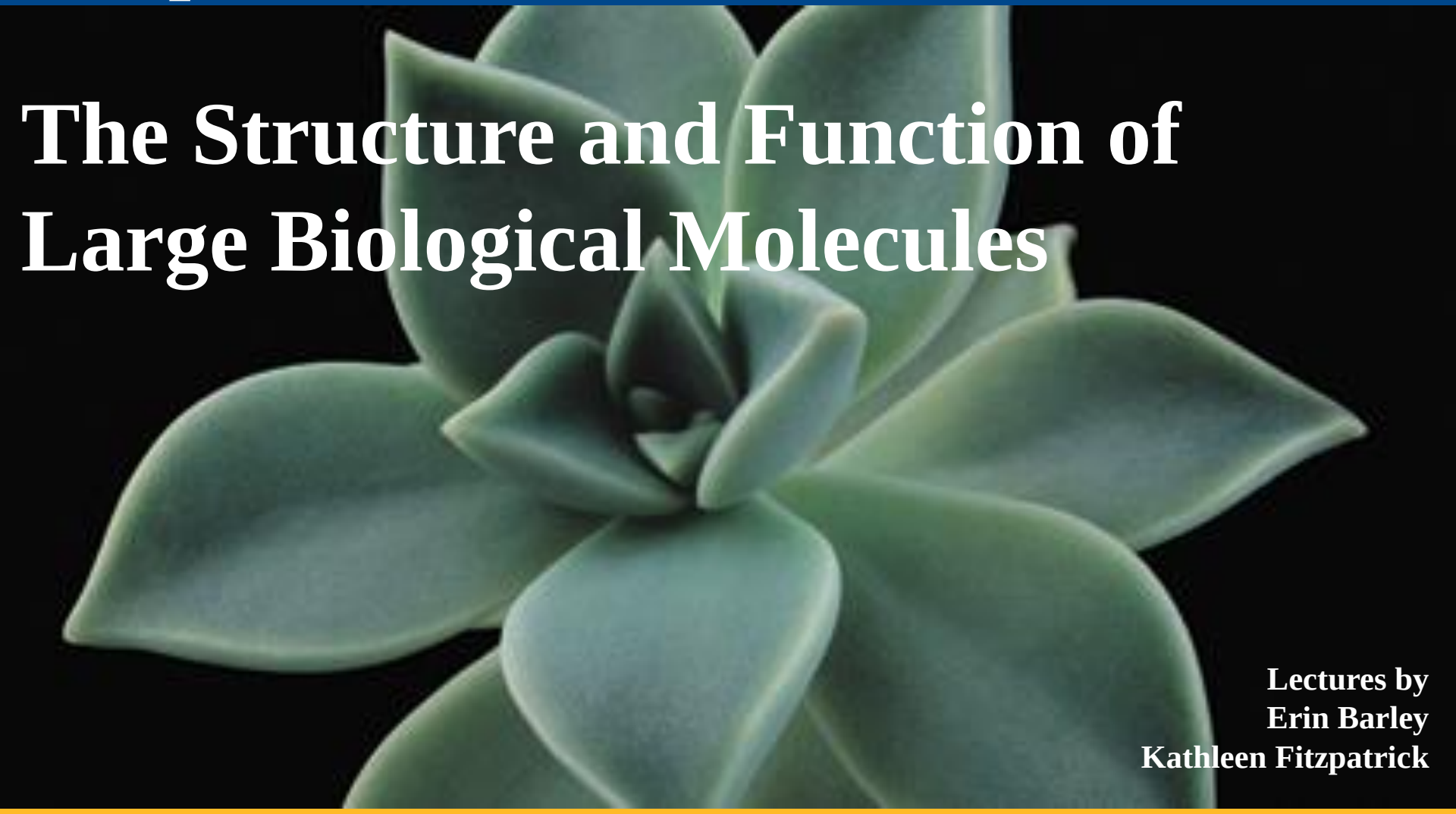
LECTURE PRESENTATIONS

For CAMPBELL BIOLOGY, NINTH EDITION

Jane B. Reece, Lisa A. Urry, Michael L. Cain, Steven A. Wasserman, Peter V. Minorsky, Robert B. Jackson

