# Chemical Reactions

〉When do chemical reactions take place?

〉Chemical reactions occur when substances undergo chemical changes to form new substances.

- Possible signs of a chemical reaction:
  - gas formation
  - solid formation
  - release of energy

# Chemical Reactions, *continued*

- Chemical reactions rearrange atoms.
  - **reactant**: a substance or molecule that participates in a chemical reaction
  - **product:** a substance that forms in a chemical reaction
  - Chemical reactions do not create the atoms of the products or destroy the atoms of the reactants.

# Energy and Reactions

〉 What is the role of energy in chemical reactions?

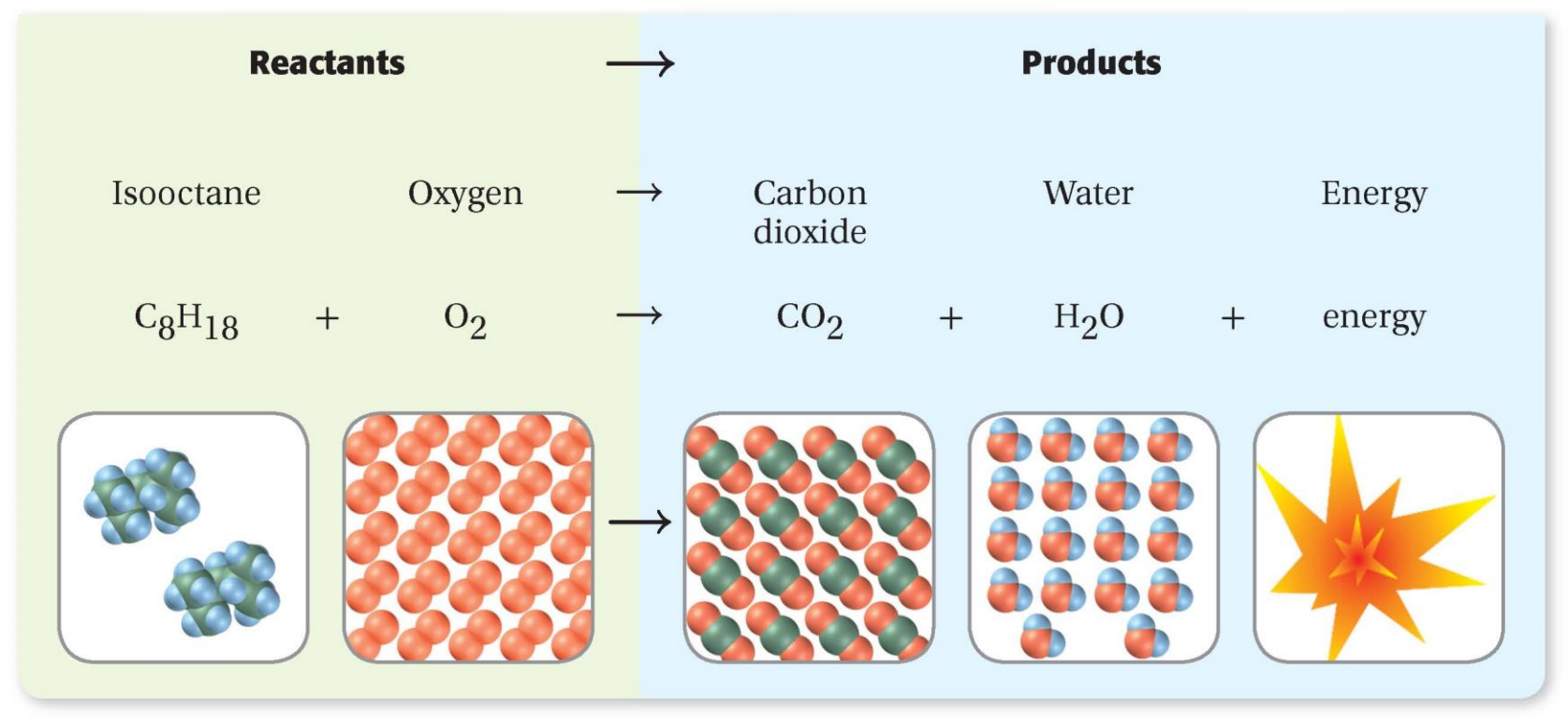
〉 Chemical reactions always involve changes in energy.

