Chapter 02 Lecture and Animation Outline

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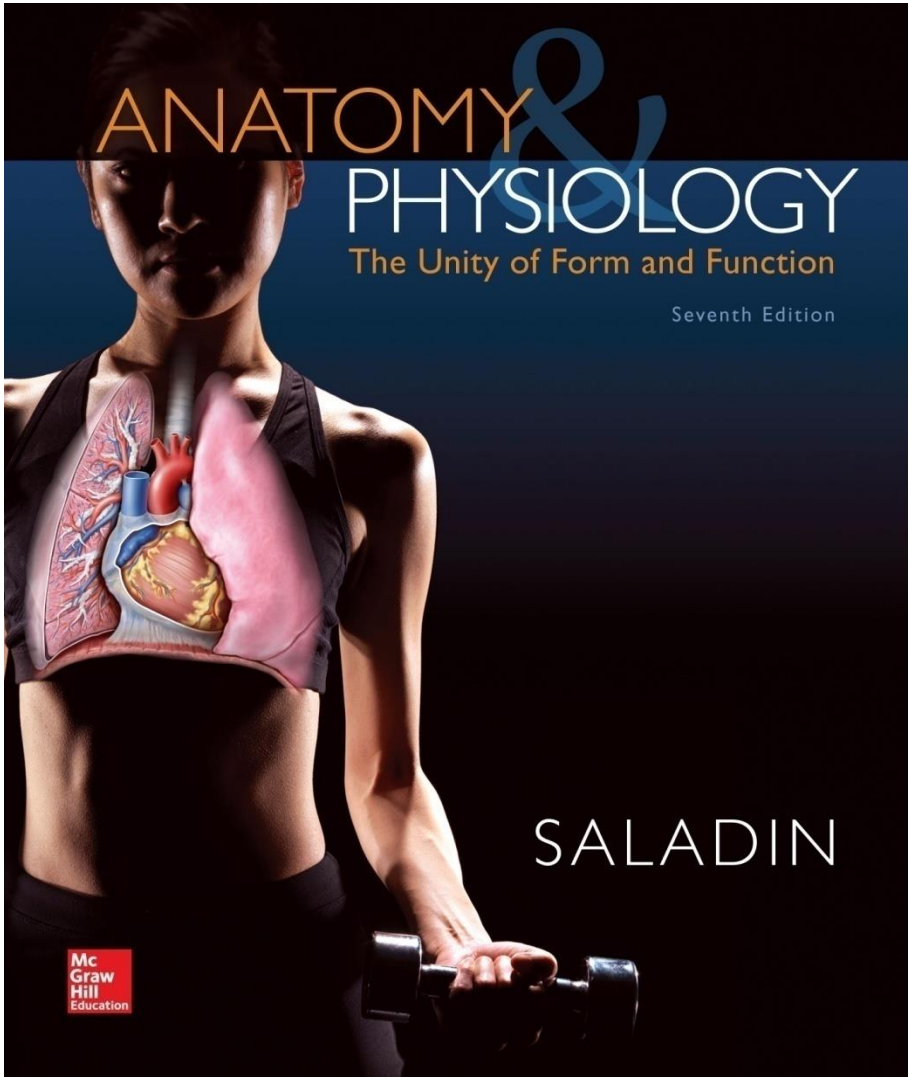

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Introduction

- **Biochemistry**
  - The study of the molecules that compose living organisms
  - Carbohydrates, fats, proteins, and nucleic acids
  - Useful for understanding cellular structures, basic physiology, nutrition, and health

Atoms, Ions, and Molecules

- **Expected Learning Outcomes**
  - Name the chemical elements of the body from their chemical symbols.
  - Distinguish between chemical elements and compounds.
  - State the functions of minerals in the body.
  - Explain the basis for radioactivity and the types of hazards of ionizing radiation.
  - Distinguish between ions, electrolytes, and free radials.
  - Define the types of chemical bonds.

The Chemical Elements

- **Element**—simplest form of matter to have unique chemical properties
- **Atomic number** of an element—number of protons in its nucleus
  - **Periodic table**
    - Elements arranged by atomic number
    - Elements represented by one- or two-letter symbols
  - **24 elements have biological role**
    - 6 elements = 98.5% of body weight
      - Oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus
    - Trace elements in minute amounts, but play vital roles

The Chemical Elements

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TABLE 2.1 Elements of the Human Body

Name	Symbol	Percentage of Body Weight
Major Elements (Total 98.5%)		
Oxygen	O	65.0
Carbon	C	18.0
Hydrogen	H	10.0
Nitrogen	N	3.0
Calcium	Ca	1.5
Phosphorus	P	1.0
Lesser Elements (Total 0.8%)		
Sulfur	S	0.25
Potassium	K	0.20
Sodium	Na	0.15
Chlorine	Cl	0.15
Magnesium	Mg	0.05
Iron	Fe	0.006

Trace Elements (Total 0.7%)			
Chromium	Cr	Molybdenum	Mo
Cobalt	Co	Selenium	Se
Copper	Cu	Silicon	Si
Fluorine	F	Tin	Sn
Iodine	I	Vanadium	V
Manganese	Mn	Zinc	Zn

The Chemical Elements

- **Minerals**—inorganic elements extracted from soil by plants and passed up food chain to humans
  - Ca, P, Cl, Mg, K, Na, and S
  - Constitute about 4% of body weight
  - Important for body structure (Ca crystals in teeth, bones, etc.)
  - Important for enzymes' functions
  - **Electrolytes**—mineral salts needed for nerve and muscle function

Atomic Structure

- Neils Bohr proposed **planetary model** of atomic structure in 1913
- **Nucleus—**center of atom
  - **Protons:** single (+) charge; mass = 1 atomic mass unit (amu)
  - **Neutrons:** no charge; mass = 1 amu
  - Atomic mass is approximately equal to total number of protons and neutrons
- **Electrons—**in concentric clouds surrounding nucleus
  - **Electrons:** single (-) charge, very low mass
    - An atom is electrically neutral, as number of electrons equals number of protons
    - **Valence electrons** orbit in the outermost shell and determine chemical bonding properties of an atom

Bohr Planetary Models of Elements

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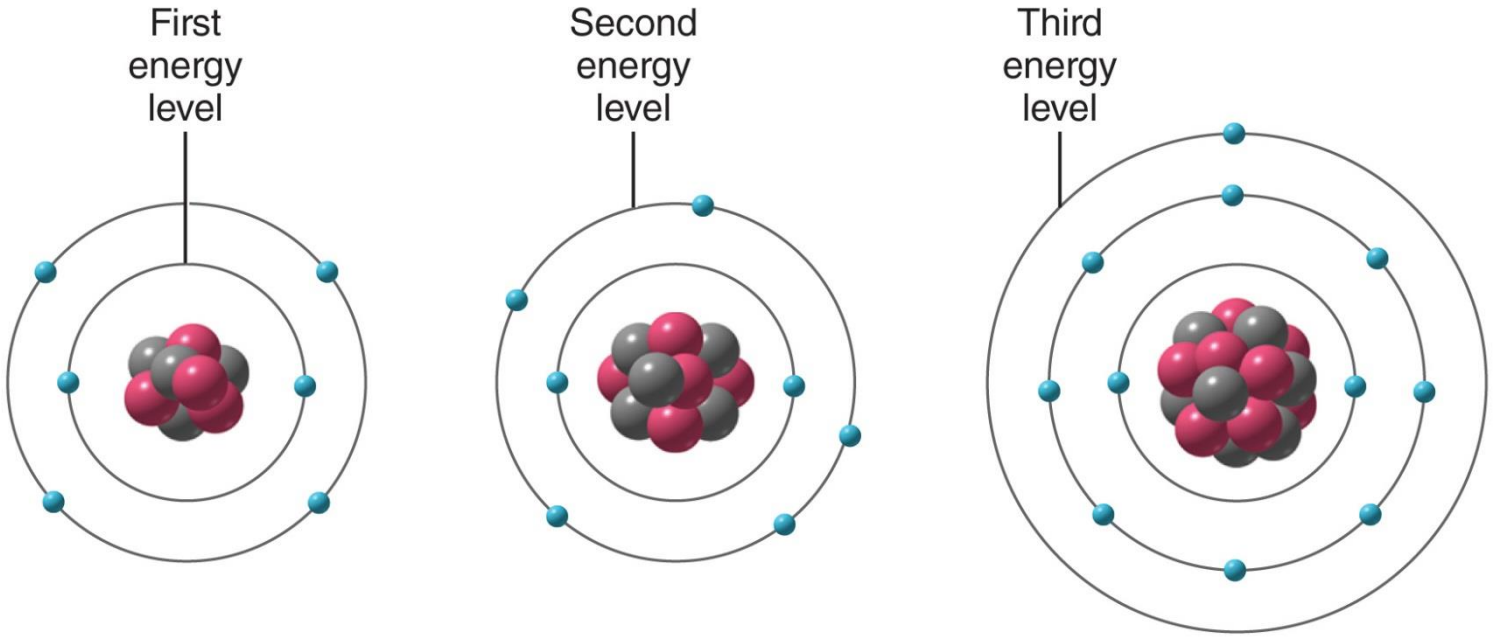

Carbon (C)	Nitrogen (N)	Sodium (Na)
$6p^+$, $6e^-$, $6n^0$	$7p^+$, $7e^-$, $7n^0$	$11p^+$, $11e^-$, $12n^0$
Atomic number = 6	Atomic number = 7	Atomic number = 11
Atomic mass = 12	Atomic mass = 14	Atomic mass = 23

Figure 2.1

Isotopes and Radioactivity

- **Isotopes**—varieties of an element that differ only in the number of neutrons
  - Extra neutrons increase atomic weight
  - Isotopes of an element are chemically similar because they have the same number of valence electrons
- **Atomic weight (relative atomic mass) of an element accounts for the fact that an element is a mixture of isotopes**

Isotopes of Hydrogen

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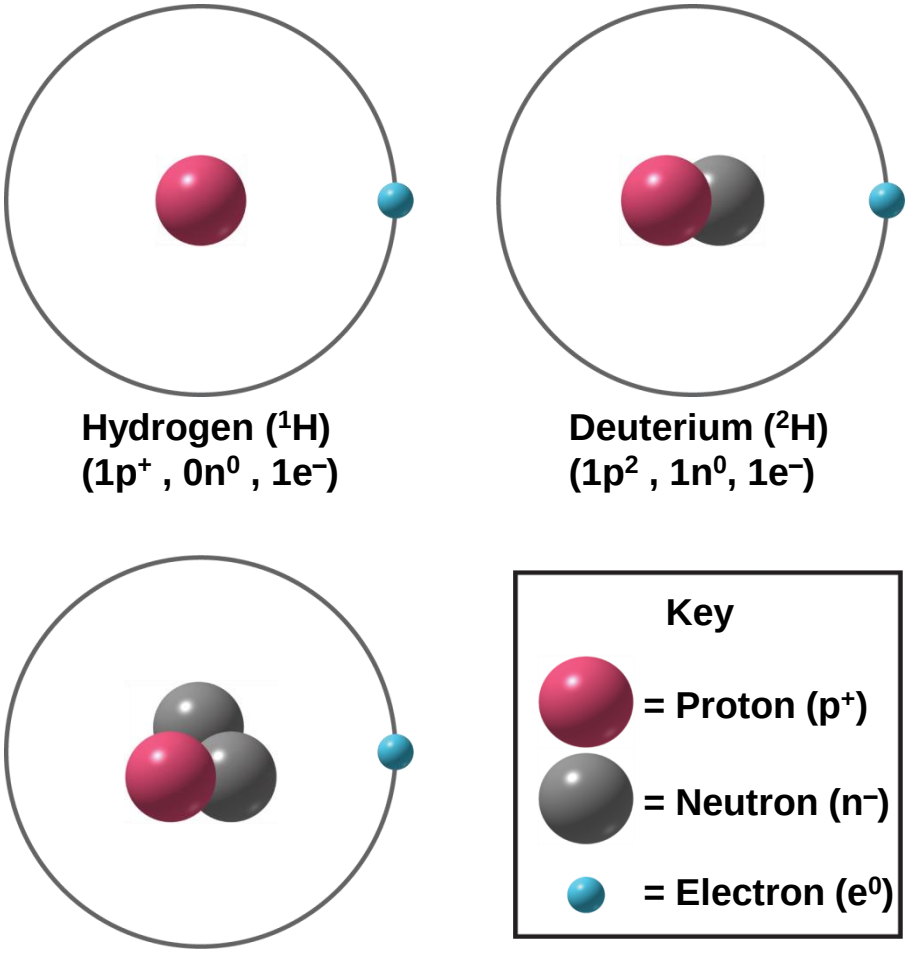

Figure 2.2

Isotopes and Radioactivity

- **Radioisotopes**
  - Unstable isotopes that decay and give off radiation
  - Every element has at least one radioisotope
- Intense radiation can be **ionizing (ejects electrons, destroys molecules, creates free radicals)** and can cause genetic mutations and cancer
  - Examples: UV radiation, X-rays, alpha particles, beta particles, gamma rays
- **Physical half-life** of radioisotopes
  - Time required for 50% to decay to a stable state
- **Biological half-life** of radioisotopes
  - Time required for 50% to disappear from the body

Isotopes and Radioactivity

- Unit of radiation dosage in **sievert (Sv)**
  - 5 Sv or more is usually fatal
  - Background radiation = natural sources such as radon gas and cosmic rays
    - 2.4 millisieverts (mSv) per year is average background exposure
  - Artificial sources of radiation = X-rays, color TVs, etc…
    - 0.6 mSV is average exposure from artificial sources
  - U.S. government sets standard acceptable exposure at 50 mSv per year

Radiation and Madame Curie

- **First woman to receive Nobel Prize (1903)**
- **First woman in world to receive a Ph.D.**
  - Coined term *radioactivity*
  - Discovered radioactivity of polonium and radium
  - Trained physicians in use of X-rays and pioneered radiation therapy as cancer treatment
- **Died of radiation poisoning at age 67**

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Figure 2.3

Ions, Electrolytes, and Free Radicals

- **Ion—charged particle (atom or molecule) with unequal number of protons and electron**

- **Ionization—transfer of electrons from one atom to another**

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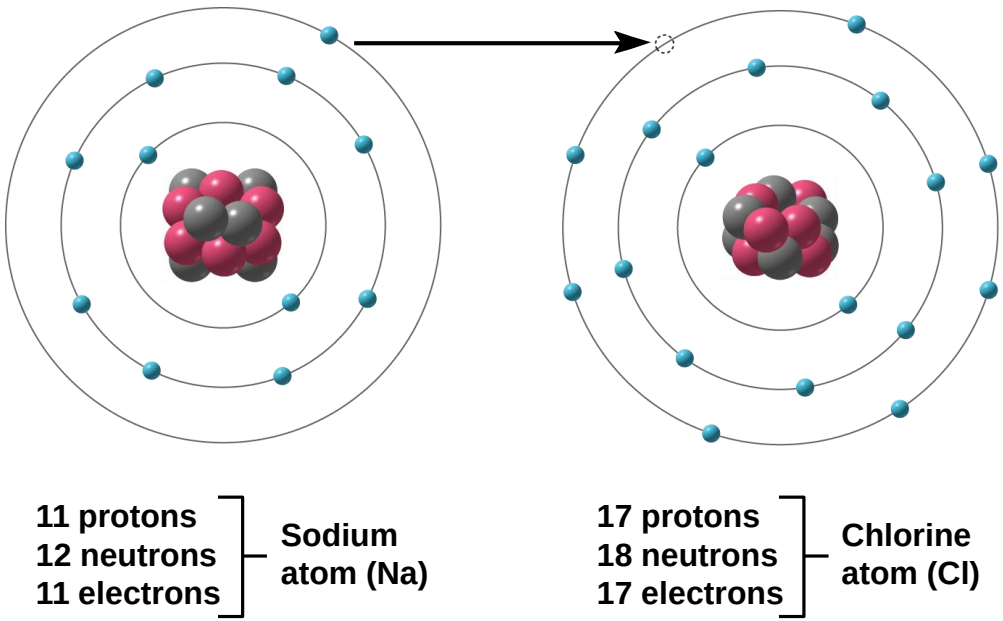

1 Transfer of an electron from a sodium atom to a chlorine atom

Figure 2.4 (1)

Ions, Electrolytes, and Free Radicals

- **Anion**—particle that gains electron(s) (net negative charge)
- **Cation**—particle that loses electron(s) (net positive charge)
- **Ions with opposite charges are attracted to each other**

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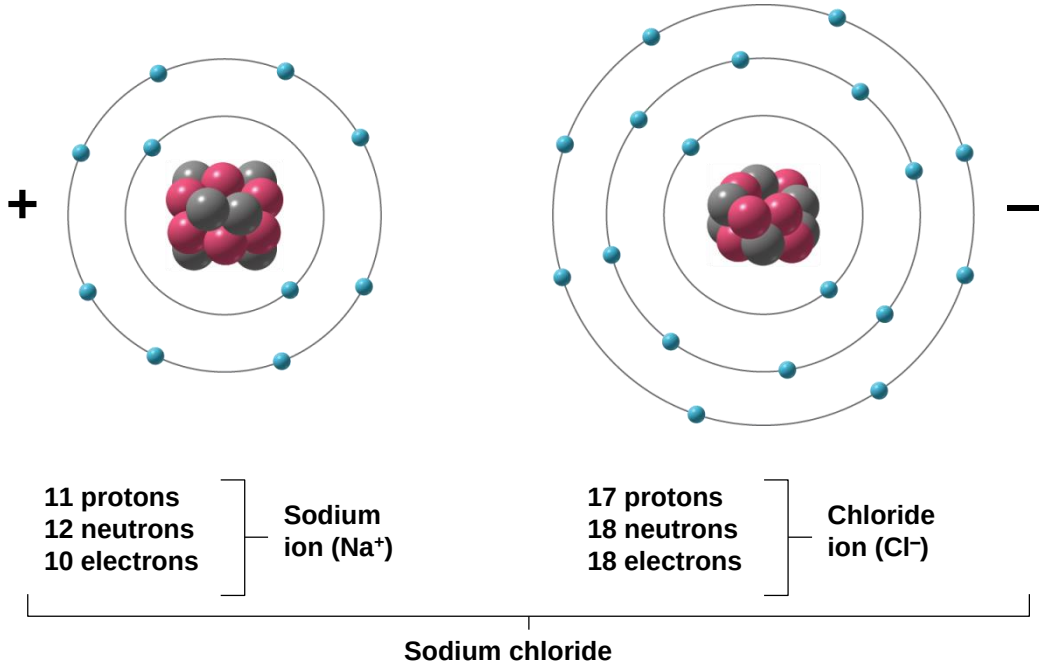