Chapter 5

The Structure and Function of Large Biological Molecules



Lectures by
Erin Barley
Kathleen Fitzpatrick

Overview: The Molecules of Life

- All living things are made up of four classes of large biological molecules: carbohydrates, lipids, proteins, and nucleic acids
- **Macromolecules** are large molecules composed of thousands of covalently connected atoms
- Molecular structure and function are inseparable

Concept 5.1: Macromolecules are polymers, built from monomers

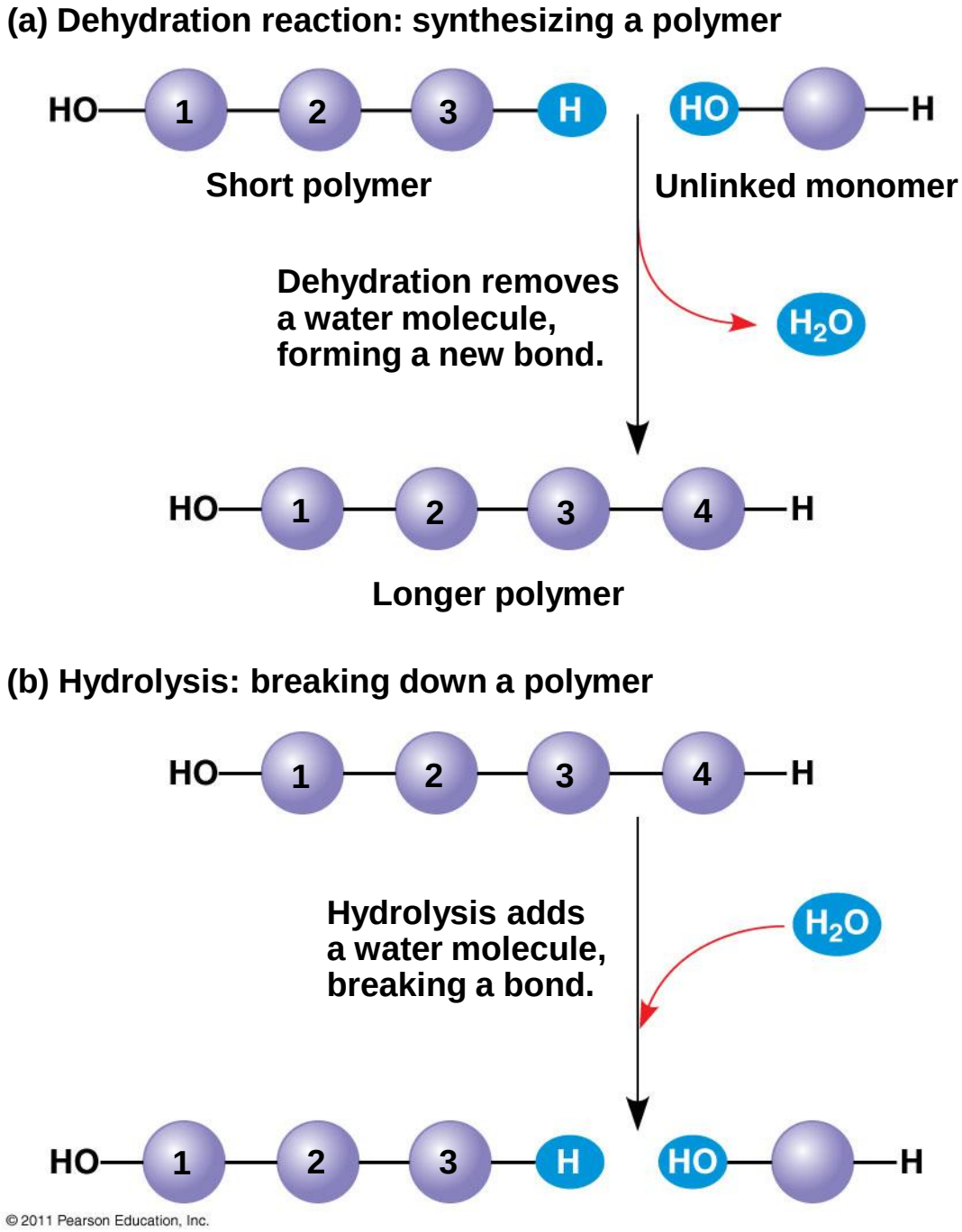
- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**