- Energy must be added to break bonds.
  - Many forms of energy can be used to break bonds:
    - heat
    - electricity
    - sound
    - light

# Energy and Reactions, *continued*

- Forming bonds releases energy.
- Energy is conserved in chemical reactions.
  - **chemical energy:** the energy released when a chemical compound reacts to produce new compounds
  - The total energy that exists before the reaction is equal to the total energy of the products and their surroundings.
  - Energy in a chemical reaction can change form.
    - Energy is never created or destroyed.

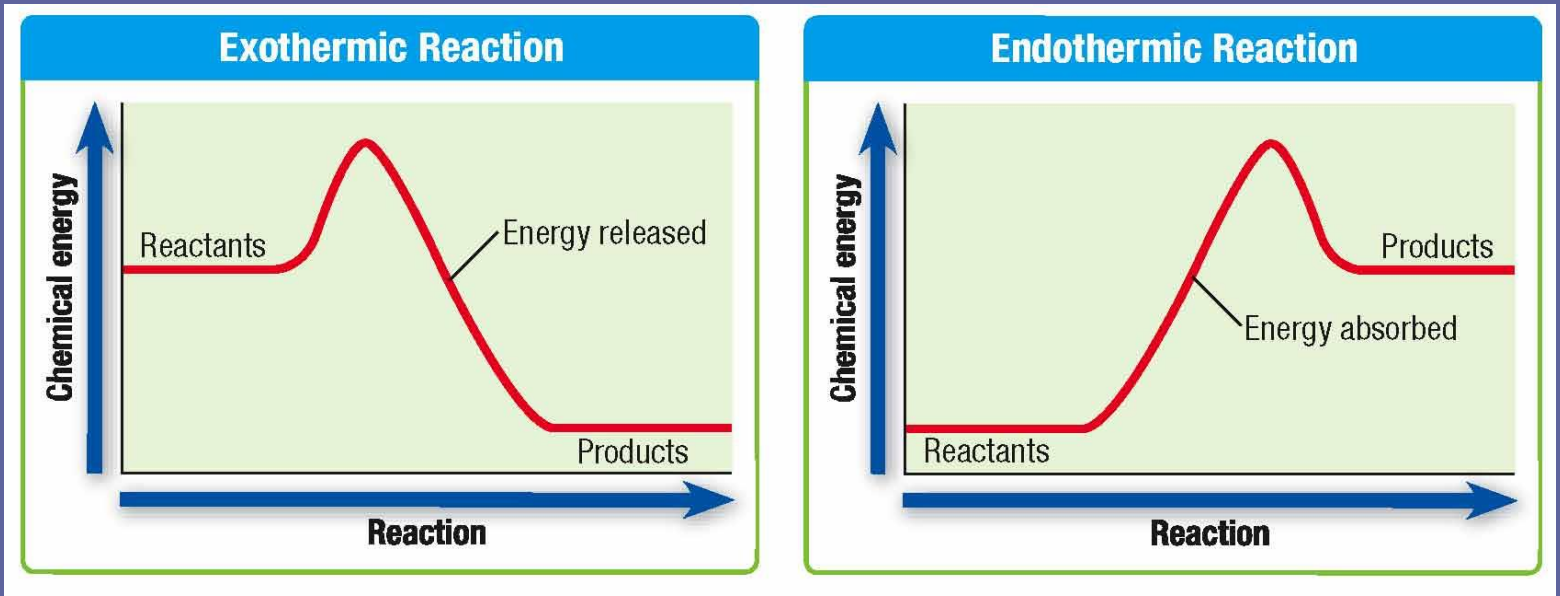
# Reaction Model



# Energy and Reactions, *continued*

- Reactions that release energy are exothermic.
  - The amount of energy released as the products form is greater than the amount of energy absorbed to break the bonds in the reactants.
- Reactions that absorb energy are endothermic.
  - More energy is needed to break the bonds in the reactants than is given off by forming bonds in the products.
- **exothermic reaction:** a chemical reaction in which energy is released to the surroundings as heat
- **endothermic reaction:** a chemical reaction that requires energy input