Figure 2.4 (2)

2 The charged sodium ion (Na^+) and chloride ion (Cl^-) that result

Ions, Electrolytes, and Free Radicals

- **Electrolytes**—substances that ionize in water and form solutions capable of conducting electric current
- **Electrolyte importance**
  - Chemical reactivity, osmotic effects, electrical excitability of nerve and muscle
  - Electrolyte balance is one of the most important considerations in patient care (imbalances can lead to coma or cardiac arrest)

Ions, Electrolytes, and Free Radicals

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TABLE 2.2 Major Electrolytes and the Ions Released by their Dissociation

Electrolyte		Cation	Anion
Calcium chloride ($CaCl_2$)	$\rightarrow$	Ca^{2+}	$2\ Cl^-$
Disodium phosphate (Na_2HPO_4)	$\rightarrow$	$2\ Na^+$	HPO_4^{2-}
Magnesium chloride ($MgCl_2$)	$\rightarrow$	Mg^{2+}	$2\ Cl^-$
Potassium chloride (KCl)	$\rightarrow$	K^+	Cl^-
Sodium bicarbonate ($NaHCO_3$)	$\rightarrow$	Na^+	HCO_3^-
Sodium chloride ($NaCl$)	$\rightarrow$	Na^+	Cl^-

Ions, Electrolytes, and Free Radicals

- **Free radicals**—short-lived particles with an unusual number of electrons
  - Produced by normal metabolic reactions, radiation, certain chemicals
  - Trigger reactions that destroy molecules, and can cause cancer, death of heart tissue, and aging
- **Antioxidants**
  - Chemicals that neutralize free radicals
  - Superoxide dismutase (SOD) is an antioxidant enzyme in the body
  - Selenium, vitamin E, vitamin C, and carotenoids are antioxidants obtained through the diet

Molecules and Chemical Bonds

- **Molecule**—chemical particle composed of two or more atoms united by a chemical bond
- **Compound**—molecule composed of two or more different elements
- **Molecular formula**—identifies constituent elements and how many atoms of each are present
- **Structural formula**—identifies location of each atom

Molecules and Chemical Bonds

- **Isomers**—molecules with identical molecular formulae but different arrangement of their atoms

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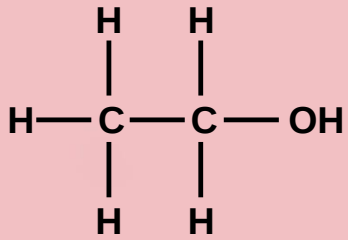
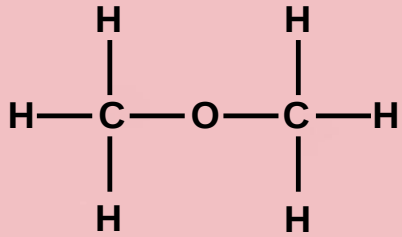
	Structural formulae	Condensed structural formulae	Molecular formulae
Ethanol		CH_3CH_2OH	C_2H_6O
Ethyl ether		CH_3CH_2OH	C_2H_6O

Figure 2.5

Molecules and Chemical Bonds

- The **molecular weight (MW)** of a compound is the sum of the atomic weights of its atoms.
- **Calculate: MW of glucose ($C_6H_{12}O_6$)**

6 C atoms x 12 amu each = 72 amu

12 H atoms x 1 amu each = 12 amu

6 O atoms x 16 amu each = 96 amu

Molecular weight (MW) = 180 amu

Molecules and Chemical Bonds

- **Chemical bonds**—hold atoms together within a molecule or attract one molecule to another

- **Most important types of chemical bonds: ionic bonds, covalent bonds, hydrogen bonds, van der Walls forces**

- **Ionic bonds**
  - Attractions between anions and cations (example, NaCl)
  - Electrons donated from one atom to another
  - Easily broken by water

Molecules and Chemical Bonds

Single covalent bond—one pair of electrons are shared

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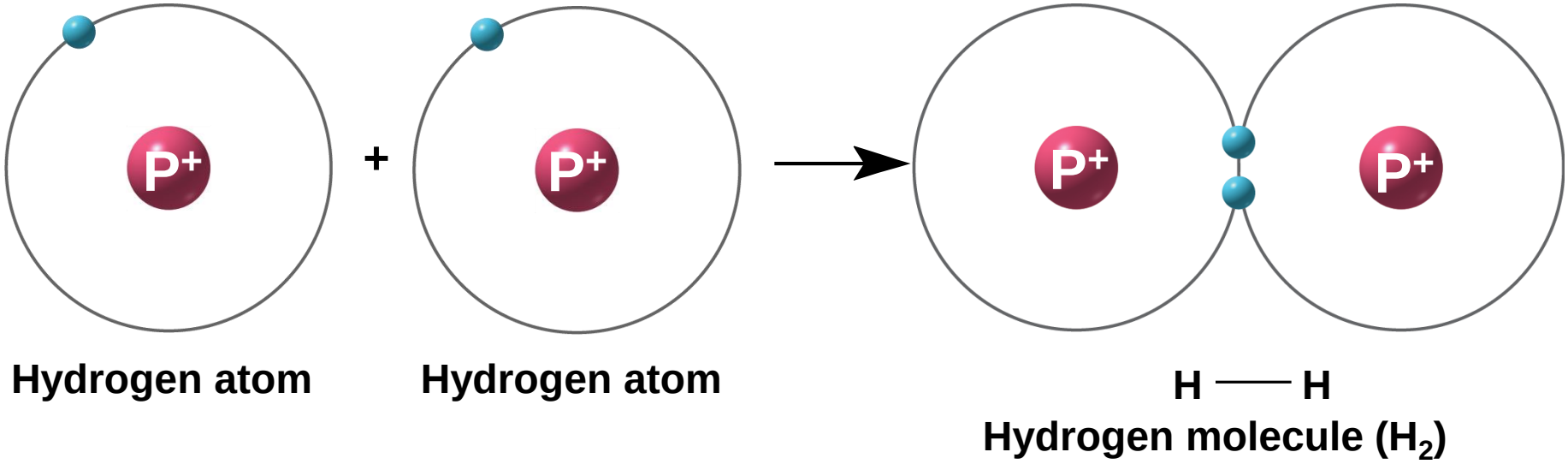

(a)

Figure 2.6a

Molecules and Chemical Bonds

Double covalent bonds—two pairs of electrons are shared

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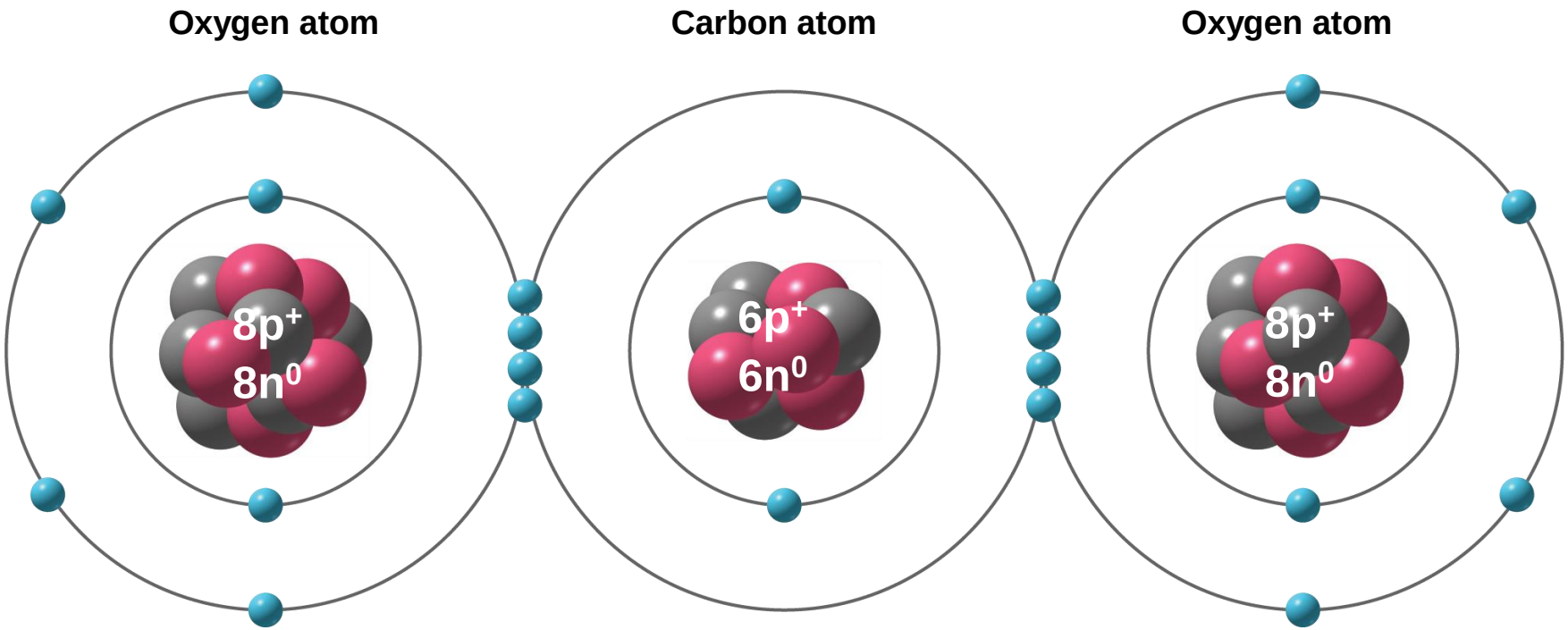

O ═ C ═ O

(b)

Carbon dioxide molecule (CO_2)

Figure 2.6b

Molecules and Chemical Bonds

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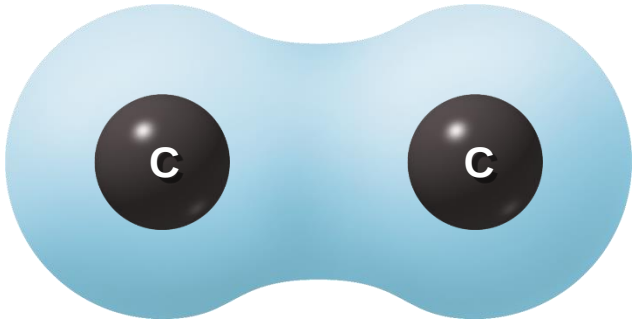
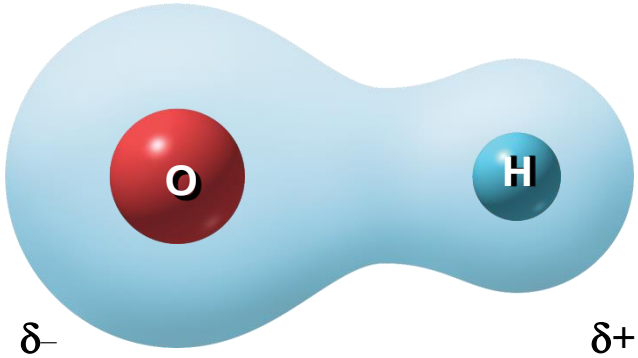


(a)

Nonpolar covalent
C — C bond

Nonpolar bond: electrons shared equally (strongest bond)



(b)

Polar covalent
O — H bond

Polar bond: electrons shared unequally (spend more time near oxygen)

Figure 2.7

Molecules and Chemical Bonds

- **Hydrogen bond**—a weak attraction between a slightly positive hydrogen atom in one molecule and a slightly negative oxygen or nitrogen atom in another
  - Water molecules are attracted to each other by hydrogen bonds
  - Large molecules (DNA and proteins) shaped by hydrogen bonds within them
  - Important to physiology

Molecules and Chemical Bonds

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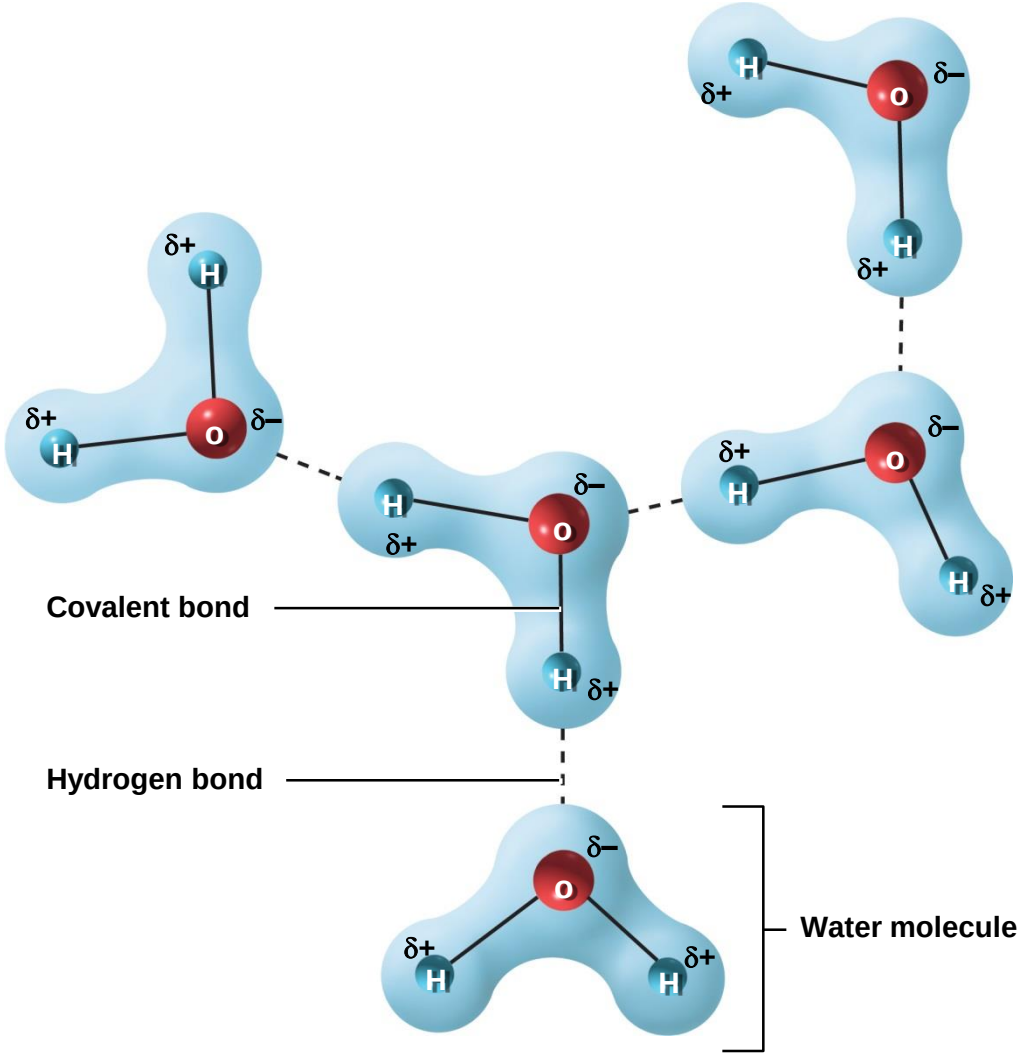

Figure 2.8

Molecules and Chemical Bonds

- **Van der Waals forces**—weak, brief attractions between neutral atoms
  - Fluctuation in electron density within an atom creates polarity for a moment, and attracts adjacent atom for a very short time
  - Only 1% as strong as a covalent bond, but important in physiology (example, protein folding)

Water and Mixtures

- **Expected Learning Outcomes**
  - Define *mixture* and distinguish between mixtures and compounds.
  - Describe the biologically important properties of water.
  - Show how three kinds of mixtures differ from each other.
  - Discuss some ways in which the concentration of a solution can be expressed, and explain why different expressions of concentration are used for different purposes.
  - Define *acid* and *base* and interpret the pH scale.

Water and Mixtures

- **Mixtures**—physically blended but not chemically combined
- **Body fluids are complex mixtures of chemicals**
- **Most mixtures in our bodies consist of chemicals dissolved or suspended in water**
- **Water is 50% to 75% of body weight**
  - Depends on age, sex, fat content, etc.