The Synthesis and Breakdown of Polymers

- A **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule
- Polymers are disassembled to monomers by **hydrolysis**, a reaction that is essentially the reverse of the dehydration reaction

PLAY Animation: Polymers

Figure 5.2



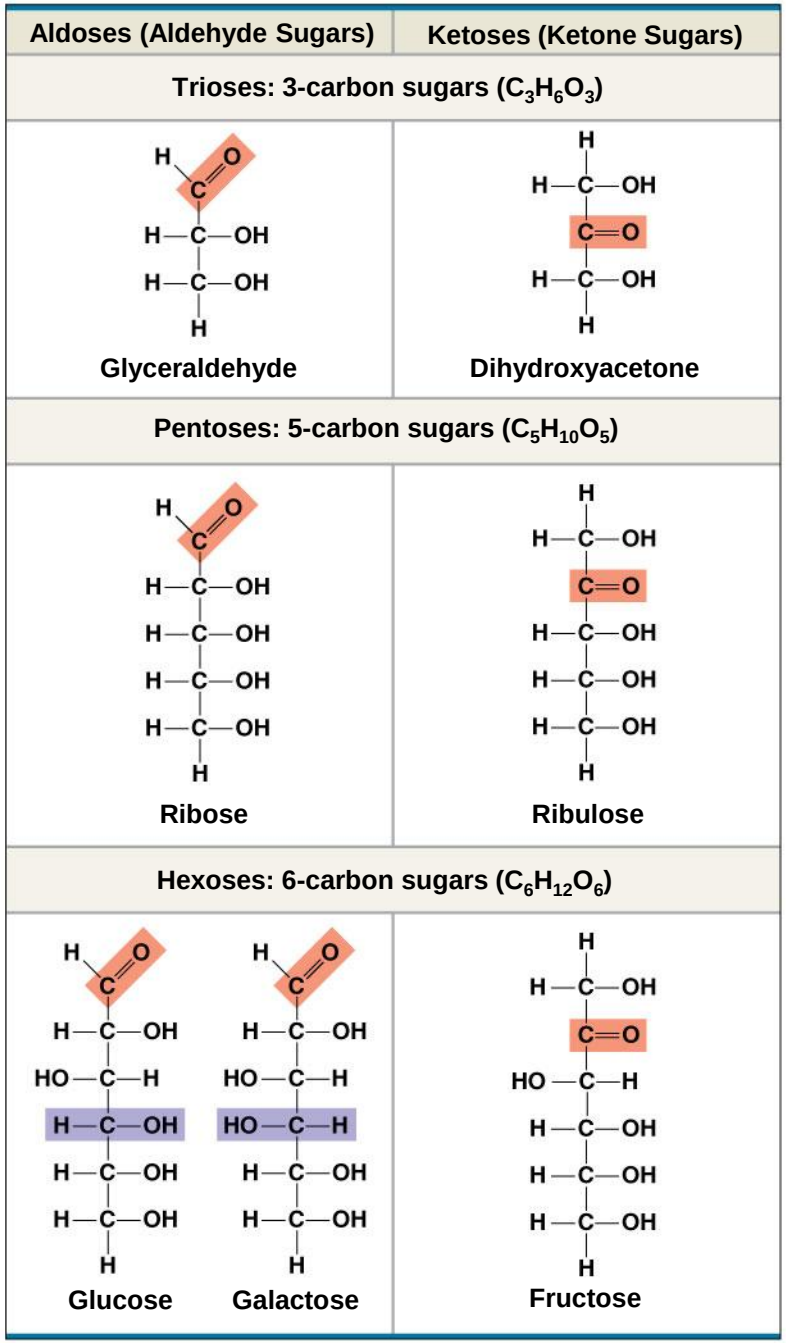
Concept 5.2: Carbohydrates serve as fuel and building material

- **Carbohydrates** include sugars and the polymers of sugars
- The simplest carbohydrates are monosaccharides, or single sugars
- Carbohydrate macromolecules are polysaccharides, polymers composed of many sugar building blocks

Sugars

- **Monosaccharides** have molecular formulas that are usually multiples of CH_2O (1:2:1)
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Monosaccharides are classified by
  - The location of the carbonyl group (as aldose or ketose)
  - The number of carbons in the carbon skeleton

