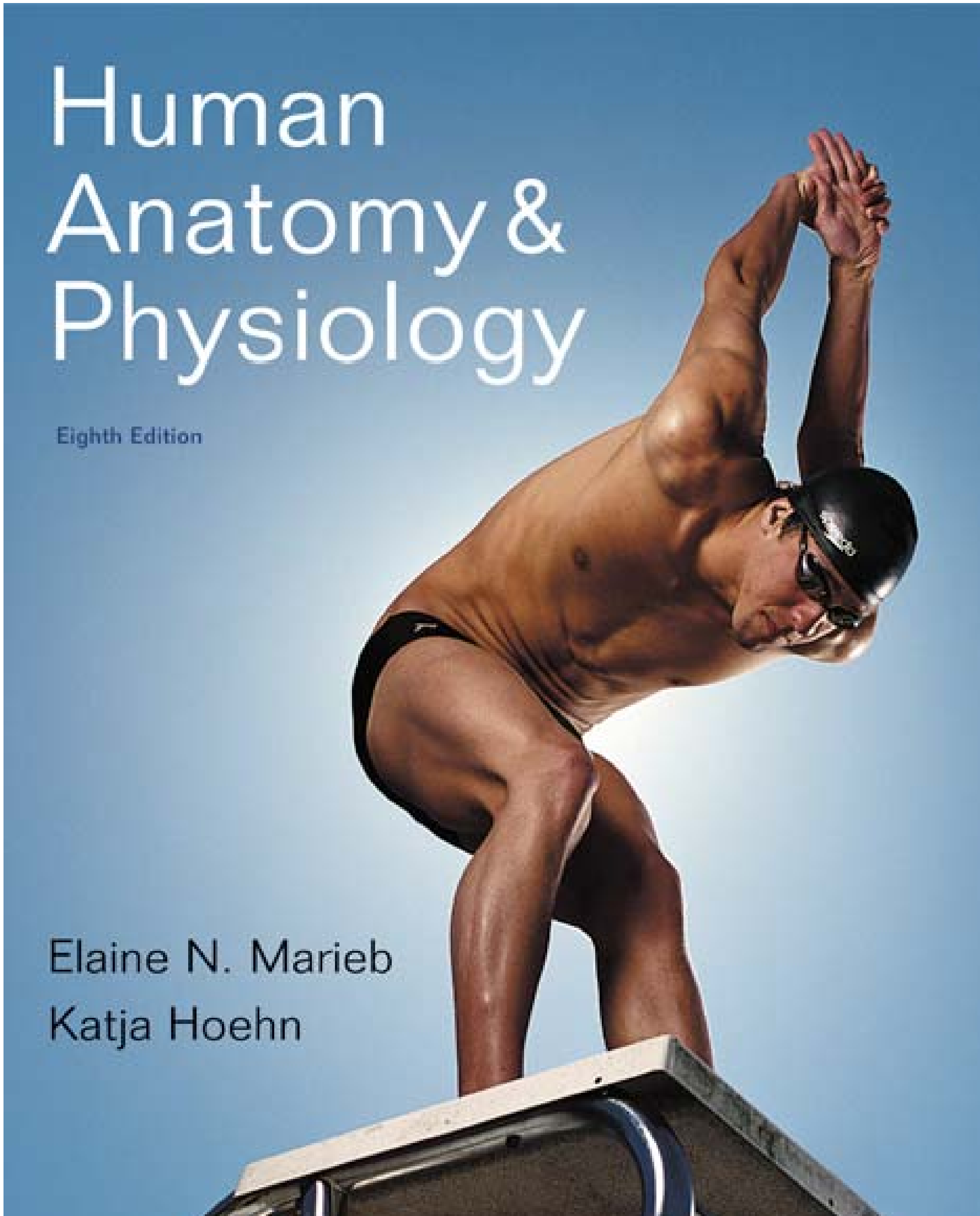




PowerPoint® Lecture Slides
prepared by
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# CHAPTER 2

# Chemistry Comes Alive: Part B

# Classes of Compounds

- Inorganic compounds
  - Water, salts, and many acids and bases
  - Do not contain carbon
- Organic compounds
  - Carbohydrates, fats, proteins, and nucleic acids
  - Contain carbon, usually large, and are covalently bonded

# Water

- 60%–80% of the volume of living cells
- Most important inorganic compound in living organisms because of its properties

# Properties of Water

- High heat capacity
  - Absorbs and releases heat with little temperature change
  - Prevents sudden changes in temperature
- High heat of vaporization
  - Evaporation requires large amounts of heat
  - Useful cooling mechanism

## Properties of Water

- Polar solvent properties
  - Dissolves and dissociates ionic substances
  - Forms hydration layers around large charged molecules, e.g., proteins (colloid formation)
  - Body's major transport medium

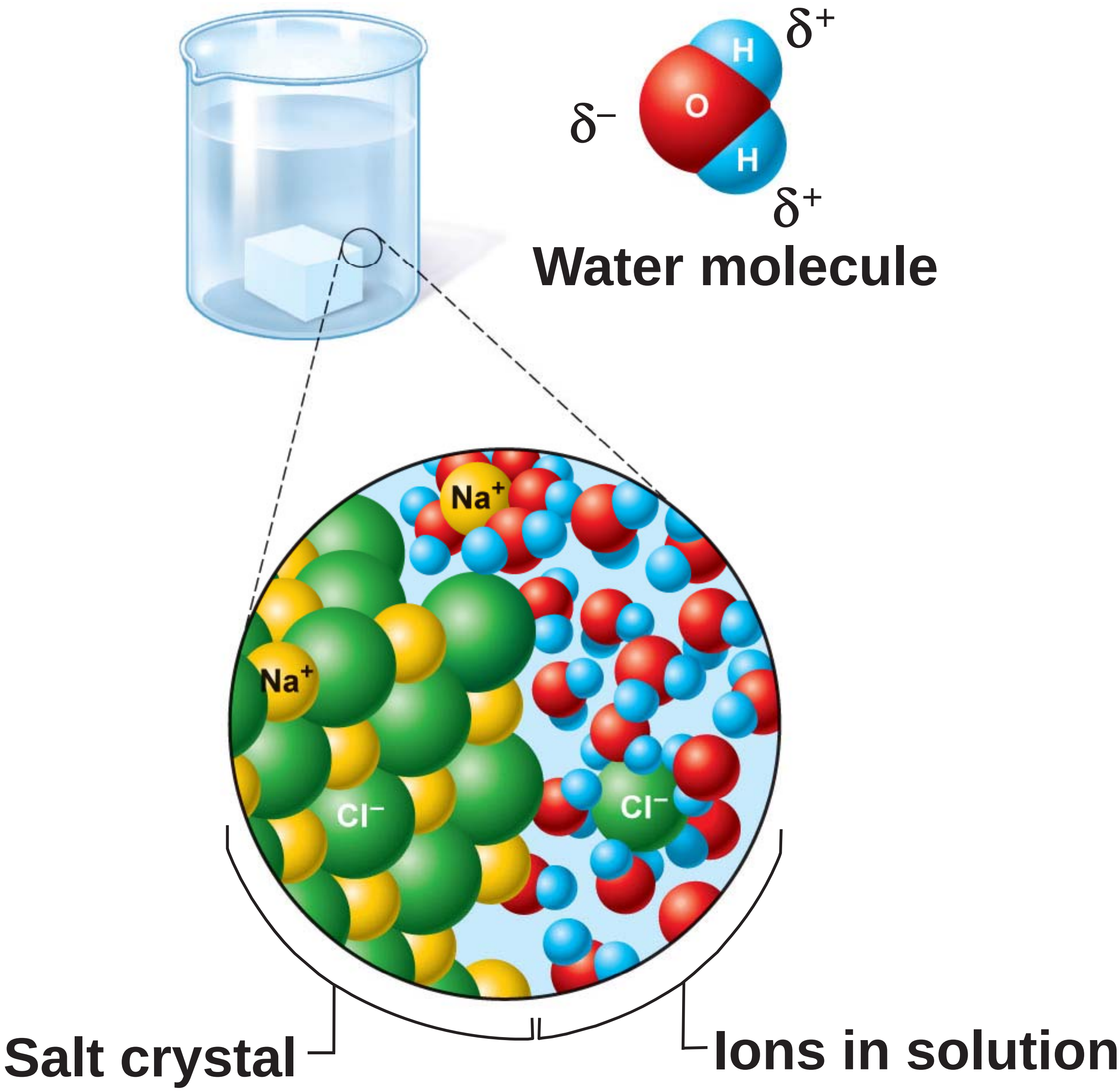

δ+
H
δ−
O
H
δ+
Water molecule
Na+
Na+
Cl−
Cl−
Salt crystal
Ions in solution



Figure 2.12

## Properties of Water

- Reactivity
  - A necessary part of hydrolysis and dehydration synthesis reactions
- Cushioning
  - Protects certain organs from physical trauma, e.g., cerebrospinal fluid

# Salts

- Ionic compounds that dissociate in water
- Contain cations other than $H^+$ and anions other than $OH^-$
- Ions (electrolytes) conduct electrical currents in solution
- Ions play specialized roles in body functions (e.g., sodium, potassium, calcium, and iron)

# Acids and Bases

- Both are electrolytes
  - Acids are proton (hydrogen ion) donors (release $H^+$ in solution)
    - $HCl \rightarrow H^+ + Cl^-$

# Acids and Bases

- Bases are proton acceptors (take up $H^+$ from solution)
  - $NaOH \rightarrow Na^+ + OH^-$
    - $OH^-$ accepts an available proton (H+)
    - $OH^- + H^+ \rightarrow H_2O$
- Bicarbonate ion ($HCO_3^-$) and ammonia ($NH_3$) are important bases in the body