Molecular View of Solution Formation

Water

- **Polar covalent bonds** and a **V-shaped molecule** give water a set of properties that account for its ability to support life.
  - **Solvency**
  - **Cohesion**
  - **Adhesion**
  - **Chemical reactivity**
  - **Thermal stability**

Water

- **Solvency**—ability to dissolve other chemicals
- Water is called the **universal solvent**
  - **Hydrophilic**—substances that dissolve in water
    - Molecules must be polarized or charged (e.g., sugar)
  - **Hydrophobic**—substances that do not dissolve in water
    - Molecules are nonpolar or neutral (e.g., fats)
- **Metabolic reactions depend on solvency of water**

Water

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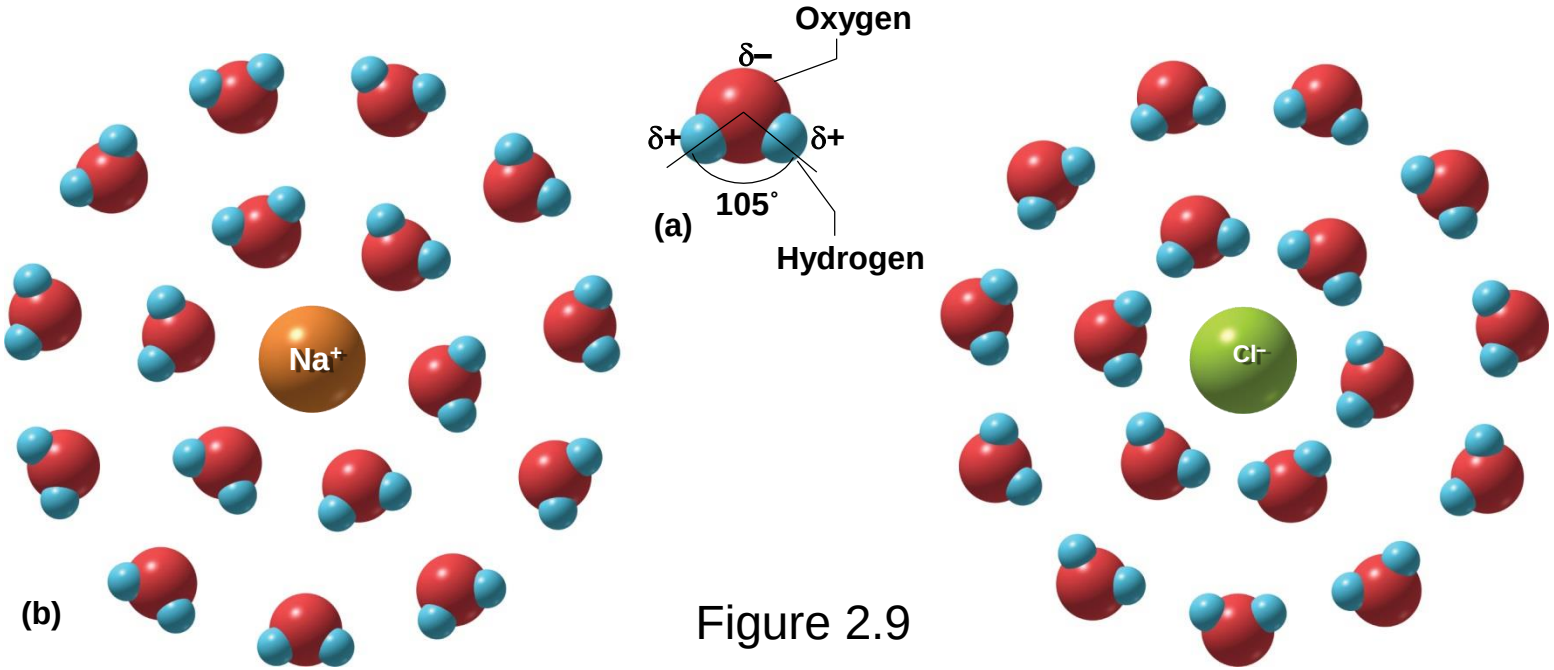

Figure 2.9

- **Attractions to water molecules overpower the ionic bond in NaCl**
  - Water forms hydration spheres around each ion and dissolves them
  - Water's negative pole faces Na^+, its positive pole faces Cl^-

Water

- **Adhesion**—tendency of one substance to cling to another
  - Water adheres to large membranes reducing friction around organs
- **Cohesion**—tendency of like molecules to cling to each other
  - Water is very cohesive due to its hydrogen bonds
  - **Surface film** on surface of water is due to molecules being held together by **surface tension**

Water

- **Chemical reactivity**—ability to participate in chemical reactions
  - **Water ionizes** into H^+ and OH^-
  - **Water ionizes many** other chemicals (acids and salts)
  - Water is involved in **hydrolysis** and **dehydration synthesis** reactions

Water

- Water's **thermal stability** helps stabilize the internal temperature of the body
  - Water has high **heat capacity**—the amount of heat required to raise the temperature of 1 g of a substance by 1°C
  - **Calorie (cal)**—the amount of heat that raises the temperature of 1 g of water 1°C
    - Hydrogen bonds inhibit temperature increases by inhibiting molecular motion
  - **Effective coolant**
    - 1 mL of perspiration removes 500 calories

Solutions, Colloids, and Suspensions

- **Solution**—consists of particles called the **solute** mixed with a more abundant substance (usually water) called the **solvent**
- **Solute** can be gas, solid, or liquid
- **Solutions are defined by the following properties:**
  - Solute particles under 1 nm
  - Solute particles do not scatter light
  - Will pass through most membranes
  - Will not separate on standing

Solutions, Colloids, and Suspensions

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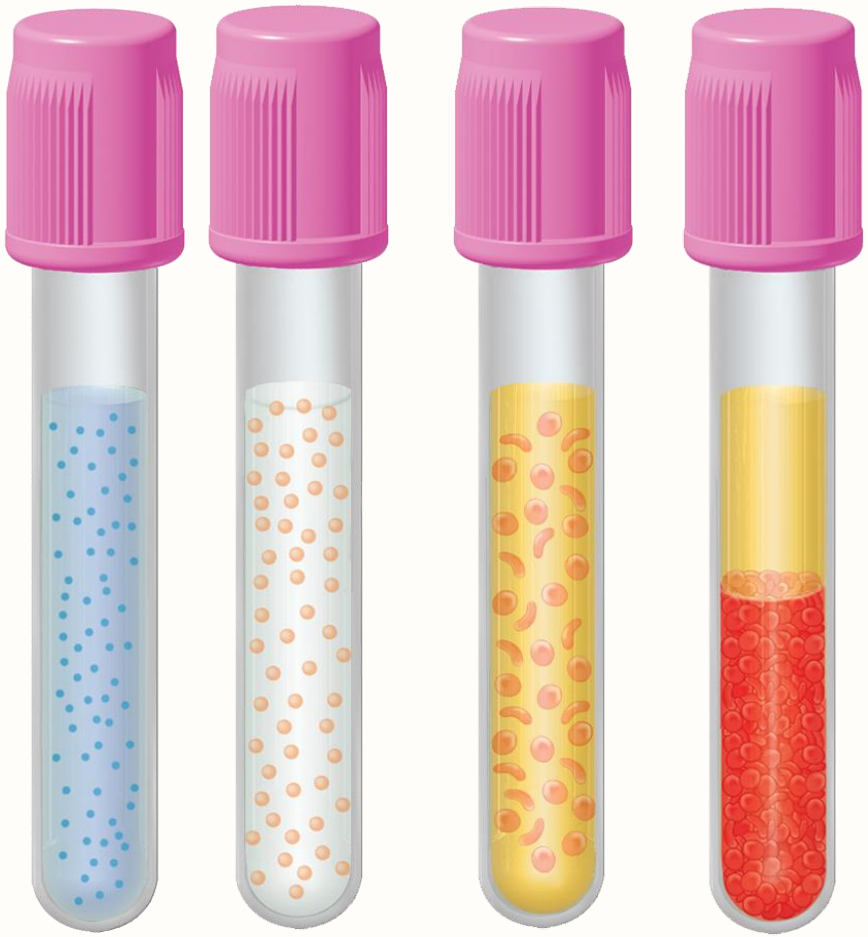

Solution **Colloid** **Suspension**

Figure 2.10

Solutions, Colloids, and Suspensions

- **Colloids** in the body are often mixtures of protein and water
  - Many can change from liquid to gel state within and between cells
- **Colloids are defined by the following physical properties:**
  - Particles range from 1–100 nm in size
  - Scatter light and are usually cloudy
  - Particles too large to pass through semipermeable membrane
  - Particles remain permanently mixed with the solvent when mixture stands

Solutions, Colloids, and Suspensions

- **Suspension**
  - Defined by the following physical properties:
    - Particles exceed 100 nm
    - Too large to penetrate selectively permeable membranes
    - Cloudy or opaque in appearance
    - Separates on standing
  - Example: blood cells are suspended in plasma

- **Emulsion**
  - Suspension of one liquid in another
    - Example: fat in breast milk is an emulsion

Solutions, Colloids, and Suspensions

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TABLE 2.4 Types of Mixtures

	Solution	Colloid	Suspension
Particle Size	<1 nm	1–100 nm	>100 nm
Appearance	Clear	Often cloudy	Cloudy-opaque
Will particles settle out?	No	No	Yes
Will particles pass through a selectively permeable membrane?	Yes	No	No
Examples	Glucose in blood O_2 in water Saline solutions Sugar in coffee	Proteins in blood Intracellular fluid Milk protein Gelatin	Blood cells Cornstarch in water Fats in blood Kaopectate

Measures of Concentration

- **How much solute in a given volume of solution?**
- **Weight per volume**
  - Weight of solute in a given volume of solution
    - IV saline: 8.5 g NaCl per liter of solution
    - Common biology units: milligrams per deciliter (mg/dL)
      - Example: serum cholesterol may be 200 mg/dL
- **Percentages**
  - Might be weight of solute (solid) per volume
    - Example: 5% dextrose solution has 5 g solute in 100 mL solution
  - Might be volume of solute (liquid) per volume of solution
    - Example: 70% ethanol has 70 ml of ethanol in 100 mL solution

Measures of Concentration

- **Molarity (M)**—moles of solute/liter of solution
  - Allows knowledge of number of solute molecules present
    - Critical for understanding physiological effects such as diffusion
  - Uses molecular weight (amu) of molecule: that many grams (g) will contain 1 mole of the molecule
  - Example: glucose weighs 180 amu; A 1M solution of glucose contains 180 g of glucose in 1 L of solution
  - Body fluids are often fairly dilute and so units are often given in millimolar (mM)

Measures of Concentration

- **Percentage**
  - # of molecules **unequal**
  - Weight of solute **equal**

- **Molar**
  - # of molecules **equal**
  - Weight of solute **unequal**

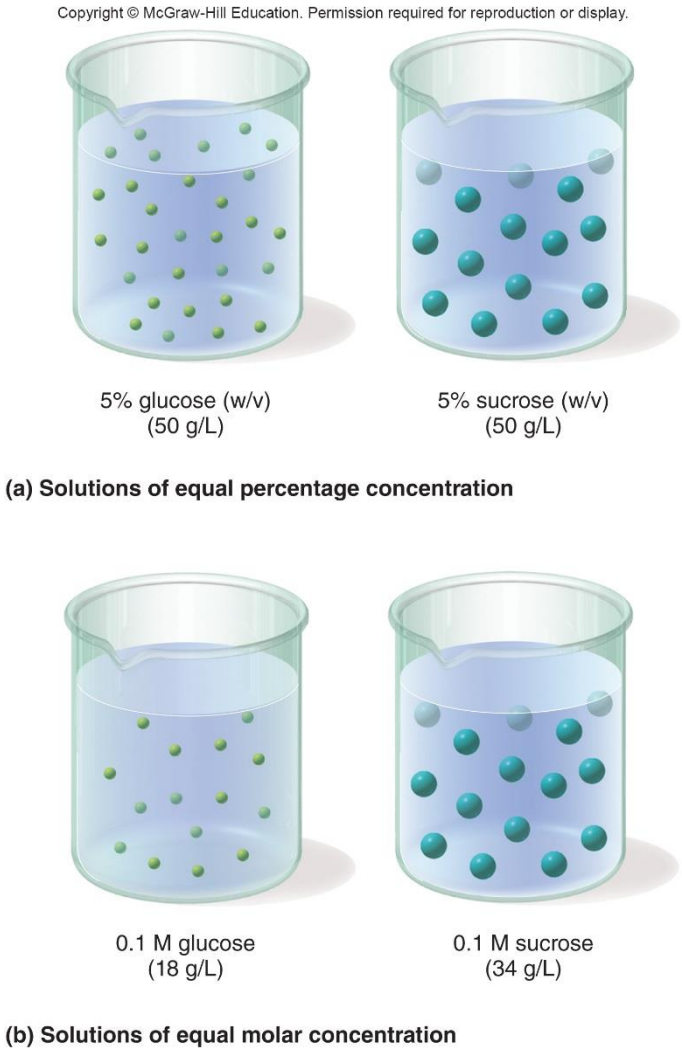

Figure 2.11

Measures of Concentration

- **Electrolytes** are crucial for heart, nerve, muscle
- Measured in **equivalents (Eq)**
  - 1 Eq is the amount of electrolyte that will neutralize 1 mole of H^+ or OH^- ions
  - Often expressed as **milliequivalents (mEq/L)**
  - Multiply molar concentration x valence of the ion
  - 1 mM Na^+ = 1 mEq/L
  - 1 mM Ca^{2+} = 2 mEq/L

Acids, Bases, and pH

- An **acid** is a proton donor (releases H^+ ions in water)

- A **base** is a proton acceptor (accepts H^+ ions)
  - Many bases release OH^-

- **pH** is a measure derived from the molarity of H+
  - a pH of 7.0 is neutral pH ($H^+ = OH^-$)
  - a pH of less than 7 is acidic solution ($H^+ > OH^-$)
  - a pH of greater than 7 is basic solution ($OH^- > H^+$)

Acids, Bases, and pH

- **pH**—measurement of molarity of H^+ ([H+]) on a logarithmic scale
  - pH = -log [H^+] thus pH = -log [10^{-3}] = 3
- **A change of one number on the pH scale represents a 10-fold change in H^+ concentration**
  - A solution with pH of 4.0 is 10 times as acidic as one with pH of 5.0
- **Buffers**—chemical solutions that resist changes in pH
  - Maintaining normal (slightly basic) pH of blood is crucial for physiological functions

Acids, Bases, and pH

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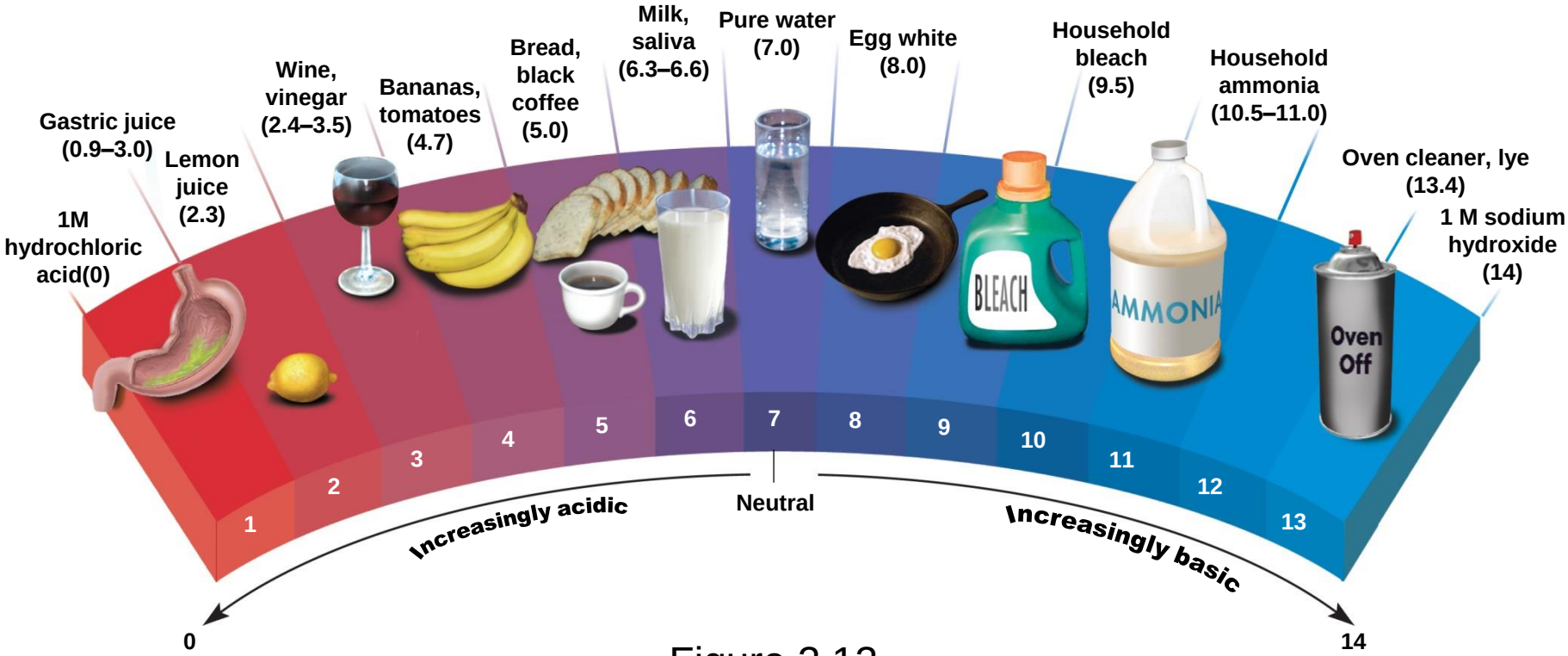

Figure 2.12

Energy and Chemical Reactions

- **Expected Learning Outcomes**
  - Define *energy* and *work,* and describe some types of energy.
  - Understand how chemical reactions are symbolized by chemical equations.
  - List and define the fundamental types of chemical reactions.
  - Identify the factors that govern the speed and direction of a reaction.
  - Define *metabolism* and its two subdivisions.
  - Define *oxidation* and *reduction* and relate these to changes in the energy content of a molecule.