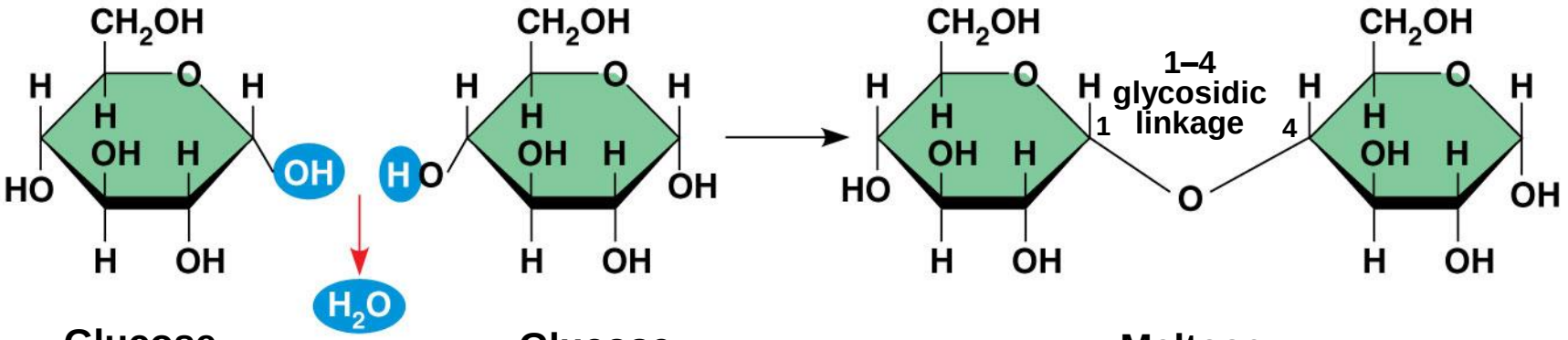
Figure 5.3



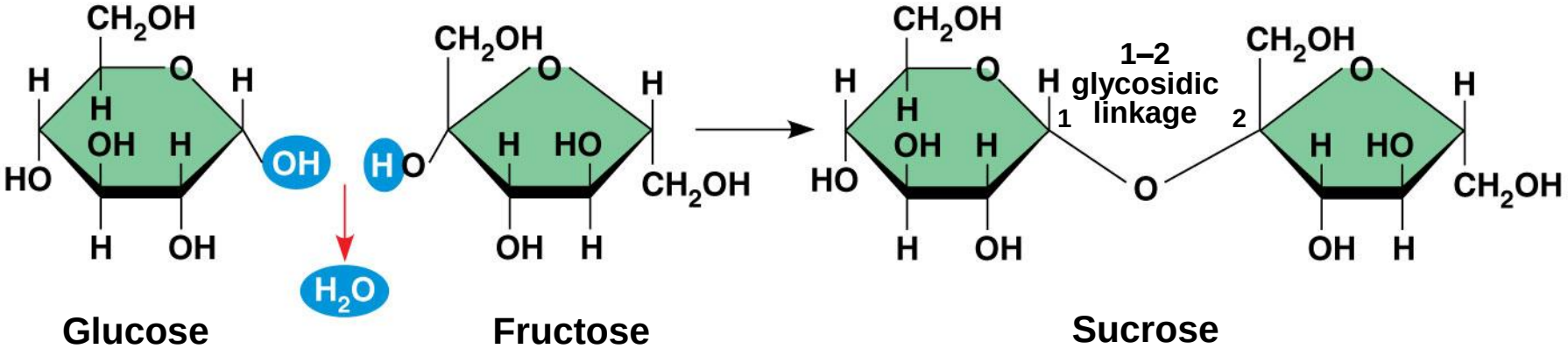
- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**