# Acid-Base Concentration

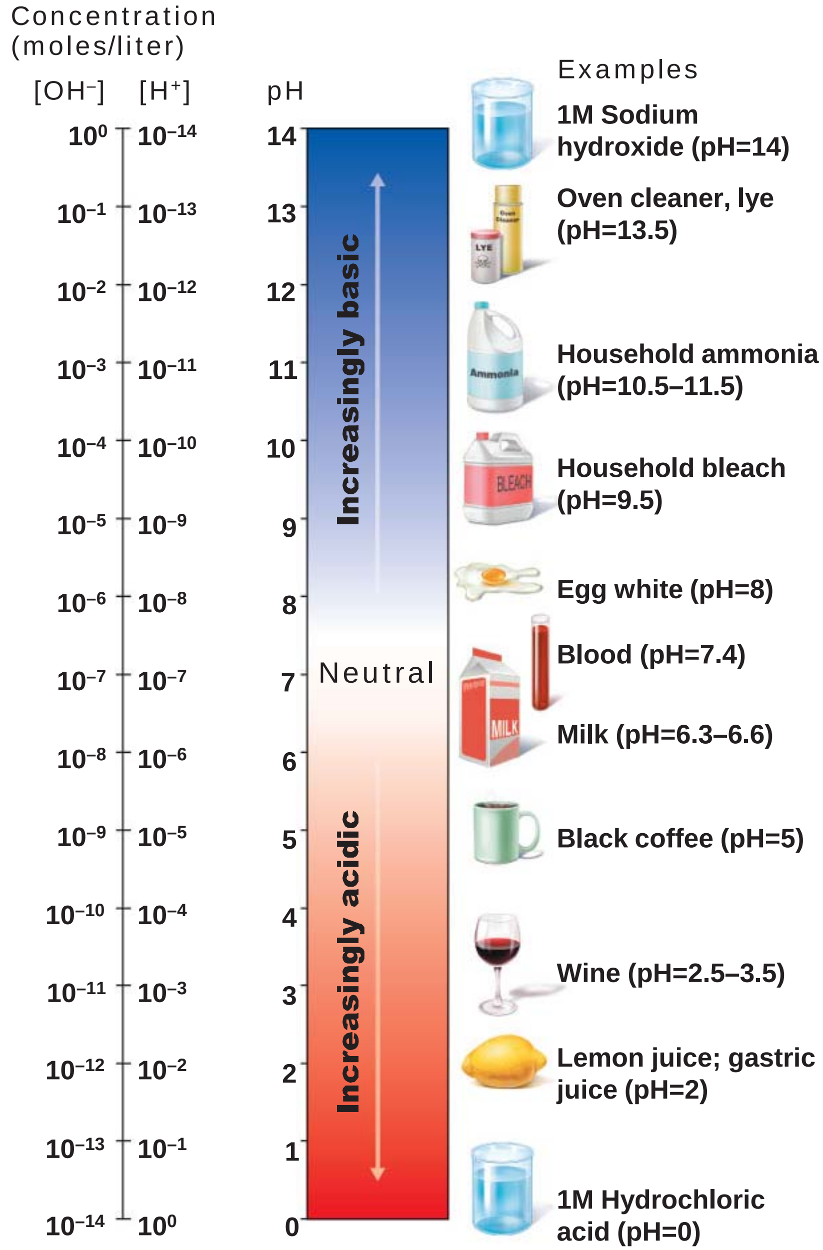
- Acid solutions contain [$H^+$]
  - As [$H^+$] increases, acidity increases
- Alkaline solutions contain bases (e.g., $OH^-$)
  - As [$H^+$] decreases (or as [$OH^-$] increases), alkalinity increases

# pH: Acid-Base Concentration

- pH = the negative logarithm of $[H^+]$ in moles per liter
- Neutral solutions:
  - Pure water is pH neutral (contains equal numbers of $H^+$ and $OH^–$)
  - pH of pure water = pH 7: $[H^+] = 10^{–7}$ M
  - All neutral solutions are pH 7

# pH: Acid-Base Concentration

- Acidic solutions
  - ↑ $[H^+]$, ↓ pH
  - Acidic pH: 0–6.99
  - pH scale is logarithmic: a pH 5 solution has 10 times more $H^+$ than a pH 6 solution
- Alkaline solutions
  - ↓ $[H^+]$, ↑ pH
  - Alkaline (basic) pH: 7.01–14



Concentration (moles/liter)
[OH⁻]
[H⁺]
pH
Examples
10⁰ 10⁻¹⁴ 14
10⁻¹ 10⁻¹³ 13
10⁻² 10⁻¹² 12
10⁻³ 10⁻¹¹ 11
10⁻⁴ 10⁻¹⁰ 10
10⁻⁵ 10⁻⁹ 9
10⁻⁶ 10⁻⁸ 8
10⁻⁷ 10⁻⁷ 7
10⁻⁸ 10⁻⁶ 6
10⁻⁹ 10⁻⁵ 5
10⁻¹⁰ 10⁻⁴ 4
10⁻¹¹ 10⁻³ 3
10⁻¹² 10⁻² 2
10⁻¹³ 10⁻¹ 1
10⁻¹⁴ 10⁰ 0
Increasingly basic
Neutral
Increasingly acidic
1M Sodium hydroxide (pH=14)
Oven cleaner, lye (pH=13.5)
LYE
Household ammonia (pH=10.5–11.5)
Ammonia
Household bleach (pH=9.5)
BLEACH
Egg white (pH=8)
Blood (pH=7.4)
Milk (pH=6.3–6.6)
MILK
Black coffee (pH=5)
Wine (pH=2.5–3.5)
Lemon juice; gastric juice (pH=2)
1M Hydrochloric acid (pH=0)




Figure 2.13

# Acid-Base Homeostasis

- pH change interferes with cell function and may damage living tissue
- Slight change in pH can be fatal
- pH is regulated by kidneys, lungs, and buffers

# Buffers

- Mixture of compounds that resist pH changes
- Convert strong (completely dissociated) acids or bases into weak (slightly dissociated) ones
  - Carbonic acid-bicarbonate system

Response to rise in pH

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

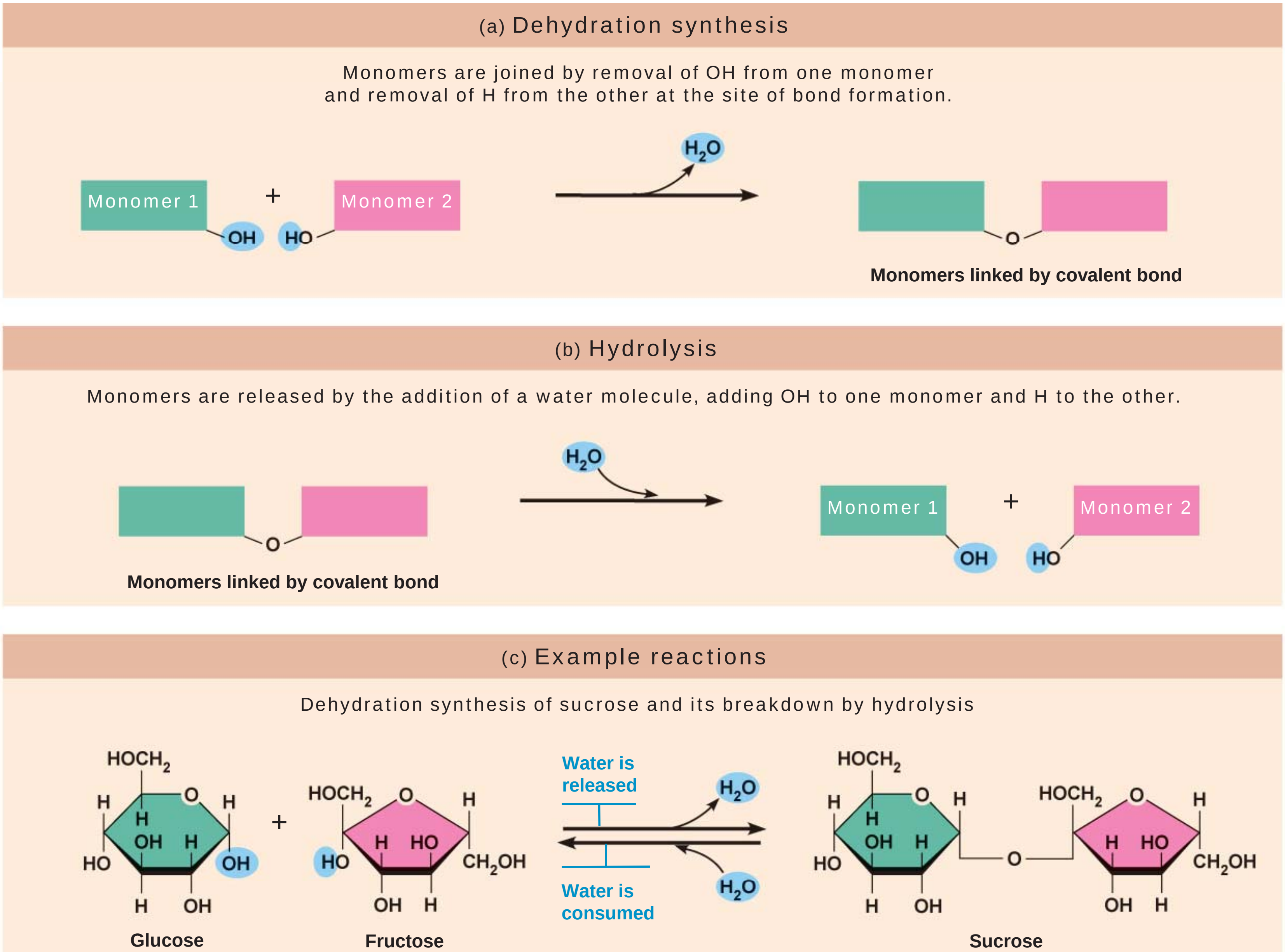
$H^+$ donor (weak acid) — Response to drop in pH — $H^+$ acceptor (weak base) — proton

# Organic Compounds

- Contain carbon (except $CO_2$ and CO, which are inorganic)
- Unique to living systems
- Include carbohydrates, lipids, proteins, and nucleic acids

# Organic Compounds

- Many are polymers—chains of similar units (monomers or building blocks)
  - Synthesized by dehydration synthesis
  - Broken down by hydrolysis reactions



(a) Dehydration synthesis
Monomers are joined by removal of OH from one monomer and removal of H from the other at the site of bond formation.
Monomer 1
+
Monomer 2
OH
HO
H2O
O
Monomers linked by covalent bond
(b) Hydrolysis
Monomers are released by the addition of a water molecule, adding OH to one monomer and H to the other.
H2O
O
Monomers linked by covalent bond
Monomer 1
+
Monomer 2
OH
HO
(c) Example reactions
Dehydration synthesis of sucrose and its breakdown by hydrolysis
HOCH2
H
O
H
H
OH
H
HO
OH
H
OH
Glucose
+
HOCH2
O
H
H
HO
HO
CH2OH
OH
H
Fructose
Water is released
H2O
Water is consumed
H2O
HOCH2
O
H
HOCH2
O
H
CH2OH
Sucrose




Figure 2.14

# Carbohydrates

- Sugars and starches
- Contain C, H, and O [$(CH_20)_n$]
- Three classes
  - Monosaccharides
  - Disaccharides
  - Polysaccharides

# Carbohydrates

- Functions
  - Major source of cellular fuel (e.g., glucose)
  - Structural molecules (e.g., ribose sugar in RNA)

