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

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

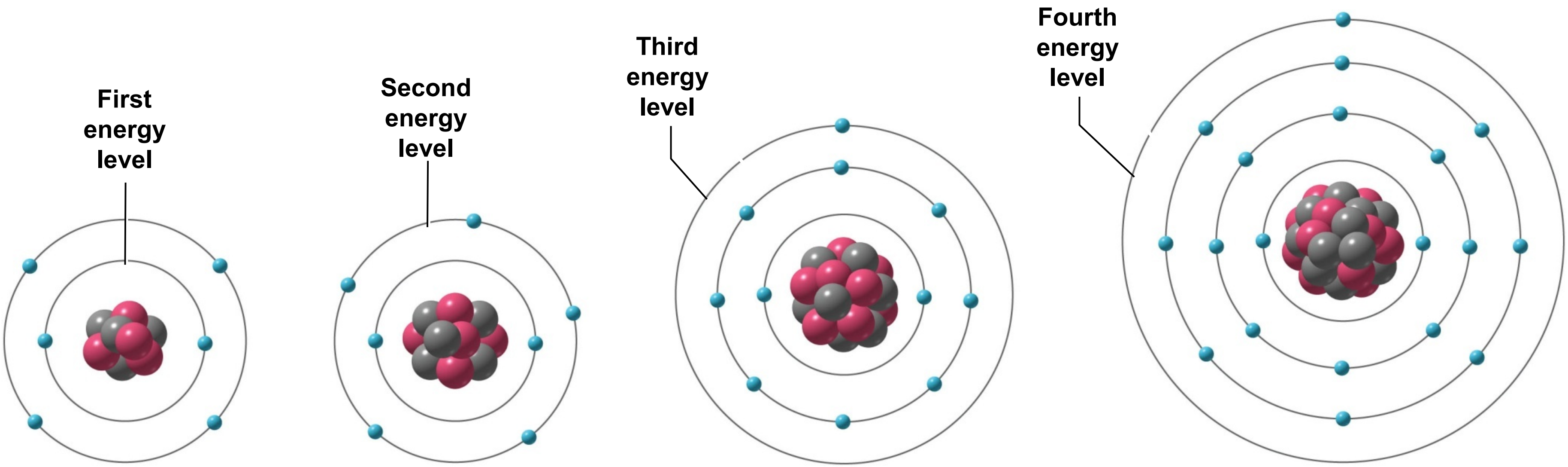
Minerals

- Inorganic elements extracted from soil by plants and passed up the food chain to humans
  - Ca, P, Cl, Mg, K, Na, I, Fe, Zn, Cu, and S
- constitute about 4% of body weight
  - structure (teeth, bones, etc)
  - enzymes
- **Electrolytes** – needed for nerve and muscle function are mineral salts

Atomic Structure

- **Nucleus** - center of atom
  - **protons:** single + charge, mass = 1 amu (atomic mass unit)
  - **neutrons:** no charge, mass = 1 amu
  - **Atomic Mass** of an element is approximately equal to its total number of protons and neutrons
- **Electrons –** in concentric clouds that surround the nucleus
  - **electrons:** single negative charge, very low mass
    - determine the chemical properties of an atom
    - the atom is electrically neutral because number of electrons is equal to the number of protons
  - **valence electrons** in the outermost shell
    - determine chemical bonding properties of an atom

Planetary Models of Elements



Carbon (C) $6p^+$, $6e^-$, $6n^0$
Atomic number = 6
Atomic mass = 12

Nitrogen (N) $7p^+$, $7e^-$, $7n^0$
Atomic number = 7
Atomic mass = 14

Sodium (Na) $11p^+$, $11e^-$, $12n^0$
Atomic number = 11
Atomic mass = 23

Potassium (K) $19p^+$, $19e^-$, $20n^0$
Atomic number = 19
Atomic mass = 39

p^+ represents protons, n^o represents neutrons

Isotopes and Radioactivity

- **Isotopes –** varieties of an element that differ from one another only in the number of neutrons and therefore in atomic mass
  - extra neutrons increase atomic weight
  - isotopes of an element are chemically similar
    - have same valence electrons
- **Atomic weight** of an element accounts for the fact that an element is a mixture of isotopes

Isotopes of Hydrogen

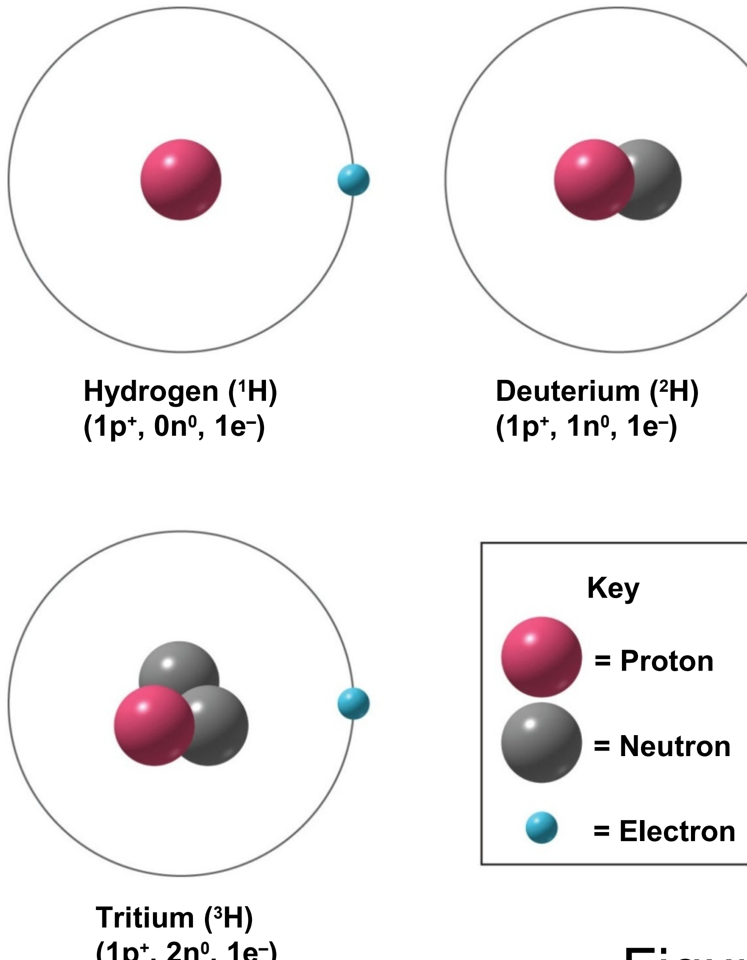


Figure 2.2

Radioisotopes and Radioactivity

- **Isotopes**
  - same chemical behavior, differ in physical behavior
  - breakdown (decay) to more stable isotope by giving off radiation
- **Radioisotopes**
  - unstable isotopes that give off radiation
  - every element has at least one radioisotope
- **Radioactivity**
  - radioisotopes decay to stable isotopes releasing radiation
  - we are all mildly radioactive

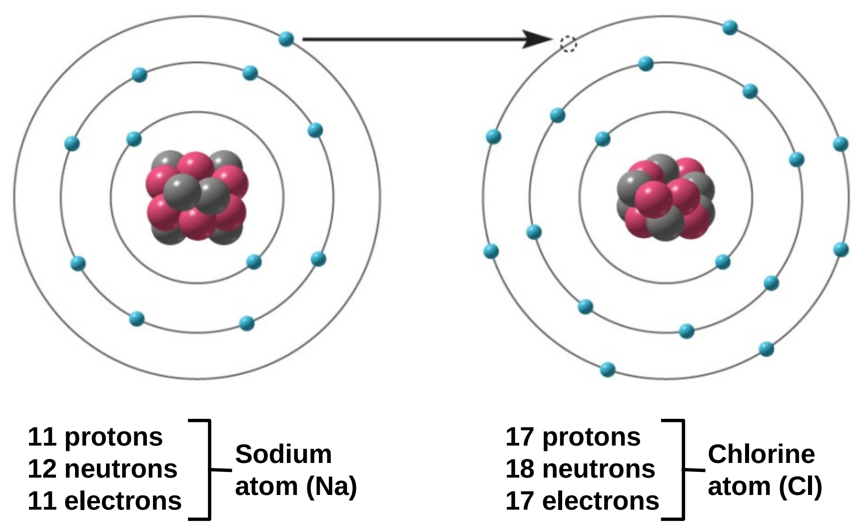
Ionizing Radiation

- High energy radiation ejects electrons from atoms converting atoms to ions
  - deadly in high doses, in low doses, mutagenic and carcinogenic
- Destroys molecules and produces dangerous free radicals and ions in human tissue
  - sources include:
    - **UV light, X rays, nuclear decay (✓, ✓, ■**

Ions and Ionization

- **Ions –** charged particles with unequal number of protons and electrons

- **Ionization -** transfer of electrons from one atom to another (✸stability of valence shell)



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

Figure 2.4 (1)

Anions and Cations

- **Anion**
  - atom that gained electrons (net negative charge)
- **Cation**
  - atom that lost an electron (net positive charge)
- Ions with opposite charges are attracted to each other

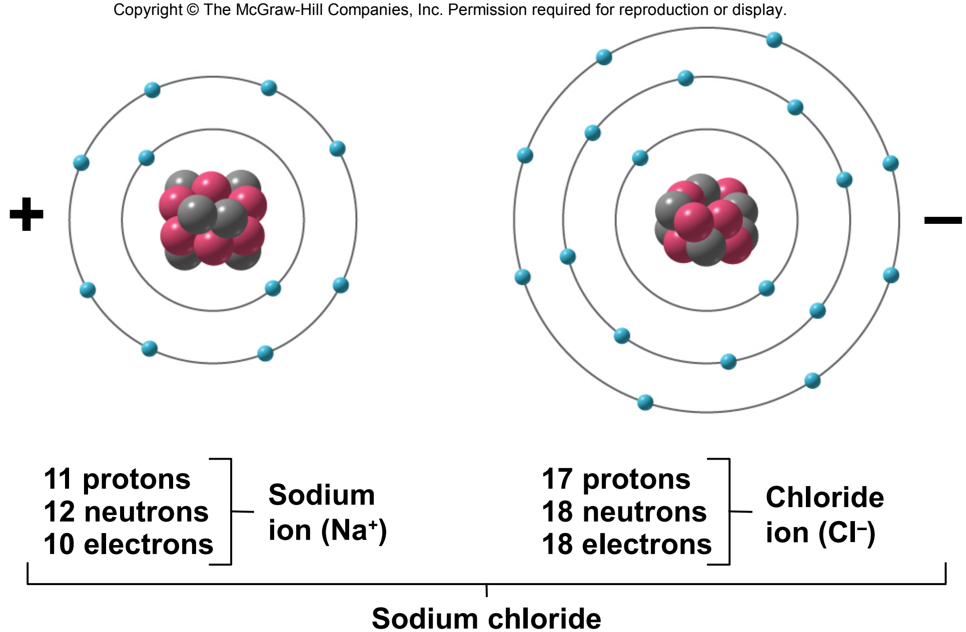


Figure 2.4 (2)

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

Electrolytes

- **Salts that ionize in water and form solutions capable of conducting an electric current.**
- **Electrolyte importance**
  - chemical reactivity
  - osmotic effects (influence water movement)
  - electrical effects on nerve and muscle tissue
- **Electrolyte balance is one of the most important considerations in patient care.**
- Imbalances have ranging effects from muscle cramps, brittle bones, to coma and cardiac arrest

TABLE 2.2 Major Electrolytes and the Ions Released by their Dissociation

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

Free Radicals

- **Chemical particles with an odd number of electrons**
- **Produced by**
  - normal metabolic reactions, radiation, chemicals
- **Causes tissue damage**
  - reactions that destroy molecules
  - causes cancer, death of heart tissue and aging
- **Antioxidants**
  - neutralize free radicals
  - in body, superoxide dismutase (SOD)
  - in diet (Selenium, vitamin E, vitamin C, carotenoids)

Molecules and Chemical Bonds

- **Molecules**
  - chemical particles composed of two or more atoms united by a chemical bond
- **Compounds**

  molecules composed of two or more different elements
- **Molecular formula**
  - shows elements and how many atoms of each are present
- **Structural formula**
  - location of each atom
  - structural isomers revealed

Molecules and Chemical Bonds

- **Molecules**
  - chemical particles composed of two or more atoms united in a chemical bond
- **Compounds**
  - molecules composed of two or more different elements
- **Molecular formula**
  - identifies constituent elements and shows how many of each are present

Structural Formula of Isomers

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

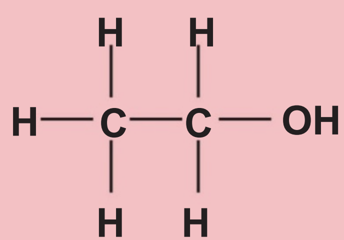
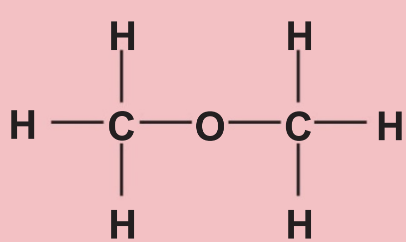
	Structural formulae	Condensed Structural formulae	Molecular formulae
Ethanol		CH_3CH_2OH	C_2H_6O
Ethyl ether		CH_3OCH_3	C_2H_6O

Figure 2.5

Molecular Weight

- **The molecular weight of a compound is the sum of atomic weights of 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

<u>6 O atoms x 16 amu each = 96 amu</u>

Molecular weight (MW) = 180 amu

Chemical Bonds

- **Chemical bonds –** forces that hold molecules together, or attract one molecule to another
- **Types of Chemical Bonds**
  - Ionic bonds
  - Covalent bonds
  - Hydrogen bonds
  - Van der Waals force

Ionic Bonds

- The attraction of a cation to an anion
- electron donated by one and received by the other
- Relatively weak attraction that is easily disrupted in water, as when salt dissolves

Covalent Bonds

- **Formed by sharing electrons**
- **Types of covalent bonds**
  - **single -** sharing of single pair electrons
  - **double -** sharing of 2 pairs of electrons
  - **nonpolar covalent bond**
    - shared electrons spend approximately equal time around each nucleus
    - strongest of all bonds
  - **polar covalent bond**
    - if shared electrons spend more time orbiting one nucleus than they do the other, they lend their negative charge to the area they spend most time

Single Covalent Bond

- One pair of electrons are shared

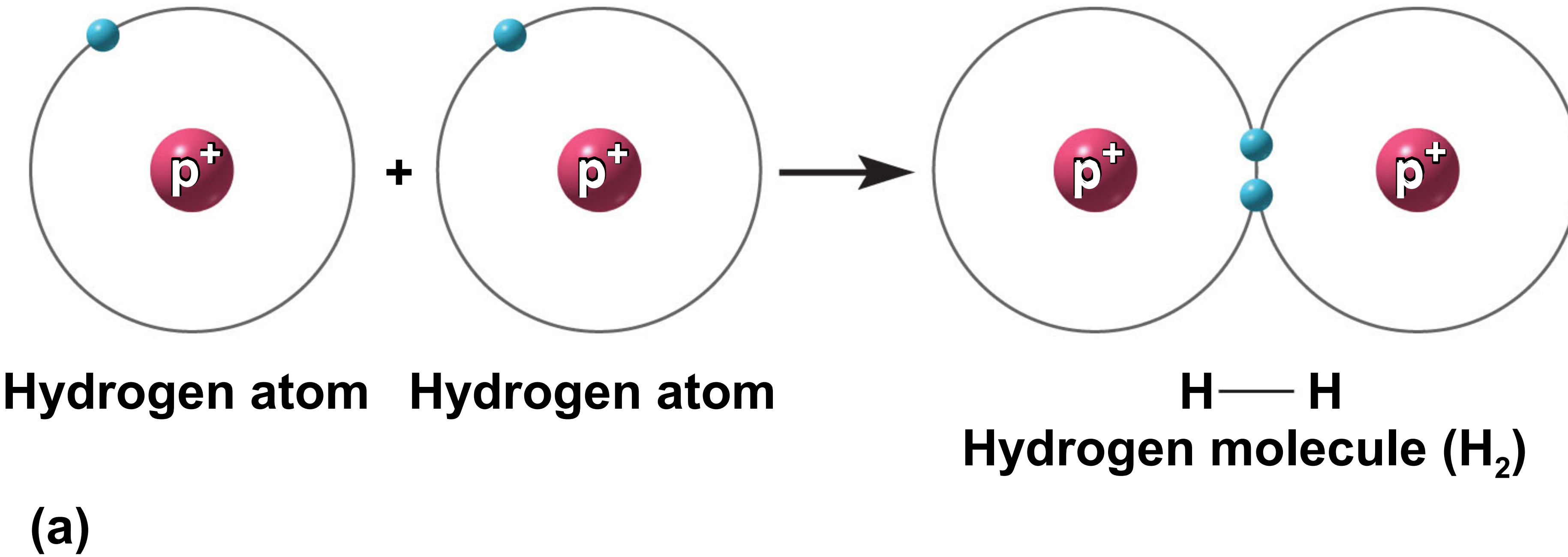
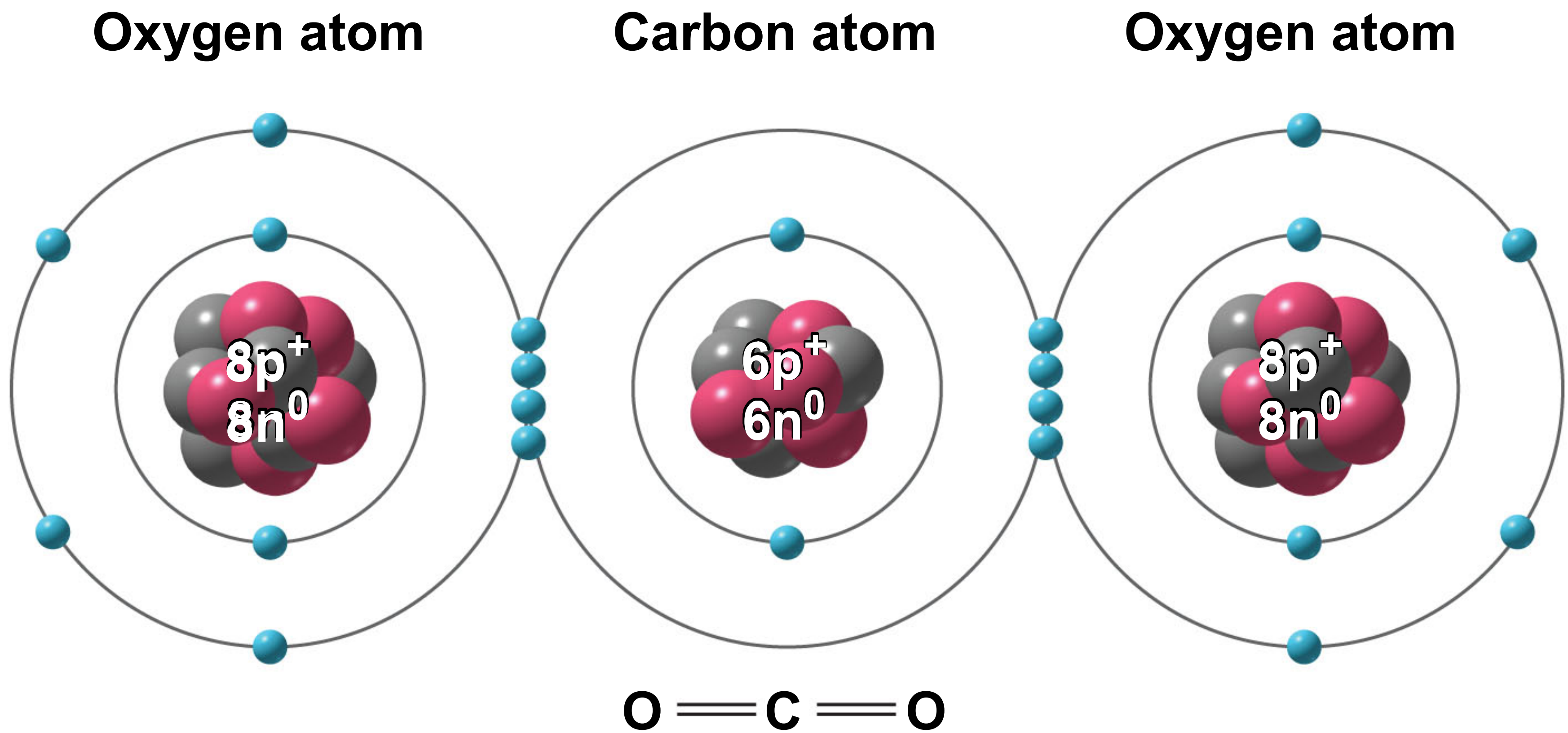