Energy and Work

- **Energy**—capacity to do work
  - To do work means to move something
  - All body activities are forms of work

- **Potential energy**—energy stored in an object, but not currently doing work
  - Example: water behind a dam
  - **Chemical energy**—potential energy in molecular bonds
  - **Free energy**—potential energy available in a system to do useful work

Energy and Work

- **Kinetic energy**—energy of motion, doing work
  - Example: water flowing through a dam, generating electricity
  - **Heat**—kinetic energy of molecular motion
  - **Electromagnetic energy**—the kinetic energy of moving “packets” of radiation called **photons**

Classes of Chemical Reactions

- **Chemical reaction**—a process in which a covalent or ionic bond is formed or broken
- **Chemical equation**—symbolizes the course of a chemical reaction
  - Reactants (on left) $\rightarrow$ products (on right)
- **Classes of chemical reactions**
  - Decomposition reactions
  - Synthesis reactions
  - Exchange reactions

Classes of Chemical Reactions

- **Decomposition reactions**—large molecule breaks down into two or more smaller ones
- **AB → A + B**

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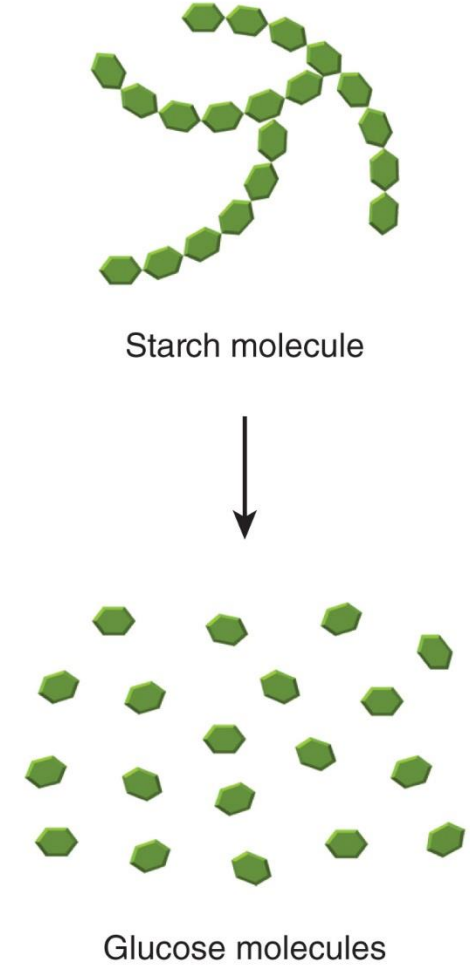

Figure 2.13a

(a) Decomposition reaction

Classes of Chemical Reactions

- **Synthesis reactions**—two or more small molecules combine to form a larger one
- **A + B → AB**

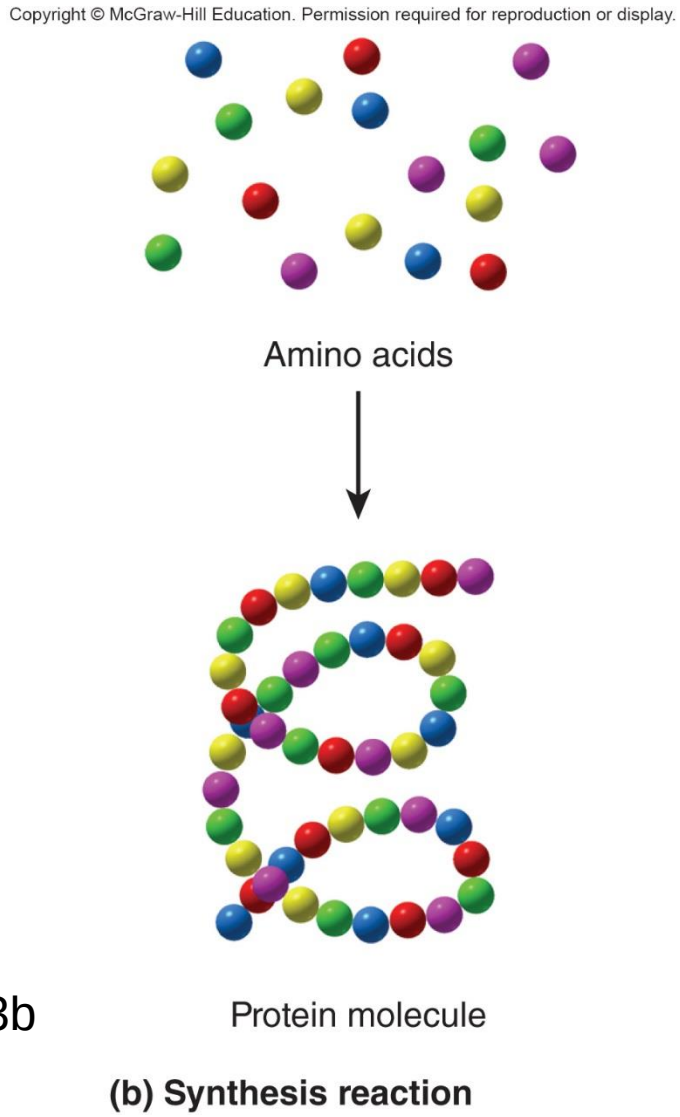

Figure 2.13b

Classes of Chemical Reactions

- **Exchange reactions**—two molecules exchange atoms or group of atoms
- **AB+CD → ABCD → AC + BD**

Stomach acid (HCl) and sodium bicarbonate ($NaHCO_3$) from the pancreas combine to form NaCl and H_2CO_3

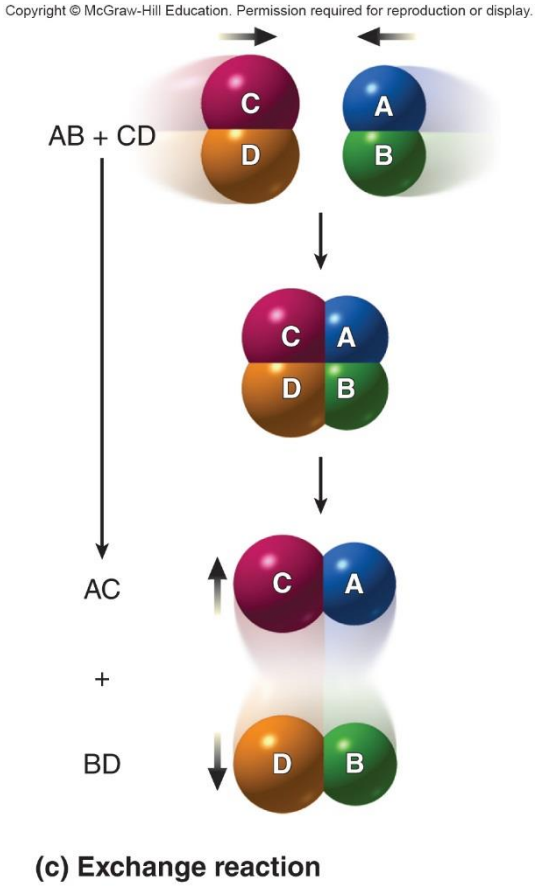

Figure 2.13c

Classes of Chemical Reactions

- **Reversible reactions**
  - Can go in either direction under different circumstances
  - Symbolized with double-headed arrow
  - Example: $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO^{3-} + H^+$
    - An important reaction in respiratory, urinary, digestive physiology
  - **Law of mass action**—direction of reaction determined by relative abundance of substances on either side of equation
    - More abundant substances serve as reactants
  - Reach **equilibrium** when ratio of products to reactants is stable

Reaction Rates

- **Reactions occur when molecules collide with enough force and correct orientation**
- **Reaction rates increase when…**
  - the reactants are more **concentrated**
  - the **temperature** rises
  - a **catalyst** is present
    - Enzyme catalysts bind to reactants and hold them in orientations that facilitate the reaction
    - Catalysts are not changed by the reaction and can repeat the process frequently

Metabolism, Oxidation, and Reduction

- **Metabolism**—all chemical reactions of the body
- **Catabolism**
  - Energy-releasing (exergonic) decomposition reactions
    - Breaks covalent bonds
    - Produces smaller molecules
- **Anabolism**
  - Energy-storing (endergonic) synthesis reactions
    - Requires energy input
    - Production of protein or fat
- **Catabolism and anabolism are inseparably linked**
  - Anabolism is driven by energy released by catabolism

Metabolism, Oxidation, and Reduction

- **Oxidation**
  - A chemical reaction in which a molecule gives up electrons and releases energy
  - Molecule **oxidized** in this process
  - Electron acceptor molecule is the **oxidizing agent**
    - Oxygen is often involved as the electron acceptor
- **Reduction**
  - Any chemical reaction in which a molecule gains electrons and energy
  - Molecule is **reduced** when it accepts electrons
  - Molecule that donates electrons is the **reducing agent**

Metabolism, Oxidation, and Reduction

- **Oxidation-reduction (redox) reactions**
  - Oxidation of one molecule is always accompanied by reduction of another
  - Electrons are often transferred as hydrogen atoms

Metabolism, Oxidation, and Reduction

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TABLE 2.5 Energy-Transfer Reactions in the Human Body

Exergonic Reactions	Reactions in which there is a net release of energy. The products have less total free energy than the reactants did.
Oxidation	An exergonic reaction in which electrons are removed from a reactant. Electrons may be removed one or two at a time and may be removed in the form of hydrogen atoms (H or H_2). The product is then said to be oxidized.
Decomposition	A reaction such as digestion and cell respiration, in which larger molecules are broken down into smaller ones.
Catabolism	The sum of all decomposition reactions in the body.
Endergonic Reactions	Reactions in which there is a net input of energy. The products have more total free energy than the reactants did.
Reduction	An endergonic reaction in which electrons are donated to a reactant. The product is then said to be reduced.
Synthesis	A reaction such as protein and glycogen synthesis, in which two or more smaller molecules are combined into a larger one.
Anabolism	The sum of all synthesis reactions in the body.

Organic Compounds

- **Expected Learning Outcomes**
  - Explain why carbon is especially well suited to serve as the structural foundation of many biological molecules.
  - Identify some common functional groups of organic molecules from their formulae.
  - Discuss the relevance of polymers to biology and explain how they are formed and broken by dehydration synthesis and hydrolysis.
  - Discuss the types and functions of carbohydrates, lipids, and proteins.
  - Explain how enzymes function.
  - Describe the structure, production, and function of ATP.
  - Identify other nucleotide types and their functions; and the principal types of nucleic acids.

Carbon Compounds and Functional Groups

- **Organic chemistry**—the study of compounds containing carbon
- **Four categories of carbon compounds**
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids

Carbon Compounds and Functional Groups

- **Carbon has four valence electrons**
  - Binds with other atoms that can provide it with four more electrons to fill its valence shell
- **Carbon atoms bind readily with each other to form carbon backbones**
  - Form long chains, branched molecules, and rings
  - Form covalent bonds with hydrogen, oxygen, nitrogen, sulfur, and other elements
- **Carbon backbones** carry a variety of functional groups

Carbon Compounds and Functional Groups

- **Functional groups**—small clusters of atoms attached to carbon backbone
- Determine many of the properties of organic molecules
- Examples: hydroxyl, methyl, carboxyl, amino, phosphate

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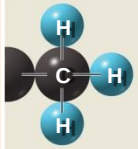
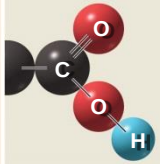
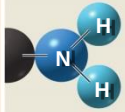
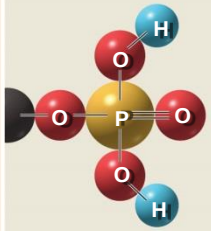
Name and Symbol	Structure	Occurs in
Hydroxyl (—OH)		Sugars, alcohols
Methyl (—CH_3)		Fats, oils, steroids, amino acids
Carboxyl (—COOH)		Amino acids, sugars, proteins
Amino (—NH_2)		Amino acids, proteins
Phosphate (—$H2PO_4$)		Nucleic acids, ATP

Figure 2.14

Monomers and Polymers

- **Macromolecules**—very large organic molecules with high molecular weights
- **Polymers**—macromolecules made of a repetitive series of identical or similar subunits (**monomers**)
  - Starch is a polymer of about 3,000 glucose monomers
- **Polymerization**—joining monomers to form a polymer

Monomers and Polymers

- **Dehydration synthesis (condensation)** is how living cells form polymers
  - A hydroxyl (-OH) group is removed from one monomer, and a hydrogen (-H) from another
    - Producing water as a by-product
- **Hydrolysis**—digestion; the opposite of dehydration synthesis
  - A water molecule ionizes into –OH and -H
  - The covalent bond linking one monomer to the other is broken
  - The -OH is added to one monomer
  - The -H is added to the other

Monomers and Polymers

- **Dehydration synthesis**—monomers covalently bind together to form a polymer with the removal of a water molecule

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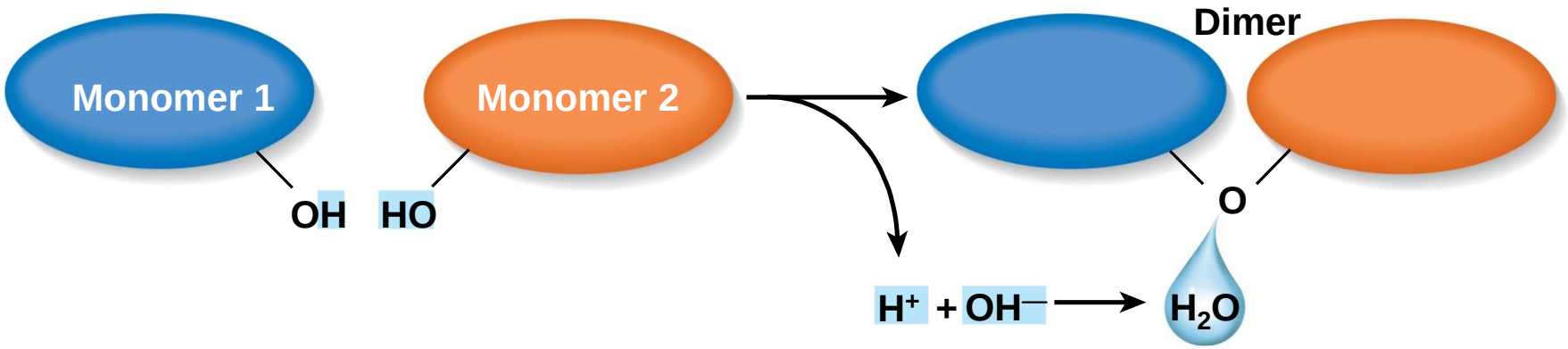

(a) Dehydration synthesis

Figure 2.15a

Monomers and Polymers

- **Hydrolysis**—splitting a polymer by the addition of a water molecule

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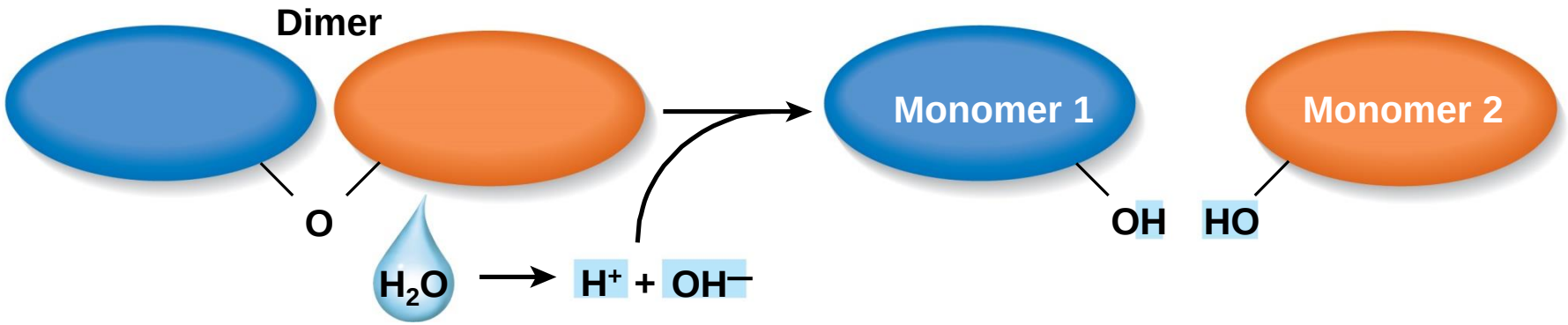

(b) Hydrolysis

Figure 2.15b

Carbohydrates

- **Hydrophilic organic molecule**
  - Examples: sugars and starches
- **General formula**
  - **$(CH_2O)_n$**, *n* = number of carbon atoms
  - Glucose, *n* = 6, so formula is $C_6H_{12}O_6$
  - 2:1 ratio of hydrogen to oxygen
- **Names of carbohydrates often built from the root "*sacchar-*" and the suffix "*-ose*" both meaning sugar, sweet**

Carbohydrates

- **Three important monosaccharides**
  - **Glucose, galactose,** and **fructose**
  - Same molecular formula: $\mathbf{C_6H_{12}O_6}$
    - All i**somers** of each other
  - Produced by digestion of complex carbohydrates
    - **Glucose is blood sugar**

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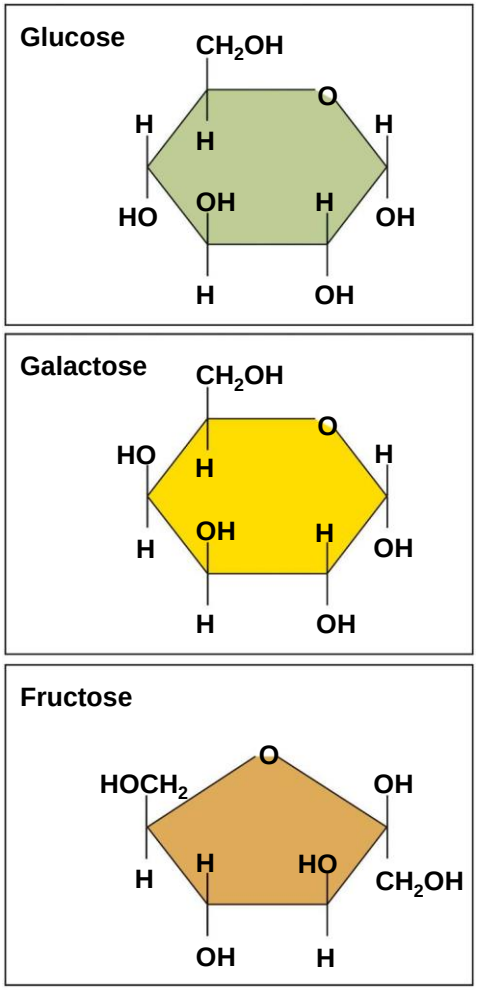