# Monosaccharides

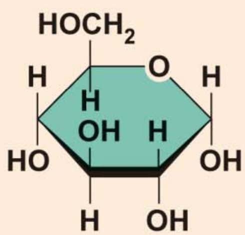
- Simple sugars containing three to seven C atoms
- $(CH_2 0)_n$

# (a) Monosaccharides

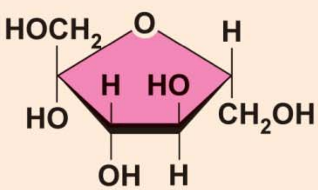
Monomers of carbohydrates

Example

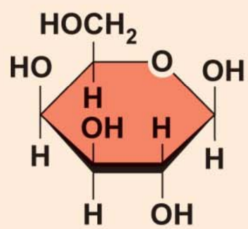
**Hexose sugars (the hexoses shown here are isomers)**




**Glucose**



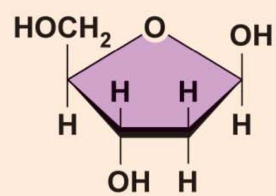

**Fructose**



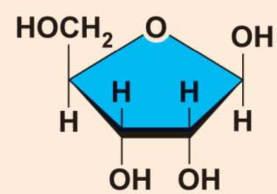

**Galactose**

Example

**Pentose sugars**




**Deoxyribose**




**Ribose**



Figure 2.15a

# Disaccharides

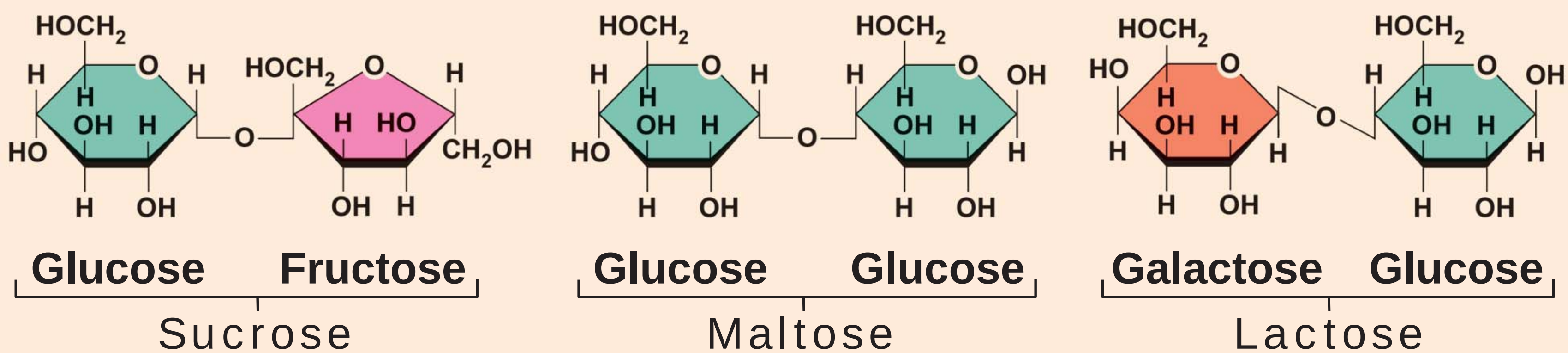
- Double sugars
- Too large to pass through cell membranes

## (b) Disaccharides

Consist of two linked monosaccharides

Example

**Sucrose, maltose, and lactose**
**(these disaccharides are isomers)**




PLAY **Animation: Disaccharides**



Figure 2.15b

# Polysaccharides

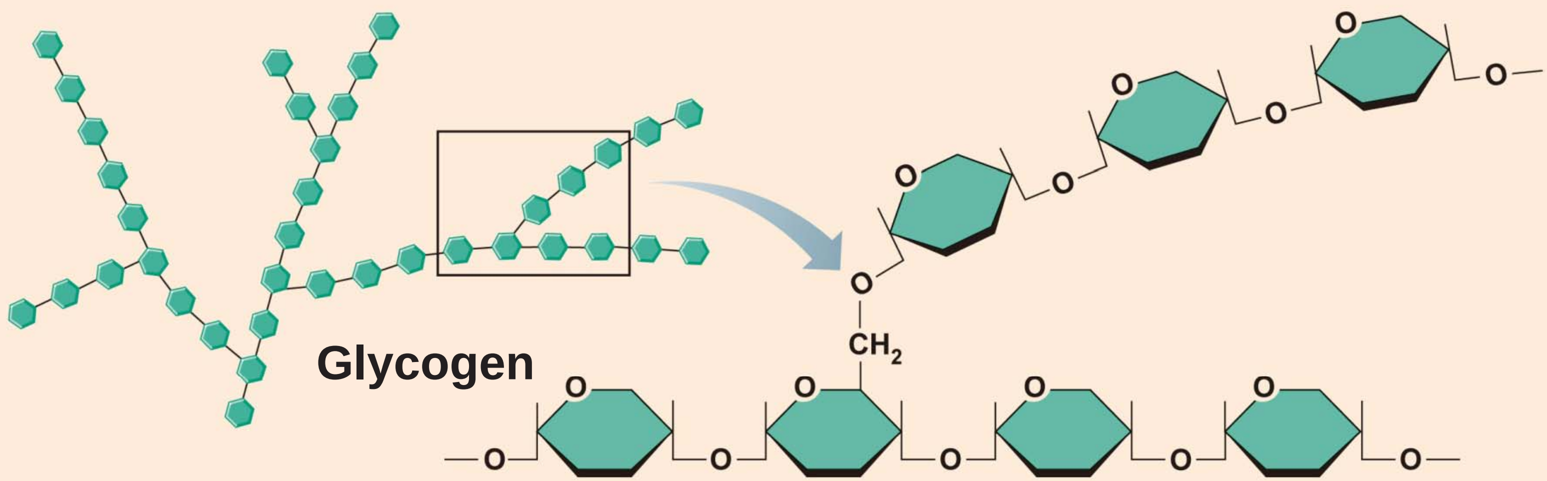
- Polymers of simple sugars, e.g., starch and glycogen
- Not very soluble

## (c) Polysaccharides

Long branching chains (polymers) of linked monosaccharides

Example

**This polysaccharide is a simplified representation of glycogen, a polysaccharide formed from glucose units.**




PLAY **Animation: Polysaccharides**



**Figure 2.15c**

# Lipids

- Contain C, H, O (less than in carbohydrates), and sometimes P
- Insoluble in water
- Main types:
  - Neutral fats or triglycerides
  - Phospholipids
  - Steroids
  - Eicosanoids

PLAY **Animation: Fats**

# Triglycerides

- Neutral fats—solid fats and liquid oils
- Composed of three fatty acids bonded to a glycerol molecule
- Main functions
  - Energy storage
  - Insulation
  - Protection

## (a) Triglyceride formation

Three fatty acid chains are bound to glycerol by dehydration synthesis

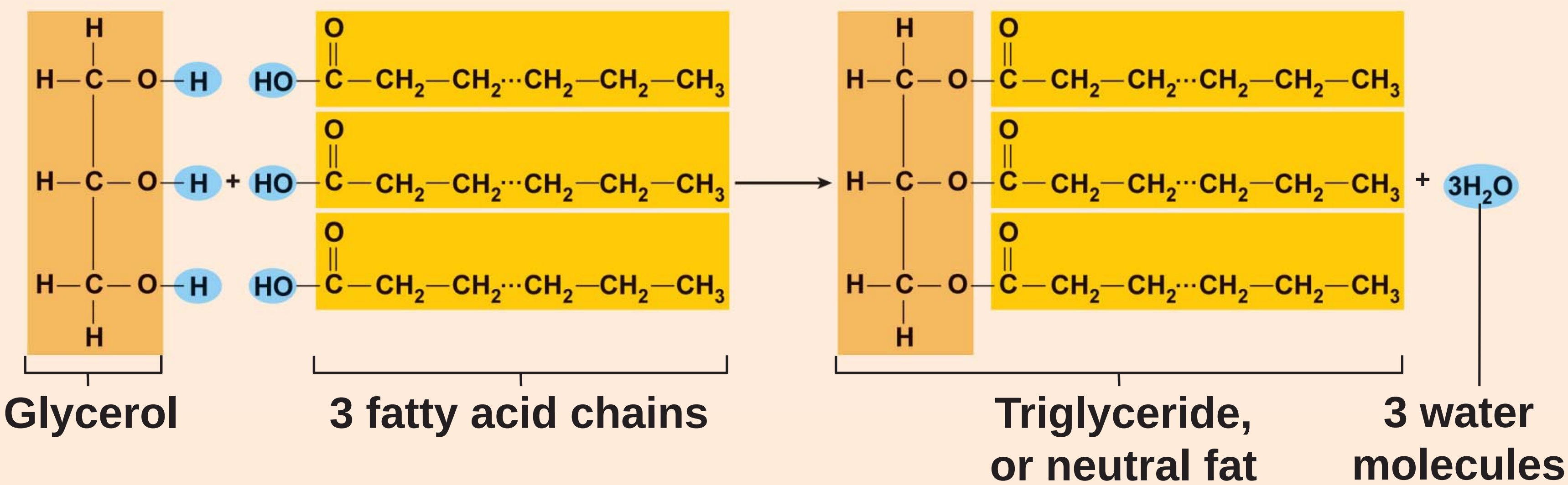





Figure 2.16a

# Saturation of Fatty Acids

- Saturated fatty acids
  - Single bonds between C atoms; maximum number of H
  - Solid animal fats, e.g., butter
- Unsaturated fatty acids
  - One or more double bonds between C atoms
  - Reduced number of H atoms
  - Plant oils, e.g., olive oil

# Phospholipids

- Modified triglycerides:
  - Glycerol + two fatty acids and a phosphorus (P)-containing group
- “Head” and “tail” regions have different properties
- Important in cell membrane structure

## (b) "Typical" structure of a phospholipid molecule

Two fatty acid chains and a phosphorus-containing group are attached to the glycerol backbone.