Figure 2.6a

Double covalent bonds:

Two pairs of electrons are shared each C=O bond

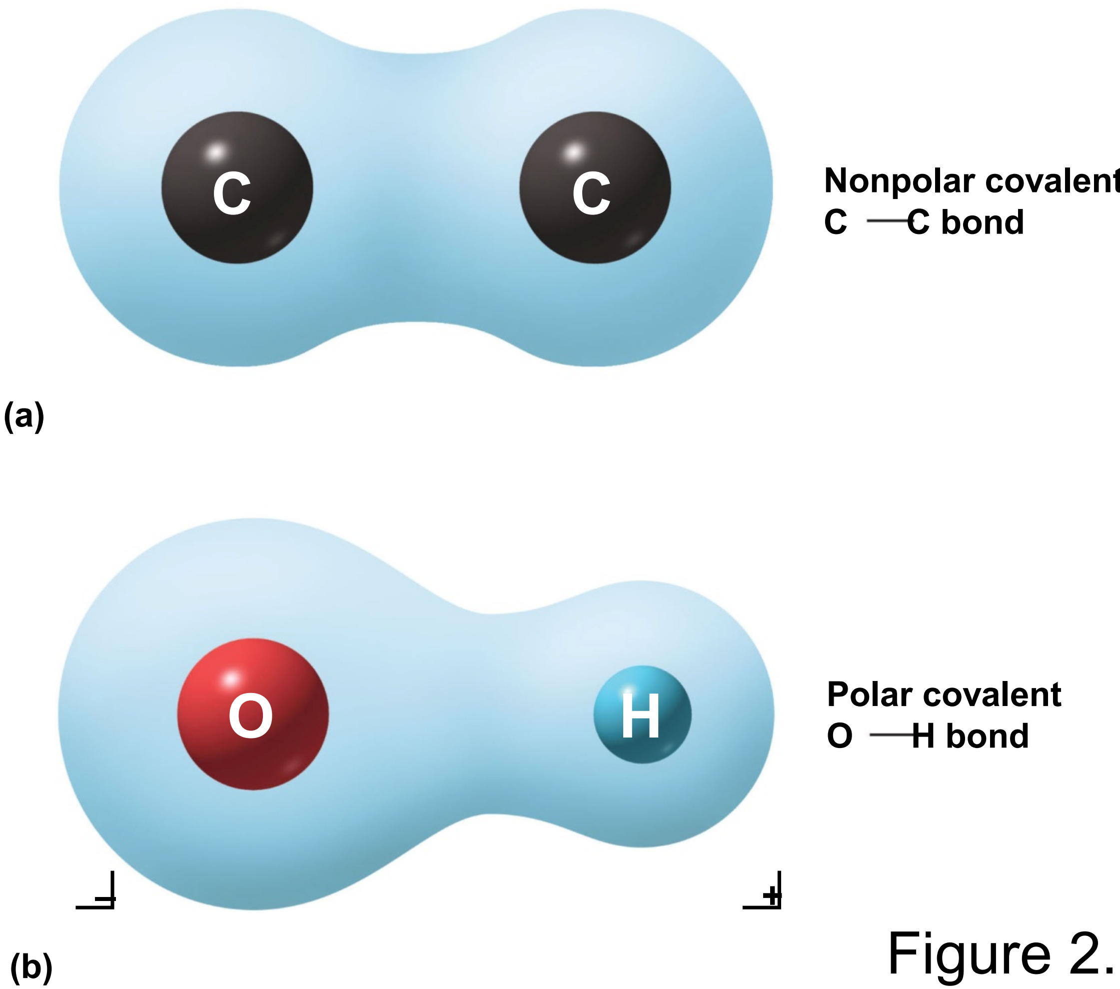


Carbon dioxide molecule (CO_2)

(b)

Figure 2.6b

Nonpolar /Polar Covalent Bonds



Electrons shared equally

Electrons shared unequally

Figure 2.7

Hydrogen 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 weakly attracted to each other by hydrogen bonds
- relatively weak bonds
- very important to physiology
  - protein structure
  - DNA structure

Hydrogen Bonding in Water

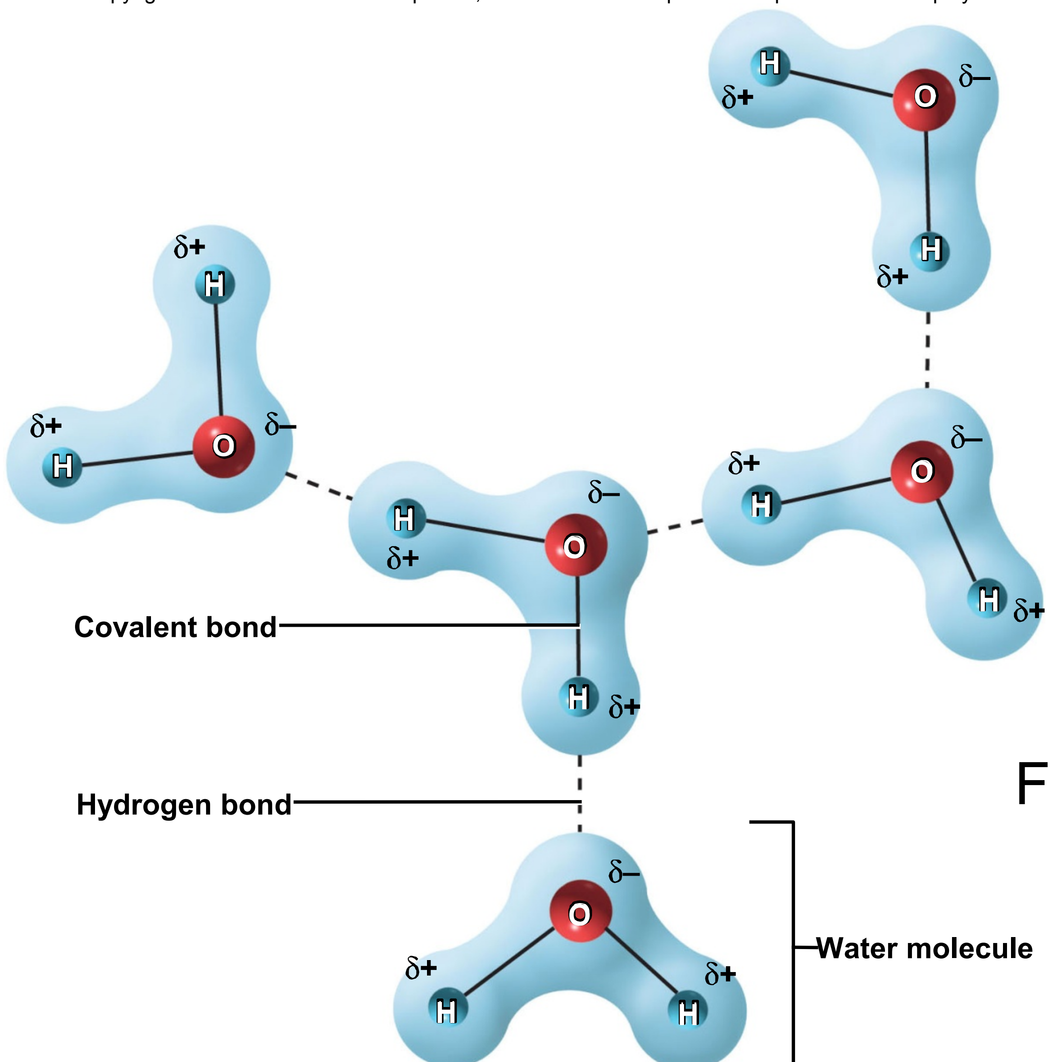


Figure 2.8

Van der Waals Forces

- **Van der Waals Forces –** weak, brief attractions between neutral atoms
- Fluctuations in electron density in electron cloud of a molecule creates polarity for a moment, and can attract adjacent molecules in the region for a very short instant in time
- Only 1% as strong as a covalent bond
- when two surfaces or large molecules meet, the attraction between large numbers of atoms can create a very strong attraction
  - important in protein folding
  - important with protein binding with hormones
  - association of lipid molecules with each other

Water and Mixtures

- **Mixtures –** consists of substances physically blended, but not chemically combined
- body fluids are complex mixtures of chemicals
  - each substance maintains its own chemical properties
- Most mixtures in our bodies consist of chemicals dissolved or suspended in water
- Water 50-75% of body weight
  - depends on age, sex, fat content, etc.

Water

- Water's **polar covalent bonds** and its **V-shaped molecule** gives water a set of properties that account for its ability to support life.
  - **solvency**
  - **cohesion**
  - **adhesion**
  - **chemical reactivity**
  - **thermal stability**

Solvency

- **Solvency** - ability to dissolve other chemicals
- water is called the **Universal Solvent**
  - **Hydrophilic –** substances that dissolve in water
    - molecules must be polarized or charged
  - **Hydrophobic -** substances that do not dissolve in water
    - molecules are non-polar or neutral (fat)
- Virtually all metabolic reactions depend on the solvency of water

Water as a Solvent

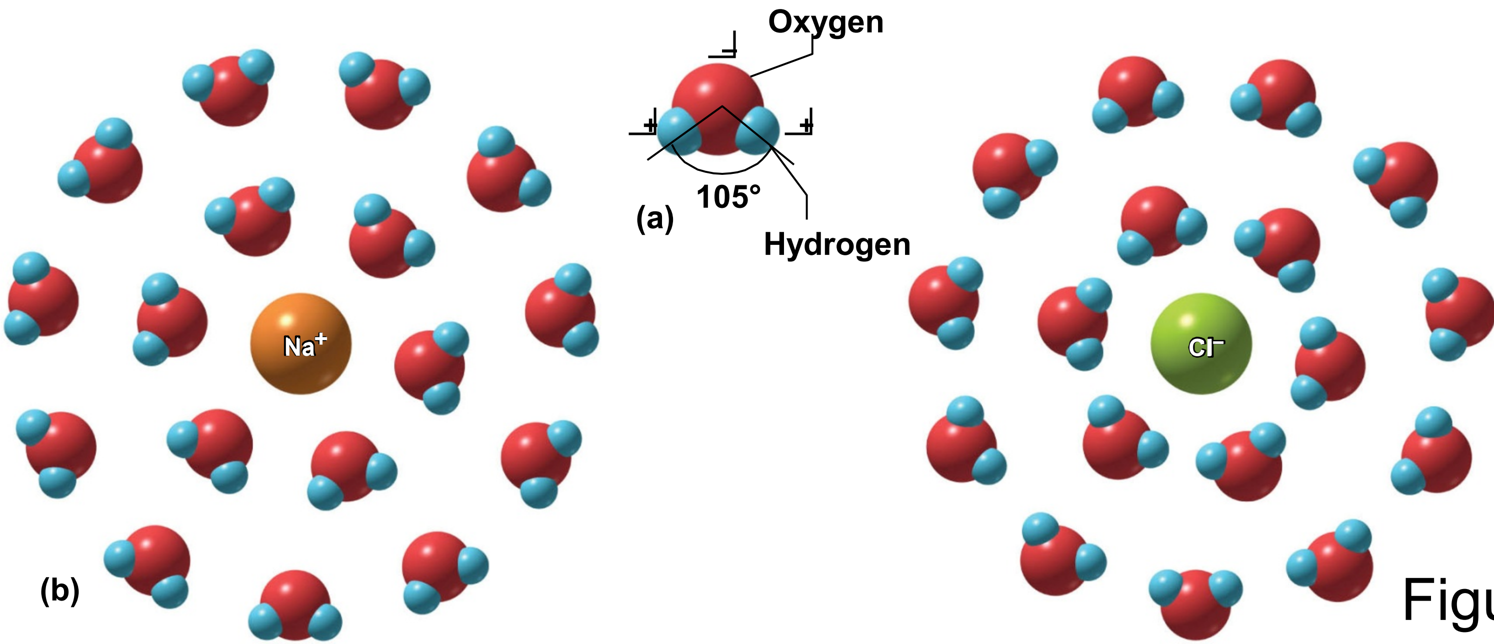


Figure 2.9

- Polar water molecules overpower the ionic bond in $Na^+ Cl^-$
  – forming hydration spheres around each ion
  – water molecules: negative pole faces Na^+, positive pole faces Cl^-

Adhesion and Cohesion

- **Adhesion –** tendency of one substance to cling to another

- **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 a force called **surface tension**

Chemical Reactivity of Water

- **is the ability to participate in chemical reactions**
  - **water ionizes** into H^+ and OH^-
  - **water ionizes** other chemicals (acids and salts)
  - water involved in **hydrolysis** and **dehydration synthesis** reactions

Thermal Stability of Water

- **Water helps stabilize the internal temperature of the body**
  - has high **heat capacity –** the amount of heat required to raise the temperature of 1 g of a substance by 1 degree C.
  - **calorie (cal)** – the amount of heat that raises the temperature of 1 g of water 1 degree C.
    - hydrogen bonds inhibit temperature increases by inhibiting molecular motion
    - water absorbs heat without changing temperature very much
  - **effective coolant**
    - 1 ml of perspiration removes 500 calories

