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***

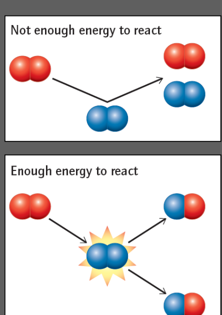
KINETIC-MOLECULAR THEORY & REACTIONS

- **Energy** is the capacity to do work or transfer heat:

Kinetic energy	**Potential energy**
Energy of Movement	*Energy of position*
Heat Mechanical	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.

CHEMICAL REACTIONS



$O_2 + N_2 \rightarrow 2\ NO$

- 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***

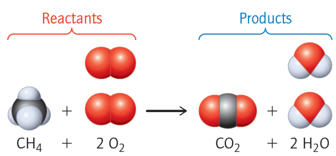
OUTLINE

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

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….



WRITING CHEMICAL EQUATIONS

- 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)

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$

COMBUSTION REACTIONS

- In combustion reactions, *organic compounds* react with *oxygen* to form carbon dioxide and water
  - ***Reactants***: $C_XH_Y(Z)$ + O_2
  - ***Products***: CO_2 + H_2O
- **Energy** (heat and/or light) is always released

Coefficients

$$\underbrace{C_6H_{12}O_6(aq) + 6\,O_2(g)}_{\text{Reactants}} \longrightarrow \underbrace{6\,CO_2(g) + 6\,H_2O(g)}_{\text{Products}}$$

BALANCING CHEMICAL EQUATIONS

- *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

Coefficients

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$$

Oxygen subscripts

$$(1 \times 6) + (6 \times 2) \qquad (6 \times 2) + (6 \times 1)$$

$$6 + 12 \qquad 12 + 6$$

$$\boxed{\text{18 oxygen atoms} = \text{18 oxygen atoms}}$$

Balanced chemical reactions demonstrate the ***molar ratios*** of each component in the reaction

GUIDELINES FOR BALANCING EQUATIONS

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!

CHAPTER 8: Chemical Reaction Basics

PRACTICE PROBLEMS

Balance the following chemical equations by inserting the appropriate coefficients:

a. ___CH_2O_2 (l) + ___O_2 (g) ⟶ ___ CO_2 (g) + ___ H_2O (g)

b. ___N_2O_5 (g) ⟶ ___NO_2 (g) + ___ O_2 (g)

c. ___$C_6H_{12}O_2$ (l) + ___ O_2 (g) ⟶ ___CO_2 (g) + ___ H_2O (g)

d. ___$CaCO_3$ (s) + ___HCl (aq) ⟶ ___ CO_2 (g) +___ H_2O (l) +___ $CaCl_2$ (aq)

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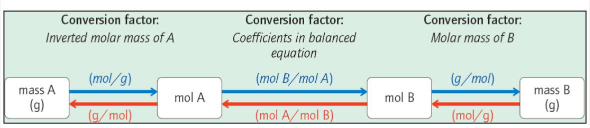
REACTION STOICHIOMETRY CALCULATIONS

- **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



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PRACTICE PROBLEM

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.

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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 10^3 calories

Table 8-1 Common Units of Energy and Their Conversions

Unit	Conversion
calorie (cal)	1 cal = 4.184 J (exact)
Calorie (Cal) (note capital C)	1 Cal = 1 kcal
kilocalorie (kcal)	1 kcal = 10^3 cal

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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?

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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**

$$C_3H_8\,(g) + 5\ O_2\,(g) \rightarrow 3\ CO_2\,(g) + 4\ H_2O\,(g) + \textbf{Heat Energy}$$

- *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

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ENTHALPY & BOND ENERGIES

- The total amount of energy stored in the covalent bonds of a molecule is called its **enthalpy**:

  Enthalpy = 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

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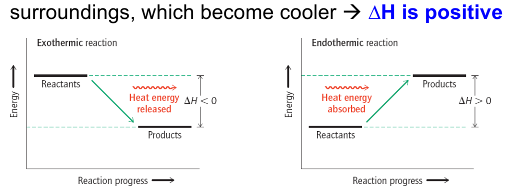
ENERGY DIAGRAMS & ENTHALPY

- **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 → **ΔH is negative**
  - In an **endothermic** reaction, heat is absorbed from the surroundings, which become cooler → **ΔH is positive**



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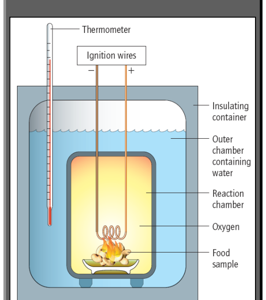
CALORIMETRY

- **Calorimetry** is the measurement of enthalpy change (ΔH) 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