Figure 2.16

Carbohydrates

- **Disaccharide**—sugar made of two monosaccharides
- **Three important disaccharides**
  - **Sucrose**—table sugar
    - Glucose + fructose
  - **Lactose**—sugar in milk
    - Glucose + galactose
  - **Maltose**—grain products
    - Glucose + glucose

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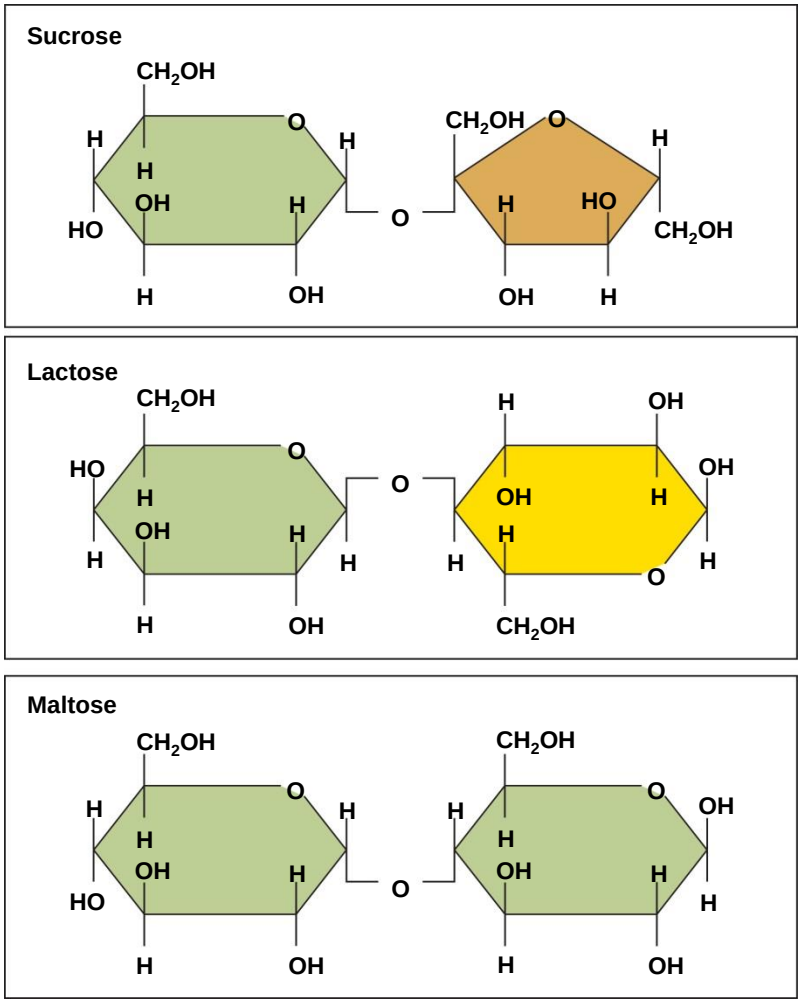

Figure 2.17

Carbohydrates

- **Oligosaccharides**—short chains of 3 or more monosaccharides (at least 10)
- **Polysaccharides**—long chains of monosaccharides (at least 50); three key examples:
  - **Glycogen**—energy storage in cells of liver, muscle, brain, uterus, vagina
  - **Starch**—energy storage in plants that is digestible by humans
  - **Cellulose**—structural molecule in plants that is important for human dietary fiber (but indigestible to us)

Glycogen

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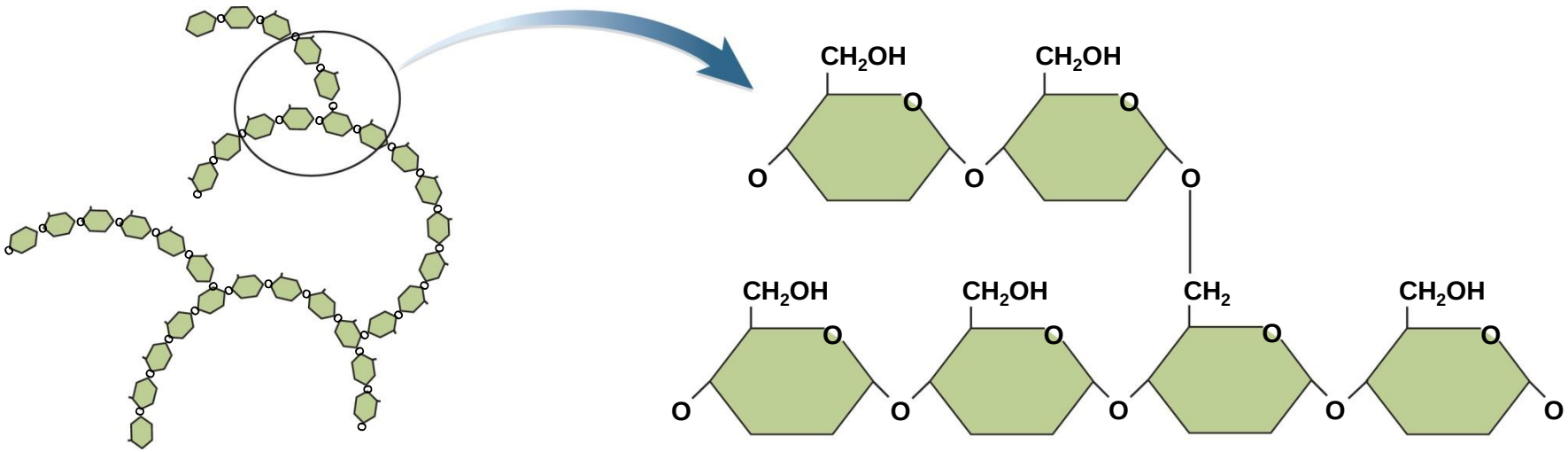

Figure 2.18

Carbohydrates

- **Carbohydrates are a quickly mobilized source of energy**
  - All digested carbohydrates converted to glucose
  - Oxidized to make ATP
- **Conjugated carbohydrate**—covalently bound to lipid or protein moiety
  - **Glycolipids**
    - External surface of cell membrane
  - **Glycoproteins**
    - External surface of cell membrane
    - Mucus of respiratory and digestive tracts
  - **Proteoglycans**—more carbohydrate than protein
    - Gels that hold cells and tissues together
    - Gelatinous filler in umbilical cord and eye
    - Joint lubrication and cartilage texture

Carbohydrates

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TABLE 2.6 Carbohydrate Functions

Type	Function
Monosaccharides	
Glucose	Blood sugar—energy source for most cells
Galactose	Converted to glucose and metabolized
Fructose	Fruit sugar—converted to glucose and metabolized
Disaccharides	
Sucrose	Cane sugar—digested to glucose and fructose
Lactose	Milk sugar—digested to glucose and galactose; important in infant nutrition
Maltose	Malt sugar—product of starch digestion, further digested to glucose
Polysaccharides	
Cellulose	Structural polysaccharide of plants; dietary fiber
Starch	Energy storage in plant cells
Glycogen	Energy storage in animal cells (liver, muscle, brain, uterus, vagina)
Conjugated Carbohydrates	
Glycoprotein	Component of the cell surface coat and mucus, among other roles
Glycolipid	Component of the cell surface coat
Proteoglycan	Cell adhesion; lubrication; supportive filler of some tissues and organs

Lipids

- Lipids are hydrophobic organic molecules with a high ratio of hydrogen to oxygen
- Have more calories per gram than carbohydrates
- Five primary types in humans
  - Fatty acids
  - Triglycerides
  - Phospholipids
  - Eicosanoids
  - Steroids

Lipids

- **Fatty acids**
  - Chains of 4-24 carbon atoms with carboxyl group on one end and methyl group on the other
  - Saturated fatty acids have a lot of hydrogen
  - Unsaturated fatty acids contain some double bonds between carbons in chain (potential to add hydrogen)
    - Polyunsaturated fatty acids have multiple double bonds between carbons in chain
  - Essential fatty acids must be obtained from food

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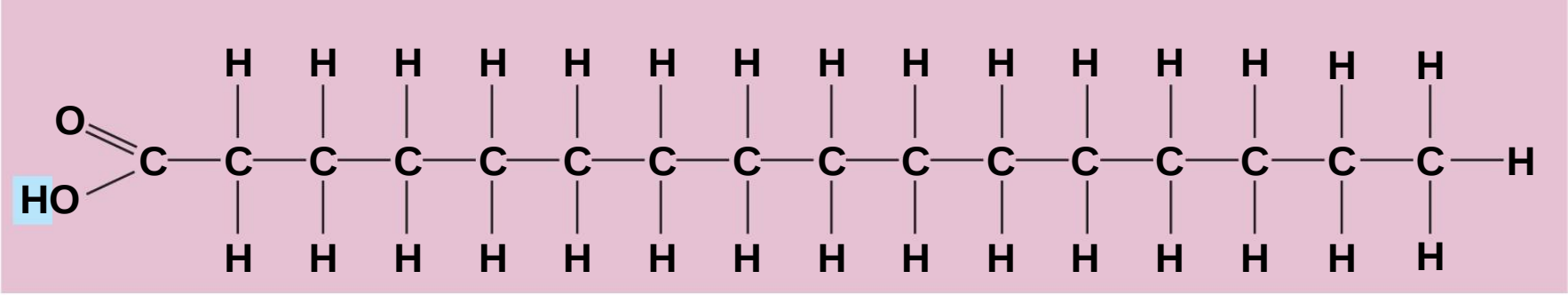

Palmitic acid (saturated)
$CH_3(CH_2)_{14}COOH$

Figure 2.19

Lipids

- **Triglycerides (Neutral Fats)**
  - Three fatty acids linked to glycerol
  - Each bond formed by dehydration synthesis
  - Broken down by hydrolysis
- **Triglycerides at room temperature**
  - When liquid, called oils
    - Often polyunsaturated fats from plants
  - When solid, called fat
    - Saturated fats from animals
- **Primary function:** energy storage
  - Also help with insulation and shock absorption (adipose tissue)

Trans Fats and Cardiovascular Health

- **Trans-fatty acids**
  - Two covalent single C-C bonds angle in opposites (trans, “across from each other”) on each side of the C=C double bond
  - Resist enzymatic breakdown in the human body, remain in circulation longer, deposits in the arteries; thus, raises the risk of **heart disease**
- **Cis-fatty acids**
  - Two covalent single C-C bonds angle in the same direction adjacent to the C=C double bond

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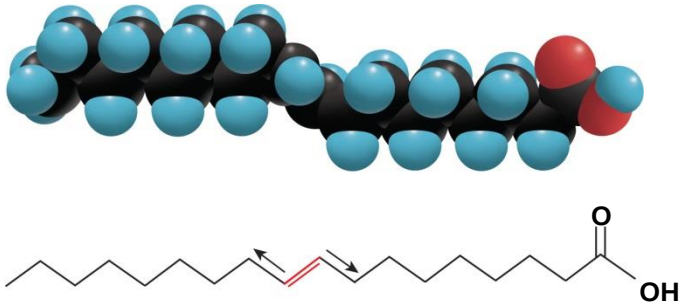
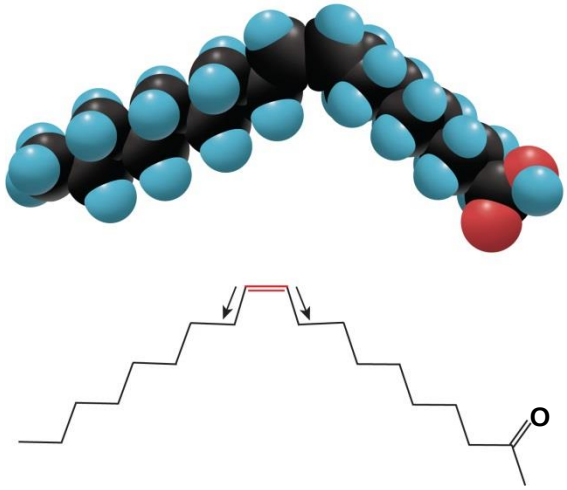


(a) A trans-fatty acid (elaidic acid)



(b) A cis-fatty acid (oleic acid)

Figure 2.20

Lipids

- **Phospholipids**—similar to neutral fats except one fatty acid is replaced by a phosphate group
- **Structural foundation of cell membrane**
- **Amphipathic**
  - Fatty acid "tails" are **hydrophobic**
  - Phosphate "head" is **hydrophilic**

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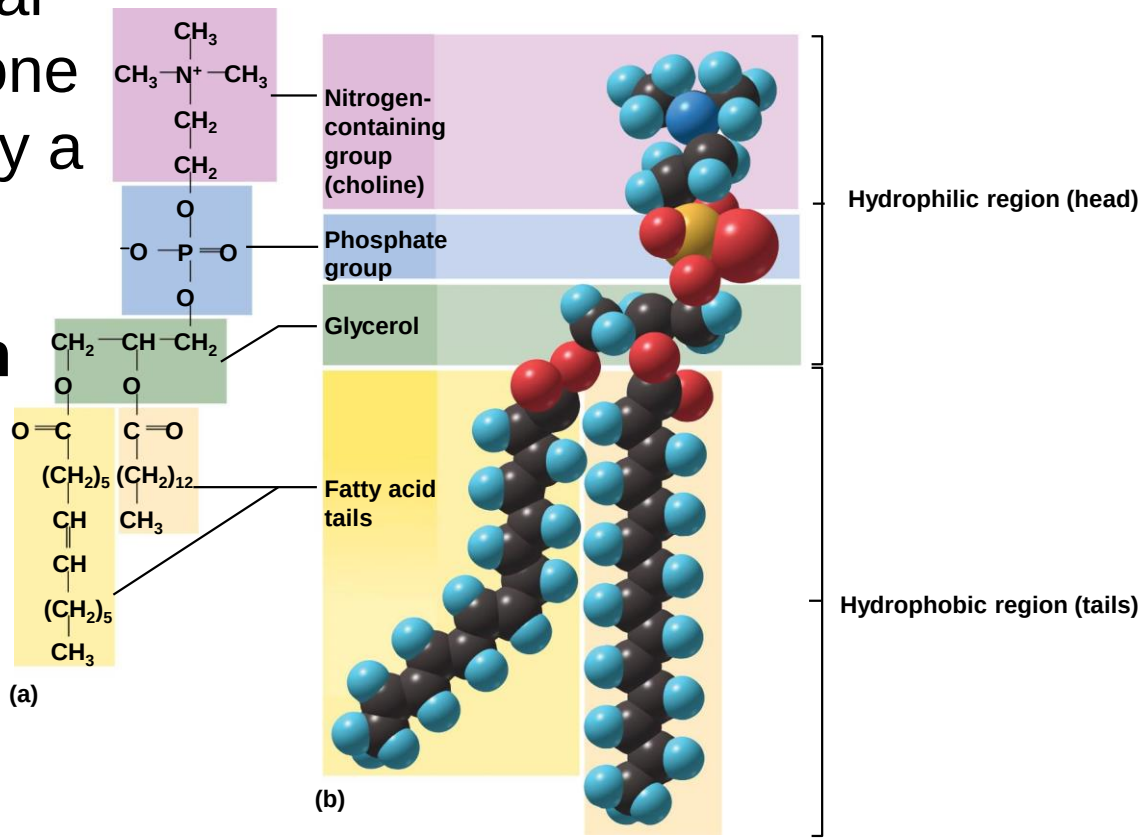

Figure 2.21a,b

Lipids

- **Eicosanoids**
  - 20-carbon compounds derived from **arachidonic acid**
- **Hormone-like chemical signals between cells**
- Includes **prostaglandins**
  - Role in inflammation, blood clotting, hormone action, labor contractions, blood vessel diameter

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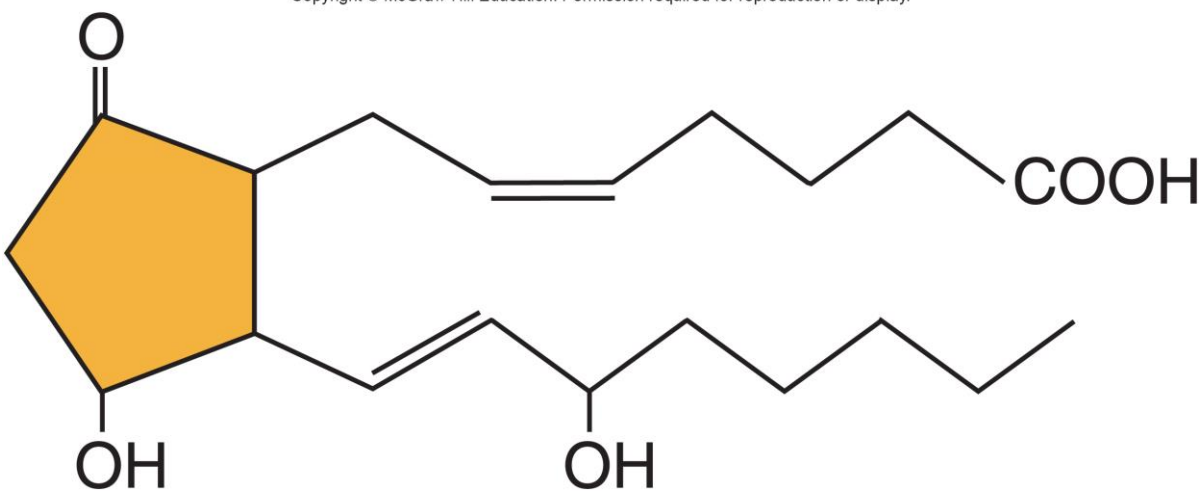