Example

**Phosphatidylcholine**

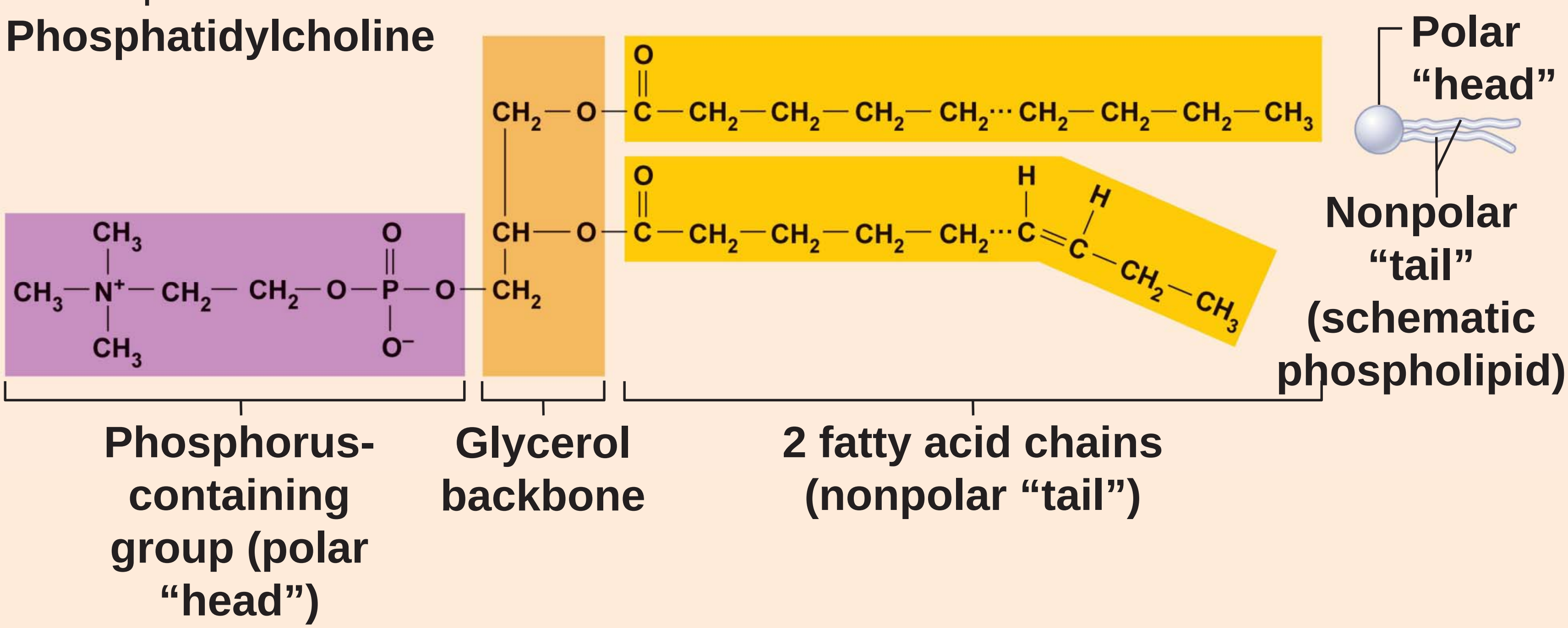





Figure 2.16b

# Steroids

- Steroids—interlocking four-ring structure
- Cholesterol, vitamin D, steroid hormones, and bile salts

## (c) Simplified structure of a steroid

Four interlocking hydrocarbon rings form a steroid.

Example

**Cholesterol (cholesterol is the basis for all steroids formed in the body)**

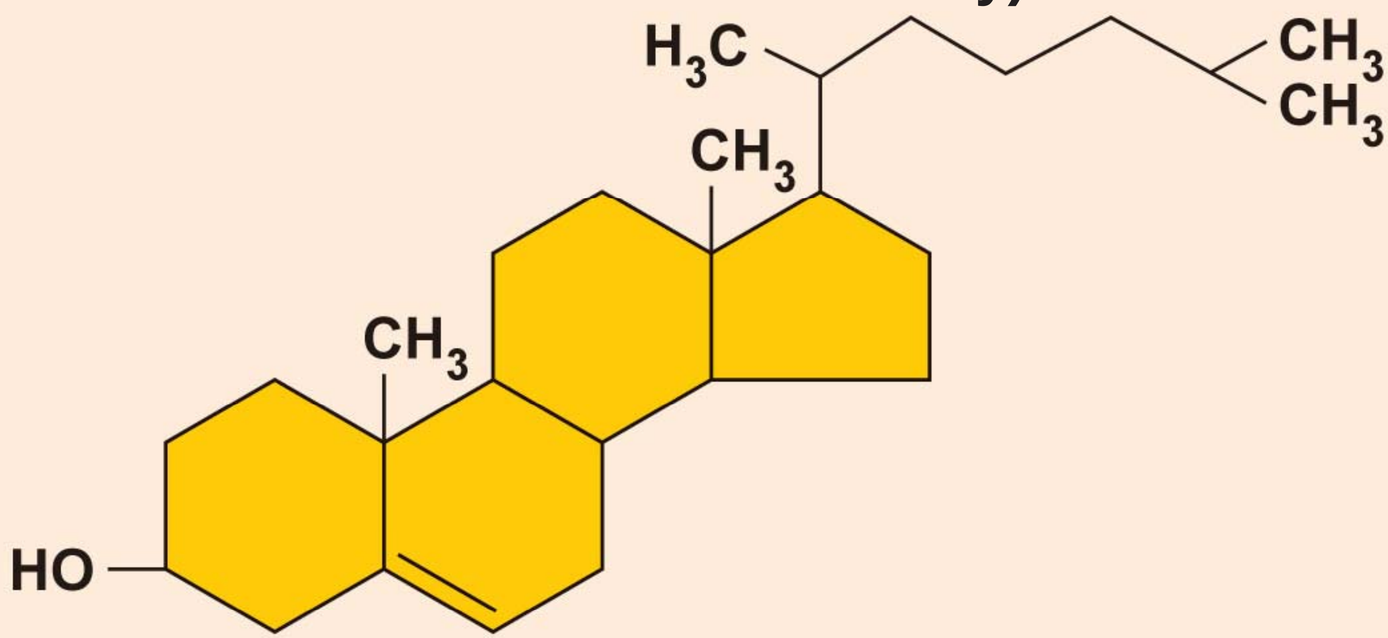





Figure 2.16c

# Eicosanoids

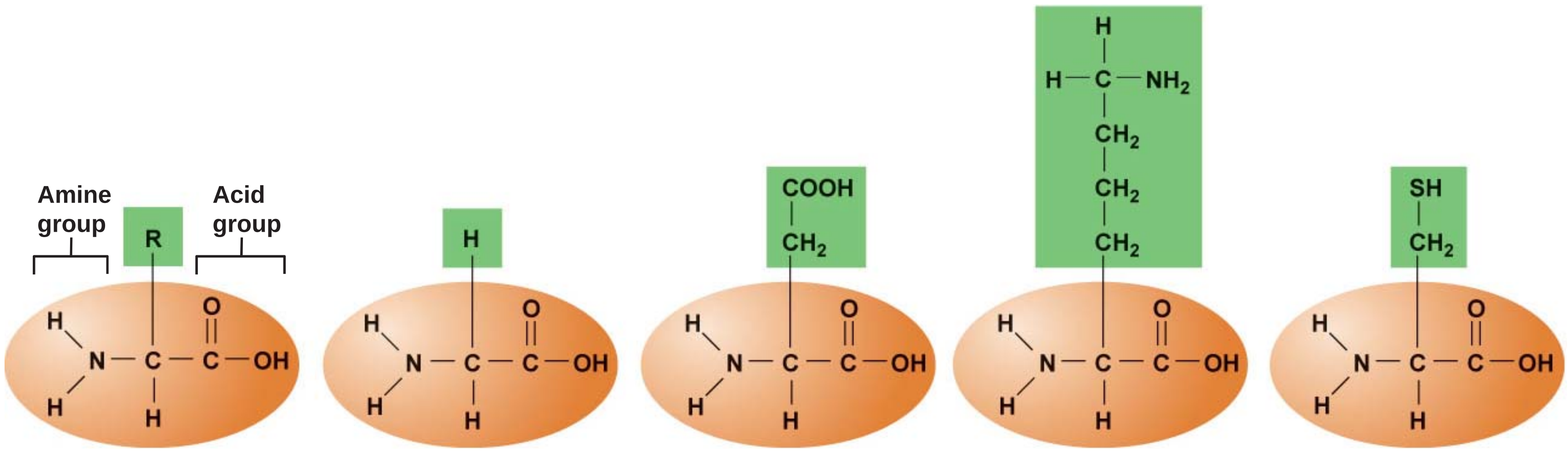
- Many different ones
- Derived from a fatty acid (arachidonic acid) in cell membranes
- Prostaglandins

# Other Lipids in the Body

- Other fat-soluble vitamins
  - Vitamins A, E, and K
- Lipoproteins
  - Transport fats in the blood

# Proteins

- Polymers of amino acids (20 types)
  - Joined by peptide bonds
- Contain C, H, O, N, and sometimes S and P




(a) Generalized structure of all amino acids.

(b) Glycine **is the simplest amino acid.**

(c) Aspartic acid **(an acidic amino acid) has an acid group (—COOH) in the R group.**

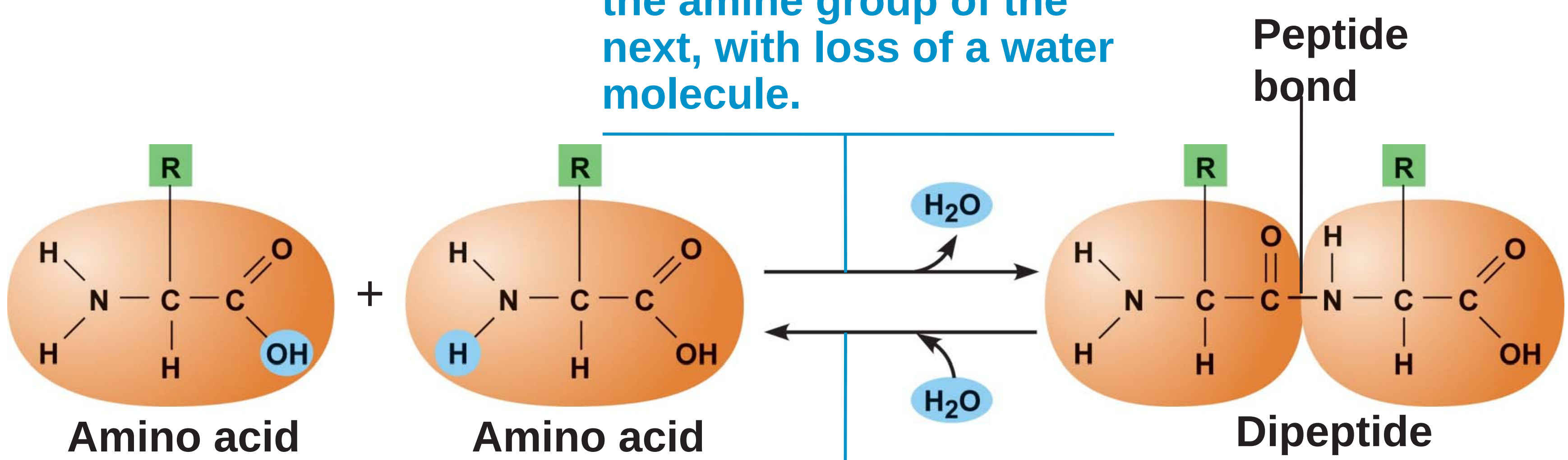
(d) Lysine **(a basic amino acid) has an amine group ($–NH_2$) in the R group.**