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CALORIC CONTENT OF FOOD & DIETARY VALUE FOR NUTRITION

- 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?*

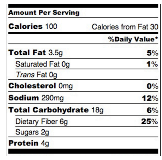

Table 8-2 Caloric Content of Carbohydrates, Proteins, and Fats

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

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METABOLISM & BIOENERGETICS

- **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

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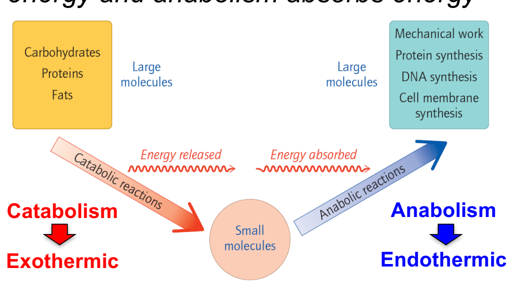
METABOLISM AND ENERGY

Generally speaking, catabolism releases energy and anabolism absorbs energy



PRACTICE PROBLEM

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

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

CHEMICAL KINETICS & REACTION RATE

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

$$\textbf{\textit{Rate}} = \frac{\text{change in a quantity}}{\text{change in time}} \qquad \textbf{\textit{Velocity}} = \frac{\text{change in distance}}{\text{change in time}}$$

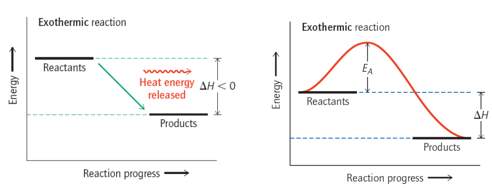
  - Reaction rates are measured by following concentration changes of product or reactant over time.

$$\boxed{\textbf{\textit{Reaction Rate}} = \frac{\text{change in product concentration}}{\text{change in time}} = \frac{\Delta\,[\text{product}]}{\Delta\,\text{time}}}$$

- 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

ENERGY DIAGRMS & ACTIVATION ENERGY

- The change in **enthalpy** (Δ**H**) 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



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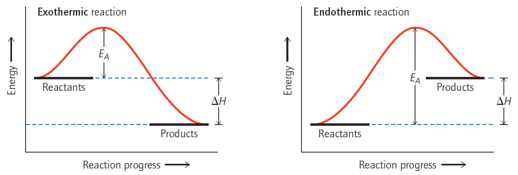
ACTIVATION ENERGY AS BARRIER

- **Activation energy** (**E_A**) is the energy barrier to a reaction occurring when two molecules collide:
  - If the activation energy is *low* → the reaction goes *fast*
  - If the activation energy is *high* → the reaction is *slow*
- **Reaction diagrams** showing activation energy allow us to predict the rate of a chemical reaction.



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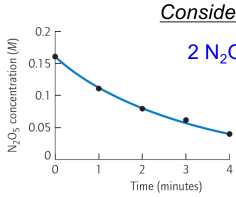
THE VARIABLES OF REACTION RATE

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

*Consider the **decomposition reaction**:*

$2\ N_2O_5\ (g) \rightarrow 4\ NO_2\ (g) + O_2\ (g)$



Reactant concentration & time to completion are indirectly related

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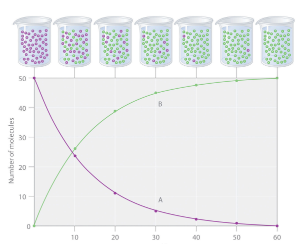
REACTION RATE AND CONCENTRATION

- Chemical reactions are about **molecule collisions**:
  - More molecules…….more collisions!
  - The reaction rate will increase when more molecules are present

$2\ N_2O_5\ (g) \rightarrow 4\ NO_2\ (g) + O_2\ (g)$



Reaction rate** is directly proportional to **[reactants]

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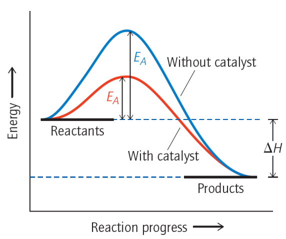
REACTION RATE AND TEMPERATURE

- **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

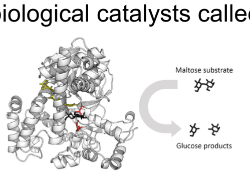
REACTION RATE AND CATALYSTS

- 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
    → ***ΔH is constant***



BIOCHEMICAL CATALYSIS

- 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!

CHAPTER 8: Chemical Reaction Basics

PRACTICE PROBLEMS

For the following reactions, determine whether the indicated change in conditions would *increase* or *decrease* the reaction rate.

a. $2\ H_2O_{2\ (aq)} \longrightarrow 2\ H_2O_{\ (l)} + O_{2\ (g)}$
   More H_2O_2 is added to the reaction.

b. $CO_{\ (g)} + NO_{2\ (g)} \longrightarrow CO_{2\ (g)} + NO_{\ (g)}$
   The temperature is reduced from 430ºC to 330ºC.

c. $2\ H_2O_{2\ (aq)} \longrightarrow 2\ H_2O_{\ (l)} + O_{2\ (g)}$
   Sodium iodide, a catalyst, is added to the reaction.