Figure 2.22

Lipids

- **Steroid**—a lipid with 17 carbon atoms in four rings
- **Cholesterol**—the “parent” steroid from which the other steroids are synthesized
  - Important for nervous system function and structural integrity of all cell membranes
  - 15% of our cholesterol comes from diet
  - 85% is internally synthesized (mostly in liver)
- **Other steroids: cortisol, progesterone,estrogens, testosterone, and bile acids**

Cholesterol

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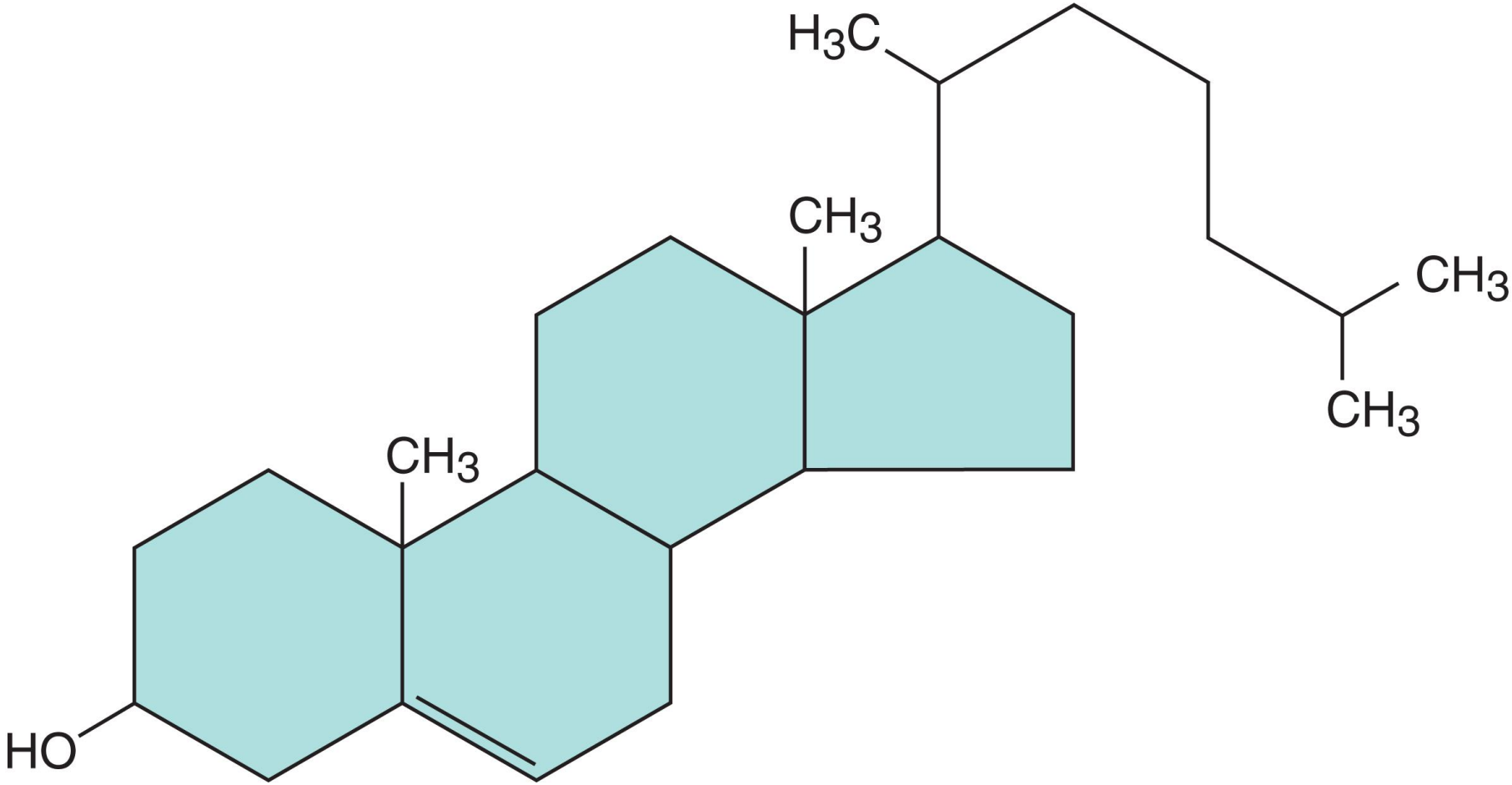

Figure 2.23

“Good” and “Bad” Cholesterol

- **There is only one kind of cholesterol**
  - Does more good than harm
- **“Good” and “bad” cholesterol refer to droplets of lipoprotein in the blood**
  - Complexes of cholesterol, fat, phospholipid, and protein
- **HDL (high-density lipoprotein):** “good” cholesterol
  - Lower ratio of lipid to protein
  - May help to prevent cardiovascular disease
- **LDL (low-density lipoprotein):** “bad” cholesterol
  - High ratio of lipid to protein
  - Contributes to cardiovascular disease

Lipids and Functions

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TABLE 2.7 Lipid Functions

Type	Function
Bile acids	Steroids that aid in fat digestion and nutrient absorption
Cholesterol	Component of cell membranes; precursor of other steroids
Eicosanoids	Chemical messengers between cells
Fat-soluble vitamins (A, D, E, and K)	Involved in a variety of functions including blood clotting, wound healing, vision, and calcium absorption
Fatty acids	Precursor of triglycerides; source of energy
Phospholipids	Major component of cell membranes; aid in fat digestion
Steroid hormones	Chemical messengers between cells
Triglycerides	Energy storage; thermal insulation; filling space; binding organs together; cushioning organs

Proteins

- **Protein**—a polymer of amino acids
- **Amino acid**—central carbon with three attachments
  - Amino group (NH_2), carboxyl group (—COOH), and radical group (R group)
- **20 amino acids used to make the proteins are identical except for the radical (R) group**
  - Properties of amino acid determined by R group

Proteins

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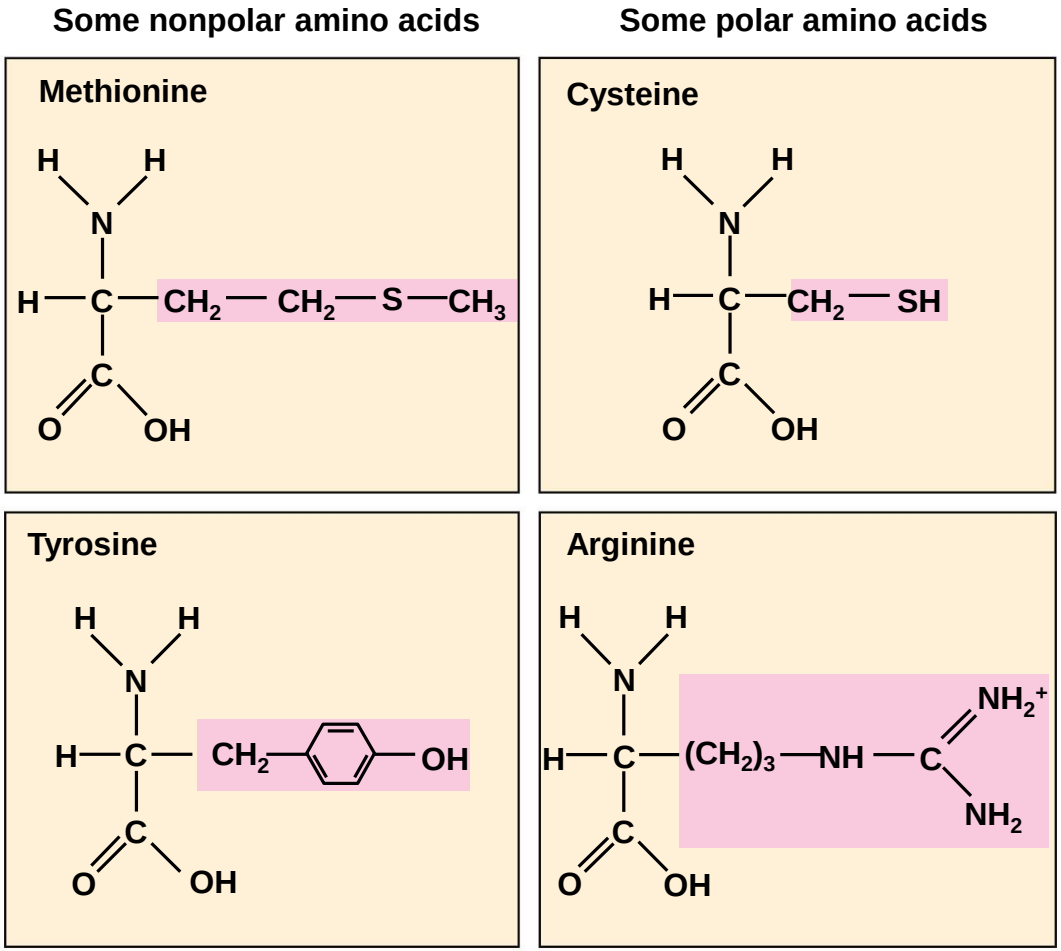

(a)

Figure 2.24a

Amino acids differ only in the R group

Proteins

- **Peptide**—any molecule composed of two or more amino acids joined by peptide bonds
- **Peptide bond**—joins the amino group of one amino acid to the carboxyl group of the next
  - Formed by dehydration synthesis
- **Peptides named for the number of amino acids**
  - **Dipeptides** have 2
  - **Tripeptides** have 3
  - **Oligopeptides** have fewer than 10 or 15
  - **Polypeptides** have more than 15
  - **Proteins** have more than 50

Proteins

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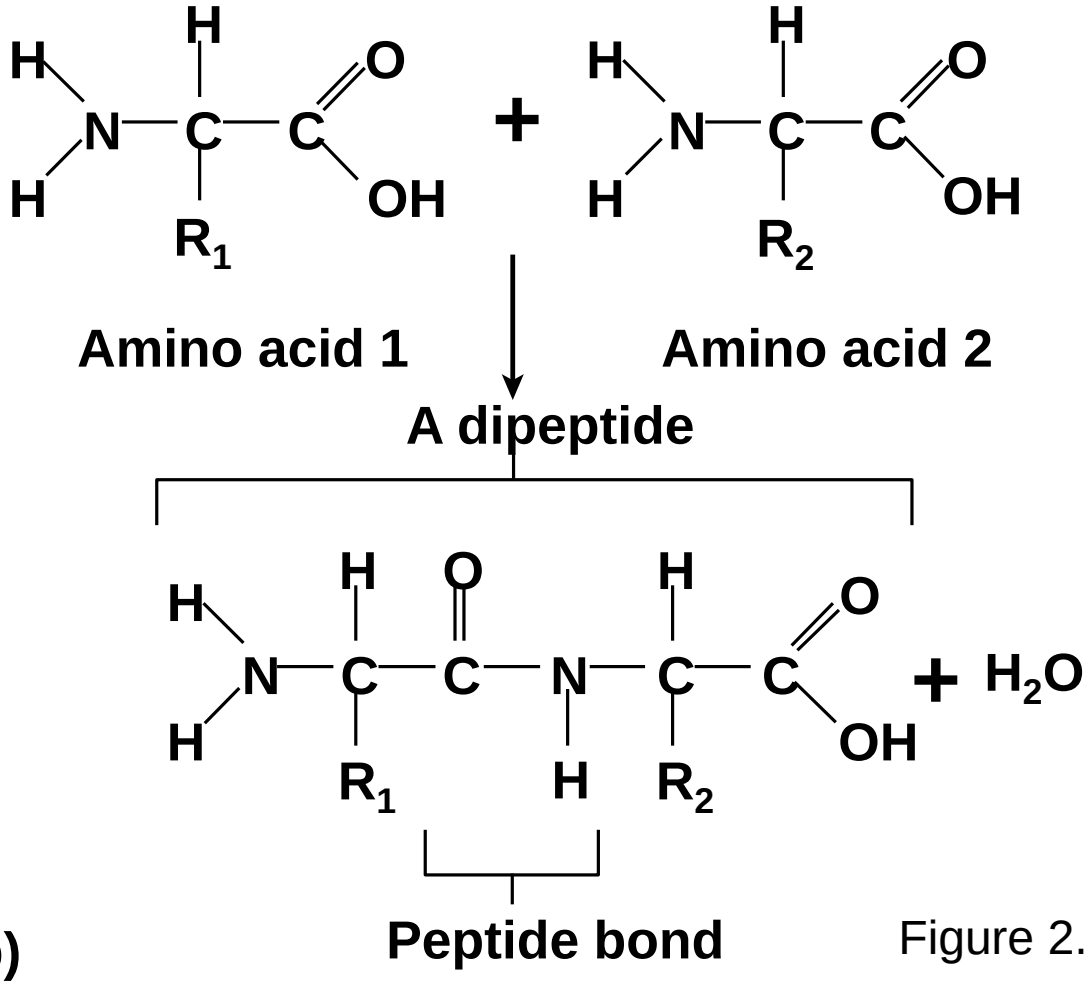

(b)

Figure 2.24b

Dehydration synthesis creates a peptide bond that joins the amino acid of one group to the carboxyl group of the next.

Protein Structure

- **Conformation**—unique, three-dimensional shape of protein crucial to function
  - Proteins can reversibly change conformation and thus function
    - Important examples seen in muscle contraction, enzyme catalysis, membrane channel opening
- **Denaturation**
  - Extreme conformational change that destroys function
    - Extreme heat or pH
    - Example: when you cook an egg

Protein Structure

- **Primary structure**
  - Protein's sequence of amino acids which is encoded in the genes

- **Secondary structure**
  - Coiled or folded shape held together by hydrogen bonds
  - Hydrogen bonds between slightly negative C=O and slightly positive N-H groups
  - Most common secondary structures are:
    - Alpha helix—spring-like shape
    - Beta helix—pleated, ribbon-like shape

Protein Structure

- **Tertiary structure**
  - Further bending and folding of proteins into globular and fibrous shapes due to hydrophobic-hydrophilic interactions and van der Waals forces
    - **Globular proteins**—compact tertiary structure for proteins within cell membrane and proteins that move freely in body fluids
    - **Fibrous proteins**—slender filaments suited for roles in muscle contraction and strengthening of skin and hair

- **Quaternary structure**
  - Associations of two or more polypeptide chains due to ionic bonds and hydrophobic-hydrophilic interactions
  - Occurs only in some proteins
  - Example: hemoglobin has four peptide chains

Protein Structure

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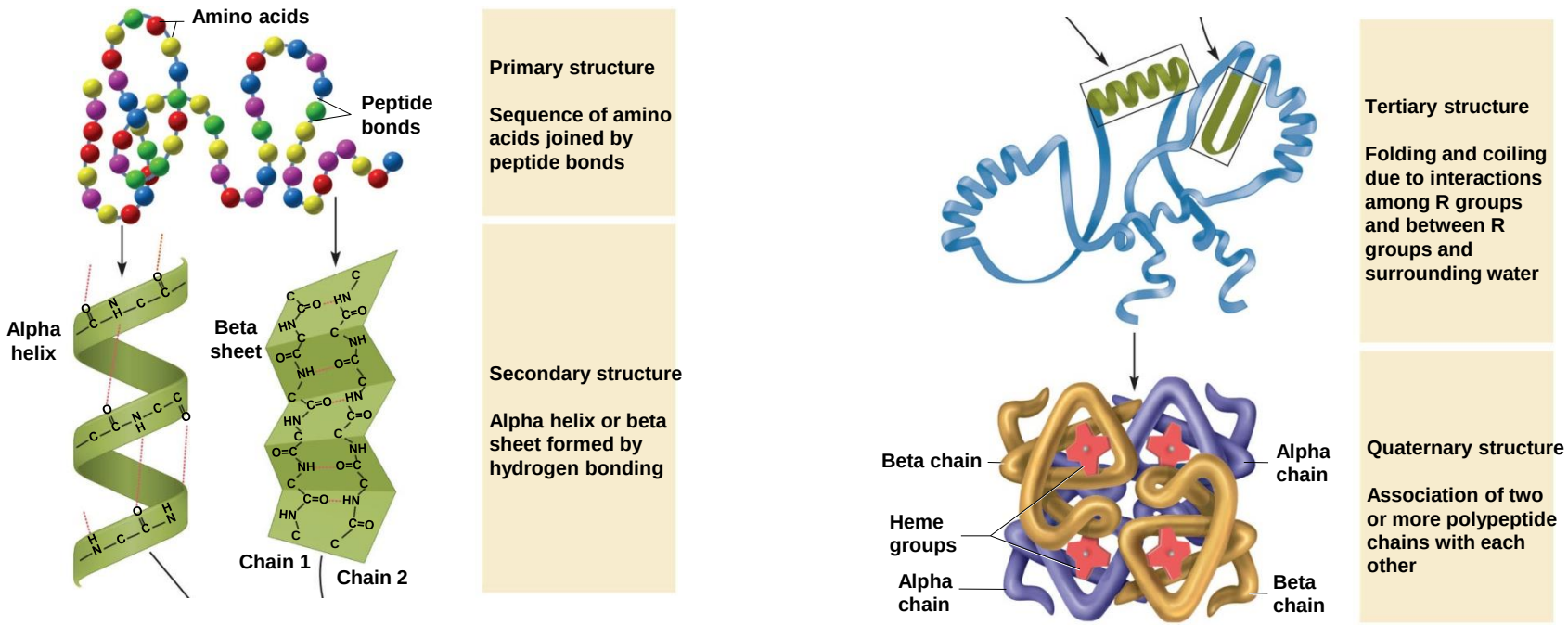

Figure 2.25

Protein Structure

- Conjugated proteins contain a non–amino acid moiety called a **prosthetic group**

- Hemoglobin contains four complex iron-containing rings called a ***heme* moiety**

