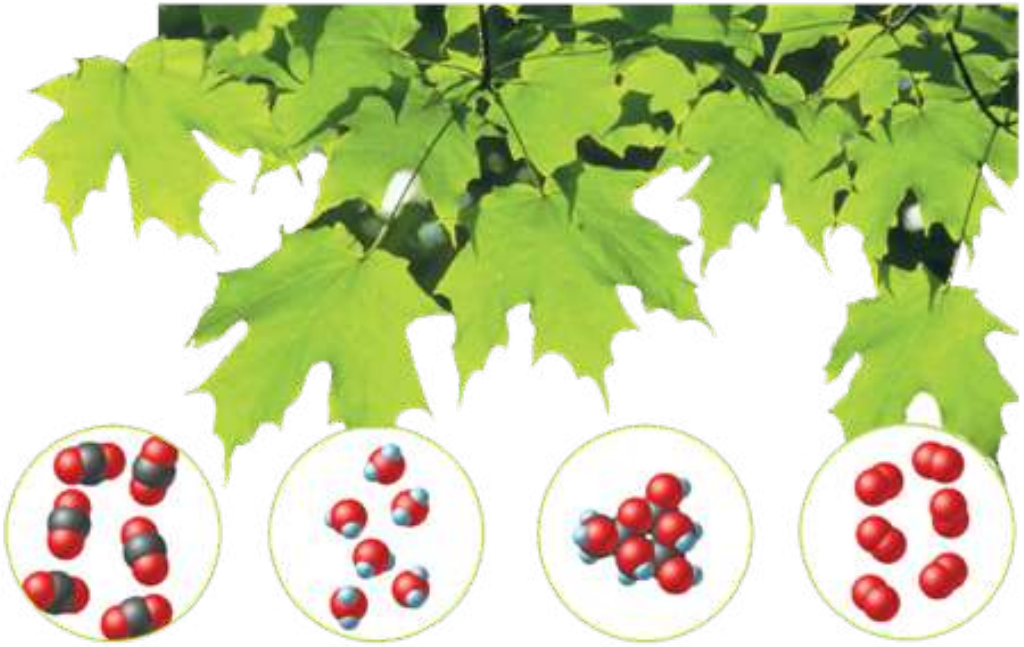
  d) the amount of O_2 to increase.

18.4 Entropy and Free Energy

Free Energy and Spontaneous Reactions

- A **spontaneous reaction** occurs naturally and favors the formation of products at the specified conditions.

- A **nonspontaneous reaction** is a reaction that does not favor the formation of products at the specified conditions.



$$6CO_2 + 6H_2O \xrightarrow{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

Photosynthesis is a nonspontaneous reaction that requires an input of energy.