Solution, Colloid and Suspension

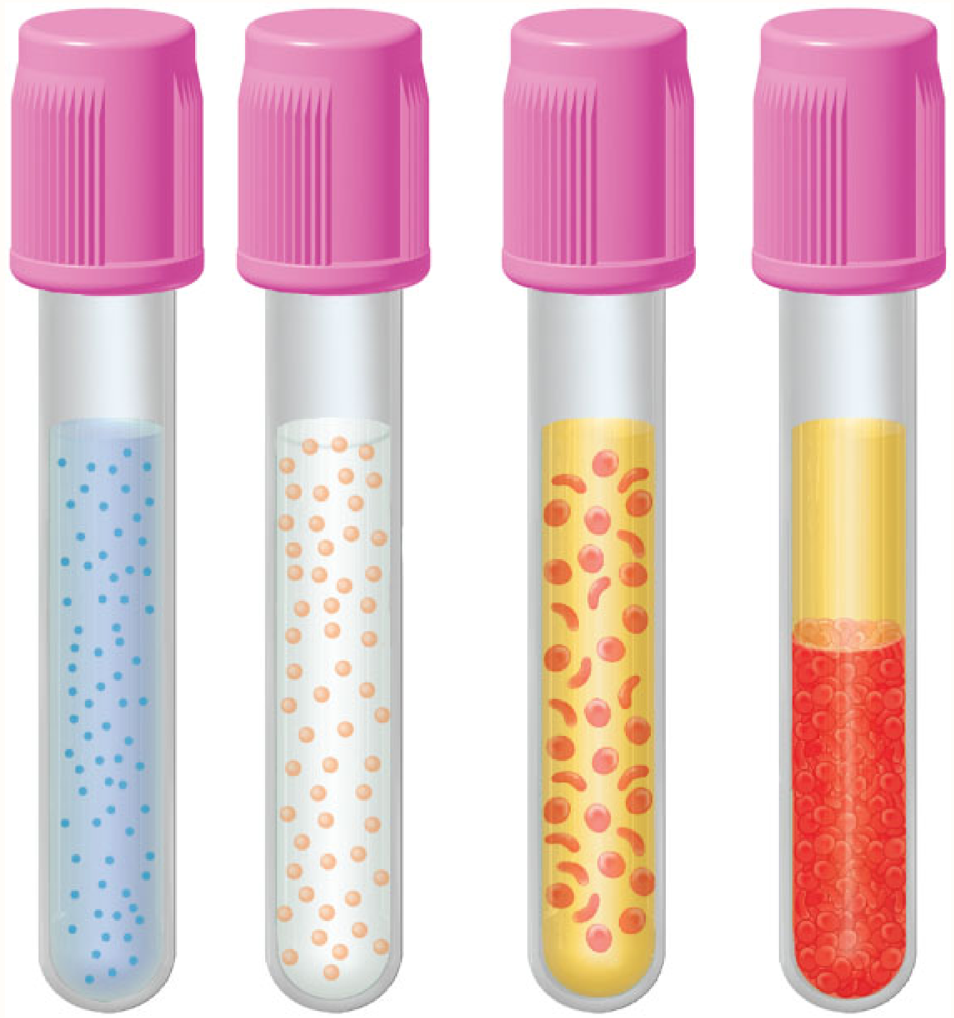
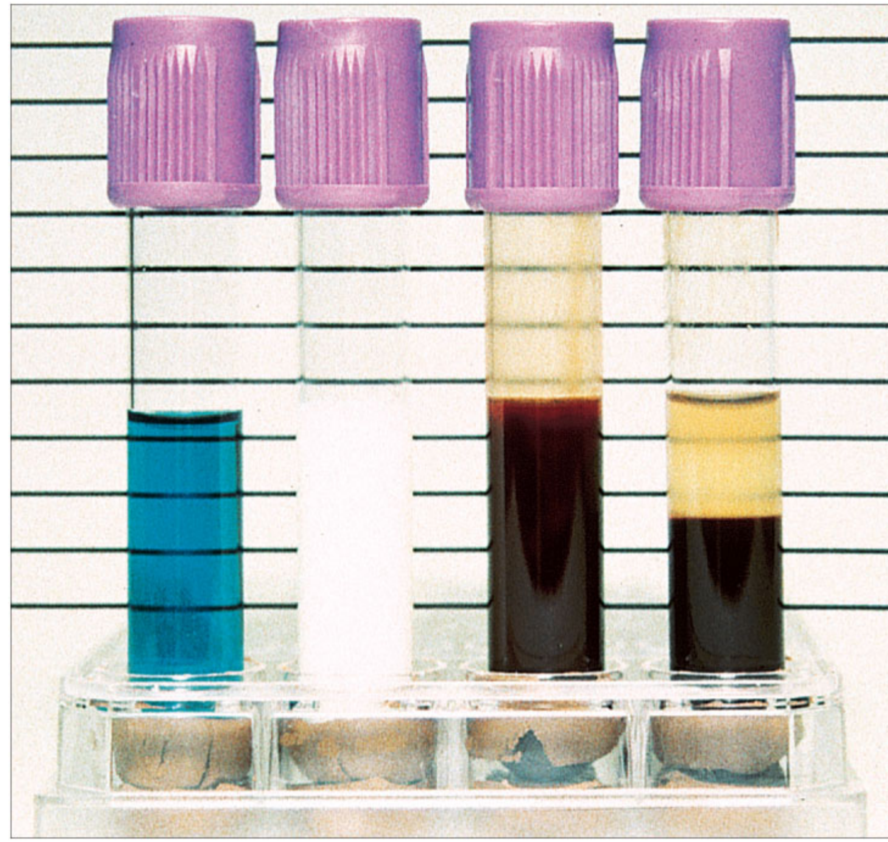


Figure 2.10 (2)

Solutions

- **Solution –** consists of particles of matter 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 1nm
  - solute particles do not scatter light
  - will pass through most membranes
  - will not separate on standing

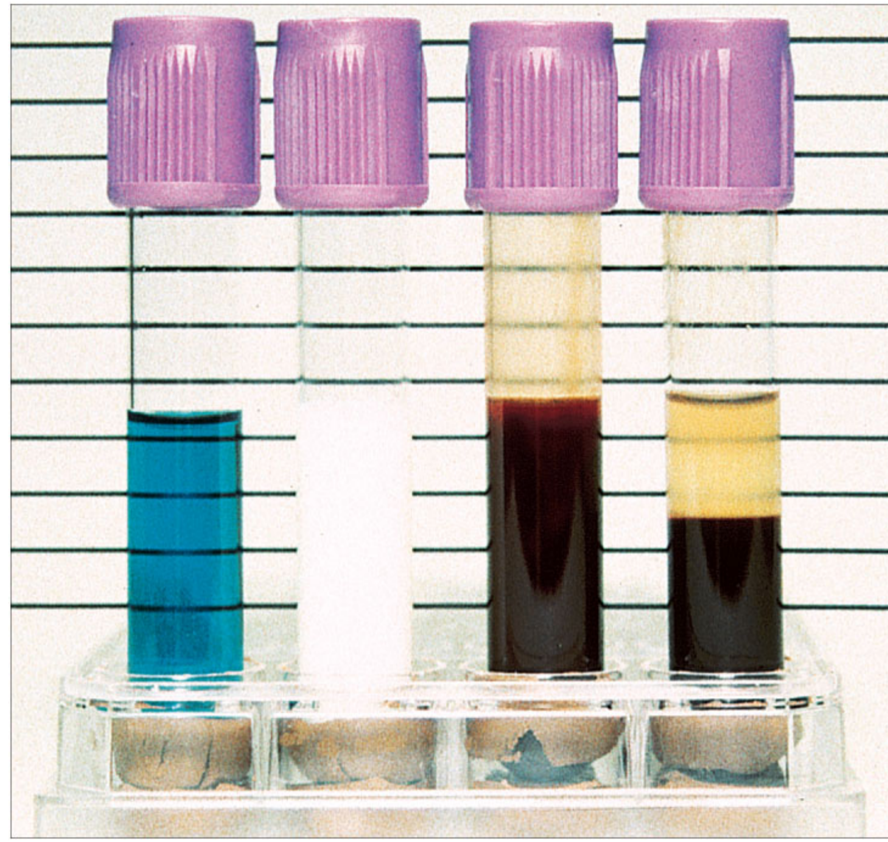


(a) (b) (c) (d)

Figure 2.10 (1)

Colloids

- Most common colloids in the body are mixtures of protein and water
- Many can change from liquid to gel state within and between cells
- Colloids 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



(a) (b) (c) (d)

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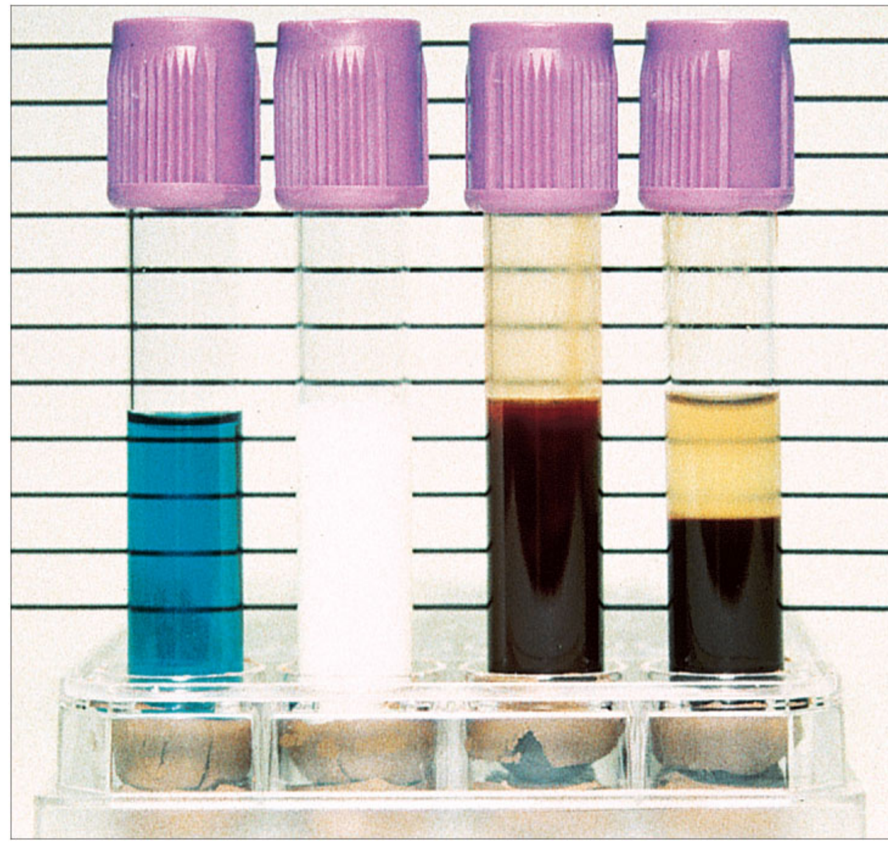
Figure 2.10 (1)

Suspensions and Emulsions

- **Suspension**
  - defined by the following physical properties
    - particles exceed 100nm
    - too large to penetrate selectively permeable membranes
    - cloudy or opaque in appearance
    - separates on standing
- **Emulsion**
  - suspension of one liquid in another
    - fat in breast milk



(a) (b) (c) (d)

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Figure 2.10 (1)

Measures of Concentration

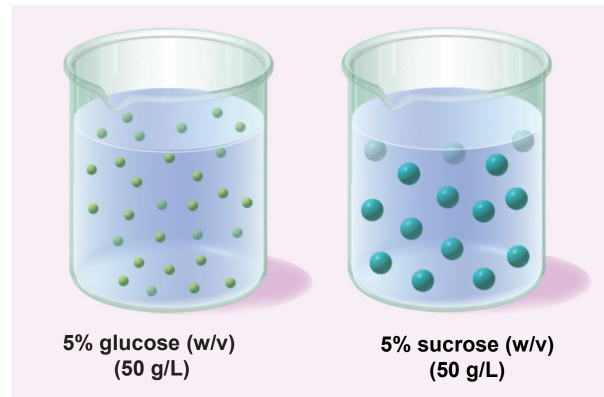
- how much solute in a given volume of solution
- **Weight per Volume**
  - weight of solute in given volume of solution
    - IV saline: 8.5 grams NaCl/liter of solution
    - biological purposes – milligrams per deciliter
      - mg/dL (deciliter = 100 ml)
- **Percentages**
  - Weight/volume of solute in solution
    - IV D_5W (5% w/v dextrose in distilled water)
      - 5 grams of dextrose and fill to 100 ml water
- **Molarity –** known number of molecules per volume
  - moles of solute/liter of solution
  - physiologic effects based on number of molecules in solution not on weight

Molarity

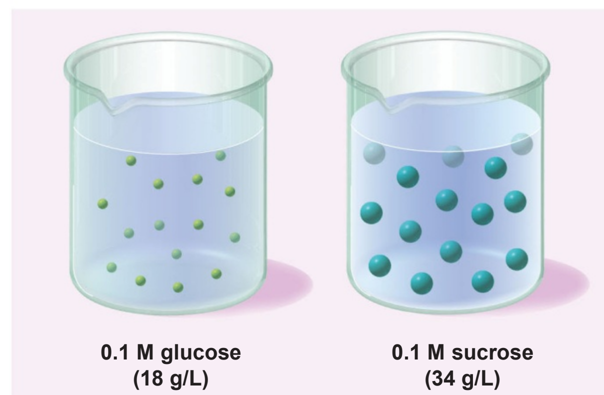
- **1 mole** of a substance is its molecular weight in grams
- 1 mole of a substance is equal to **Avogadro's number** of molecules
  - 6.023×10^{23}
- **Molarity** (M) is the number of moles of solute/ liter of solution
  - MW of glucose is 180
  - one-molar (1.0M) glucose solution contains 180g/L

Percentage vs. Molar Concentrations

- **Percentage**
  - # of molecules **unequal**
  - weight of solute **equal**
- **Molar**
  - # of molecules **equal**
  - weight of solute **unequal**



(a) Solutions of equal percentage concentration



(b) Solutions of equal molar concentration

Figure 2.11

Electrolyte Concentrations

- **Electrolytes** are important for their chemical, physical, and electrical effects on the body.
  - electrical effects determine nerve, heart, and muscle actions
- Measured in **equivalents** (Eq)
  - 1 Equivalent is the amount of electrolyte that will electrically neutralize 1 mole of H^+ or OH^- ions
  - in the body, expressed as **milliequivalents** (mEq/L)
  - multiply molar concentration x valence of the ion
  - 1 M Na^+ = 1 Eq/L
  - 1 M Ca^{2+} = 2 Eq/L

Acids, Bases and pH

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

- A **base** is proton acceptor (accepts H^+ ions)
  - releases OH- ions in water

- **pH** – 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$^+$)

pH

- **pH** - measurement of molarity of H^+ [H+] on a logarithmic scale
- 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

- Our body uses **buffers** to resist changes in pH
  - slight pH disturbances can disrupt physiological functions and alter drug actions
  - pH of blood ranges from **7.35 to 7.45**
  - deviations from this range cause tremors, paralysis or even death

pH Scale

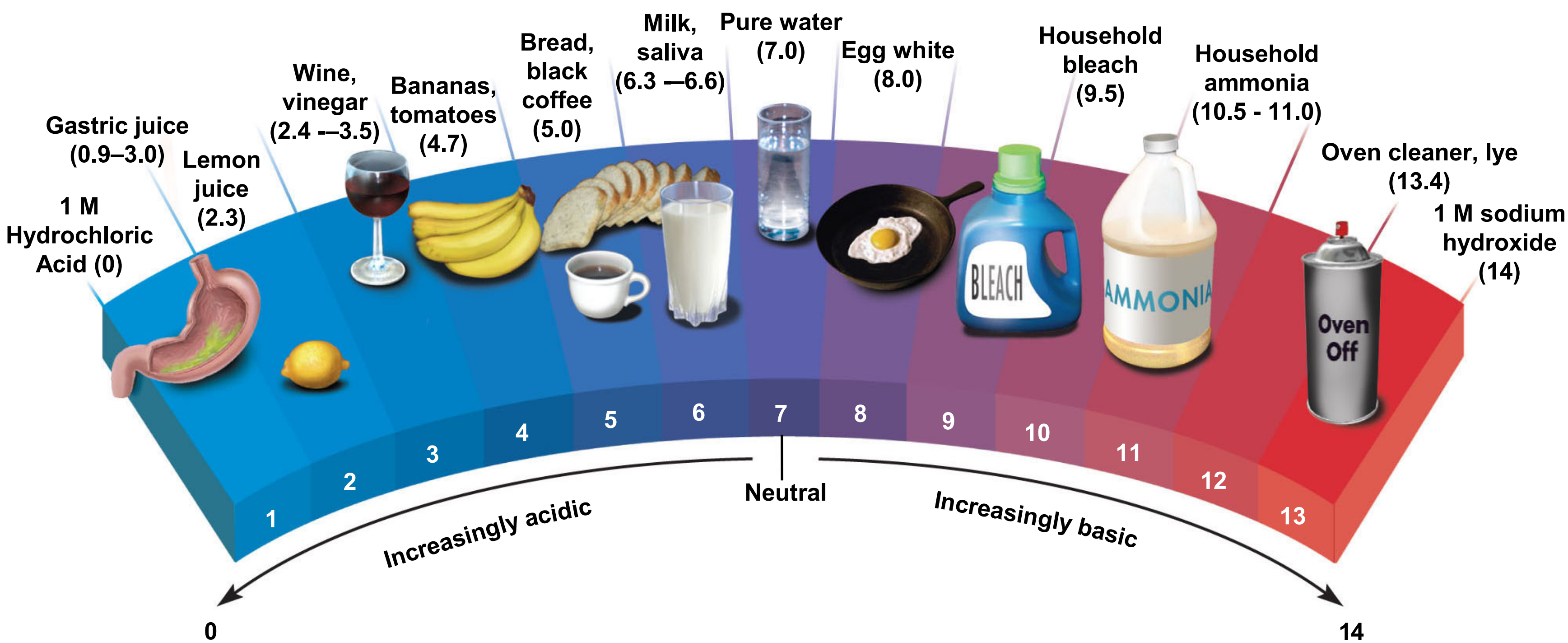


Figure 2.12

Work and Energy

- **Energy -** capacity to do work
  - to do work means to move something
  - all body activities are a form of work
- **Potential energy-** energy contained in an object because of its position or internal state
  - not doing work at the time
  - water behind a dam
  - **chemical energy** - potential energy stored in the bonds of molecules
  - **free energy** – potential energy available in a system to do useful work
- **Kinetic energy -** energy of motion; energy that is actively doing work
  - moving water flowing through a dam
  - **heat** - kinetic energy of molecular motion
  - **electromagnetic energy** – the kinetic energy of moving ‘packets’ of radiation called **photons**

Chemical Reaction

- **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) ✹ products (on right)
- **classes of chemical reactions**
  - decomposition reactions
  - synthesis reactions
  - exchange reactions