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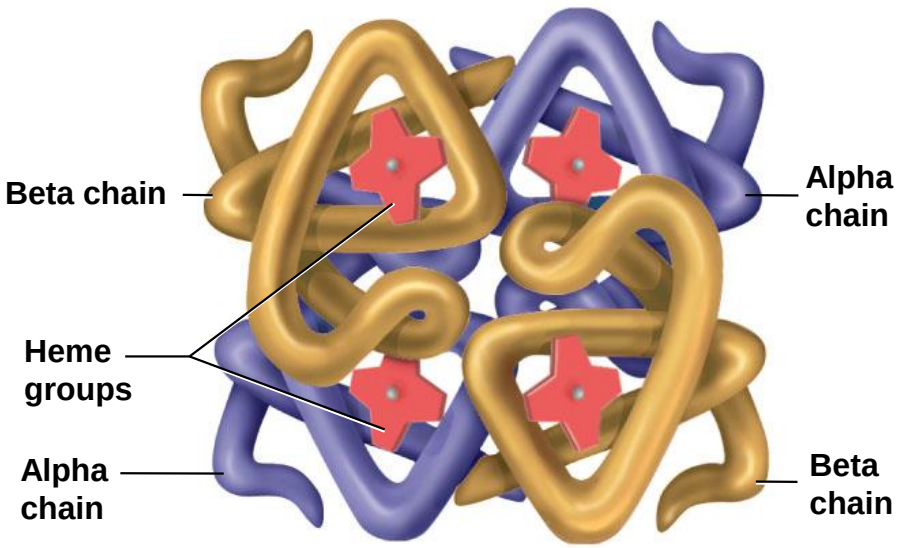

Quaternary structure

Association of two or more polypeptide chains with each other

Figure 2.25 (4)

Protein Functions

- **Structure**
  - Keratin—tough structural protein of hair, nails, skin surface
  - Collagen—contained in deeper layers of skin, bones, cartilage, and teeth
- **Communication**
  - Some hormones and other cell-to-cell signals are proteins
    - Ligand—a molecule that reversibly binds to a protein
  - Receptors to which signal molecules bind are proteins
- **Membrane transport**
  - Channel proteins in cell membranes govern what passes
  - Carriers—transport solutes to other side of membrane
- **Catalysis**
  - Most enzymes are globular proteins

Protein Functions

- **Recognition and protection**
  - Glycoproteins are important for immune recognition
  - Antibodies are proteins
- **Movement**
  - **Motor proteins**—molecules with the ability to change shape repeatedly
- **Cell adhesion**
  - Proteins bind cells together
    - Example: sperm to egg
  - Keeps tissues from falling apart

Enzymes and Metabolism

- **Enzymes**—proteins that function as biological catalysts
  - Permit reactions to occur rapidly at body temperature
- **Substrate**—substance enzyme acts upon
- **Naming convention**
  - Named for substrate with -*ase* as the suffix
    - Amylase enzyme digests starch (amylose)
- Enzymes lower **activation energy**—energy needed to get reaction started

Enzymes and Metabolism

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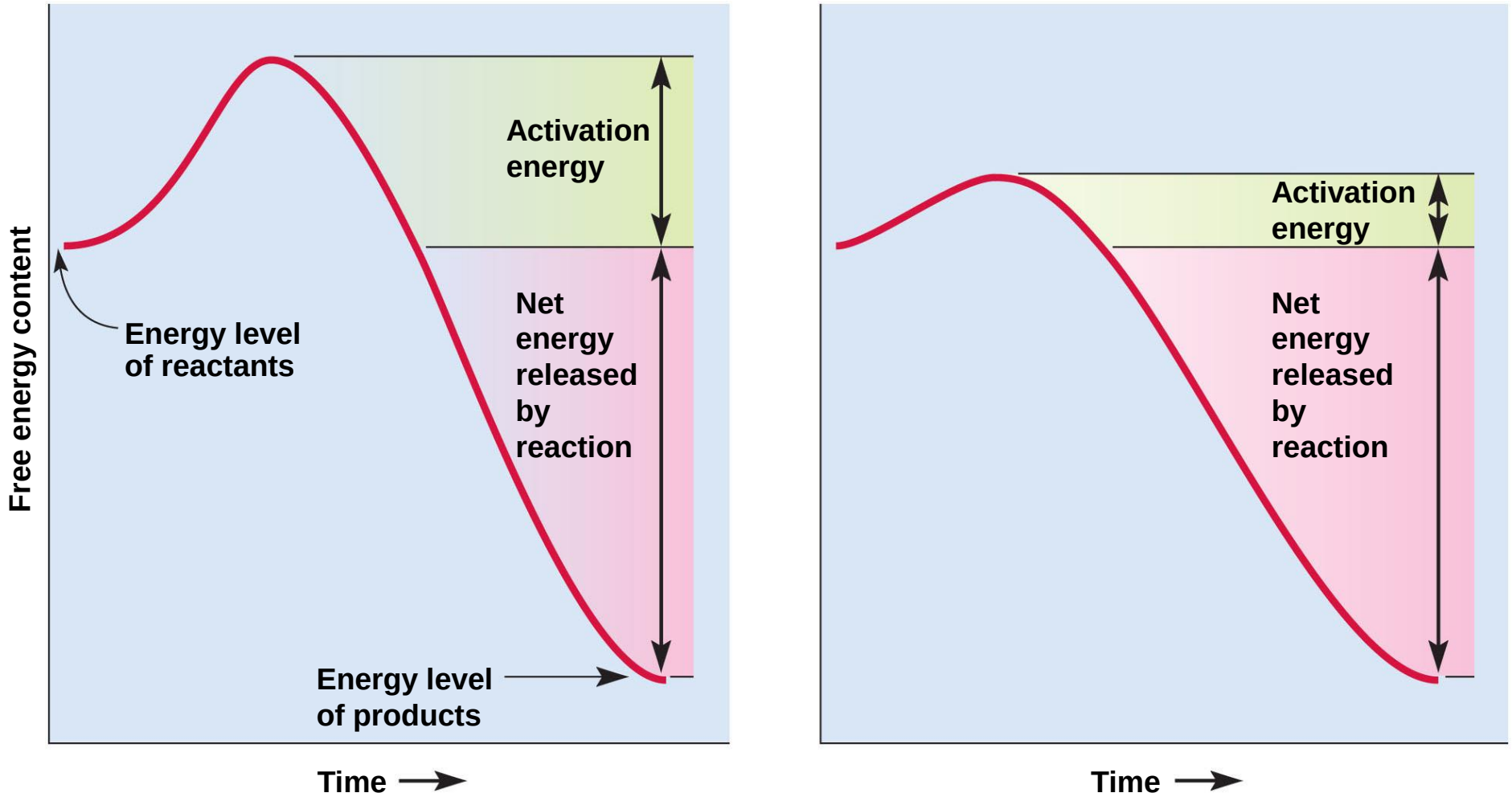

(a) Reaction occurring without a catalyst

(b) Reaction occurring with a catalyst

Figure 2.27a, b

Enzyme Structure and Action

- **Enzyme action**
  - Substrate approaches enzyme's **active site**
  - Molecules bind together forming **enzyme–substrate complex**
    - **Enzyme–substrate specificity**—lock and key
  - Enzyme releases reaction products
  - Enzyme unchanged and can repeat process

How Enzymes Work

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Enzymes are proteins that speed up chemical reactions in the cell.

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Enzyme Structure and Action

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- **Enzyme action example of sucrose hydrolysis**
  - Sucrose approaches sucrase's **active site**
  - Molecules bind together forming **enzyme–substrate complex**
  - Sucrase breaks bonds between sugar subunits and adds H^+ and OH^-
  - Enzyme unchanged and can repeat process

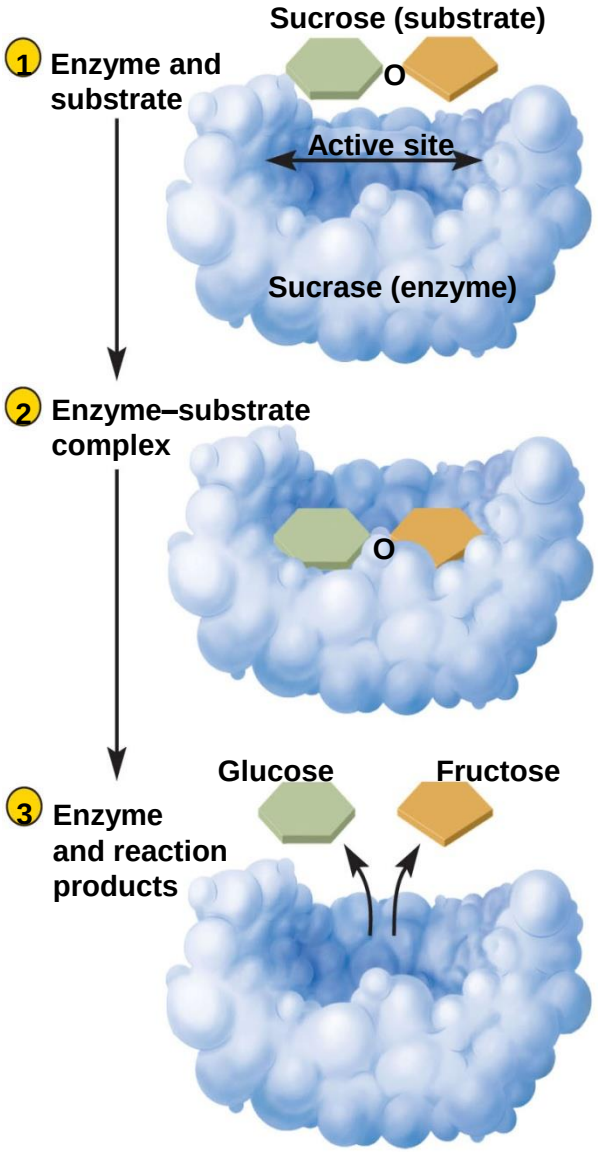
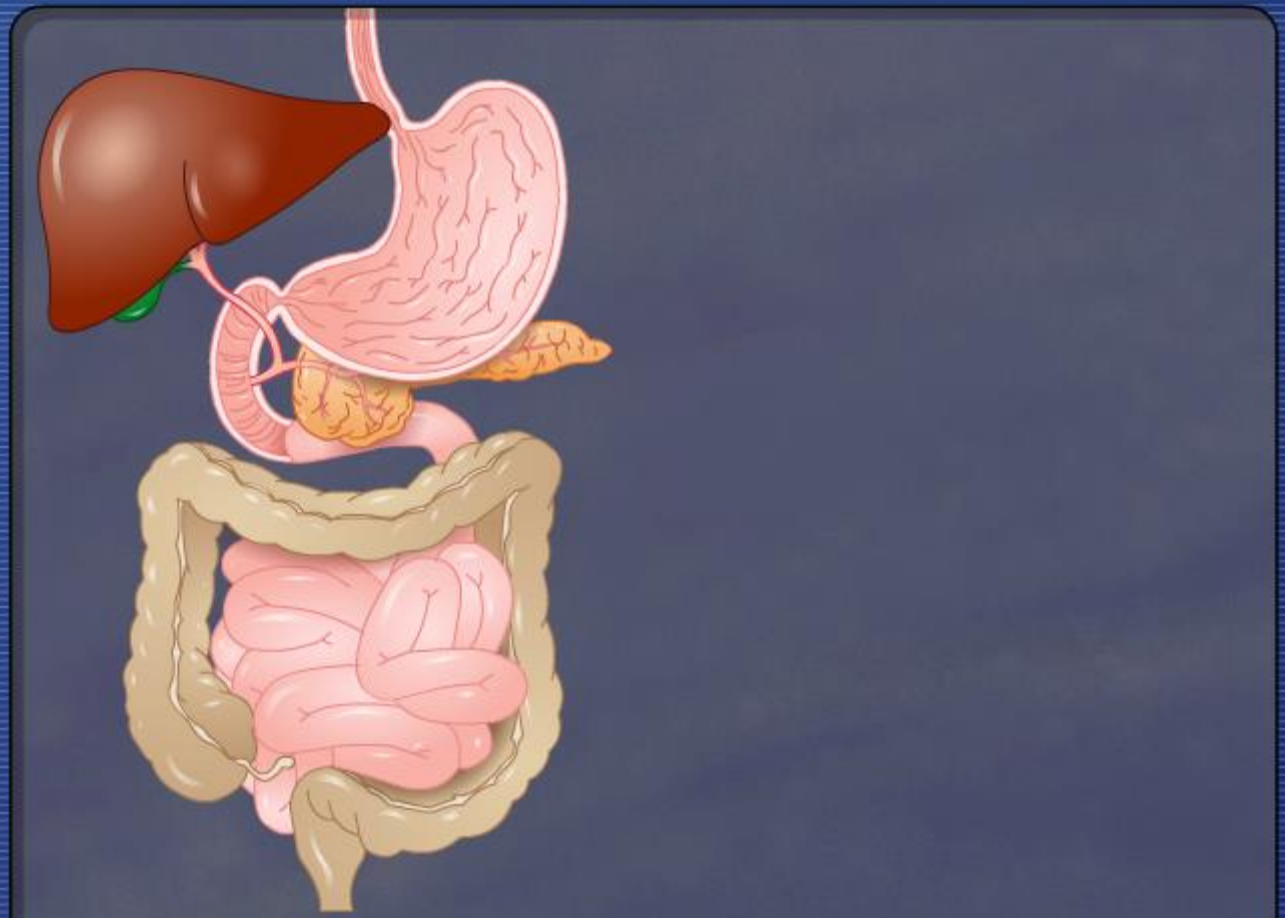


Figure 2.28

Enzyme Action and the Hydrolysis of Sucrose



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An example of how enzymes function in the body is from the enzyme sucrase. Sucrase resides on the surface of the microvilli on the intestinal epithelial (mucosal) cell surfaces.

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Enzyme Structure and Action

- **Reusability of enzymes**
  - Enzymes are not consumed by the reactions
- **Astonishing speed**
  - One enzyme molecule can consume millions of substrate molecules per minute
- **Temperature, pH and other factors can change enzyme shape and function**
  - Can alter ability of enzyme to bind to substrate
  - Enzymes vary in optimum pH
    - Salivary amylase works best at pH 7.0
    - Pepsin in stomach works best at pH 2.0
  - Temperature optimum for human enzymes—near body temperature (37°C)

Cofactors

- **Cofactors**
  - About two-thirds of human enzymes require a nonprotein cofactor
  - Some are inorganic (iron, copper, zinc, magnesium, and calcium ions)
  - Some bind to enzyme and induce a change in its shape, which activates the active site
  - Essential to function
  - **Coenzymes**—organic cofactors derived from water-soluble vitamins (niacin, riboflavin)
    - Accept electrons from an enzyme in one metabolic pathway and transfer them to an enzyme in another
    - For example, NAD^+

Action of a Coenzyme

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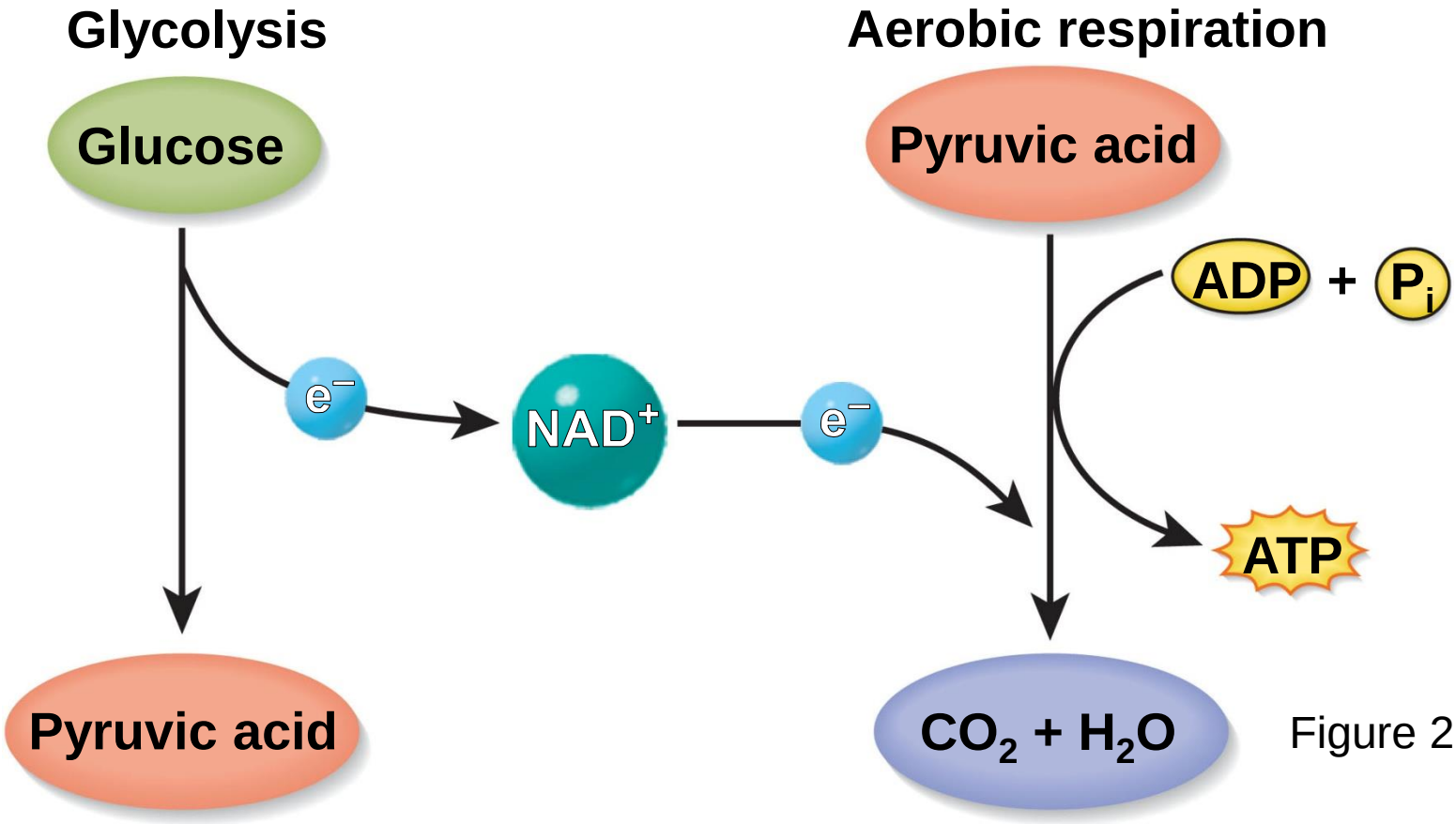

Figure 2.29

NAD^+ transports electrons from one metabolic pathway to another

B Vitamins

B Vitamins
Function in Two Ways
as Coenzymes

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This animation demonstrates how B vitamin coenzymes must be present in order to enable some enzymes to carry out their functions.