(e) Cysteine **(a basic amino acid) has a sulfhydryl (–SH) group in the R group, which suggests that this amino acid is likely to participate in intramolecular bonding.**



**Figure 2.17**

Dehydration synthesis: **The acid group of one amino acid is bonded to the amine group of the next, with loss of a water molecule.**



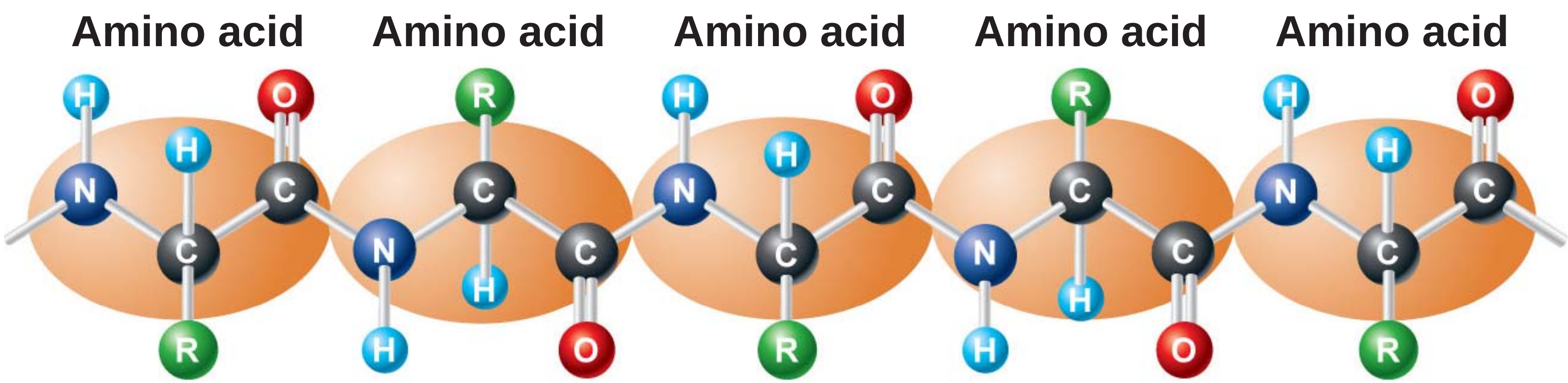

Hydrolysis: **Peptide bonds linking amino acids together are broken when water is added to the bond.**



**Figure 2.18**

# Structural Levels of Proteins

PLAY **Animation: Introduction to Protein Structure**



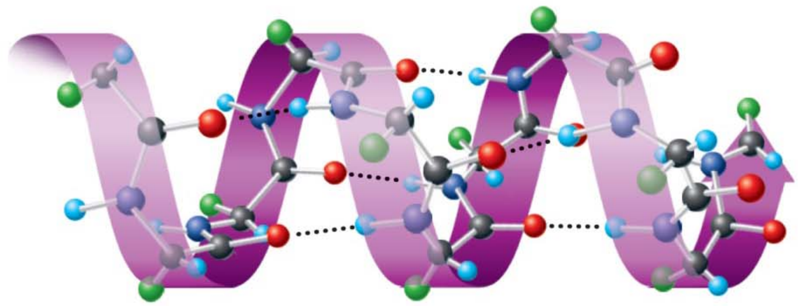

(a) Primary structure:

**The sequence of amino acids forms the polypeptide chain.**

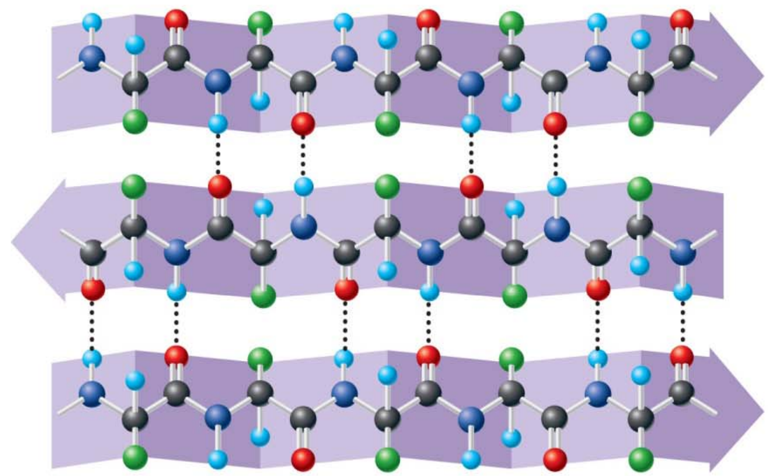
PLAY **Animation: Primary Structure**



**Figure 2.19a**



α-Helix: **The primary chain is coiled to form a spiral structure, which is stabilized by hydrogen bonds.**



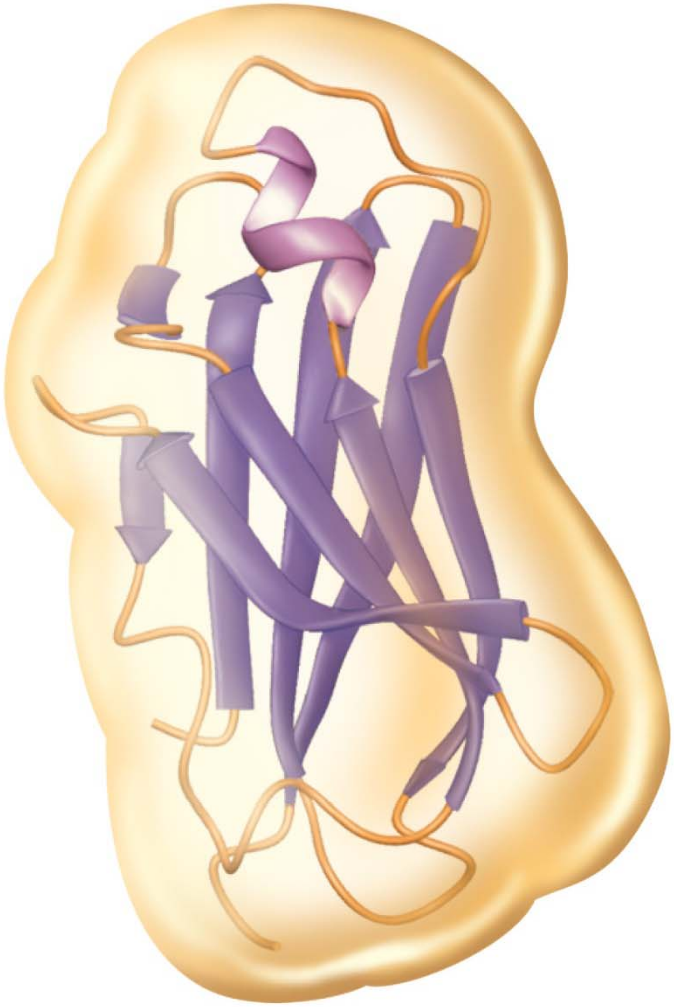
β-Sheet: **The primary chain "zig-zags" back and forth forming a "pleated" sheet. Adjacent strands are held together by hydrogen bonds.**

(b) Secondary structure:
**The primary chain forms spirals (α-helices) and sheets (β-sheets).**

**PLAY** **Animation: Secondary Structure**



**Figure 2.19b**



Tertiary structure of prealbumin (transthyretin), a protein that transports the thyroid hormone thyroxine in serum and cerebrospinal fluid.

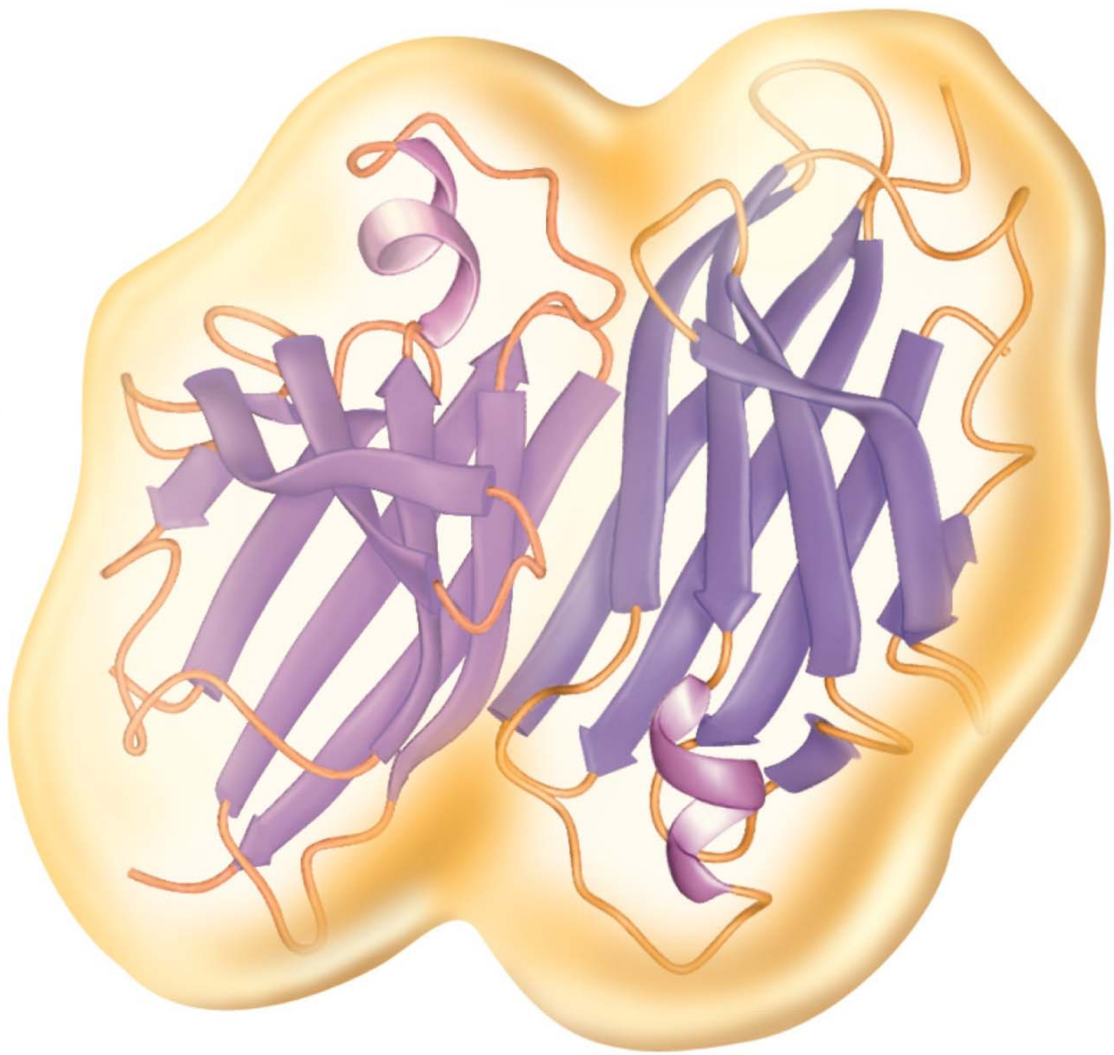
(c) Tertiary structure:

**Superimposed on secondary structure. α-Helices and/or β-sheets are folded up to form a compact globular molecule held together by intramolecular bonds.**

**PLAY** **Animation: Tertiary Structure**



**Figure 2.19c**



Quaternary structure of a functional prealbumin molecule. Two identical prealbumin subunits join head to tail to form the dimer.

