CHEMICAL REACTIONS

• All substances have characteristic chemical properties:
  - These properties describe the tendency of a chemical to react with other substances to form new substances
• These changes are termed chemical reactions:
  1. Bonds between atoms are broken
  2. New arrangements of the atoms are formed
  3. Requires either the release or absorption of energy

  In living systems, these reactions are collectively termed metabolism

CHAPTER 8: Chemical Reaction Basics

KINETIC-MOLECULAR THEORY & REACTIONS

• Energy is the capacity to do work or transfer heat:
  - Kinetic energy: Energy of Movement
    - Heat
    - Mechanical
  - Potential energy: Energy of position
    - Chemical
    - Tension (e.g. “spring”)
• The kinetic-molecular view of matter holds that atoms and molecules are in constant motion:
  - As heat is added to a substance, its molecules gain kinetic energy, and thus move faster.
  - Temperature is a measure of the average kinetic energy of the particles in a substance.

CHAPTER 8: Chemical Reaction Basics

CHEMICAL REACTIONS

• When two molecules collide, one of two things can happen:
  1. They bounce off each other
     - Nothing happens
  2. They combine in a new way
     - Bonds are broken & reformed
• Chemical reactions are the productive result of molecular collisions that change bonds:
  - Starting materials = reactants
  - Final materials = products

O₂ + N₂ → 2 NO
• 8.1 Writing and Balancing a Chemical Equation
• 8.2 Energy and Chemical Reactions
• 8.3 Kinetics: Reaction Rates

**CHAPTER 8: Chemical Reaction Basics**

**OUTLINE**

- 8.1 Writing and Balancing a Chemical Equation
- 8.2 Energy and Chemical Reactions
- 8.3 Kinetics: Reaction Rates

**CHAPTER 8: Chemical Reaction Basics**

**LAW OF CONSERVATION OF MASS**

- In every chemical reaction, the number and types of atoms in the reactants is always the same as the number and types of atoms in the products
  - This is a fundamental principle of nature, and is called the law of conservation of mass

Combustion of natural gas on a stovetop….

- A chemical equation is a short-hand way to describe a complete chemical reaction
- Chemical equations include:
  1. All the chemical components of the reaction
  2. Relative numbers of each component (coefficients)
  3. An arrow separating reactants and products in the order of their appearance
  4. Physical states of each component (only if they are expected to change)

\[
\text{CH}_4(g) + 2 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{H}_2\text{O}(g)
\]
In combustion reactions, organic compounds react with oxygen to form carbon dioxide and water.

- Reactants: $C_\text{X}_4H_\text{Y}(Z) + O_2$
- Products: $CO_2 + H_2O$

Energy (heat and/or light) is always released.

Chemical reactions MUST follow the law of conservation of matter....so they MUST balance!

Coefficients for each reactant & product are used to demonstrate balanced chemical reactions.

1. Assess the equation.
   - Determine the number and types of atoms in each reactant and product. If the numbers are not equal on both sides, the equation is not balanced.

2. Balance the equation one atom type at a time by inserting coefficients.
   - Systematically insert coefficients, and see if the equation is balanced.
   - Never change the subscripts!

3. Check that the coefficients cannot be divided by a common divisor.
   - Proper annotation uses only integers for coefficients.
   - Always use the lowest common denominator!
Balance the following chemical equations by inserting the appropriate coefficients:

a. \( \_\_ \text{CH}_2\text{O}_2 \text{(l)} + \_\_ \text{O}_2 \text{(g)} \rightarrow \_\_ \text{CO}_2 \text{(g)} + \_\_ \text{H}_2\text{O} \text{(g)} \)

b. \( \_\_ \text{N}_2\text{O}_5 \text{(g)} \rightarrow \_\_ \text{NO}_2 \text{(g)} + \_\_ \text{O}_2 \text{(g)} \)

c. \( \_\_ \text{Cu}_3\text{H}_2\text{O}_2 \text{(l)} + \_\_ \text{O}_2 \text{(g)} \rightarrow \_\_ \text{CO}_2 \text{(g)} + \_\_ \text{H}_2\text{O} \text{(g)} \)

d. \( \_\_ \text{CaCO}_3 \text{(s)} + \_\_ \text{HCl} \text{(aq)} \rightarrow \_\_ \text{CO}_2 \text{(g)} + \_\_ \text{H}_2\text{O} \text{(l)} + \_\_ \text{CaCl}_2 \text{(aq)} \)

**CHAPTER 8: Chemical Reaction Basics**

**PRACTICE PROBLEMS**

Stoichiometry is the process of calculating how many grams of product form from a given number of grams of reactant.