Decomposition Reactions

- Large molecule breaks down into two or more smaller ones
- **AB ✸ A + B**

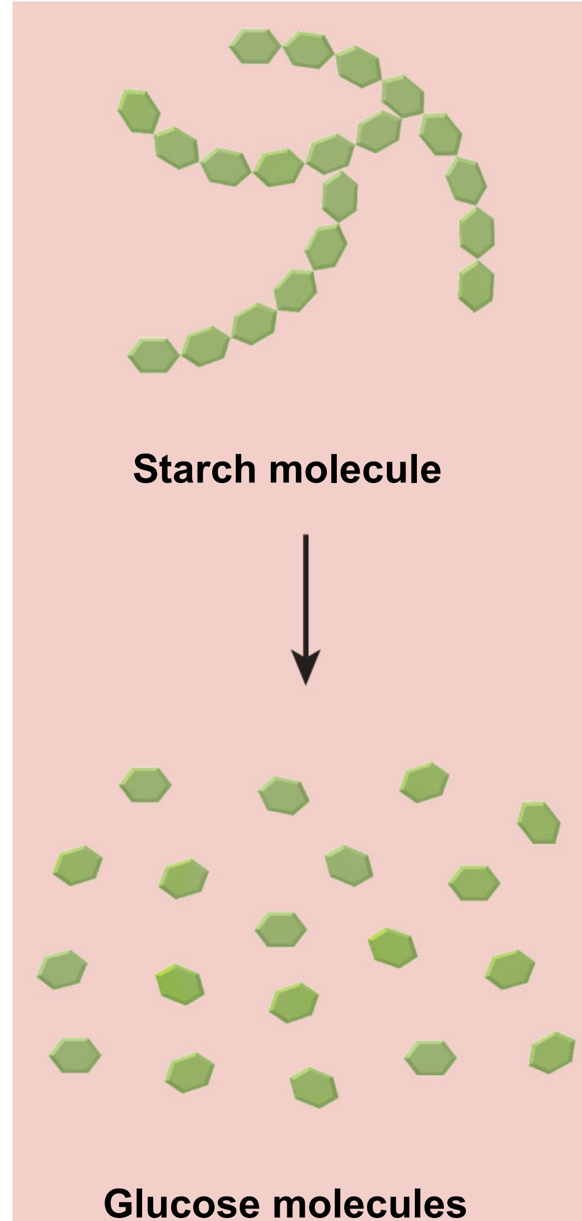


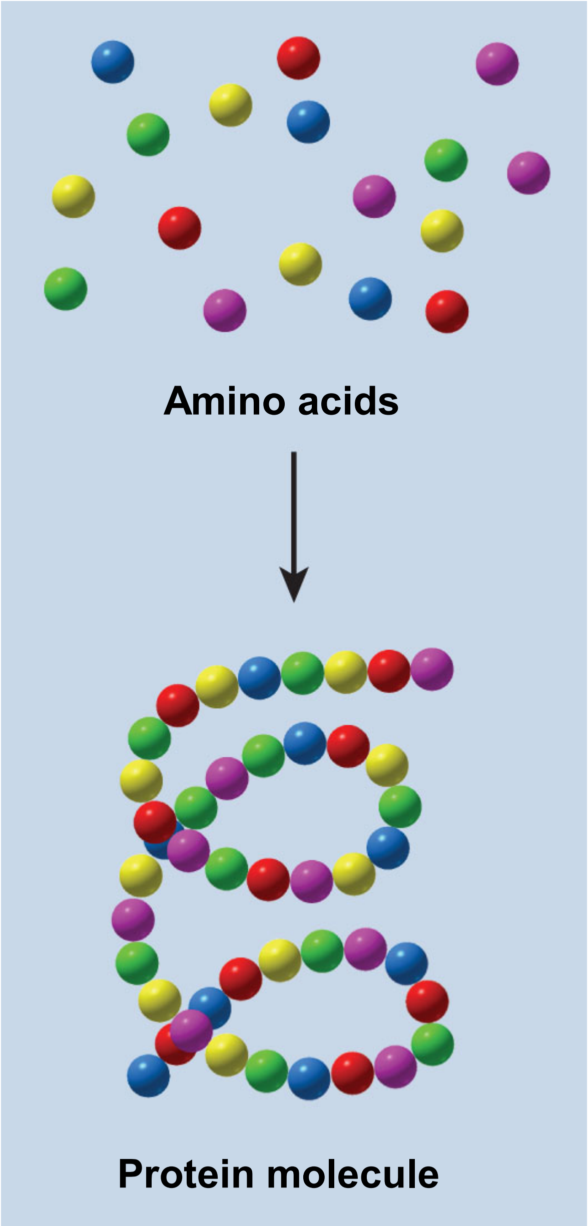
Figure 2.13a

(a) Decomposition reaction

Synthesis Reactions

- Two or more small molecules combine to form a larger one
- **A + B ✸ AB**

Figure 2.13b



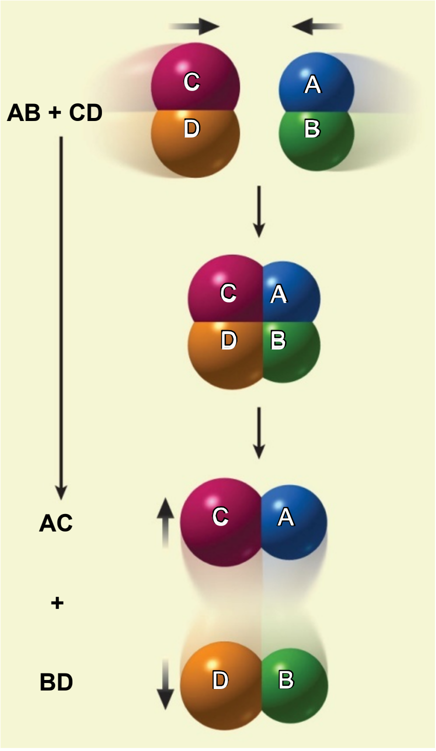
(b) Synthesis reaction

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



(c) Exchange reaction

Reversible Reactions

- Can go in either direction under different circumstances
- symbolized with double-headed arrow
- $\mathbf{CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows HCO^{3-} + H^+}$
  - most common equation discussed in this book
  - respiratory, urinary, and digestive physiology
- **Law of mass action** determines direction
  - proceeds from the side of equation with greater quantity of reactants to the side with the lesser quantity
- **Equilibrium** exists in reversible reactions when the ratio of products to reactants is stable

Reaction Rates

- Basis for chemical reactions is **molecular motion** and **collisions**
  - reactions occur when molecules collide with enough force and the correct orientation
- **Reaction Rates** affected by:
  - **concentration**
    - reaction rates increase when the reactants are more concentrated
  - **temperature**
    - reaction rates increase when the temperature rises
  - **catalysts** –substances that temporarily bond to reactants, hold them in favorable position to react with each other, and may change the shapes of reactants in ways that make them more likely to react.
    - speed up reactions without permanent change to itself
    - holds reactant molecules in correct orientation
    - catalyst not permanently consumed or changed by the reaction
    - **Enzymes** – most important biological catalysts

Metabolism

- **All the chemical reactions of the body**
- **Catabolism**
  - energy releasing (exergonic) decomposition reactions
    - breaks covalent bonds
    - produces smaller molecules
    - releases useful energy
- **Anabolism**
  - energy storing (endergonic) synthesis reactions
    - requires energy input
    - production of protein or fat
    - driven by energy that catabolism releases
- Catabolism and Anabolism are inseparably linked

Oxidation-Reduction Reactions

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

Organic Chemistry

- **Study of compounds containing carbon**
- **4 categories of carbon compounds**
  - carbohydrates
  - lipids
  - proteins
  - nucleotides and nucleic acids

Organic Molecules and Carbon

- **4 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 – carbon backbones**
  - forms long chains, branched molecules and rings
  - forms covalent bonds with hydrogen, oxygen, nitrogen, sulfur, and other elements
- **carbon backbone** carries a variety of functional groups

Functional Groups

- small clusters of atoms attached to carbon backbone
- determines many of the properties of organic molecules
- hydroxyl, methyl, carboxyl, amino, phospha

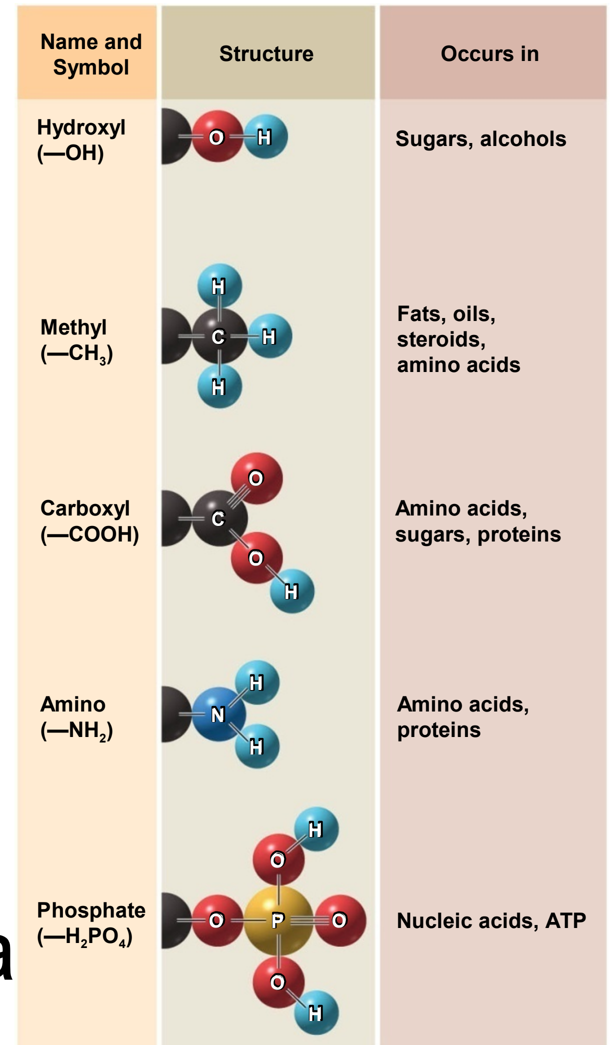


Figure 2.14

Monomers and Polymers

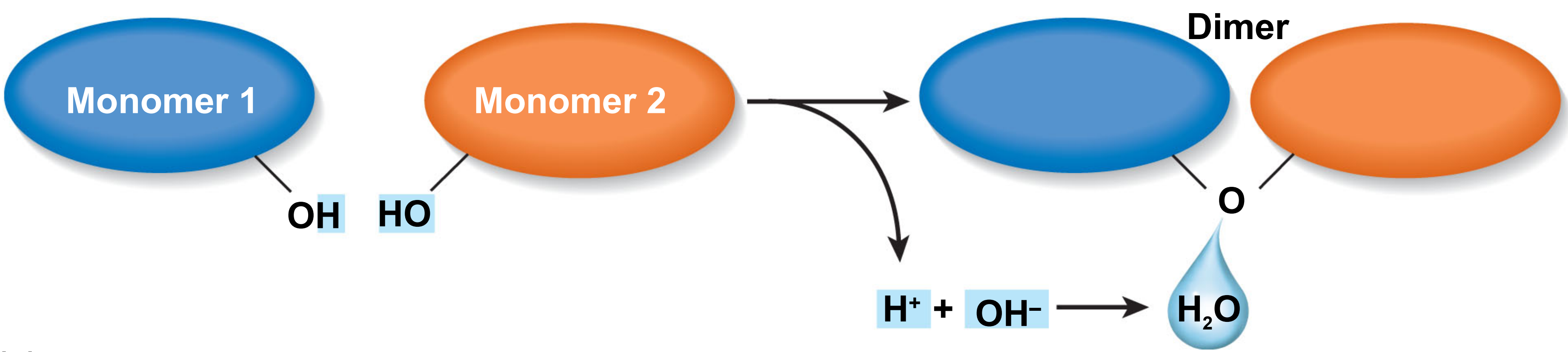
- **Macromolecules** - very large organic molecules
  - very high molecular weights
    - proteins, DNA
- **Polymers –** molecules made of a repetitive series of identical or similar subunits (monomers)
- **Monomers -** an identical or similar subunits

Polymerization

- **joining monomers to form a polymer**
- **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** – 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

Dehydration Synthesis

- **Monomers covalently bond together to form a polymer with the removal of a water molecule**
  – A hydroxyl group is removed from one monomer and a hydrogen from the next

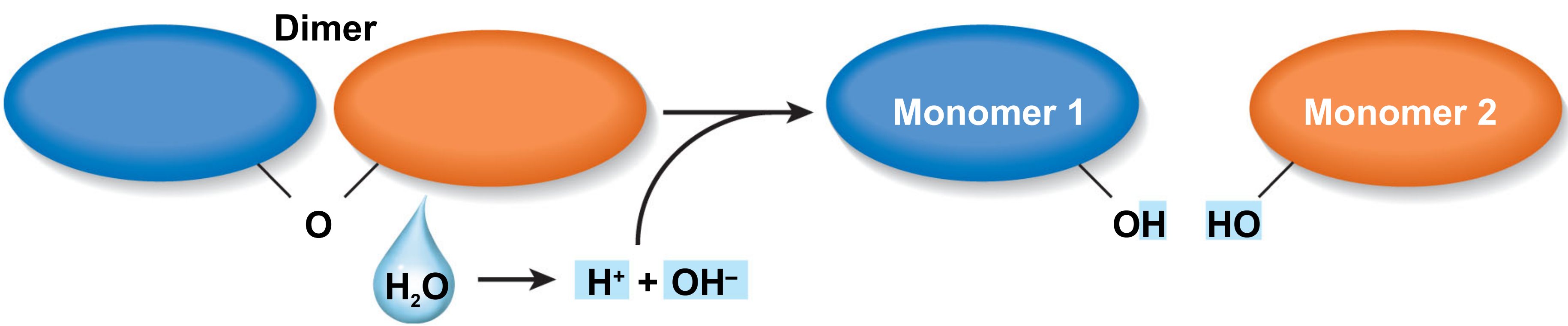


(a) Dehydration synthesis

Figure 2.15a

Hydrolysis

- **Splitting a polymer** (lysis) **by the addition of a water molecule** (hydro)
  - a covalent bond is broken
- All digestion reactions consists of hydrolysis reactions



(b) Hydrolysis

Figure 2.15b

Organic Molecules: Carbohydrates

- hydrophilic organic molecule
- **general formula**
  - **$(CH_2O)_n$** n = number of carbon atoms
  - for glucose, n = 6, so formula is $C_6H_{12}O_6$
  - 2:1 ratio of hydrogen to oxygen

Monosaccharides

- **Simplest carbohydrates**
  - **simple sugars**
- 3 important monosaccharides
  - **glucose, galactose and fructose**
  - same molecular formula - $\mathbf{C_6H_{12}O_6}$
    - **isomers**
  - produced by digestion of complex carbohydrates
    - **glucose is blood sugar**

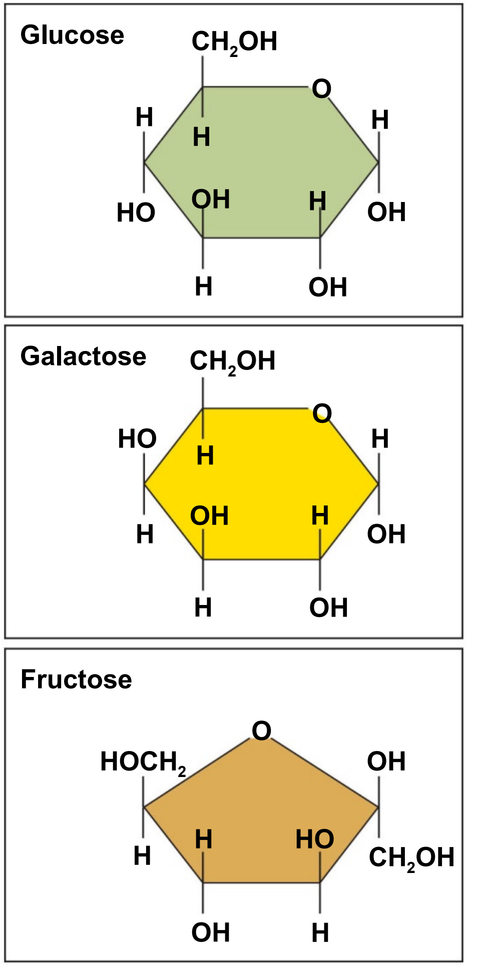


Figure 2.16

Disaccharides

- Sugar molecule composed of 2 monosaccharides
- **3 important disaccharides**
  - **sucrose -** table sugar
    - glucose + fructose
  - **lactose -** sugar in milk
    - glucose + galactose
  - **maltose -** grain products
    - glucose + glucose

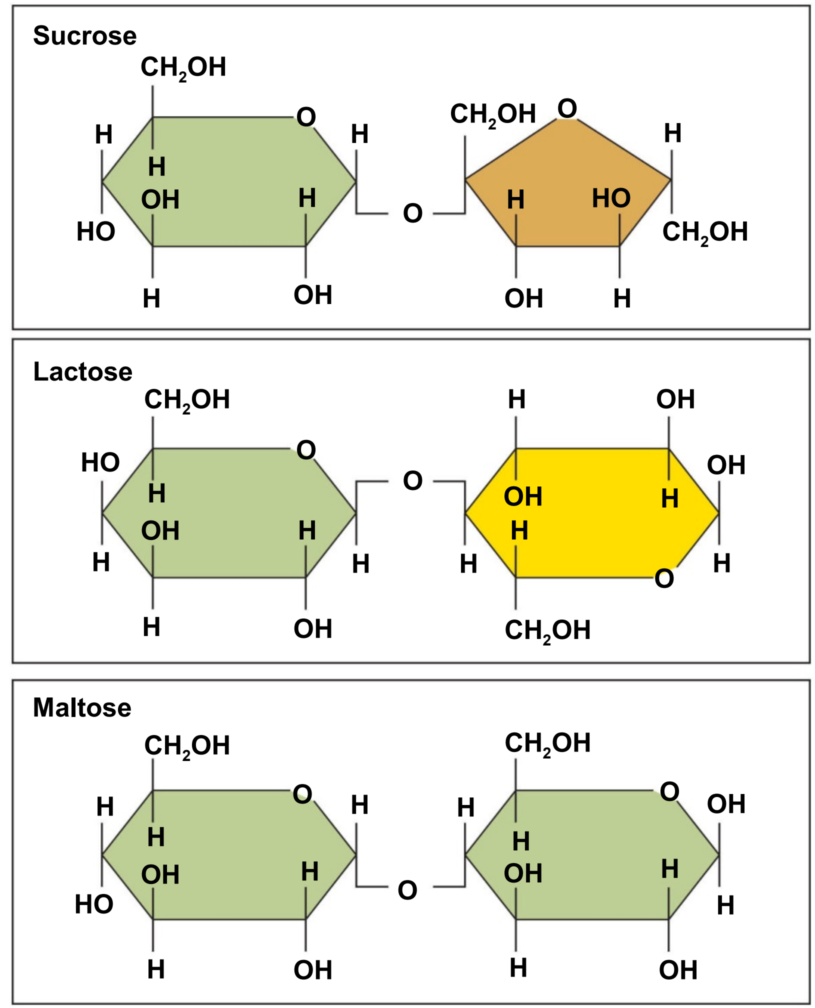


Figure 2.17

Polysaccharides

- long chains of **glucose**
- **3 polysaccharides of interest in humans**
  - **Glycogen:** energy storage polysaccharide in animals
    - made by cells of liver, muscles, brain, uterus, and vagina
    - liver produces glycogen after a meal when glucose level is high, then breaks it down between meals to maintain blood glucose levels
    - muscles store glycogen for own energy needs
    - uterus uses glycogen to nourish embryo
  - **Starch:** energy storage polysaccharide in plants
    - only significant digestible polysaccharide in the human diet
  - **Cellulose:** structural molecule of plant cell walls
    - fiber in our diet