(d) Quaternary structure:

**Two or more polypeptide chains, each with its own tertiary structure, combine to form a functional protein.**

PLAY **Animation: Quaternary Structure**



Figure 2.19d

# Fibrous and Globular Proteins

- Fibrous (structural) proteins
  - Strandlike, water insoluble, and stable
  - Examples: keratin, elastin, collagen, and certain contractile fibers

# Fibrous and Globular Proteins

- Globular (functional) proteins
  - Compact, spherical, water-soluble and sensitive to environmental changes
  - Specific functional regions (active sites)
  - Examples: antibodies, hormones, molecular chaperones, and enzymes

# Protein Denaturation

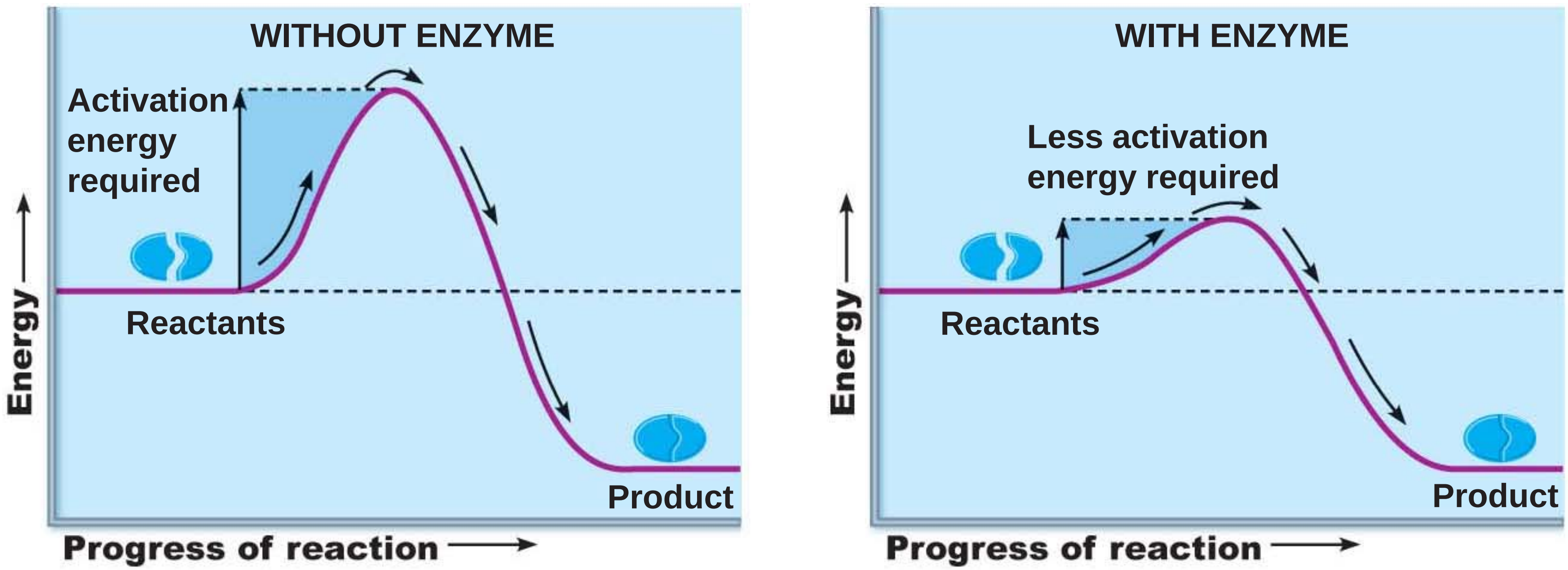
- Shape change and disruption of active sites due to environmental changes (e.g., decreased pH or increased temperature)
- Reversible in most cases, if normal conditions are restored
- Irreversible if extreme changes damage the structure beyond repair (e.g., cooking an egg)

# Molecular Chaperones (Chaperonins)

- Ensure quick and accurate folding and association of proteins
- Assist translocation of proteins and ions across membranes
- Promote breakdown of damaged or denatured proteins
- Help trigger the immune response
- Produced in response to stressful stimuli, e.g., $O_2$ deprivation

# Enzymes

- Biological catalysts
  - Lower the activation energy, increase the speed of a reaction (millions of reactions per minute!)




PLAY

**Animation: Enzymes**



Figure 2.20

# Characteristics of Enzymes

- Often named for the reaction they catalyze; usually end in *-ase* (e.g., hydrolases, oxidases)
- Some functional enzymes (holoenzymes) consist of:
  - Apoenzyme (protein)
  - Cofactor (metal ion) or coenzyme (a vitamin)

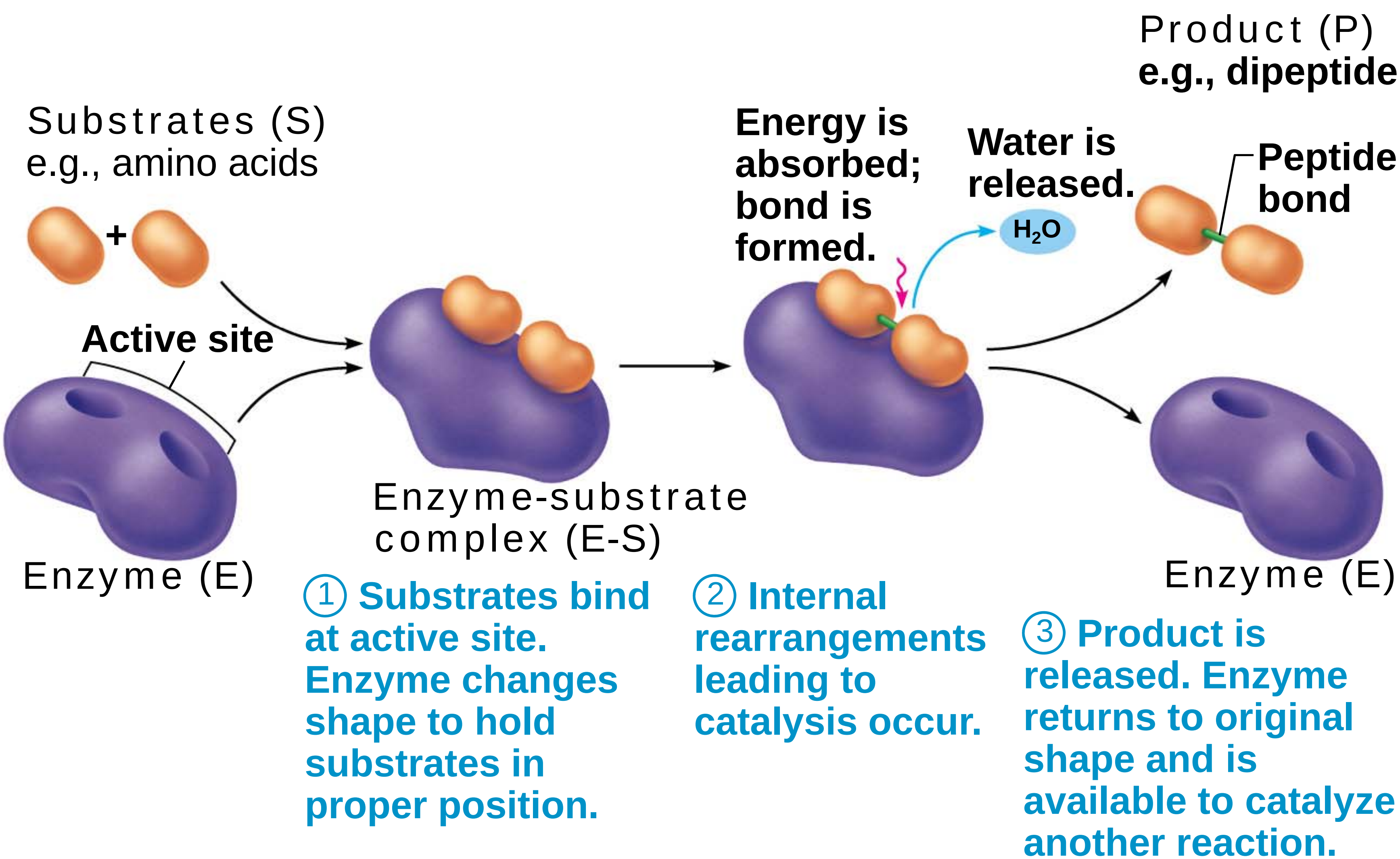
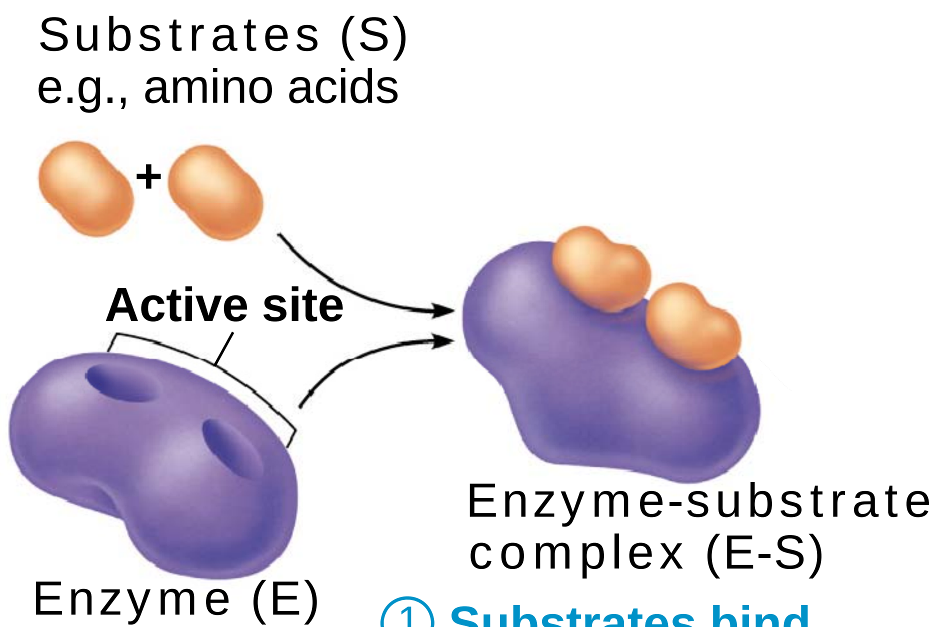

Substrates (S)
e.g., amino acids
+
Active site
Enzyme (E)
Enzyme-substrate
complex (E-S)
Energy is
absorbed;
bond is
formed.
Water is
released.
$H_2O$
Product (P)
e.g., dipeptide
Peptide
bond
Enzyme (E)
① Substrates bind at active site. Enzyme changes shape to hold substrates in proper position.
② Internal rearrangements leading to catalysis occur.
③ Product is released. Enzyme returns to original shape and is available to catalyze another reaction.