# Energy and Reactions, *continued*



# Describing Reactions

〉 What is a chemical equation?

〉 A chemical equation uses symbols to represent a chemical reaction and shows the relationship between the reactants and products of a reaction.

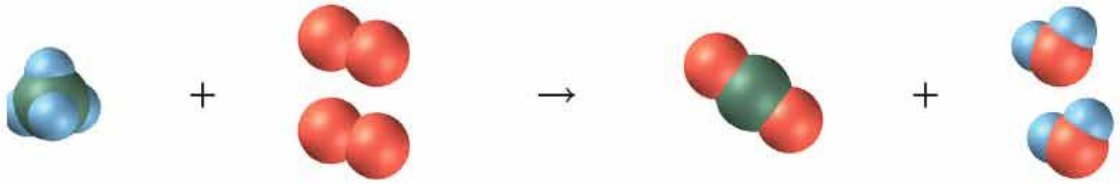
- **chemical equation**: a representation of a chemical reaction that uses symbols to show the relationship between the reactants and the products

# Describing Reactions, *continued*

**Word equation**

methane and oxygen yield carbon dioxide and water

**Molecular model**



**Chemical equation**

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

# Describing Reactions, *continued*

- Chemical equations show products and reactants.
- Balanced chemical equations account for the conservation of mass.
  - When the number of atoms of each element of the products matches the number of atoms of each element of the reactants, the chemical equation is said to be *balanced.*
  - A chemical equation is balanced by adding coefficients in front of one or more of the formulas.

# Math Skills

## Balancing Chemical Equations

Write the equation that describes the burning of magnesium in air to form magnesium oxide.

**1. Identify the reactants and products.**

Magnesium and oxygen gas are the reactants that form the product, magnesium oxide.

**2. Write a word equation for the reaction.**

magnesium + oxygen → magnesium oxide

# Math Skills, *continued*

**3. Write the equation using formulas for the elements and compounds in the word equation.**

Oxygen in air is $O_2$, not O.

$$Mg + O_2 \rightarrow MgO$$

**4. Balance the equation one element at a time.**

| | **Reactants** | | **Products** |
|---|---|---|---|
| | $Mg + O_2$ | $\rightarrow$ | $MgO$ |
| count atoms: | Mg = 1, O = 2 | | Mg = 1, O = 1 |

# Math Skills, *continued*

| | Reactants | | Products |
|---|---|---|---|
| balance oxygen: | $Mg + O_2$ | $\rightarrow$ | $2MgO$ |
| | Mg = 1, O = 2 | | Mg = 2, O = 2 |
| balance magnesium: | $2Mg + O_2$ | $\rightarrow$ | $2MgO$ |
| | Mg = 2, O = 2 | | Mg = 2, O = 2 |

# Balanced Equations and Mole Ratios

〉 What can a balanced chemical equation tell you?

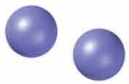
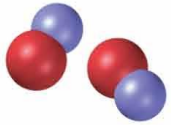
〉 A balanced equation tells you the mole ratio, or proportion of reactants and products, in a chemical reaction.