Glycogen

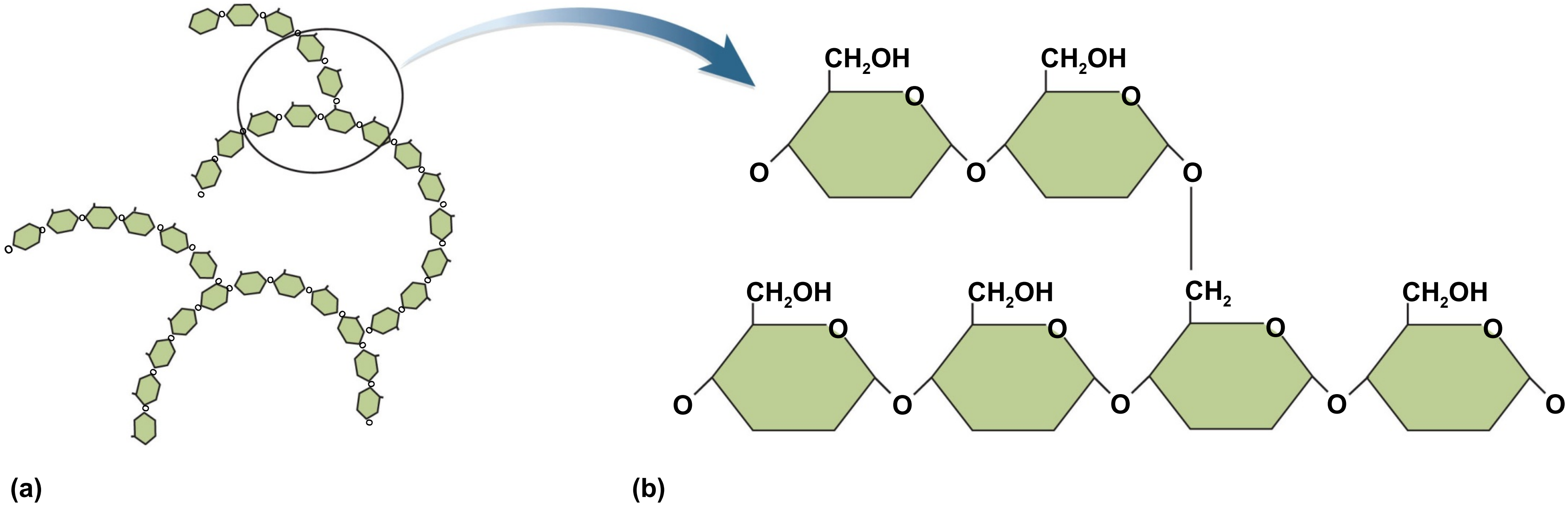


Figure 2.18

Carbohydrate Functions

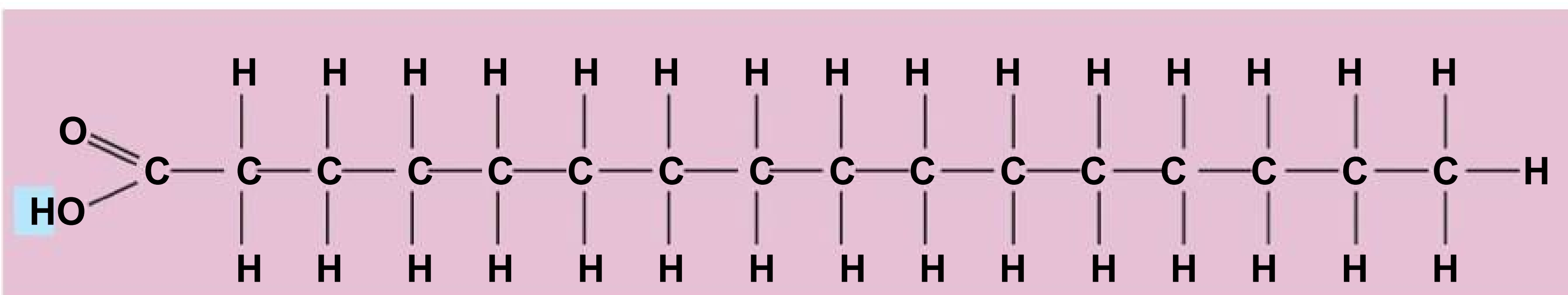
- quickly mobilized source of energy
  - all digested carbohydrates converted to glucose
  - oxidized to make ATP
- **Conjugated carbohydrate** – covalently bound to lipid or protein
  - **glycolipids**
    - external surface of cell membrane
  - **glycoproteins**
    - external surface of cell membrane
    - mucus of respiratory and digestive tracts
  - **proteoglycans** (mucopolysaccharides)
    - gels that hold cells and tissues together
    - forms gelatinous filler in umbilical cord and eye
    - joint lubrication
    - tough, rubbery texture of cartilage

Organic Molecules: Lipids

- **hydrophobic** organic molecule
  - composed of carbon, hydrogen and oxygen
  - with high ratio of hydrogen to oxygen
- Less oxidized than carbohydrates, and thus has more calories/gram
- Five primary types in humans
  - **fatty acids**
  - **triglycerides**
  - **phospholipids**
  - **eicosanoids**
  - **steroids**

Fatty Acids

- **Chain of 4 to 24 carbon atoms**
  - **carboxyl (acid) group** on one end, **methyl** group on the other and hydrogen bonded along the sides
- **Classified**
  - **saturated** - carbon atoms saturated with hydrogen
  - **unsaturated -** contains C=C bonds without hydrogen
  - **polyunsaturated** – contains many C=C bonds
  - **essential fatty acids** – obtained from diet, body can not synthesize



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

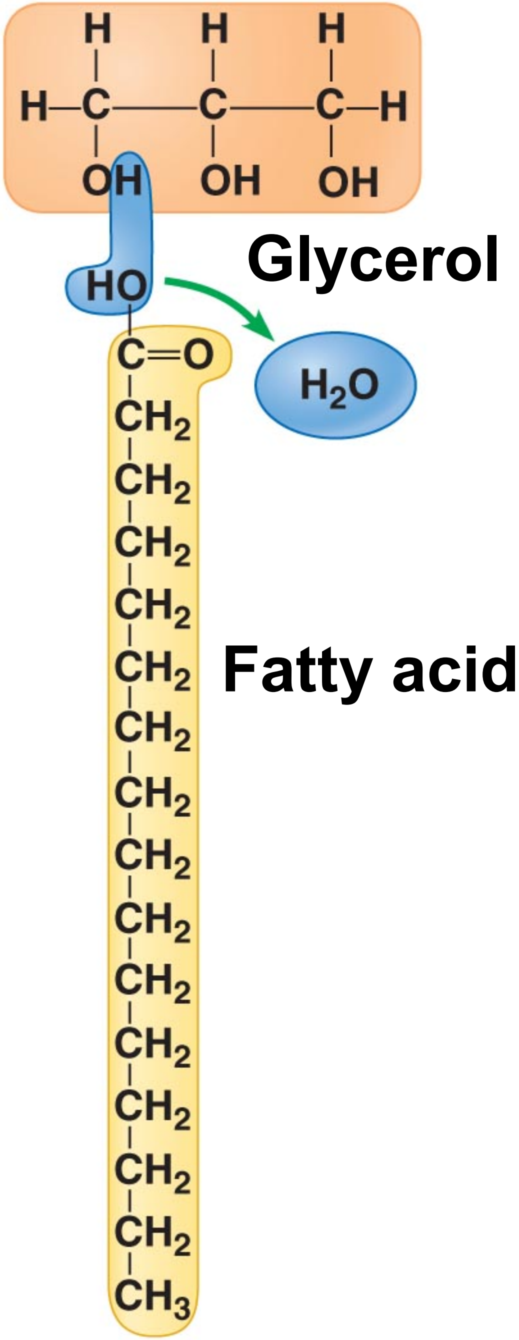
Figure 2.19

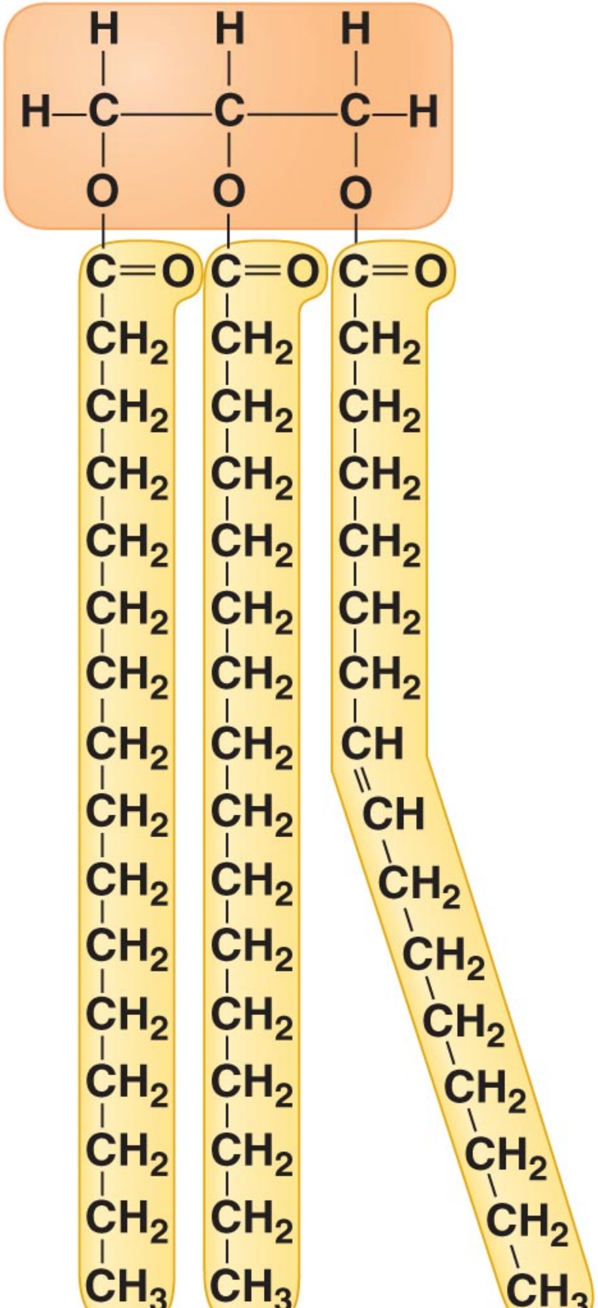
Triglycerides (Neutral Fats)

- 3 fatty acids covalently bonded to three carbon alcohol, glycerol molecule
  - each bond formed by dehydration synthesis
  - once joined to glycerol, fatty acids can no longer donate protons – **neutral fats**
  - 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, insulation and shock absorption (adipose tissue)


H
H
H
H
C
C
C
H
OH
OH
OH
HO
Glycerol
H2O
C=O
CH2
CH2
CH2
CH2
CH2
CH2
CH2
CH2
CH2
CH2
CH2
CH2
CH2
CH2
CH3
Fatty acid



Phospholipids

- similar to neutral fat except that one fatty acid replaced by a phosphate group
- structural foundation of cell membrane
- **Amphiphilic**
  - fatty acid “tails” are **hydrophobic**
  - phosphate “head” is **hydrophilic**

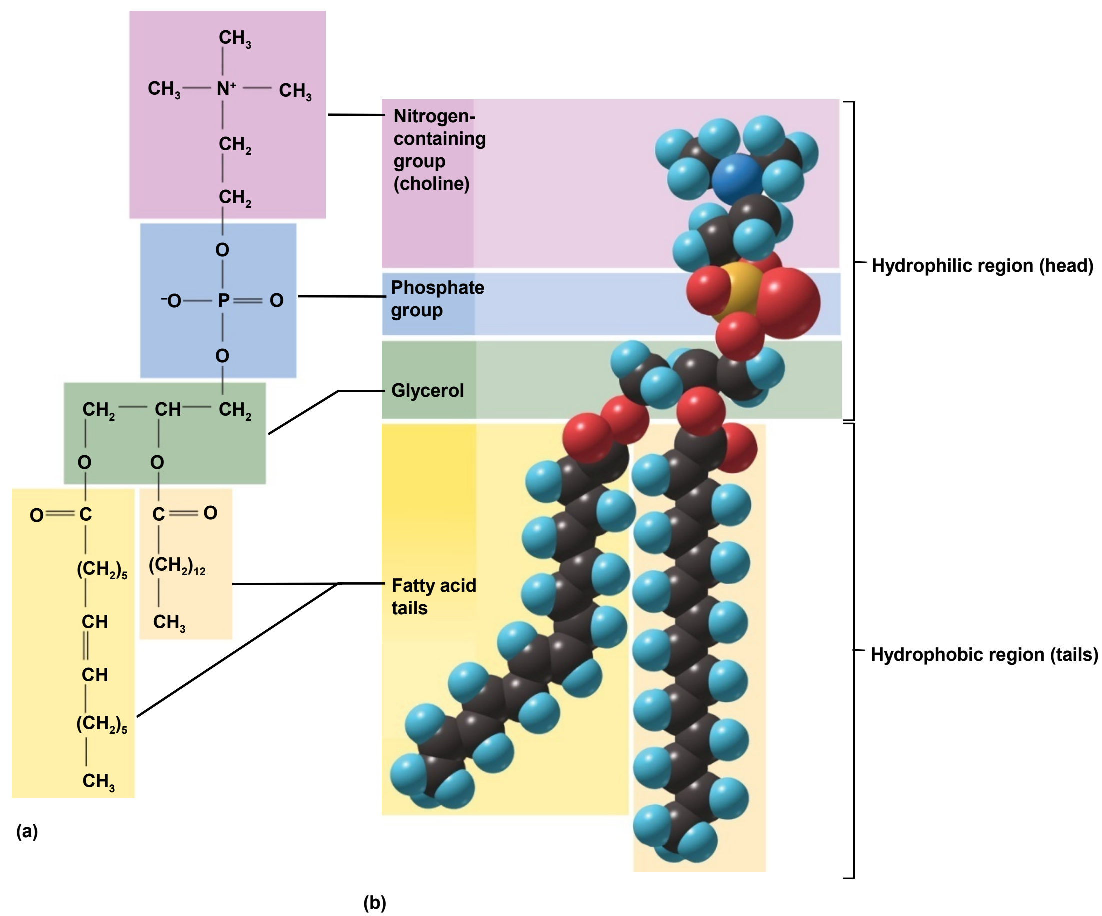


Figure 2.20a,b

Eicosanoids

- 20 carbon compounds derived from a fatty acid called **arachidonic acid**
- hormone-like chemical signals between cells
- includes **prostaglandins –** produced in all tissues
  - role in inflammation, blood clotting, hormone action, labor contractions, blood vessel diameter

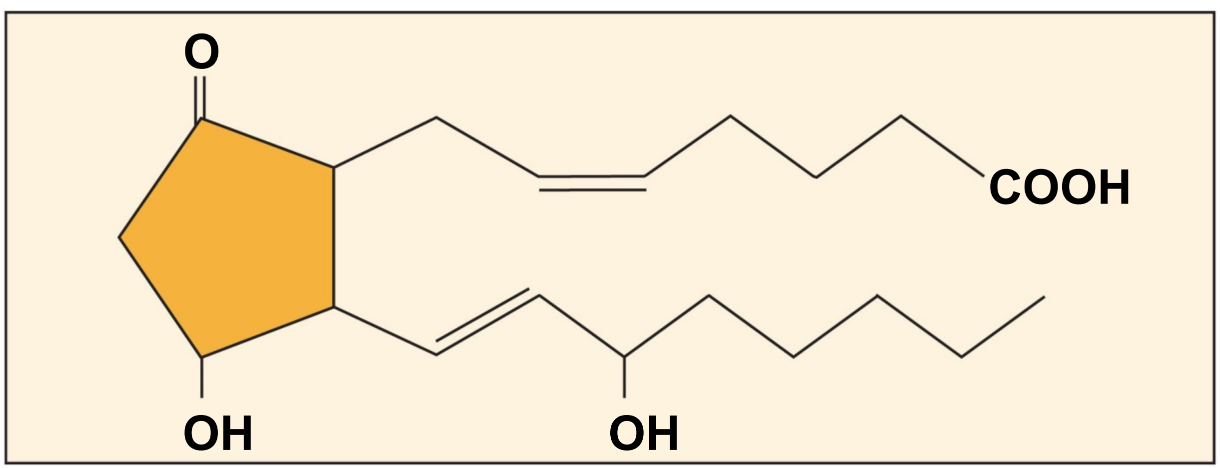


Figure 2.21

Steroids and Cholesterol

- **Steroid** – a lipid with 17 of its carbon atoms in four rings
- **Cholesterol** - the ‘parent’ steroid from which the other steroids are synthesized
  - cortisol, progesterone, estrogens, testosterone and bile acids
  - important component of cell membranes