Figure 2.21




1 **Substrates bind at active site. Enzyme changes shape to hold substrates in proper position.**



Figure 2.21, step 1

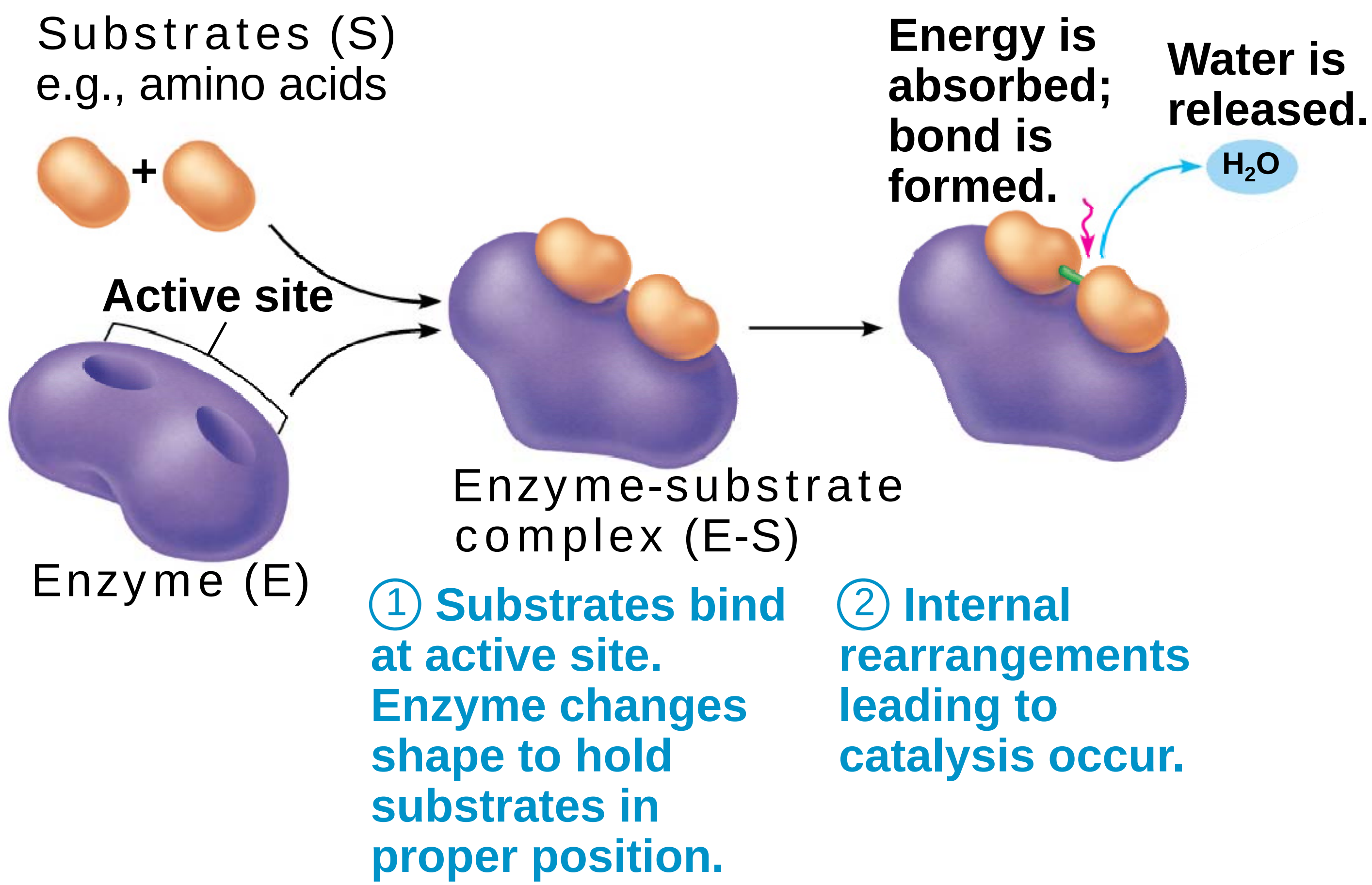





**Figure 2.21, step 2**

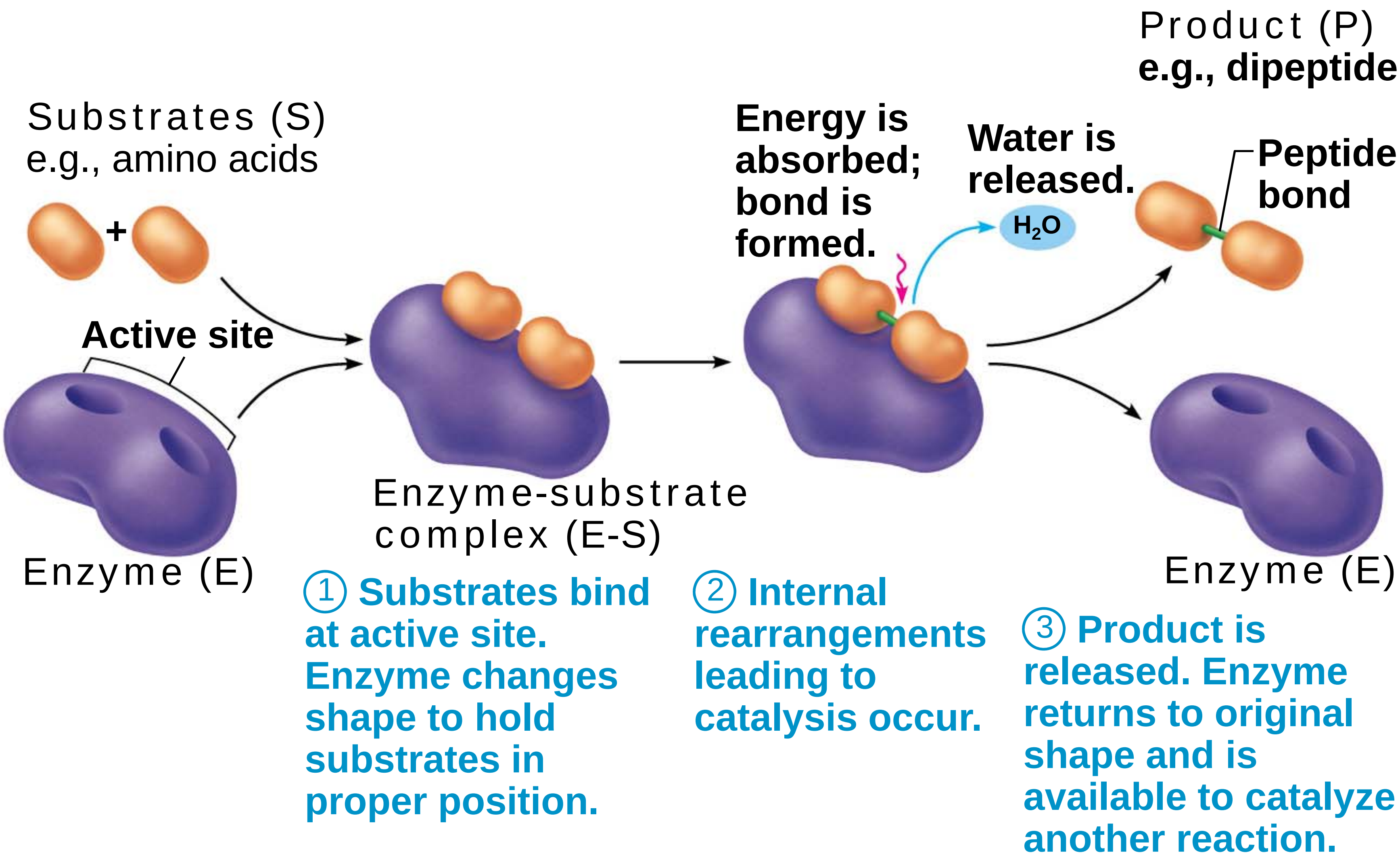





Figure 2.21, step 3

# Summary of Enzyme Action

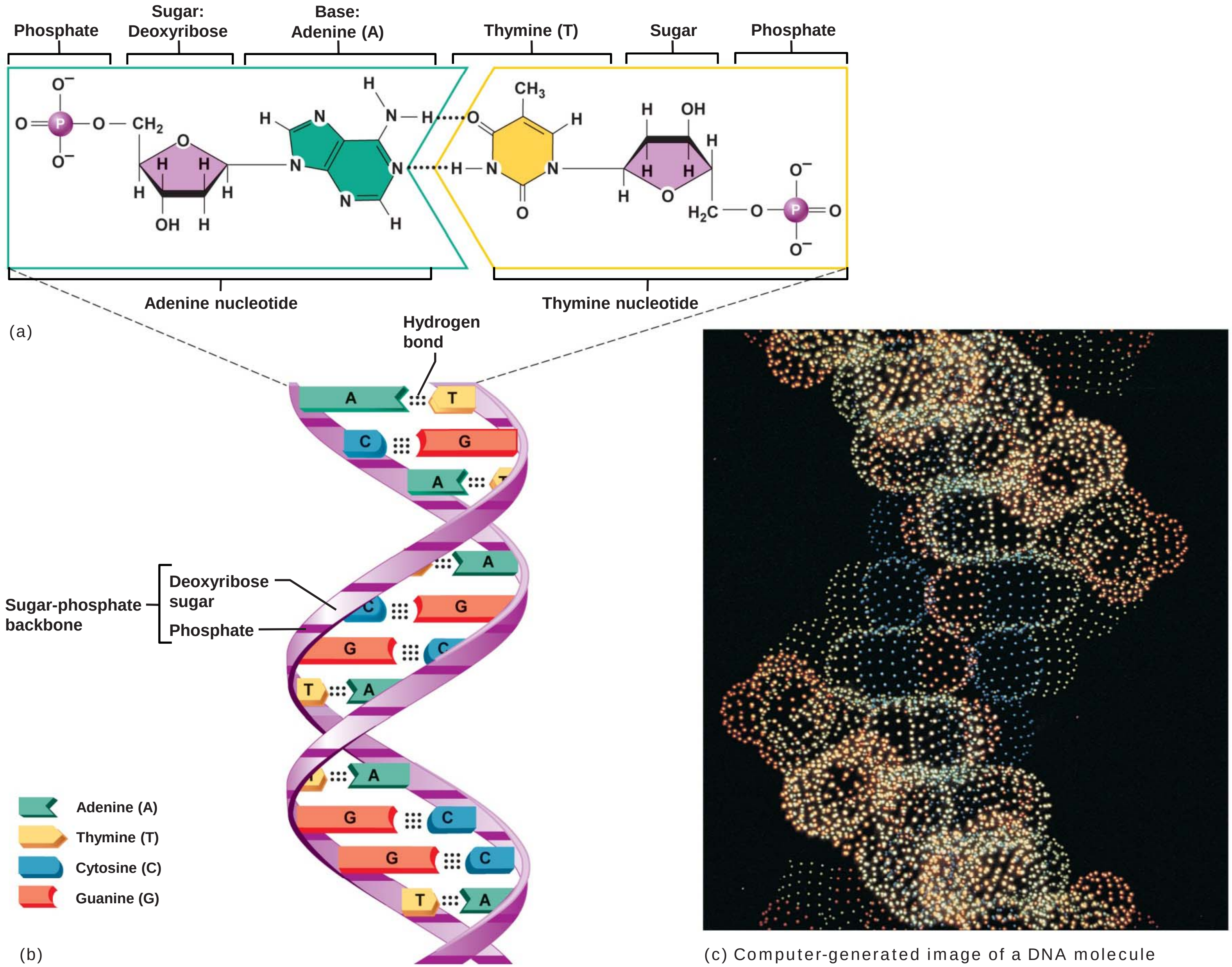
PLAY **Animation: How Enzymes Work**

# Nucleic Acids

- DNA and RNA
  - Largest molecules in the body
- Contain C, O, H, N, and P
- Building block = nucleotide, composed of N-containing base, a pentose sugar, and a phosphate group

# Deoxyribonucleic Acid (DNA)

- Four bases:
  - adenine (A), guanine (G), cytosine (C), and thymine (T)
- Double-stranded helical molecule in the cell nucleus
- Provides instructions for protein synthesis
- Replicates before cell division, ensuring genetic continuity




(a)

(b)

(c) Computer-generated image of a DNA molecule

Figure 2.22

# Ribonucleic Acid (RNA)

- Four bases:
  - adenine (A), guanine (G), cytosine (C), and uracil (U)
- Single-stranded molecule mostly active outside the nucleus
- Three varieties of RNA carry out the DNA orders for protein synthesis
  - messenger RNA, transfer RNA, and ribosomal RNA