- **Mole ratio**: the relative number of moles of the substances required to produce a given amount of product in a chemical reaction

# Balanced Equations and Mole Ratios, *continued*

- **The law of definite proportions:**

  A compound always contains the same elements in the same proportions regardless of how the compound is made or how much of the compound is formed.

| Equation: | $2Mg$ | + | $O_2$ | $\longrightarrow$ | $2MgO$ |
|---|---|---|---|---|---|
| Amount (mol) | 2 | | 1 | $\longrightarrow$ | 2 |
| Molar mass (g/mol) | 24.3 | | 32.0 | $\longrightarrow$ | 40.3 |
| Mass calculation | 24.3 g/mol × 2 mol | | 32.0 g/mol × 1 mol | $\longrightarrow$ | 40.3 g/mol × 2 mol |
| Mass (g) | 48.6 | | 32.0 | $\longrightarrow$ | 80.6 |
| Model |  | |  | |  |

# Balanced Equations and Mole Ratios, *continued*

- Mole ratios tell you the relative amounts of reactants and products.

$$2H_2O \rightarrow 2H_2 + O_2$$

  - The equation for the electrolysis of water shows that the mole ratio for $H_2O$:$H_2$:$O_2$ is 2:2:1.
- Mole ratios can be converted to masses.
  - Multiply the molecular mass of each substance by the mole ratio from the balanced equation.
    - This tells you the relative masses of the substances needed to react completely.

# Classifying Reactions

- How does learning about reaction types help in understanding chemical reactions?

- You can use patterns to identify kinds of chemical reactions and to predict the products of the chemical reactions.

# Classifying Reactions, *continued*

- Synthesis reactions combine substances.
  - **synthesis reaction:** a reaction in which two or more substances combine to form a new compound

  - The general form of a synthesis reaction is:

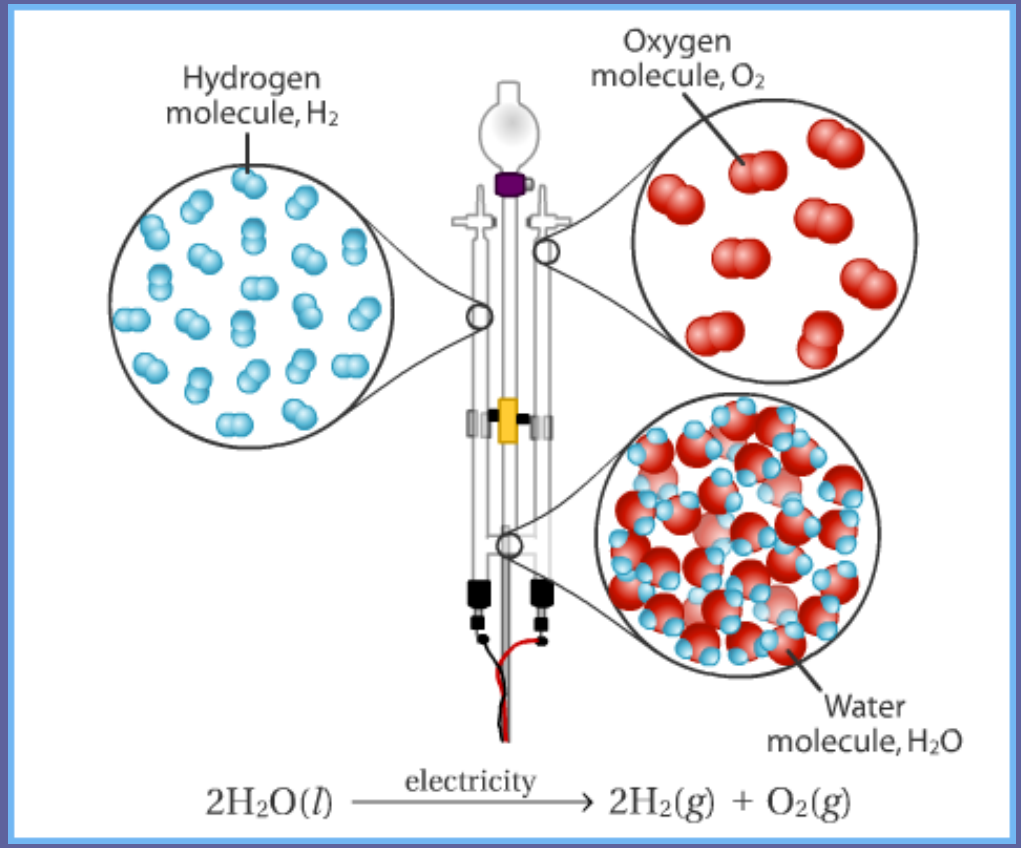
$$A + B \rightarrow AB$$

  - Example: $2Na + Cl_2 \rightarrow 2NaCl$

# Classifying Reactions, *continued*

- Decomposition reactions break substances apart.
  - **decomposition reaction:** a reaction in which a single compound breaks down to form two or more simpler substances
    - Decomposition reactions have the general form:
    - Example: $2H_2O \rightarrow 2H_2 + O_2$

# Visual Concept: Decomposition Reaction



# Classifying Reactions, *continued*

- Combustion reactions use oxygen as a reactant.
  - **combustion reaction:** the oxidation reaction of an organic compound, in which heat is released
    - Water is a common product of combustion reactions.
- In combustion reactions, the products depend on the amount of oxygen available for the reaction.
  - When there is not enough oxygen during a combustion reaction, fuels are not converted completely into carbon dioxide.

# Classifying Reactions, *continued*

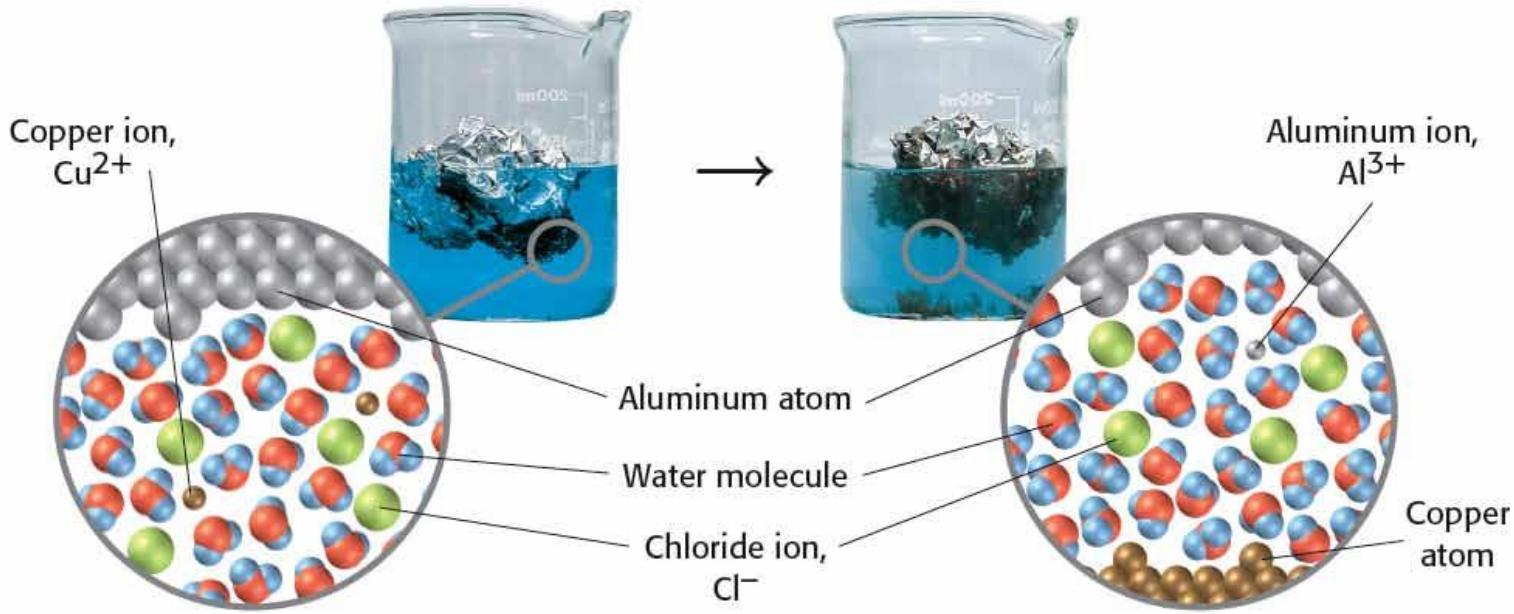
- In single-displacement reactions, elements trade places.
  - **single-displacement reaction:** a reaction in which one element or radical takes the place of another element or radical in a compound
  - In general, a more reactive element will take the place of a less reactive one.
  - All alkali metals and some other metals undergo similar single-displacement reactions with water.
  - Single-displacement reactions have the general form:

$$AX + B \rightarrow BX + A$$

- Example: $3CuCl_2 + 2Al \rightarrow 2AlCl_3 + 3Cu$

# Single Displacement

$$3CuCl_2 + 2Al \rightarrow 2AlCl_3 + 3Cu$$



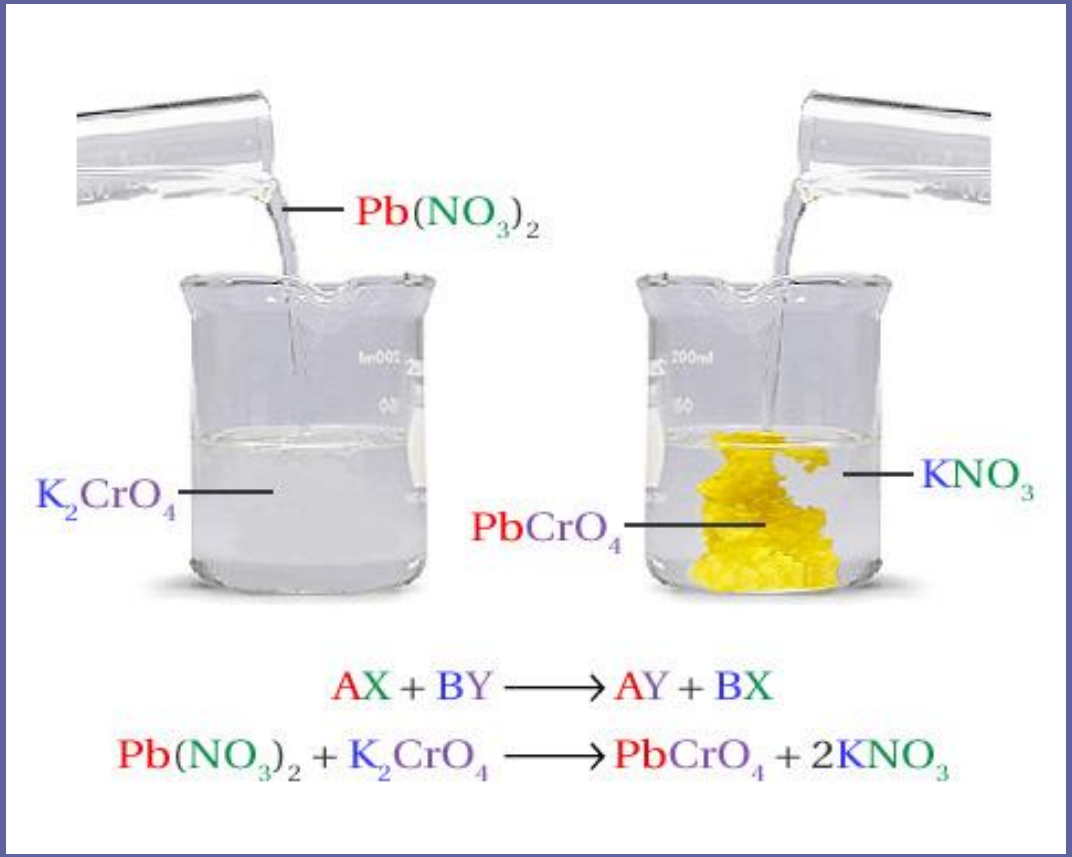
# Classifying Reactions, *continued*

- In double-displacement reactions, ions appear to be exchanged between compounds.
  - **double-displacement reaction:** a reaction in which a gas, a solid precipitate, or a molecular compound forms from the apparent exchange of atoms or ions between two compounds
  - Double-displacement reactions have the general form:

$$AX + BY \rightarrow AY + BX$$

  - Example: $Pb(NO_3)_2 + K_2CrO_4 \rightarrow PbCrO_4 + 2KNO_3$

# Double-Displacement Reaction




$$AX + BY \longrightarrow AY + BX$$

$$Pb(NO_3)_2 + K_2CrO_4 \longrightarrow PbCrO_4 + 2KNO_3$$

# Electrons and Chemical Reactions

〉 In which kinds of chemical reactions do the numbers of electrons in atoms change?

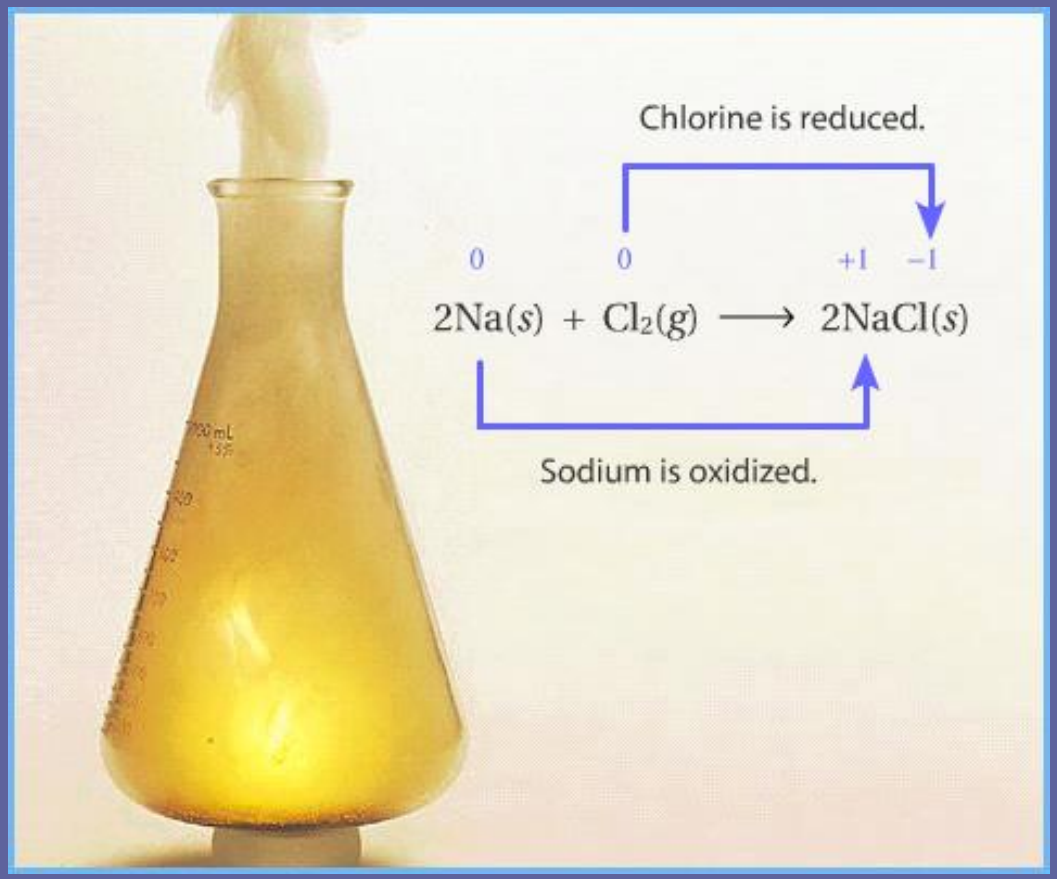
〉 Free-radical reactions and redox reactions can be understood as changes in the numbers of electrons that atoms have.