“Good” and “Bad” Cholesterol

- **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

Cholesterol

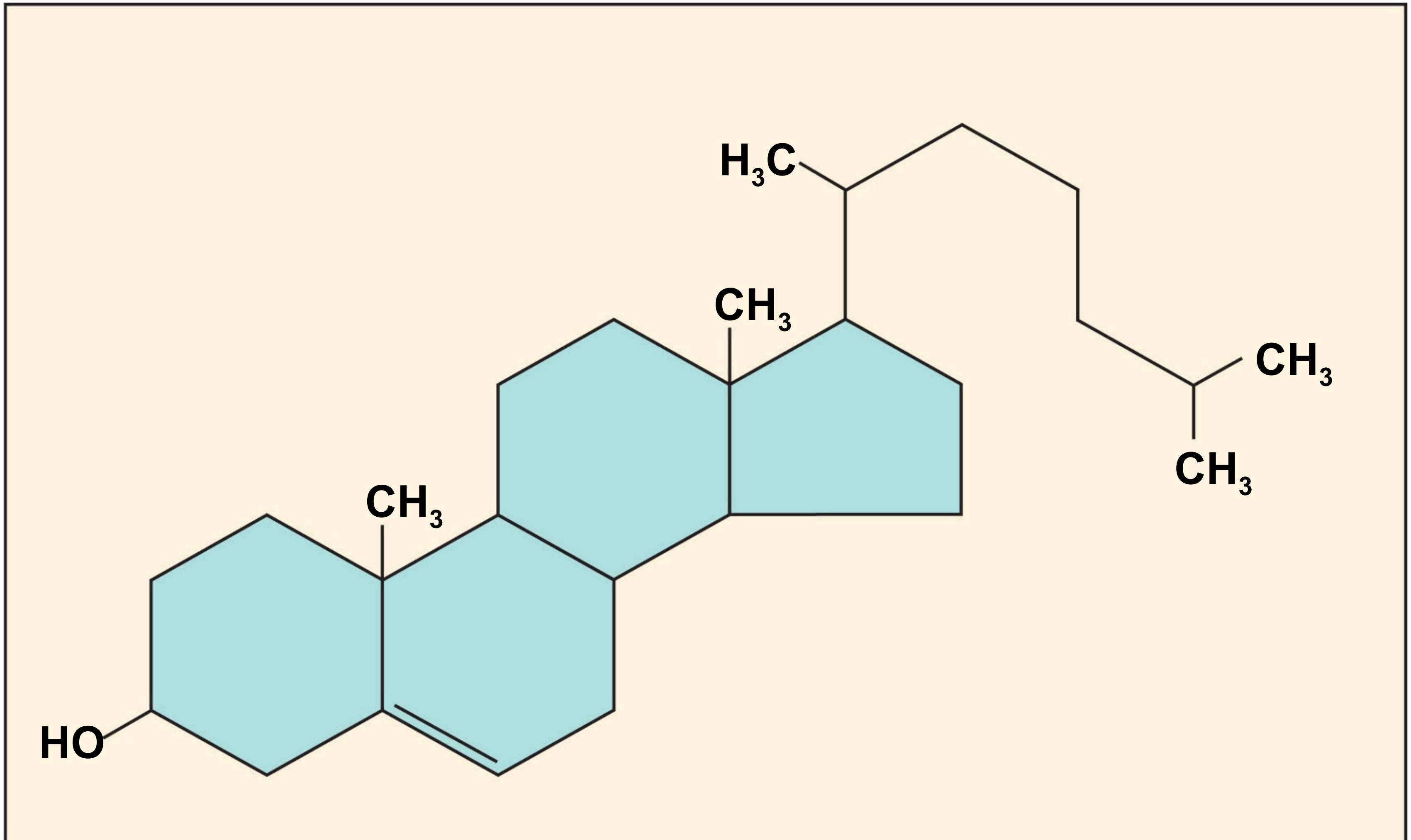
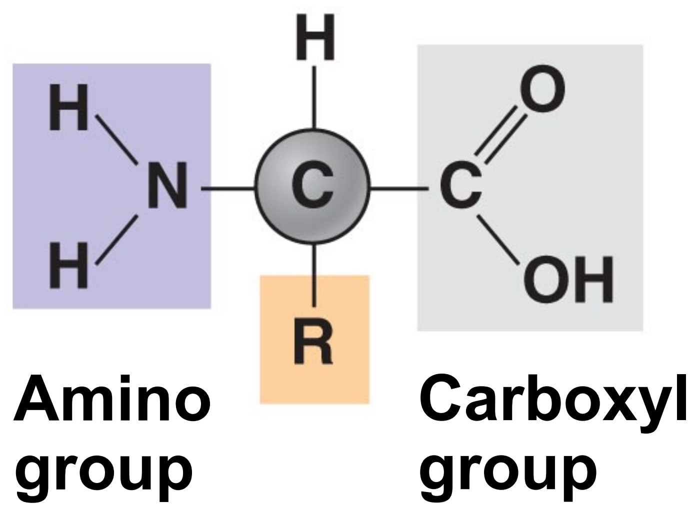


Figure 2.22

Organic Molecules: Proteins

- most versatile molecules in the body
- **protein** - a polymer of amino acids
- **amino acid** – central carbon with 3 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


H
H
N
H
C
R
O
C
OH
Amino group
Carboxyl group

Representative Amino Acids

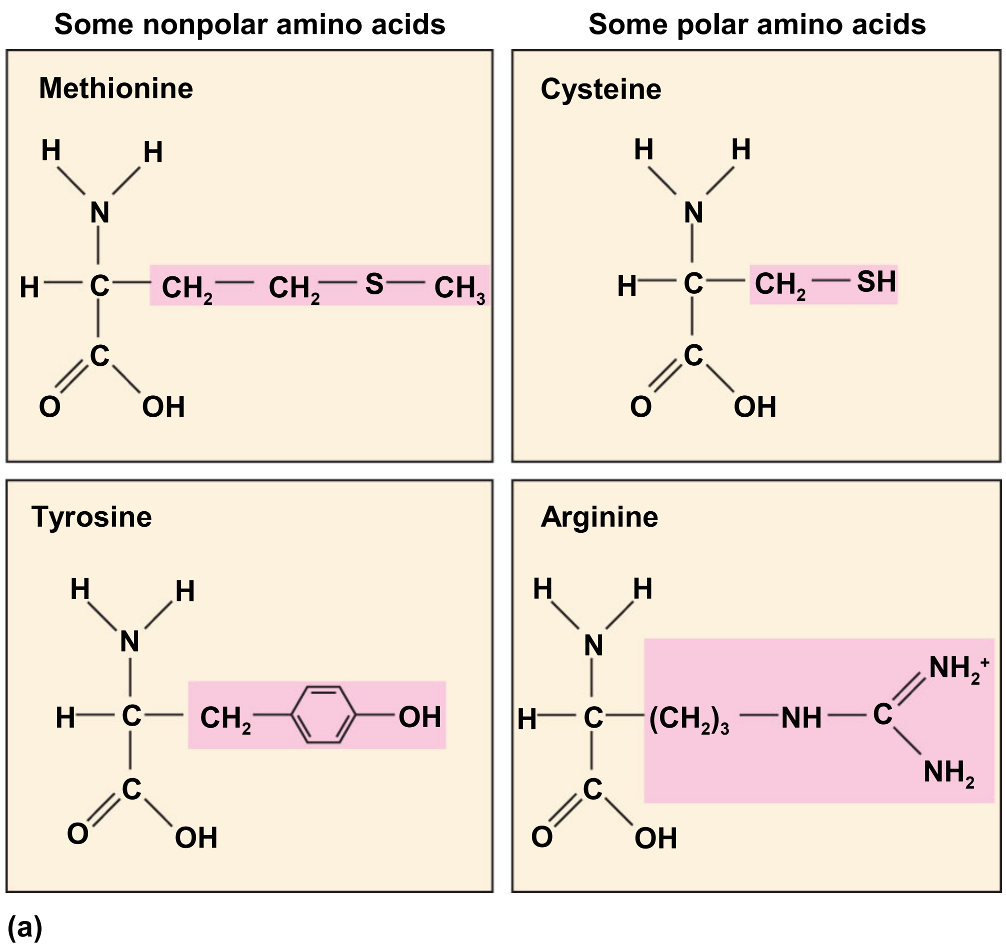


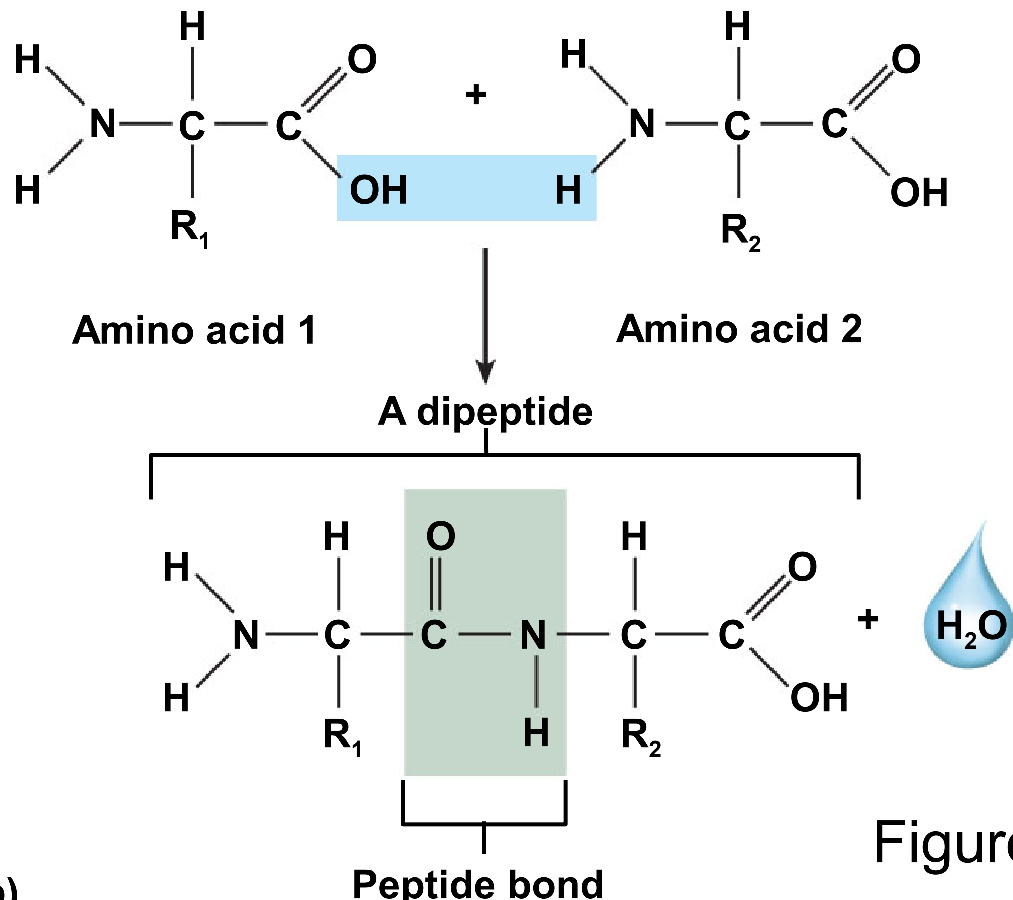
Figure 2.23a

- Note: they differ only in the R group

Naming of Peptides

- **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 to 15
  - **polypeptides** have more than 15
  - **proteins** have more than 50

Dipeptide Synthesis



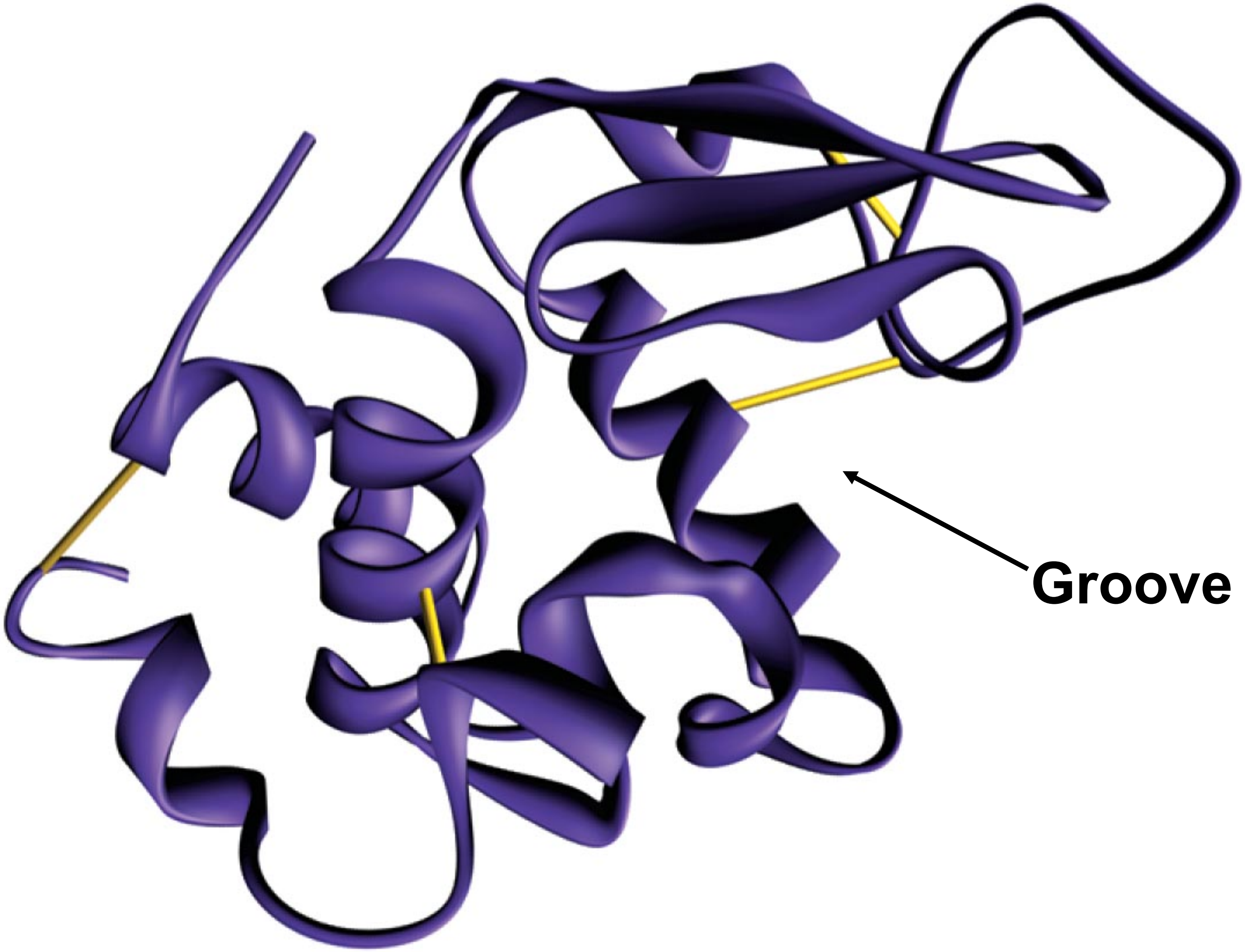
(b)

Figure 2.23b

- Dehydration synthesis creates a peptide bond that joins amino acids

Protein Structure and Shape

- **Primary structure**
  - protein's sequence amino acid which is encoded in the genes
- **Secondary structure**
  - coiled or folded shape held together by hydrogen bonds
  - For example – alpha helix, beta pleated sheet
- **Tertiary structure**
  - Three dimensional arrangement of secondary structures
- **Quaternary structure**
  - associations of two or more separate polypeptide chains
  - For example - hemoglobin


Groove

Structure of Proteins

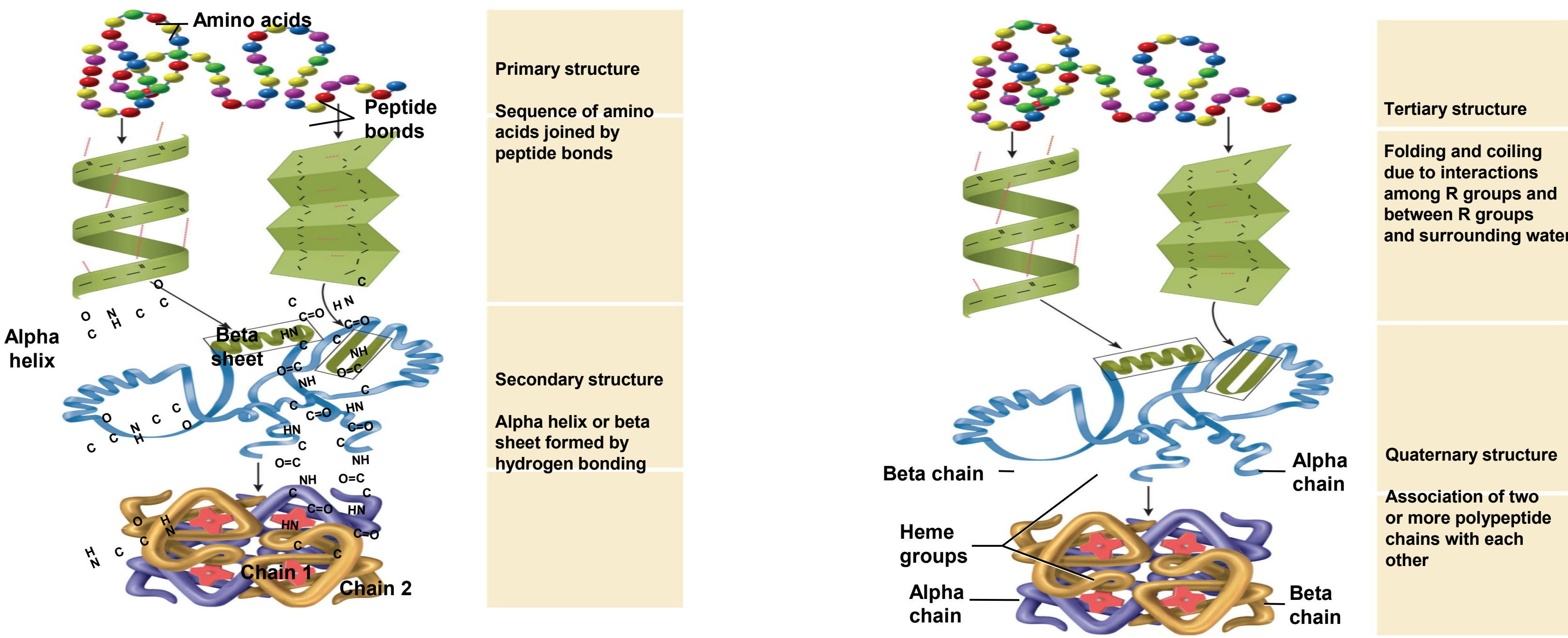


Figure 2.24

Protein Conformation and Denaturation

- **Conformation –** unique three dimensional shape of protein crucial to function
  - ability to reversibly change their conformation
    - enzyme function
    - muscle contraction
    - opening and closing of cell membrane pores
- **Denaturation**
  - extreme conformational change that destroys function
    - extreme heat or pH