Stoichiometric calculations only require:
1. A balanced chemical equation
2. The molar mass of each component

**REACTION STOICHIOMETRY CALCULATIONS**

How many grams of carbon dioxide are formed when 10.0 g of glucose undergoes combustion to form carbon dioxide and water? Begin by writing the complete balanced equation.
UNITS OF ENERGY

• The most commonly used units for energy are calories (cal) and joules (J):
  √ 1 calorie is defined as the amount of heat needed to raise 1 gram of water by 1°C (a relative unit)
  √ 1 cal = 4.184 joules (a precise ratio, so ∞ sig figs!)

• Food Calories are equal to kilocalories:
  √ Note the uppercase C in food Calories.
  √ 1 kilocalorie (kcal) is 10³ calories

Table 8-1 Common Units of Energy and Their Conversions

<table>
<thead>
<tr>
<th>Unit</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>calorie (cal)</td>
<td>1 cal = 4.184 J</td>
</tr>
<tr>
<td>Calorie (Cal)</td>
<td>1 Cal = 1 kcal</td>
</tr>
<tr>
<td>kilocalorie (kcal)</td>
<td>1 kcal = 10³ cal</td>
</tr>
</tbody>
</table>

CHAPTER 8: Chemical Reaction Basics

PRACTICE PROBLEM

How would we do the following conversions?

Note: More than one step may be required when there is not a direct conversion.

a. How many calories are in 48.8 J?

b. How many joules are in 5.79 kcal?

HEAT ENERGY

• Energy is transferred in chemical reactions, often in the form of heat energy:
  √ Other energy may also be released, such as light or kinetic (mechanical) energy

  Example: combustion reactions
  \[ \text{C}_3\text{H}_8 (g) + 5 \text{ O}_2 (g) \rightarrow 3 \text{ CO}_2 (g) + 4 \text{ H}_2\text{O} (g) + \text{ Heat Energy} \]

• So where does this heat energy come from?
  Heat energy transferred is referred to as the change in enthalpy (ΔH) of the reaction.
  √ the Δ (delta) symbol always means “change in” something
The total amount of energy stored in the covalent bonds of a molecule is called its enthalpy:

\[ \text{Enthalpy} = \text{bond energy} \]

Different types of bonds have different levels of energy.

Like mass, energy is conserved in chemical reactions:

- **First Law of Thermodynamics**: energy can never be created nor destroyed.

Energy is either released or absorbed when chemical bonds are altered in a chemical reaction:

- Energy must be absorbed to break a bond.
- Energy is released in forming a new bond.

Energy diagrams can be used to show whether energy is absorbed or released in a chemical reaction:

- In an **exothermic** reaction, heat is released to the surroundings, which become hotter \( \Delta H \) is negative.
- In an **endothermic** reaction, heat is absorbed from the surroundings, which become cooler \( \Delta H \) is positive.

**Calorimetry**

Calorimetry is the measurement of enthalpy change (\( \Delta H \)) using an instrument called a calorimeter.

“Bomb calorimetry”

If a compound can be completely combusted, its energy content is easy to determine:

- Known mass of compound
- Known mass (volume) of water in the tank
- Change in temperature of water before & after combustion allows calculation of released energy.
The caloric content of food found on nutrition labels is determined by calorimetry. Units are Calories per gram (Cal/g) or Calories per serving. Which kind of foods have the highest caloric content?

<table>
<thead>
<tr>
<th>Biomolecule</th>
<th>Foods Containing This Biomolecule</th>
<th>Caloric Content (Cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td>Rice, potatoes, bread, vegetables, fruit, milk</td>
<td>4</td>
</tr>
<tr>
<td>Proteins</td>
<td>Fish, meat, dairy products, beans, legumes, milk</td>
<td>4</td>
</tr>
<tr>
<td>Fats</td>
<td>Oils, butter, margarine, animal fats, milk</td>
<td>9</td>
</tr>
</tbody>
</table>

Metabolism is the total sum of all biochemical reactions that occur in a living organism:

- Both energy and mass are conserved throughout the entire metabolic system of an organism.
- Note difference from colloquial use of "metabolism".

Matter is conserved both when molecules are broken down and when they are synthesized:

- Catabolic reactions involve breakdown of complex molecules to harvest energy or mass.
- Anabolic reactions involve buildup of complex biomolecules from more simple precursors.