- **oxidation-reduction reaction:** any chemical change in which one species is oxidized (loses electrons) and another species is reduced (gains electrons); also called *redox reaction*

# Electrons and Chemical Reactions, *continued*

- Substances that accept electrons are said to be *reduced.*
  - The gain of electrons reduces the positive charge on an ion.
- Substances that give up electrons are said to be *oxidized.*
- Some redox reactions do not involve ions.
- Free radicals have electrons available for bonding.
  - **free radical:** an atom or a group of atoms that has one unpaired electron
  - Polymerization reactions often involve free radicals.

# Visual Concept: Redox Reactions



# Factors Affecting Reaction Rates

〉 What kinds of things speed up a reaction?

〉 Anything that increases contact between particles will increase the rate of a reaction.

- For any reaction to occur, the particles of the reactants must collide with one another.

## Factors Affecting Reaction Rates, *continued*

- Most reactions go faster at higher temperatures.
- A large surface area speeds up reactions.
- Higher concentrations of reactants react faster.
- Reactions are faster at higher pressure.
- Massive, bulky molecules react more slowly.

# Catalysts

〉 What does a catalyst do?

〉 A catalyst speeds up or slows down a reaction but is not changed by the reaction.

- **catalyst:** is substance that changes the rate of a chemical reaction without being consumed or changed significantly
- *inhibitors*: substances that slow reactions
- Catalysts are often used in industry to make reactions go faster.

# Catalyst, *continued*

- Enzymes are biological catalysts.
- **Enzyme:** a type of protein that speeds up metabolic reactions in plants and animals without being permanently changed or destroyed
  - Each enzyme controls one reaction or one set of similar reactions.
  - Most enzymes are fragile, and stop working above certain temperatures.
- **substrate:** the reactant in reactions catalyzed by enzymes
  - Example: hydrogen peroxide is the substrate for catalase

$$2H_2O_2 \xrightarrow{\text{catalase}} 2H_2O + O_2$$

# Equilibrium Systems

〉 What happens when a reaction goes backward as well as forward?

〉 Some processes may go in both directions, which results in an equilibrium system.

- *Equilibrium* can be described as a balance that is reached by two opposing processes.

# Equilibrium Systems, *continued*

- Some changes are reversible.
  - A reversible change is indicated by the ⇆ sign in a chemical equation.
  - Example: the physical change of carbon dioxide dissolving

$$CO_2\ (\text{gas above liquid}) \underset{\text{decrease pressure}}{\overset{\text{increase pressure}}{\rightleftharpoons}} CO_2\ (\text{gas dissolved in liquid})$$

- Equilibrium results when rates balance.
  - Example: Molecules of $CO_2$ are coming out of solution and dissolving back into the liquid at the same rate.

# Equilibrium

# Equilibrium Systems, *continued*

- **chemical equilibrium**: a state of balance in which the rate of a forward reaction equals the rate of the reverse reaction and the concentrations of products and reactants remain unchanged
- Systems in equilibrium respond to minimize change.
- Le Châtelier's principle predicts changes in equilibrium.

| Condition | Effect |
|---|---|
| Temperature | Increasing temperature favors the reaction that absorbs energy. |
| Pressure | Increasing pressure favors the reaction that produces fewer molecules of gas. |
| Concentration | Increasing the concentration of one substance favors the reaction that produces less of that substance. |

# Equilibrium Systems, *continued*

- **Le Châtelier's principle:**

  If a change is made to a system in chemical equilibrium, the equilibrium shifts to oppose the change until a new equilibrium is reached.

- Le Châtelier's principle can be used to control reactions.
  - –The Haber process is used to make ammonia.

$$N_2(gas) + 3H_2(gas) \rightleftarrows 2NH_3 + \text{energy}$$

  - The most ammonia is produced when the reaction is run at a high pressure and a low temperature.