Conjugated Proteins

- Proteins that contain a non-amino acid moiety called a **prosthetic group**
- Hemoglobin contains four complex iron containing rings called a ***heme* moieties**

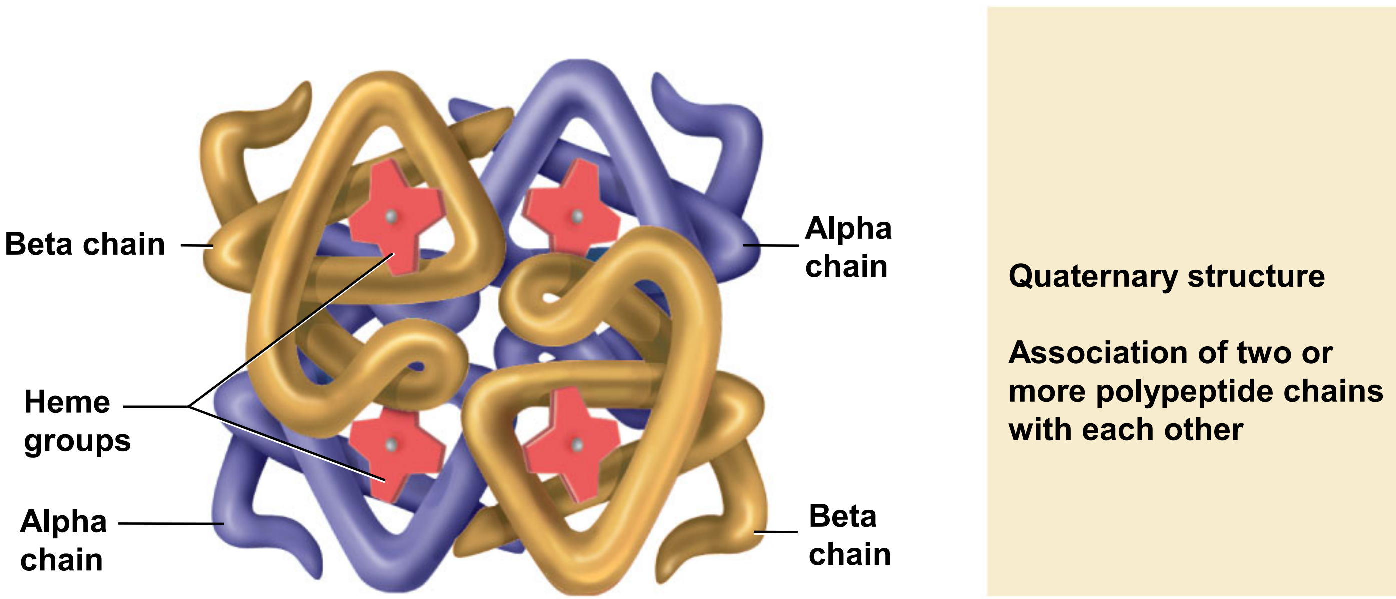


Figure 2.24 (4)

Primary Structure of Insulin

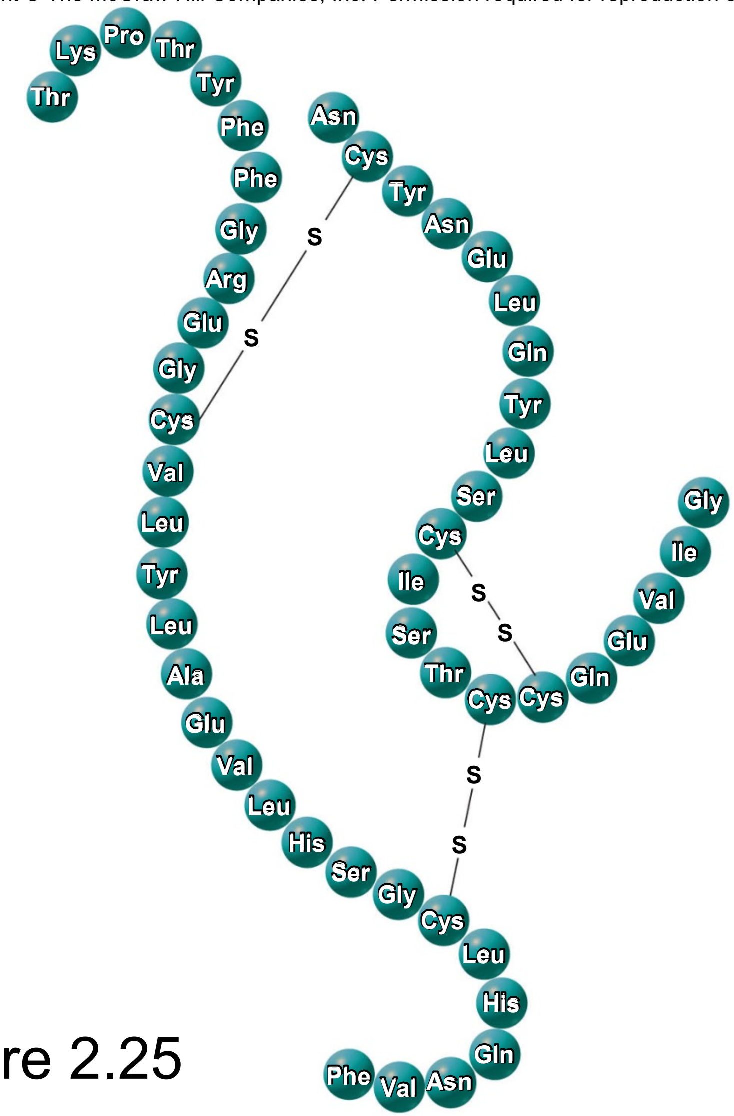


Figure 2.25

Protein Functions

- **Structure**
  - keratin – tough structural protein
    - gives strength to hair, nails, and skin surface
  - collagen – durable protein contained in deeper layers of skin, bones, cartilage, and teeth
- **Communication**
  - some hormones and other cell-to-cell signals
  - receptors to which signal molecules bind
    - ligand – any hormone or molecule that reversibly binds to a protein
- **Membrane Transport**
  - channels in cell membranes that governs what passes through
  - carrier proteins – transports solute particles to other side of membrane
  - turn nerve and muscle activity on and off

Protein Functions

- **Catalysis**
  - enzymes
- **Recognition and Protection**
  - immune recognition
  - antibodies
  - clotting proteins
- **Movement**
  - **motor proteins** - molecules with the ability to change shape repeatedly
- **Cell adhesion**
  - proteins bind cells together
  - immune cells to bind to cancer cells
  - keeps tissues from falling apart

Enzymes

- Enzymes - proteins that function as biological catalysts
  - permit reactions to occur rapidly at normal body temperature
- Substrate - substance an enzyme acts upon
- Lowers **activation energy** - energy needed to get reaction started
  - enzymes facilitate molecular interaction

Enzymes and Activation Energy

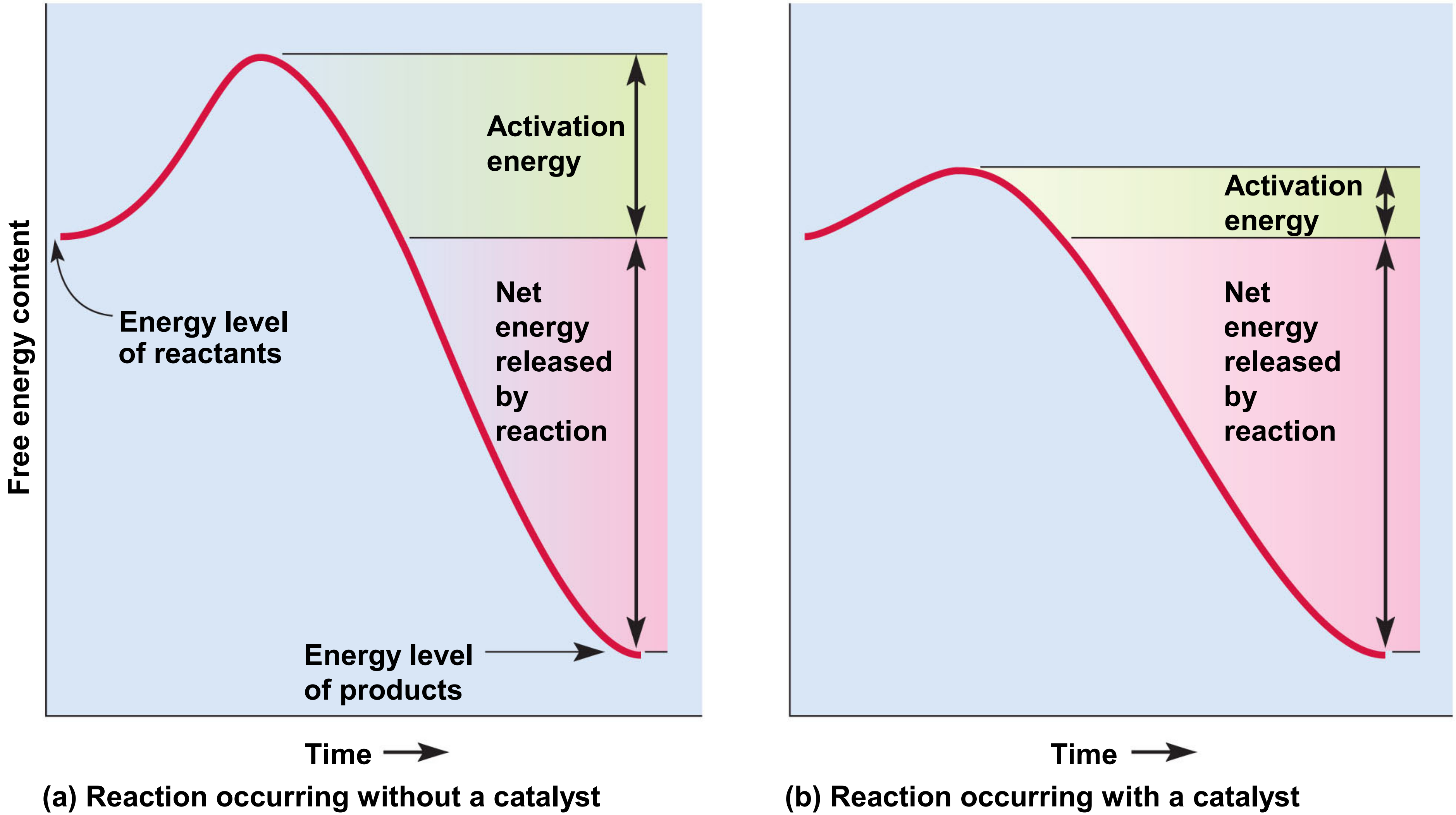


Figure 2.26a, b

Enzymatic Reaction Steps

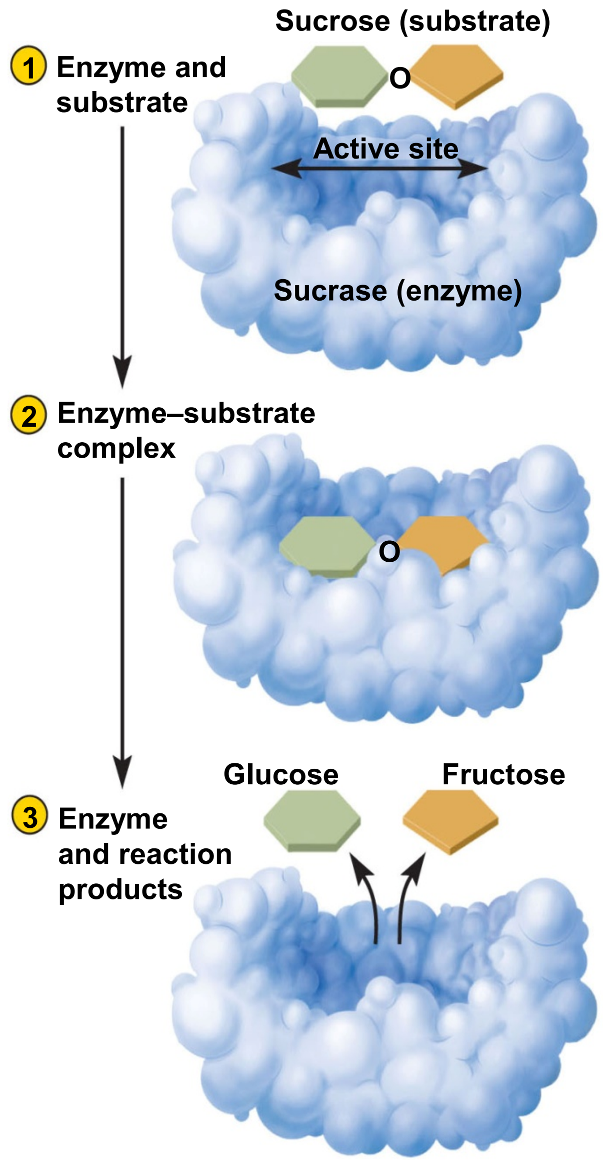


Figure 2.27

Enzymatic Action

- enzymes are not consumed by the reactions
- one enzyme molecule can consume millions of substrate molecules per minute
- **Factors that change enzyme shape**
  - pH and temperature
  - alters or destroys the ability of the enzyme to bind to substrate
  - enzymes vary in optimum pH
    - salivary amylase works best at pH 7.0
    - pepsin works best at pH 2.0
  - temperature optimum for human enzymes – body temperature (37 degrees C)

Cofactors and Coenzymes

- **Cofactors**
  - about 2/3rds of human enzymes require a nonprotein cofactor
  - inorganic partners (iron, copper, zinc, magnesium and calcium ions)
  - some bind to enzyme and induces a change in its shape, which activates the active site
  - essential to function
- **Coenzymes**
  - organic cofactors derived from water-soluble vitamins (niacin, riboflavin)
  - they accept electrons from an enzyme in one metabolic pathway and transfer them to an enzyme in another

Coenzyme NAD$^+$

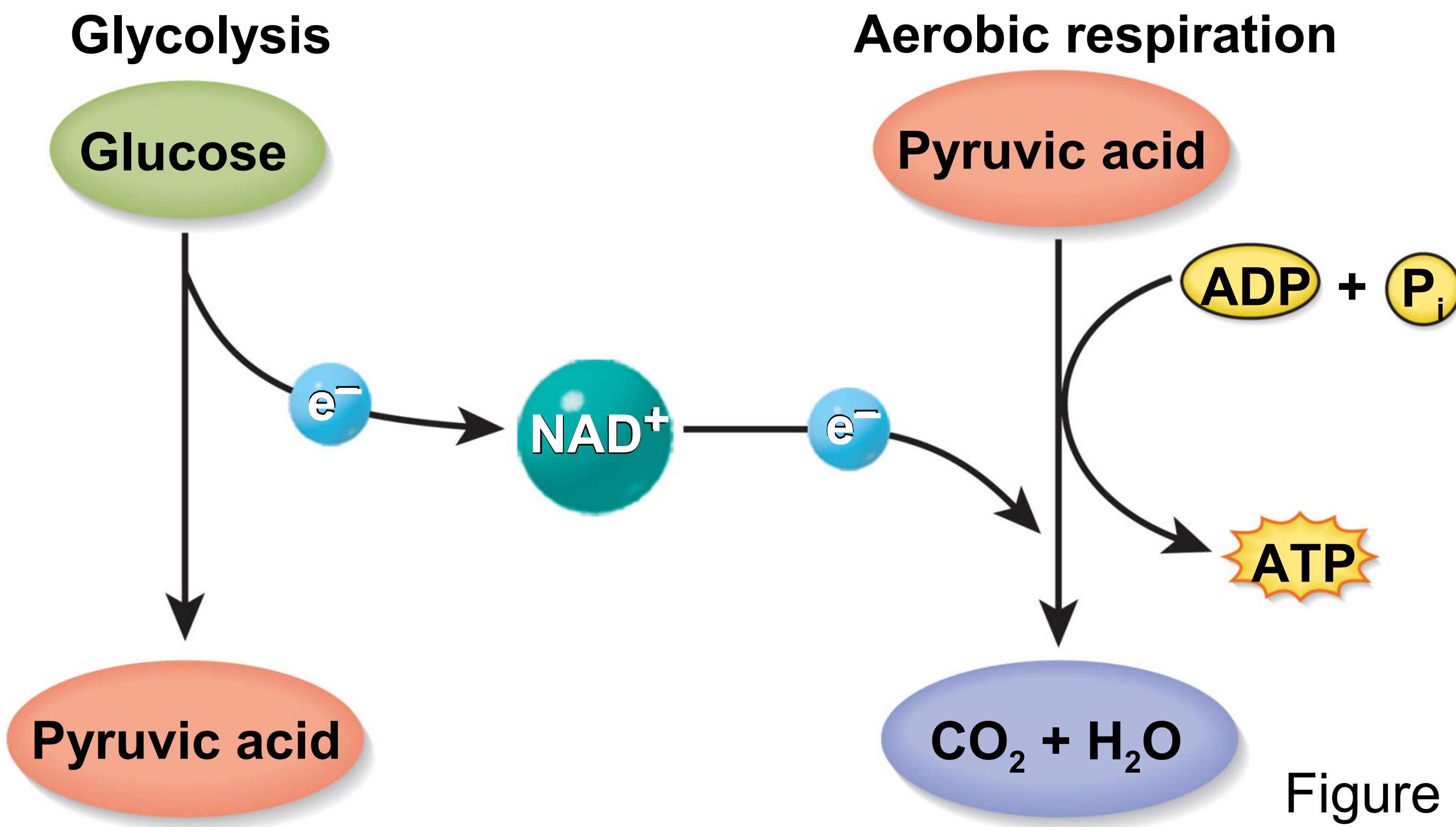


Figure 2.28

- NAD$^+$ transports electrons from one metabolic pathway to another

Metabolic Pathways

- Chain of reactions, with each step usually catalyzed by a different enzyme
- ✔ ✔ ■