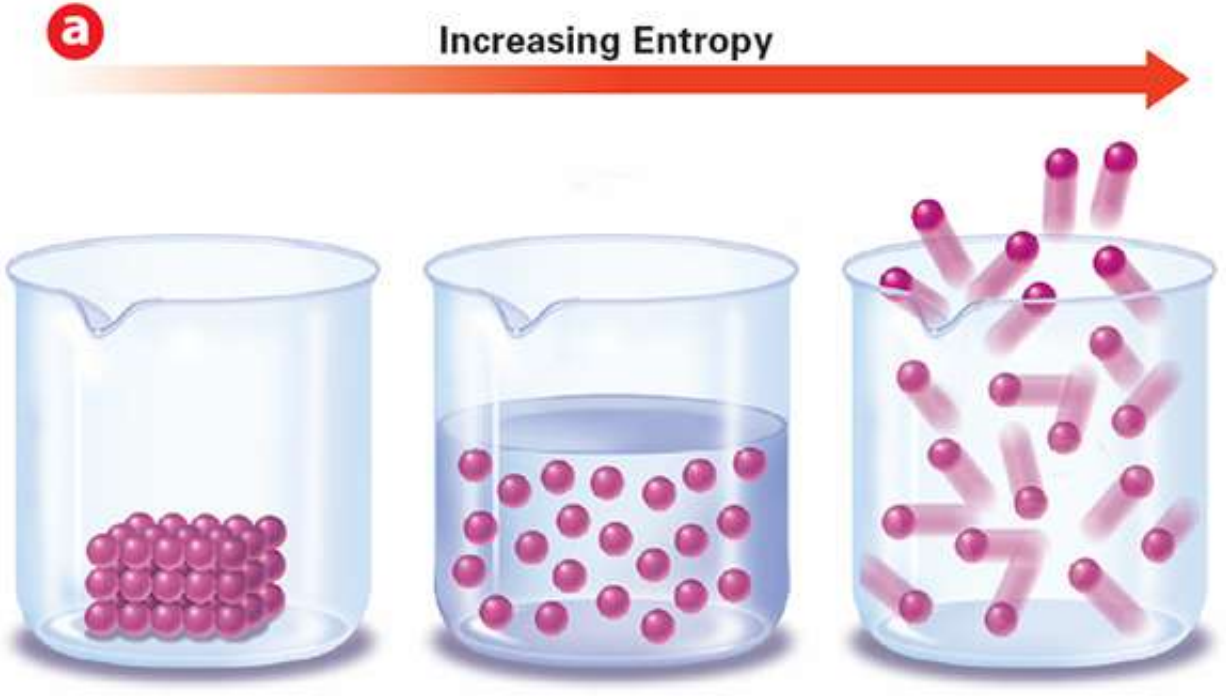
Free Energy and Spontaneous Reactions

- Spontaneous reactions produce substantial amounts of products at equilibrium and release free energy.
- Free energy **is energy that is available to do work.**

Entropy

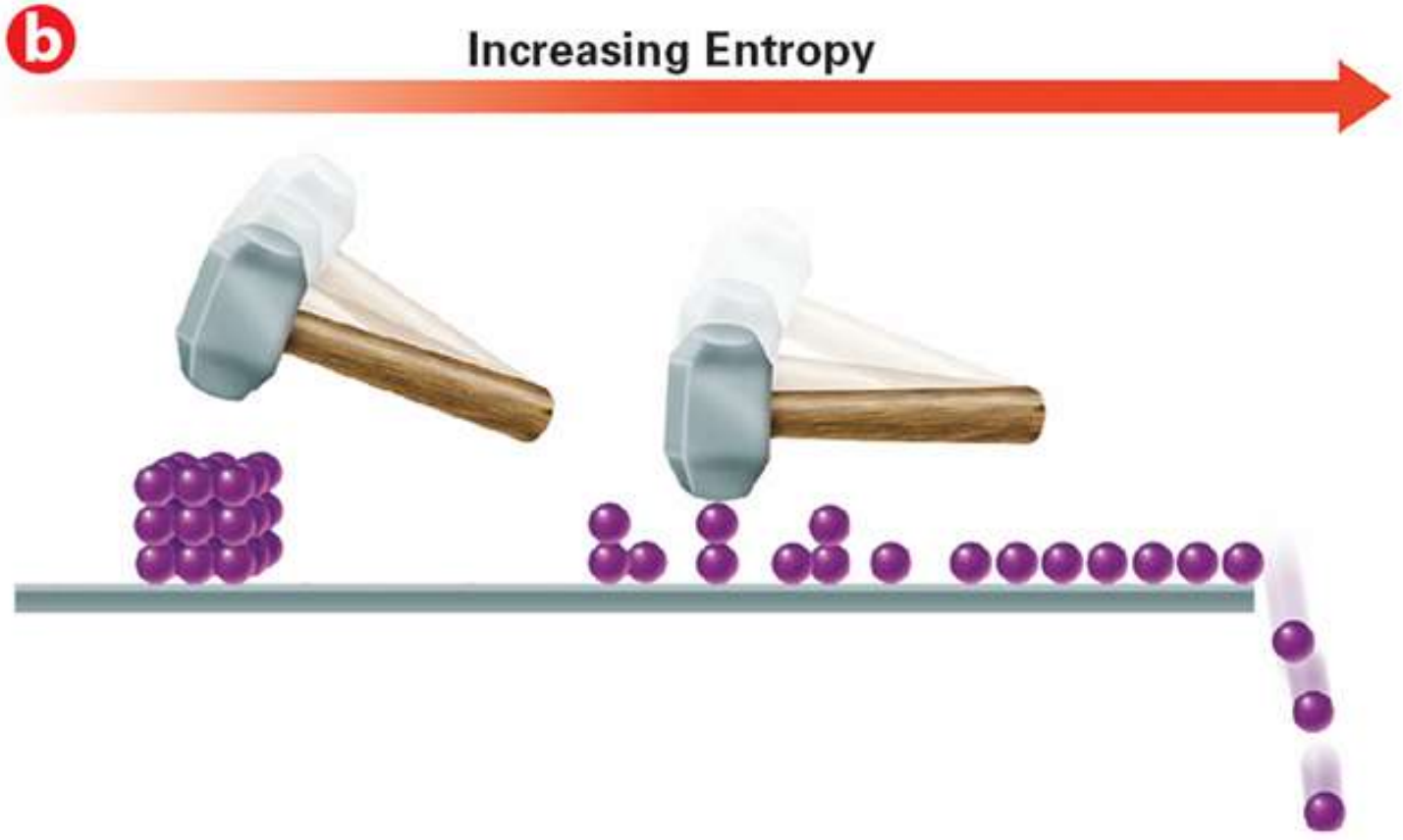
- **Entropy** is a measure of the disorder of a system.
  - Physical and chemical systems attain the lowest possible energy.
  - The **law of disorder** states that the natural tendency is for systems to move in the direction of maximum disorder or randomness.