PLAY **Animation: DNA and RNA**

# Adenosine Triphosphate (ATP)

- Adenine-containing RNA nucleotide with two additional phosphate groups

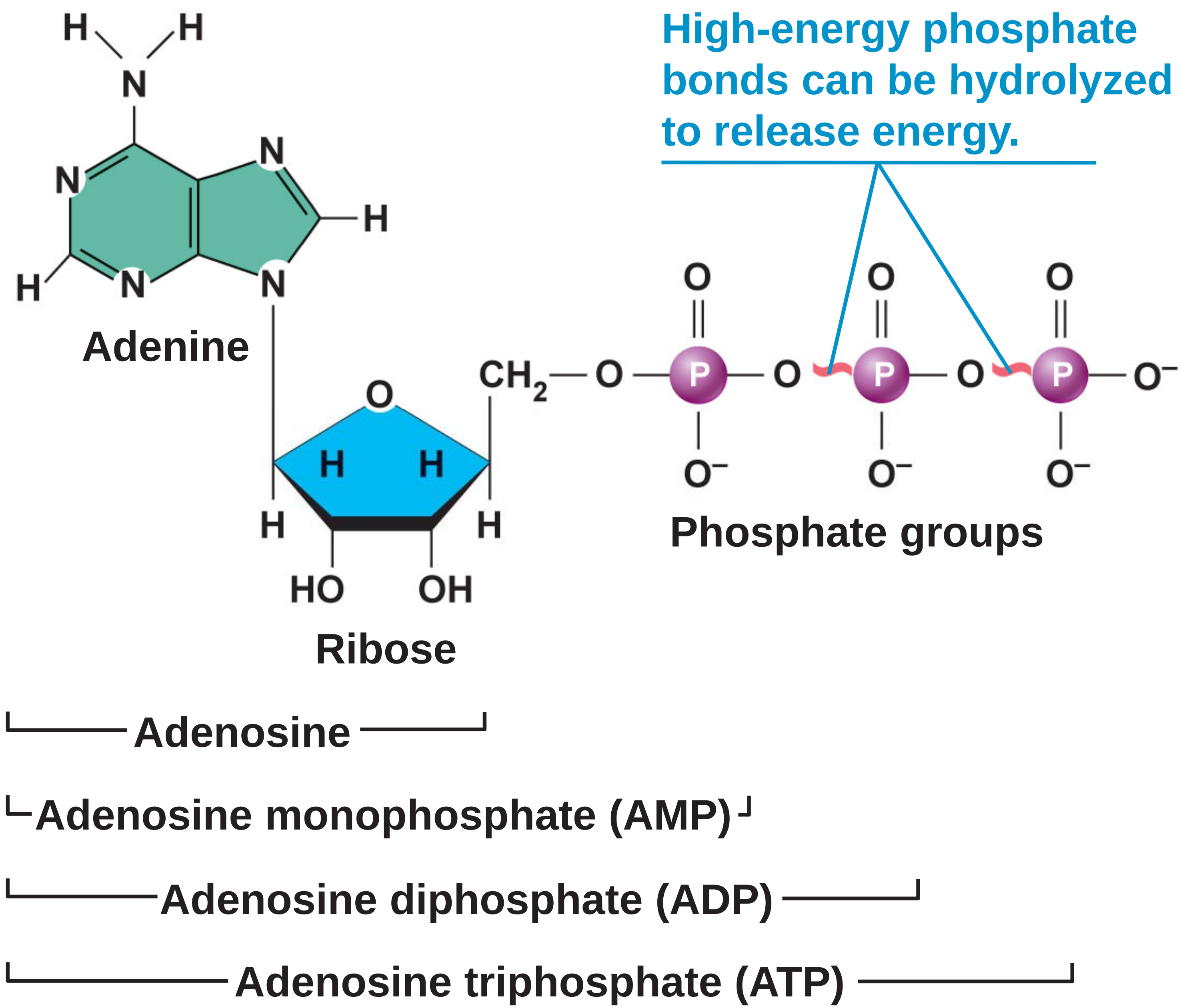
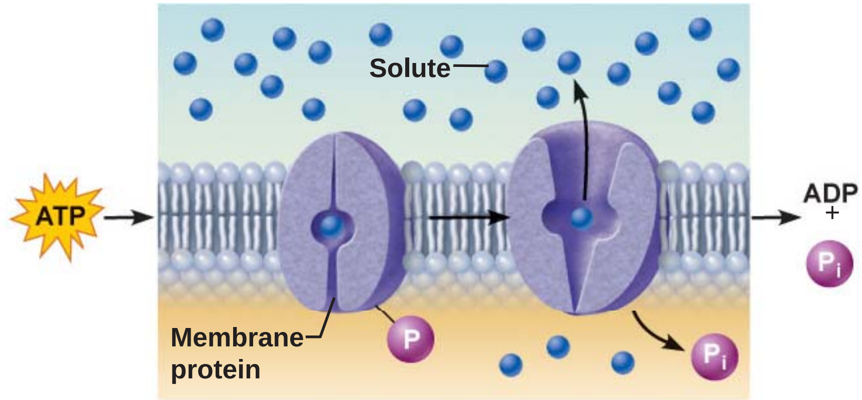

High-energy phosphate bonds can be hydrolyzed to release energy.
H
H
N
N
N
H
N
N
H
Adenine
O
H
H
H
H
HO
OH
Ribose
CH2
O
O
P
O
O
P
O
O
P
O−
O−
O−
O−
Phosphate groups
Adenosine
Adenosine monophosphate (AMP)
Adenosine diphosphate (ADP)
Adenosine triphosphate (ATP)



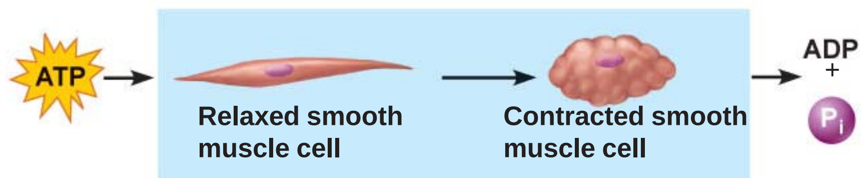
Figure 2.23

# Function of ATP

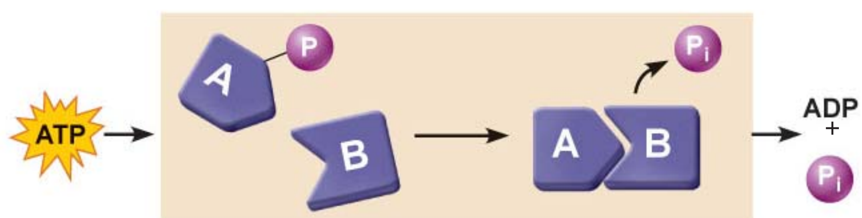
- Phosphorylation:
  - Terminal phosphates are enzymatically transferred to and energize other molecules
  - Such “primed” molecules perform cellular work (life processes) using the phosphate bond energy




(a) Transport work: **ATP phosphorylates transport proteins, activating them to transport solutes (ions, for example) across cell membranes.**




(b) Mechanical work: **ATP phosphorylates contractile proteins in muscle cells so the cells can shorten.**




(c) Chemical work: **ATP phosphorylates key reactants, providing energy to drive energy-absorbing chemical reactions.**



**Figure 2.24**