  A ✹ B ✹ C ✹ D

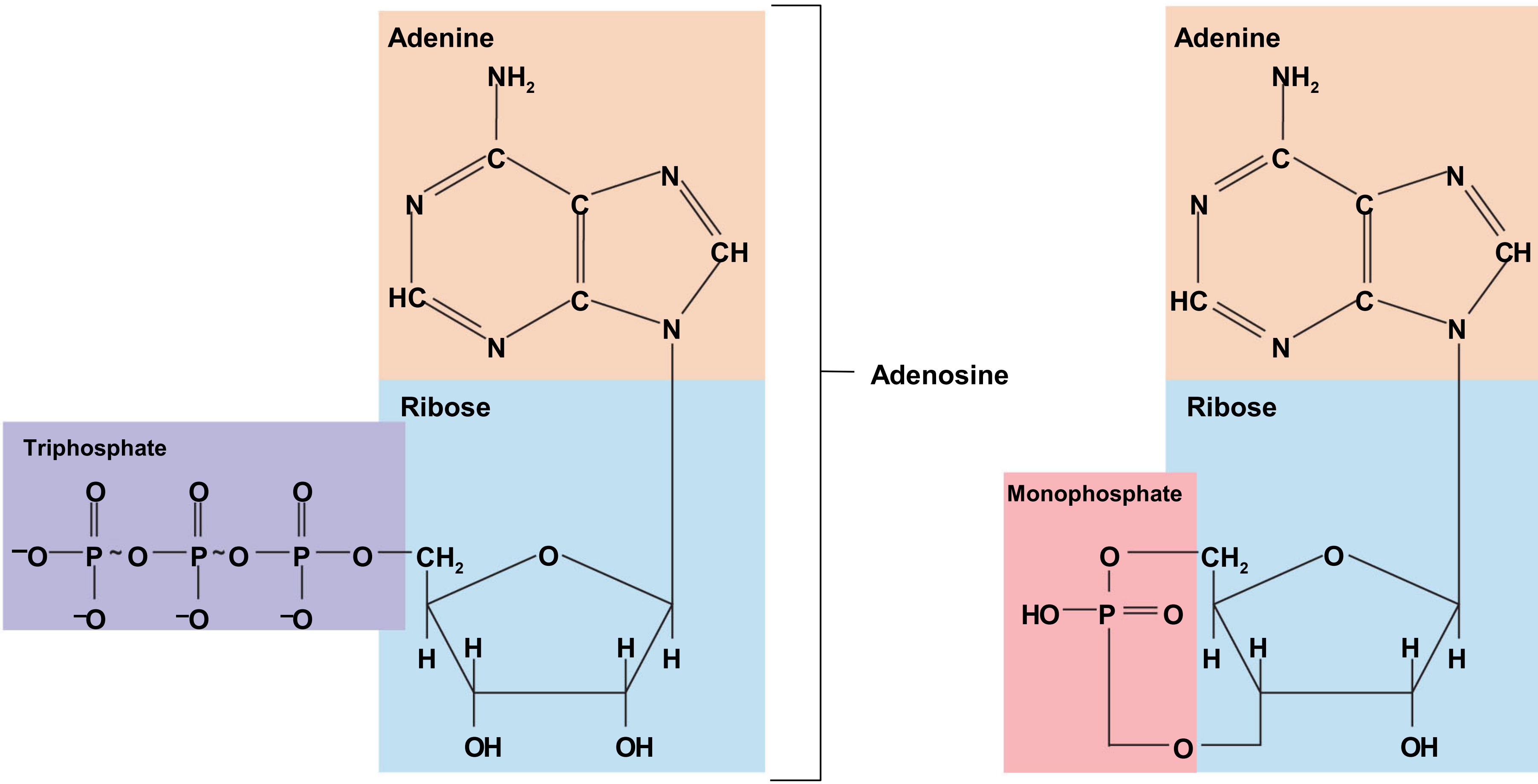
- A is **initial reactant**, B+C are **intermediates** and D is the **end product**
- Regulation of metabolic pathways
  - activation or deactivation of the enzymes
  - cells can turn on or off pathways when end products are needed and shut them down when the end products are not needed

Organic Molecules: Nucleotides

- **3 components of nucleotides**
  - **nitrogenous base** (single or double carbon-nitrogen ring)
  - **sugar** (monosaccharide)
  - one or more **phosphate groups**

- **ATP –** best know nucleotide
  - **adenine** (nitrogenous base)
  - **ribose** (sugar)
  - **phosphate groups** (3)

ATP (Adenosine Triphosphate)



(a) Adenosine triphosphate (ATP) (b) Cyclic adenosine monophosphate (cAMP)

Figure 2.29a, b

ATP contains adenine, ribose and 3 phosphate groups

Adenosine Triphosphate (ATP)

- body's most important energy-transfer molecule
- briefly stores energy gained from exergonic reactions
- releases it within seconds for physiological work
- holds energy in covalent bonds
  - 2nd and 3rd phosphate groups have high energy bonds ~
  - most energy transfers to and from ATP involve adding or removing the 3rd phosphate
- **Adenosine triphosphatases (ATPases)** hydrolyze the 3rd high energy phosphate bond
  - separates into ADP + P_i + energy
- **Phosphorylation**
  - addition of free phosphate group to another molecule
  - carried out by enzymes called **kinases** (phosphokinases)

Sources and Uses of ATP

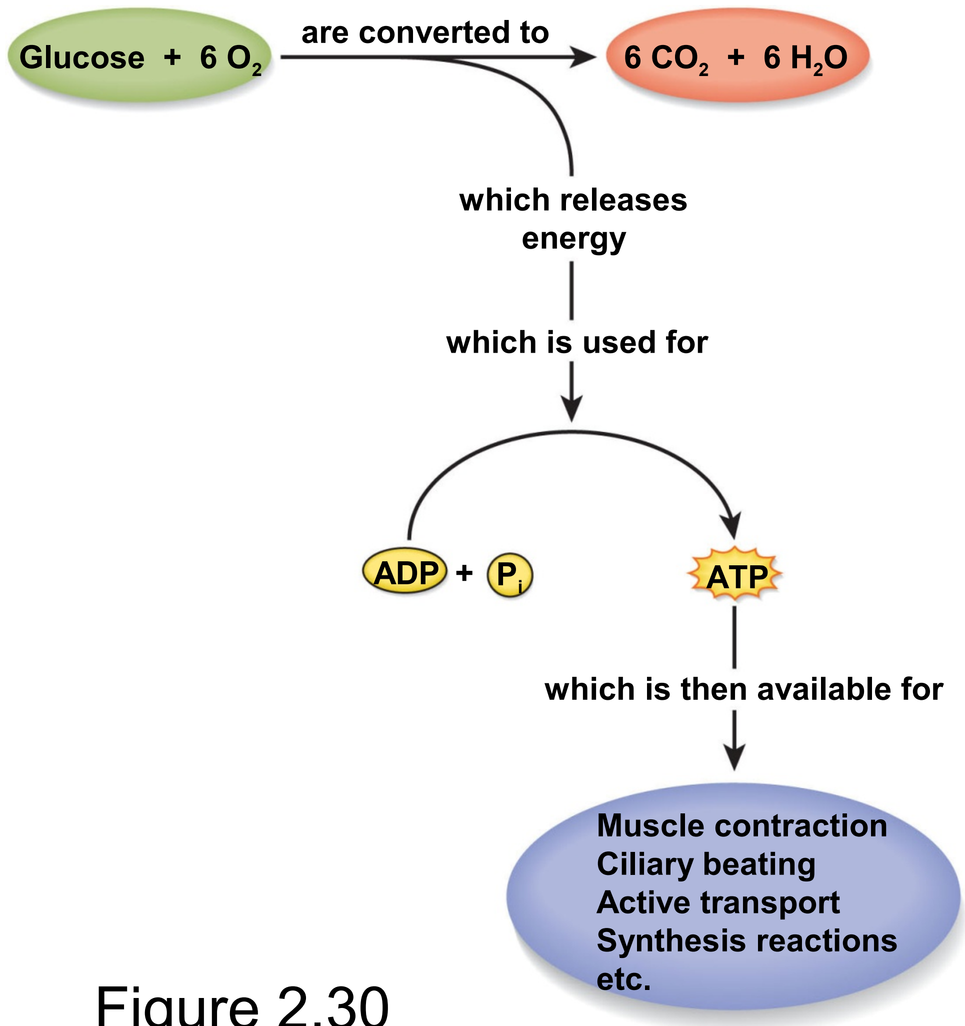


Figure 2.30

Overview of ATP Production

Stages of glucose oxidation

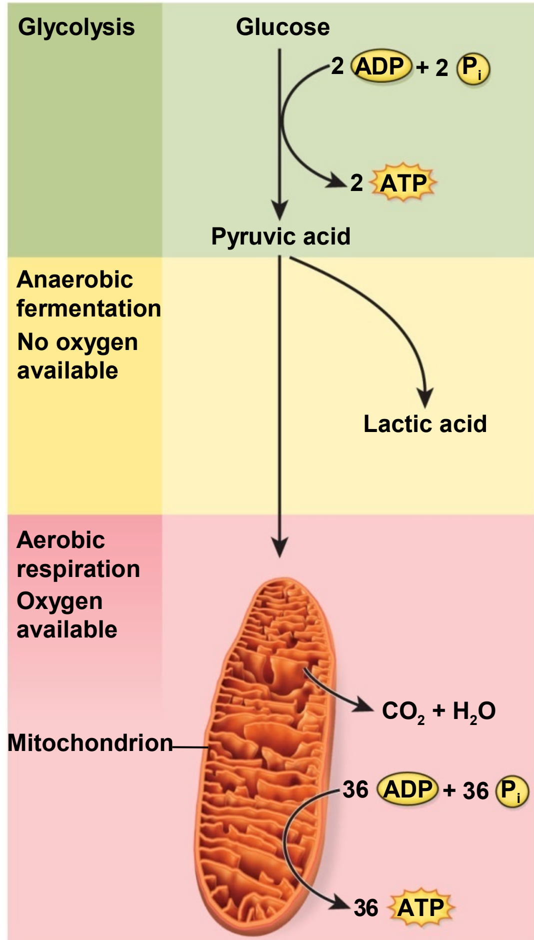


Figure 2.31

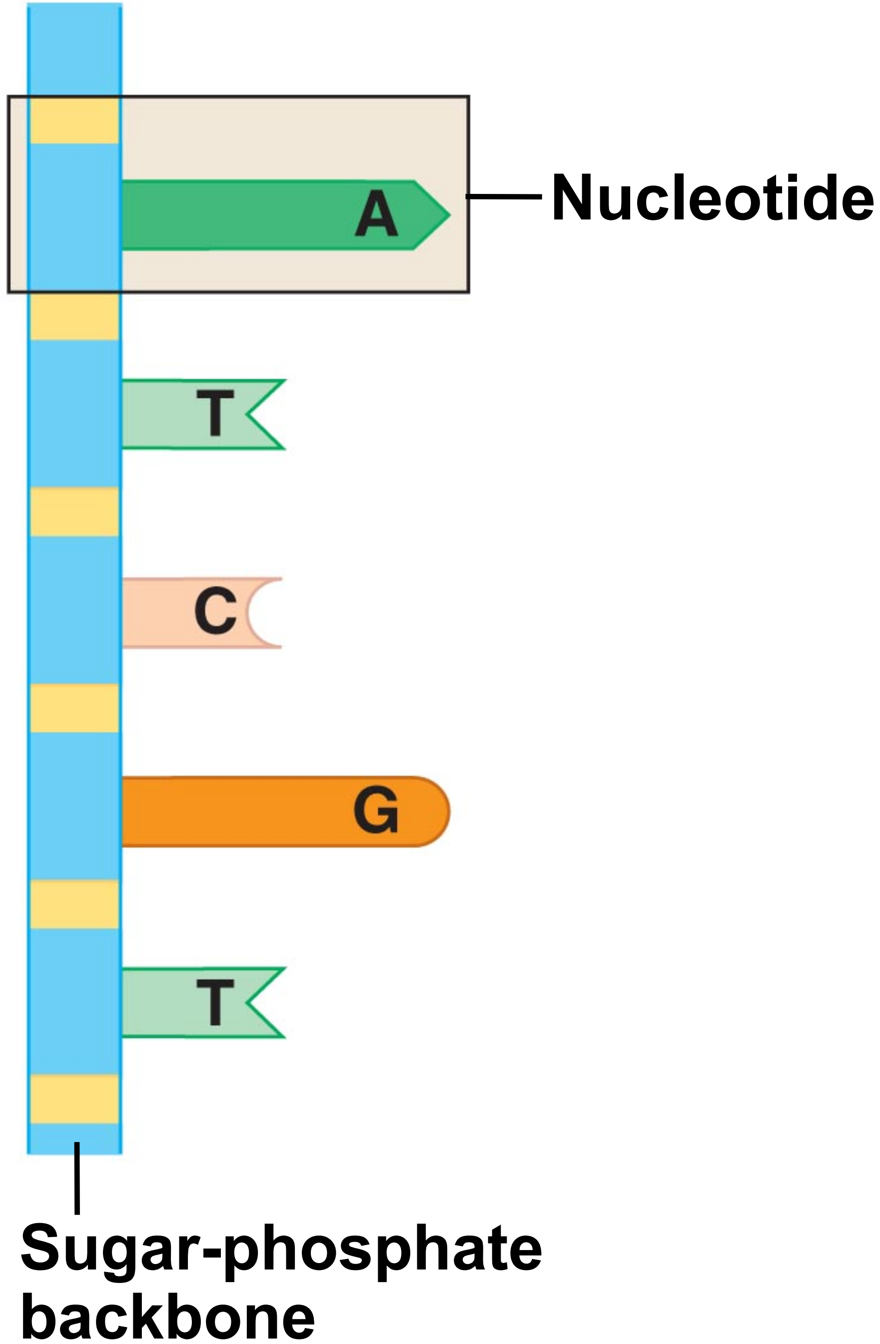
- ATP consumed within 60 seconds of formation
- entire amount of ATP in the body would support live for less than 1 minute if it were not continually replenished
- cyanide halts ATP synthesis

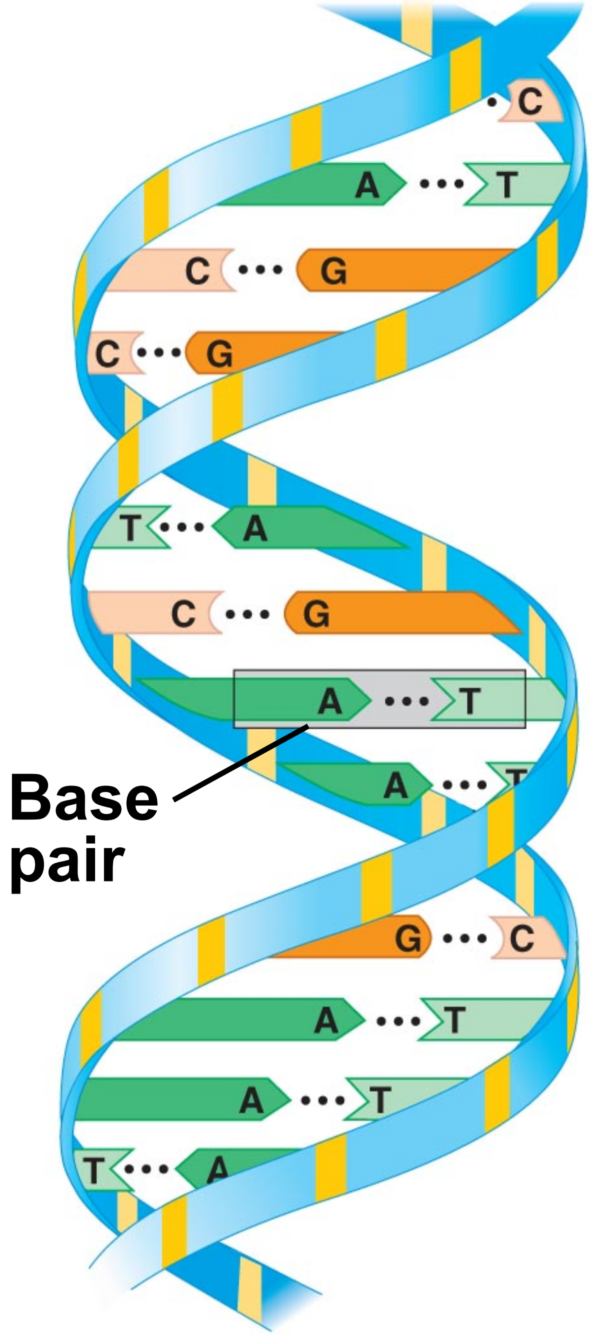
Other Nucleotides

- **Guanosine triphosphate (GTP)**
  - another nucleotide involved in energy transfer
  - donates phosphate group to other molecules
- **Cyclic adenosine monophosphate (cAMP)**
  - nucleotide formed by removal of both second and third phosphate groups from ATP
  - formation triggered by hormone binding to cell surface
  - cAMP becomes "second messenger" within cell
  - activates metabolic effects inside cell

Nucleic Acids

- polymers of nucleotides
- **DNA (deoxyribonucleic acid)**
  - 100 million to 1 billion nucleotides long
  - constitutes genes
    - instructions for synthesizing all of the body's proteins
    - transfers hereditary information from cell to cell and generation to generation
- **RNA (ribonucleic acid)** – 3 types
  - messenger RNA, ribosomal RNA, transfer RNA
  - 70 to 10,000 nucleotides long
  - carries out genetic instruction for synthesizing proteins
  - assembles amino acids in the right order to produce proteins


Nucleotide
A
T
C
G
T
Sugar-phosphate
backbone


C
A ••• T
C ••• G
C ••• G
T ••• A
C ••• G
A ••• T
A ••• T
G ••• C
A ••• T
A ••• T
T ••• A
Base pair

3.16 Nucleic acids are information-rich polymers of nucleotides

A particular nucleotide sequence that can instruct the formation of a polypeptide is called a **gene**

- Most DNA molecules consist of millions of base pairs and, consequently, many genes
- These genes, many of which are unique to the species, determine the structure of proteins and, thus, life's structures and functions