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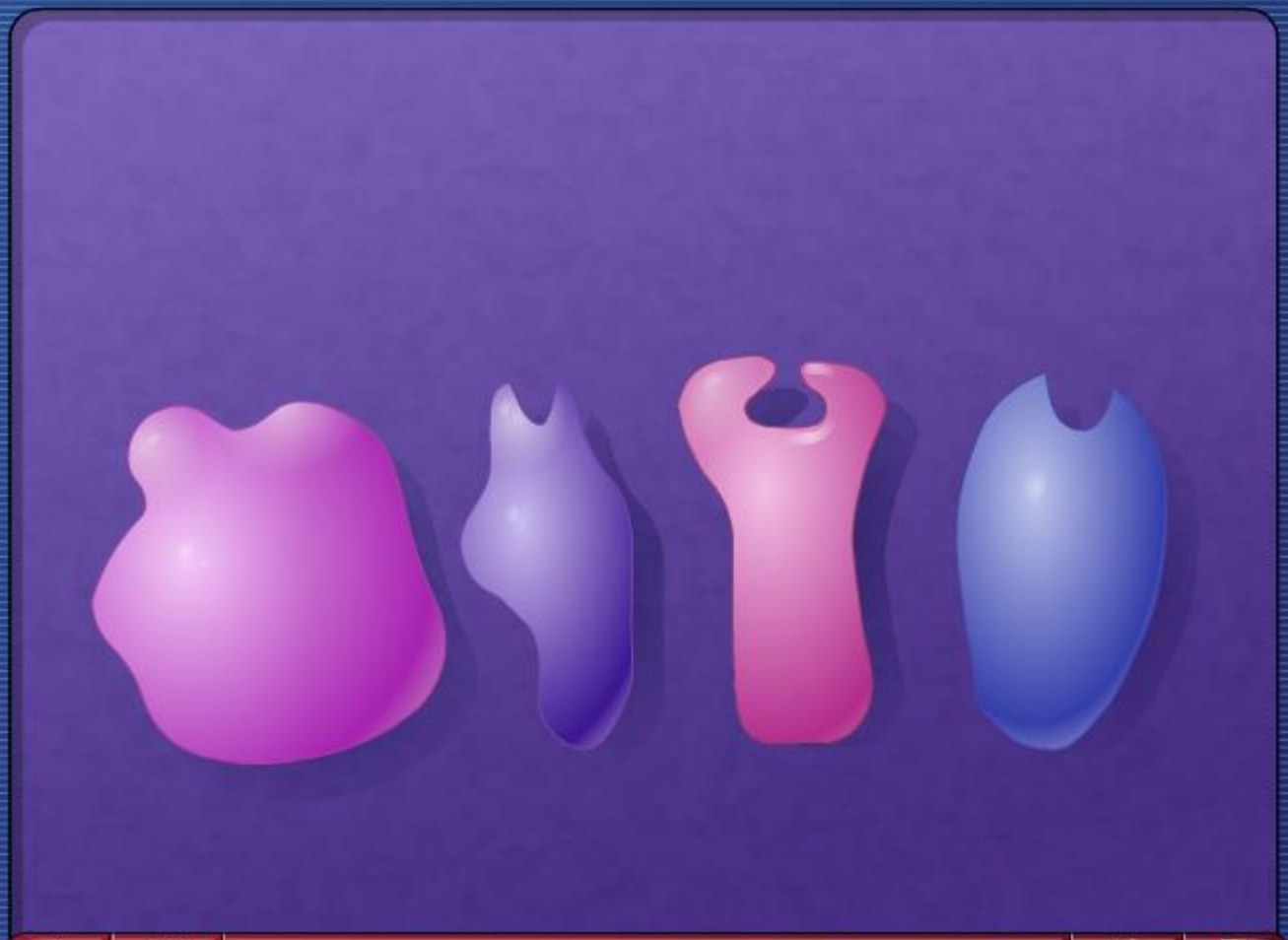
Metabolic Pathways

- **Chain of reactions, with each step usually catalyzed by a different enzyme**
- $$\mathbf{A} \xrightarrow{\alpha} \mathbf{B} \xrightarrow{\beta} \mathbf{C} \xrightarrow{\gamma} \mathbf{D}$$
- A is the **initial reactant**, B and C are **intermediates,** and D is the **end product**
- **Regulation of metabolic pathways**
  - Cells can turn on or off pathways when end products are needed or unneeded

A Biochemical Pathway



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Organisms contain many different kinds of enzymes that catalyze a variety of different reactions.

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ATP, Other Nucleotides, and Nucleic Acids

- **Three components of nucleotides**
  - **Nitrogenous base** (single or double carbon–nitrogen ring)
  - **Sugar** (monosaccharide)
  - One or more **phosphate groups**

- **ATP**—best-known nucleotide
  - **Adenine** (nitrogenous base)
  - **Ribose** (sugar)
  - **Phosphate groups** (3)

Adenosine Triphosphate

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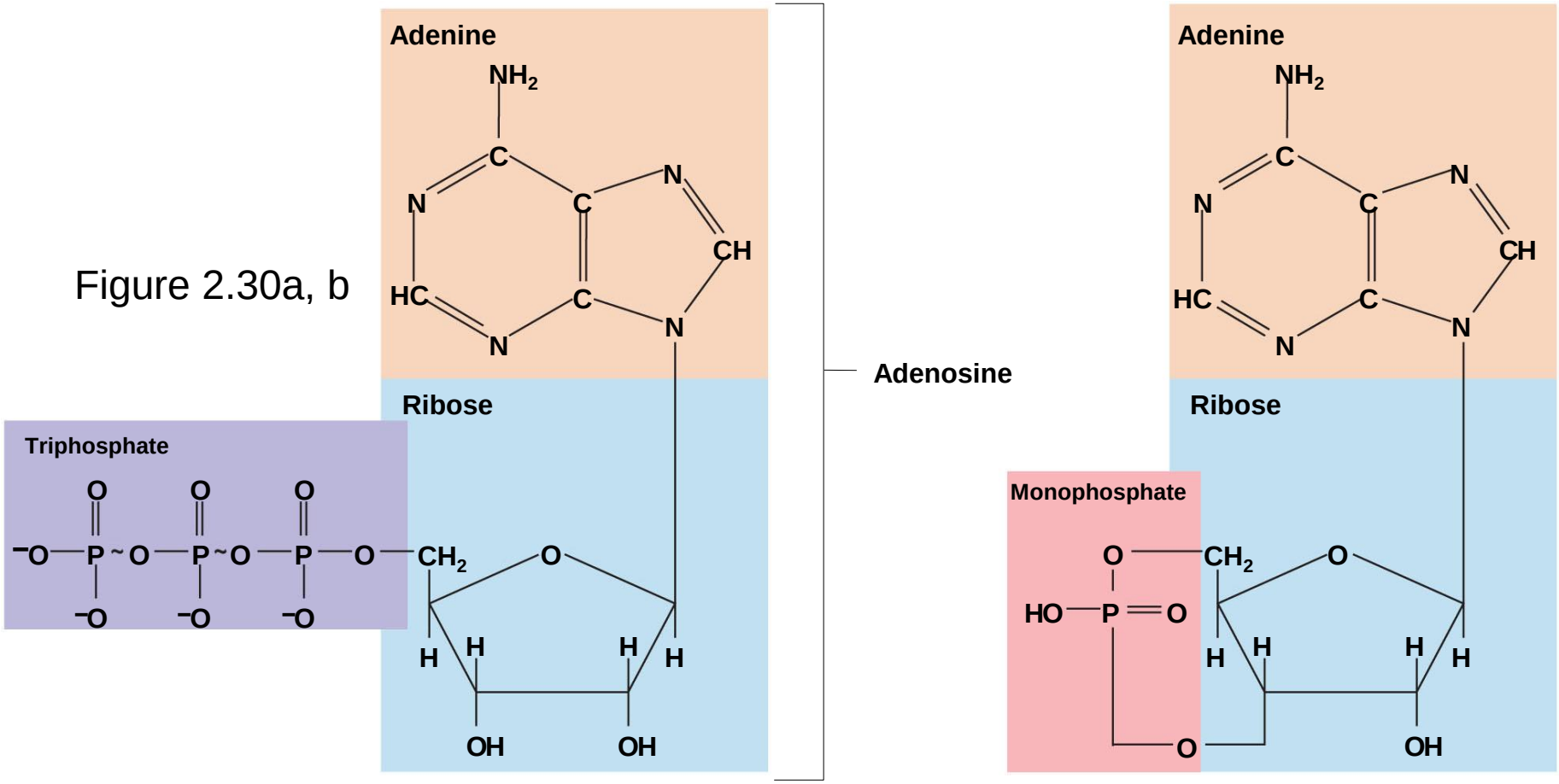
Figure 2.30a, b



(a) Adenosine triphosphate (ATP)

(b) Cyclic adenosine monophosphate (cAMP)

ATP contains adenine, ribose, and three phosphate groups

Adenosine Triphosphate

- **ATP is body's most important energy-transfer molecule**
- **Stores energy gained from exergonic reactions**
- **Releases it within seconds for physiological work**
- **Holds energy in covalent bonds**
  - Second and third phosphate groups have high energy bonds (~)
  - Most energy transfers to and from ATP involve adding or removing the third phosphate

Adenosine Triphosphate

- Hydrolysis of ATP is catalyzed by **adenosine triphosphatases (ATPases)**
  - Breaks the third high-energy phosphate bond
  - Separates ATP into ADP + P_i + energy

- **Phosphorylation**
  - Addition of free phosphate group to a molecule
  - Carried out by enzymes called **kinases**

Source and Uses of ATP

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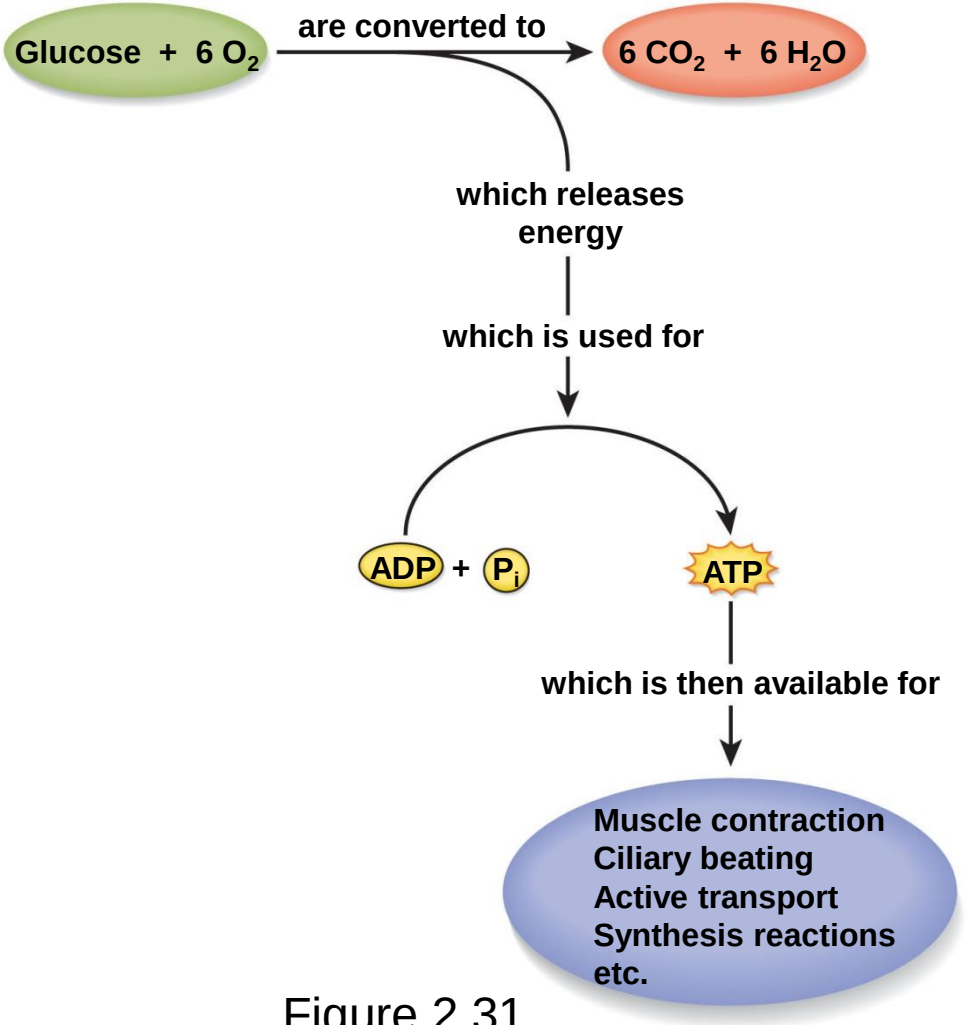

Figure 2.31

ATP Production

Stages of glucose oxidation and ATP synthesis

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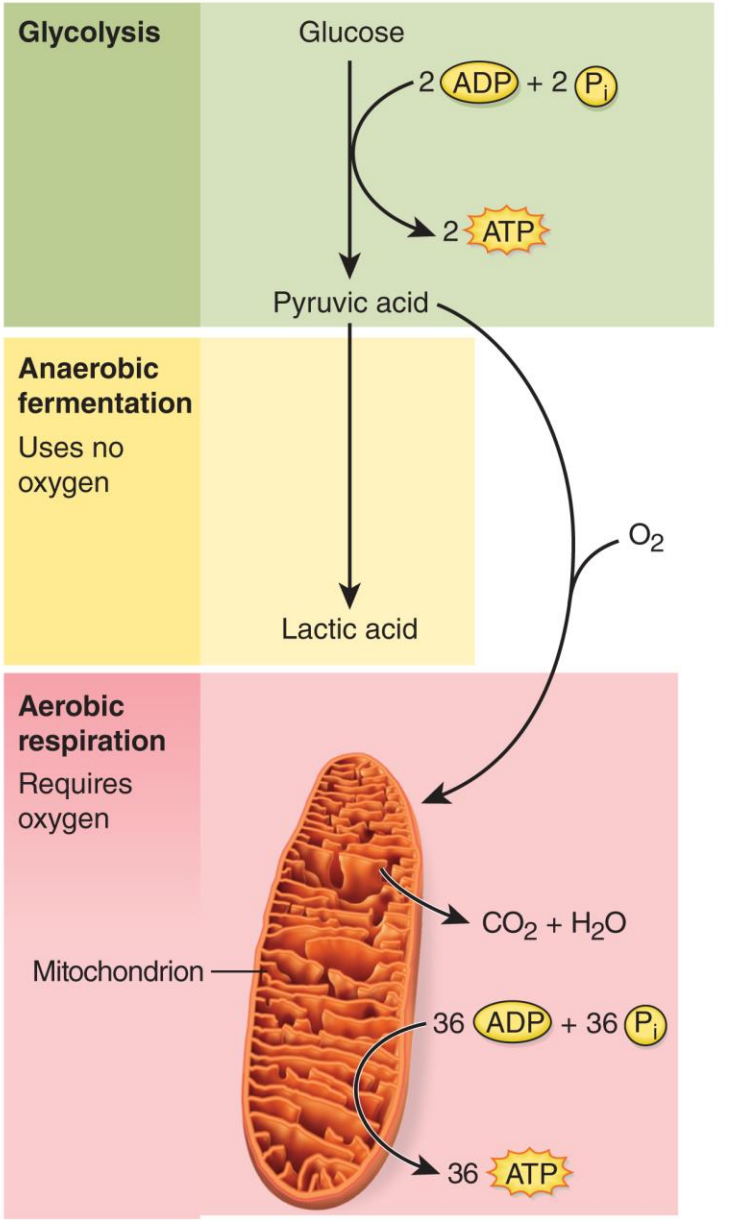

Figure 2.32

- Glycolysis: splitting glucose into two pyruvates
- If ATP demand outpaces oxygen supply pyruvic acid anaerobically ferments to lactic acid.
- If enough oxygen present aerobic respiration occurs in mitochondria

Other Nucleotides

- **Guanosine triphosphate (GTP)**
  - Another nucleotide involved in energy transfer
- **Cyclic adenosine monophosphate (cAMP)**
  - Formed by removal of second and third phosphate groups from ATP
  - Formation triggered by hormone binding to cell surface
  - cAMP becomes “second messenger” within cell

Nucleic Acids

- **Polymers of nucleotides**
- **DNA (deoxyribonucleic acid)**
  - Contains millions of nucleotides
  - Constitutes genes
    - Instructions for synthesizing proteins
- **RNA (ribonucleic acid)**—three types
  - Messenger RNA, ribosomal RNA, transfer RNA
  - 70 to 10,000 nucleotides long
  - Carries out genetic instruction for synthesizing proteins
  - Assembles amino acids in right order to produce proteins