Generally speaking, catabolism releases energy and anabolism absorbs energy.
Indicate (A) whether each of the following processes is catabolic or anabolic. Indicate (B) whether each releases energy (exothermic) or absorbs energy (endothermic) overall.

a. Building muscle protein from amino acid molecules 

b. A bear burning fat during hibernation 

b. Storing glucose in the form of large polymers, known as glycogen

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**Chemical Kinetics & Reaction Rate**

- **Chemical kinetics** is the study of how fast reactions proceed.

\[
\text{Rate} = \frac{\text{change in a quantity}}{\text{change in time}}, \quad \text{Velocity} = \frac{\text{change in distance}}{\text{change in time}}
\]

- Reaction rates are measured by following concentration changes of product or reactant over time:

\[
\text{Reaction Rate} = \frac{\text{change in product concentration}}{	ext{change in time}} = \frac{\Delta [\text{product}]}{\Delta \text{time}}
\]

- Reaction rate is **highly variable**: 
  - Some reactions occur very fast, in milliseconds
  - Other reactions would take thousands of years to occur
  - Biochemical reactions take place in an intermediate time

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**Energy Diagrams & Activation Energy**

- The change in enthalpy (ΔH) for a reaction has **no effect** on reaction rate.
  
- The change in enthalpy only tells us how much energy is being released or absorbed in a reaction.

- Reaction rate depends on another quantity called the **activation energy** (E_A) of a reaction.
**Activation energy \((E_a)\) is the energy barrier to a reaction occurring when two molecules collide:

- If the activation energy is low \(\rightarrow\) the reaction goes fast
- If the activation energy is high \(\rightarrow\) the reaction is slow

**Reaction diagrams** showing activation energy allow us to predict the rate of a chemical reaction.

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**The variables of reaction rate**

- Reaction rate is affected by several factors:
  1. concentration of reactants = \(\uparrow\) [reactants]
  2. temperature of the reaction
  3. presence of a catalyst

Consider the decomposition reaction:

\[
2 \text{N}_2\text{O}_5 (g) \rightarrow 4 \text{NO}_2 (g) + \text{O}_2 (g)
\]

Reactant concentration & time to completion are indirectly related.

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**Reaction rate and concentration**

- Chemical reactions are about molecule collisions:
  - More molecules \(\rightarrow\) more collisions!
  - The reaction rate will increase when more molecules are present

\[
2 \text{N}_2\text{O}_5 (g) \rightarrow 4 \text{NO}_2 (g) + \text{O}_2 (g)
\]

*Reaction rate is directly proportional to [reactants]*
Temperature is the average kinetic energy of a population of molecules:
- Faster moving molecules (more kinetic energy) undergo more collisions per second.
- Faster molecule velocity also means that molecules collide with greater force (more energy is transferred).

Temperature and reaction rate are also directly related to each other:
- As temperature increases, so does reaction rate.
- Reaction rate roughly doubles for every 10°C change in temperature.

A catalyst is a substance that increases the rate of a chemical reaction by lowering the activation energy ($E_a$) for the reaction:
- Enzymes can speed up reactions by factors ranging from $10^5$ – $10^{17}$ fold!
- The same amount of energy is released or absorbs in the presence of a catalyst, $\Delta H$ is constant.

Biochemical systems are "isothermic":
- Constant temperature of ~37°C.
- Increasing reaction rate by changing temperature is impossible in living organisms!

Biochemical reactions are controlled by specialized biological catalysts called enzymes:
- Most enzymes are proteins.
- The reactions they catalyze are incredibly specific.
For the following reactions, determine whether the indicated change in conditions would *increase* or *decrease* the reaction rate.

a. \( 2 \text{H}_2\text{O}_2 (\text{aq}) \rightarrow 2 \text{H}_2\text{O} (\text{l}) + \text{O}_2 (\text{g}) \)
   
   More \( \text{H}_2\text{O}_2 \) is added to the reaction.

b. \( \text{CO} (\text{g}) + \text{NO}_2 (\text{g}) \rightarrow \text{CO}_2 (\text{g}) + \text{NO} (\text{g}) \)
   
   The temperature is reduced from 430°C to 330°C.

c. \( 2 \text{H}_2\text{O}_2 (\text{aq}) \rightarrow 4 \text{H}_2\text{O} (\text{l}) + \text{O}_2 (\text{g}) \)
   
   Sodium iodide, a catalyst, is added to the reaction.