- For a given substance, the entropy of the gas is greater than the entropy of the liquid or the solid. Similarly, the entropy of the liquid is greater than that of the solid.

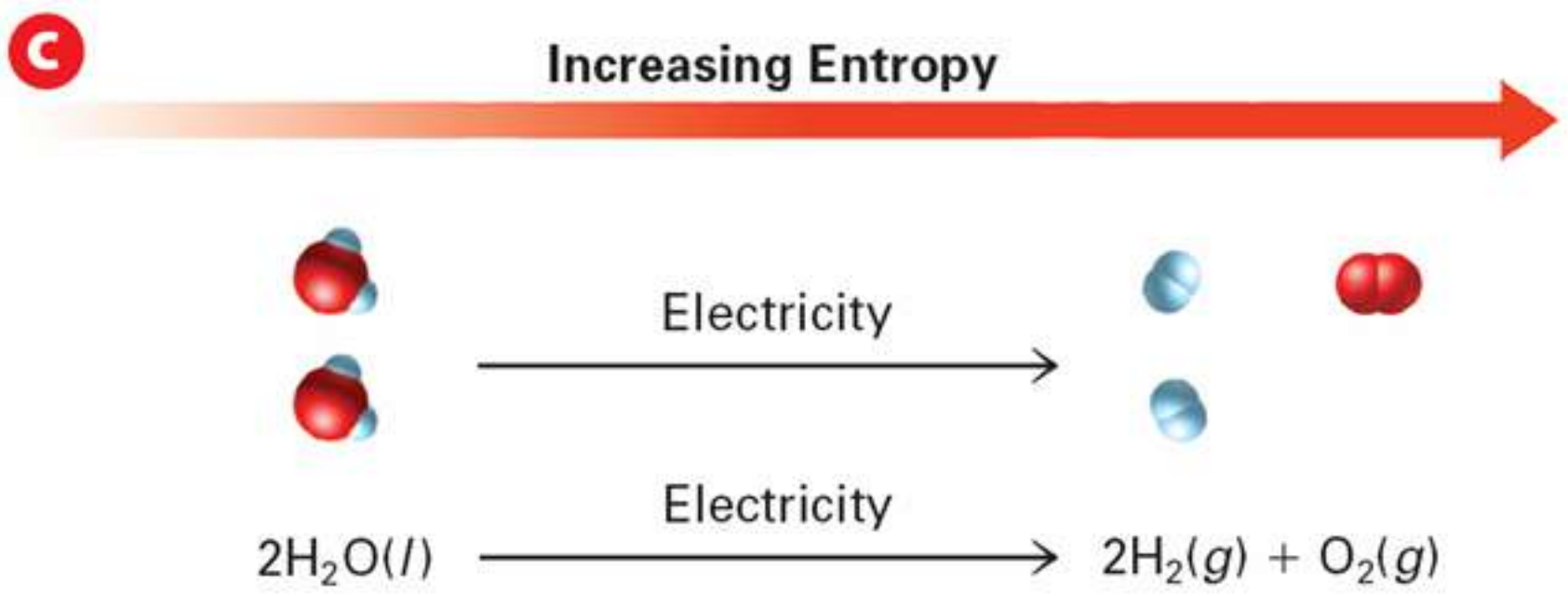


Entropy

- Entropy increases when a substance is divided into parts.

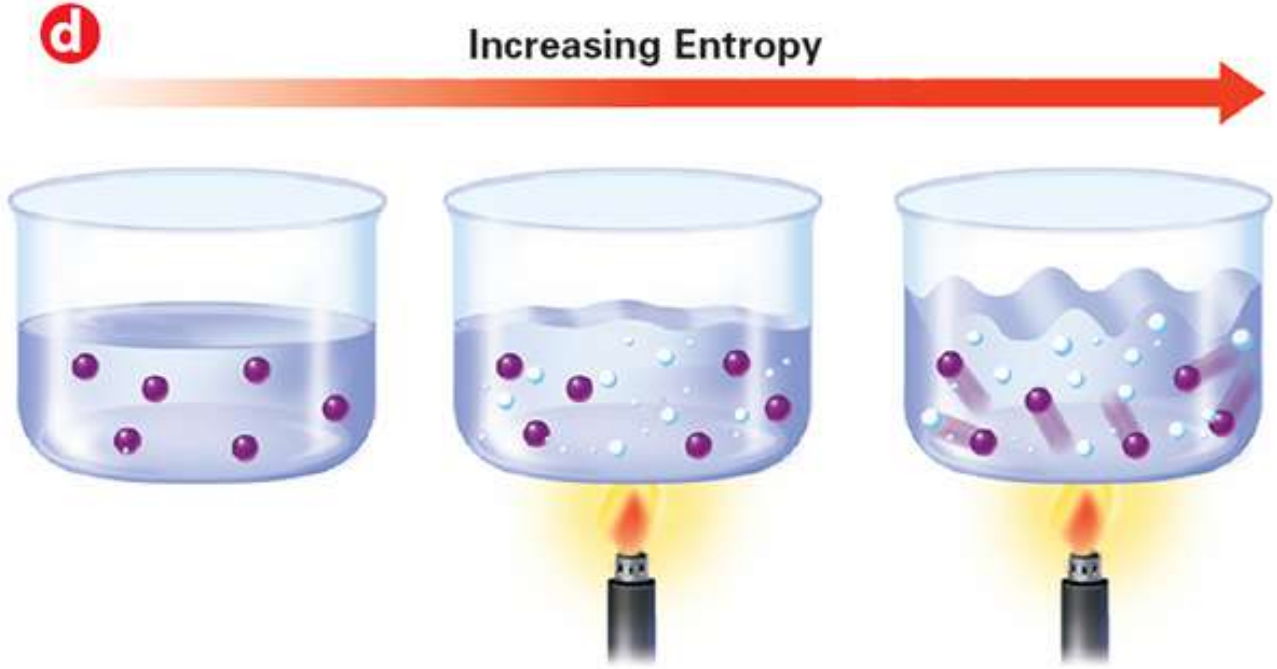


- Entropy tends to increase in chemical reactions in which the total number of product molecules is greater than the total number of reactant molecules.



Electrolysis of water

- Entropy tends to increase when temperature increases. As the temperature increases, the molecules move faster and faster, which increases the disorder.



18.4 Section Quiz.

1. Free energy from a reaction is the amount of energy that is
   - absorbed by an entropy decrease.
   - equal to the enthalpy change.
   - wasted as heat.
   - available to do work.

18.4 Section Quiz.

- 2. Which of the following involves a decrease in entropy?
  - Natural gas burns.
  - A liquid freezes.
  - Dry ice sublimes.
  - Water evaporates.