Animation: Disaccharide

Figure 5.5



(a) Dehydration reaction in the synthesis of maltose



(b) Dehydration reaction in the synthesis of sucrose

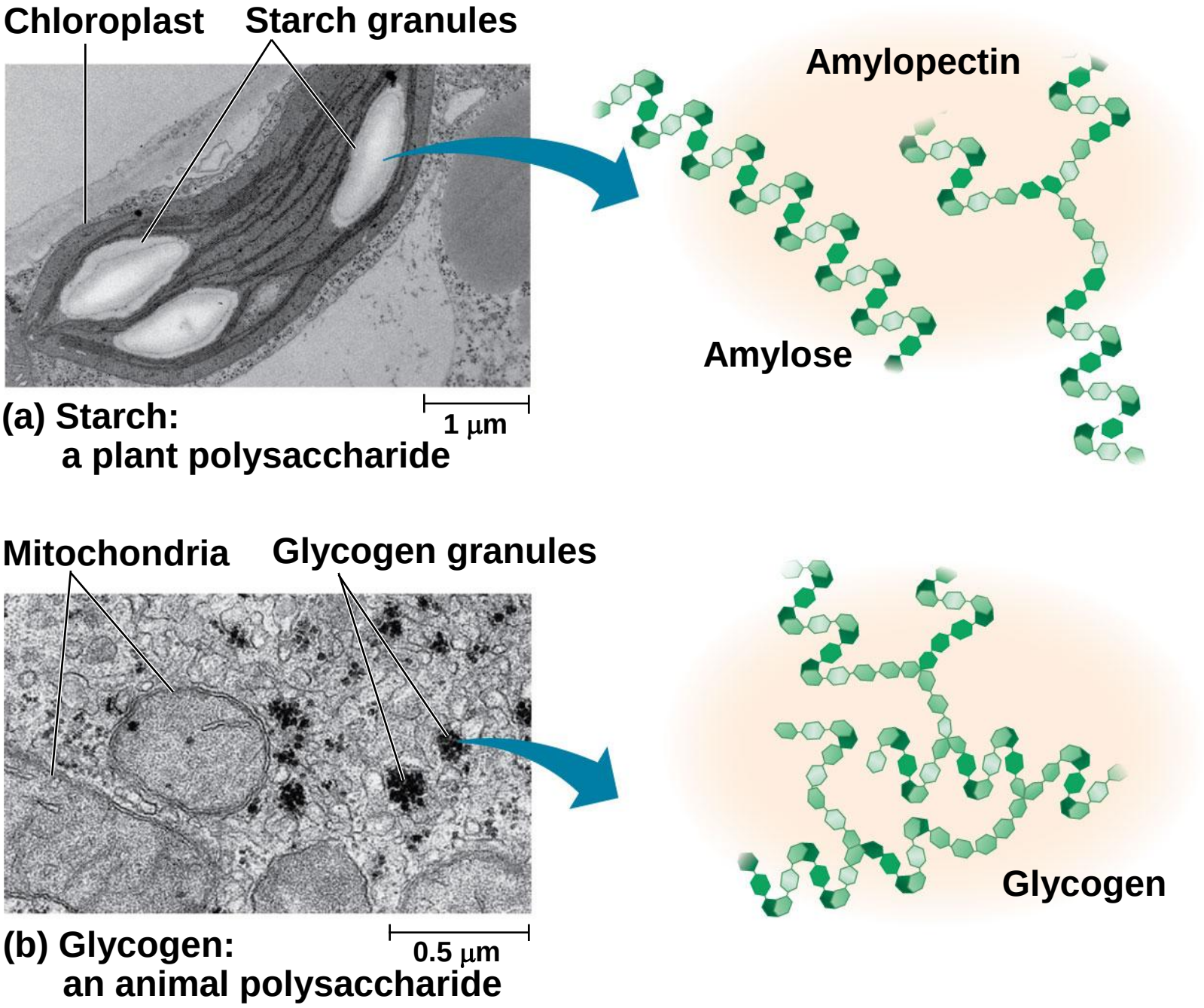
Polysaccharides

- **Polysaccharides**, the polymers of sugars, have storage and structural roles
- The structure and function of a polysaccharide are determined by its sugar monomers and the positions of glycosidic linkages

Storage Polysaccharides

- **Starch**, a storage polysaccharide of plants, consists entirely of glucose monomers
- Plants store surplus starch as granules within chloroplasts and other plastids
- The simplest form of starch is amylose

Figure 5.6



- **Glycogen** is a storage polysaccharide in animals
- Humans and other vertebrates store glycogen mainly in liver and muscle cells

Structural Polysaccharides

- The polysaccharide **cellulose** is a major component of the tough wall of plant cells
- Like starch, cellulose is a polymer of glucose, but the glycosidic linkages differ
- The difference is based on two ring forms for glucose: alpha (α) and beta (β)

PLAY Animation: Polysaccharides

Figure 5.7

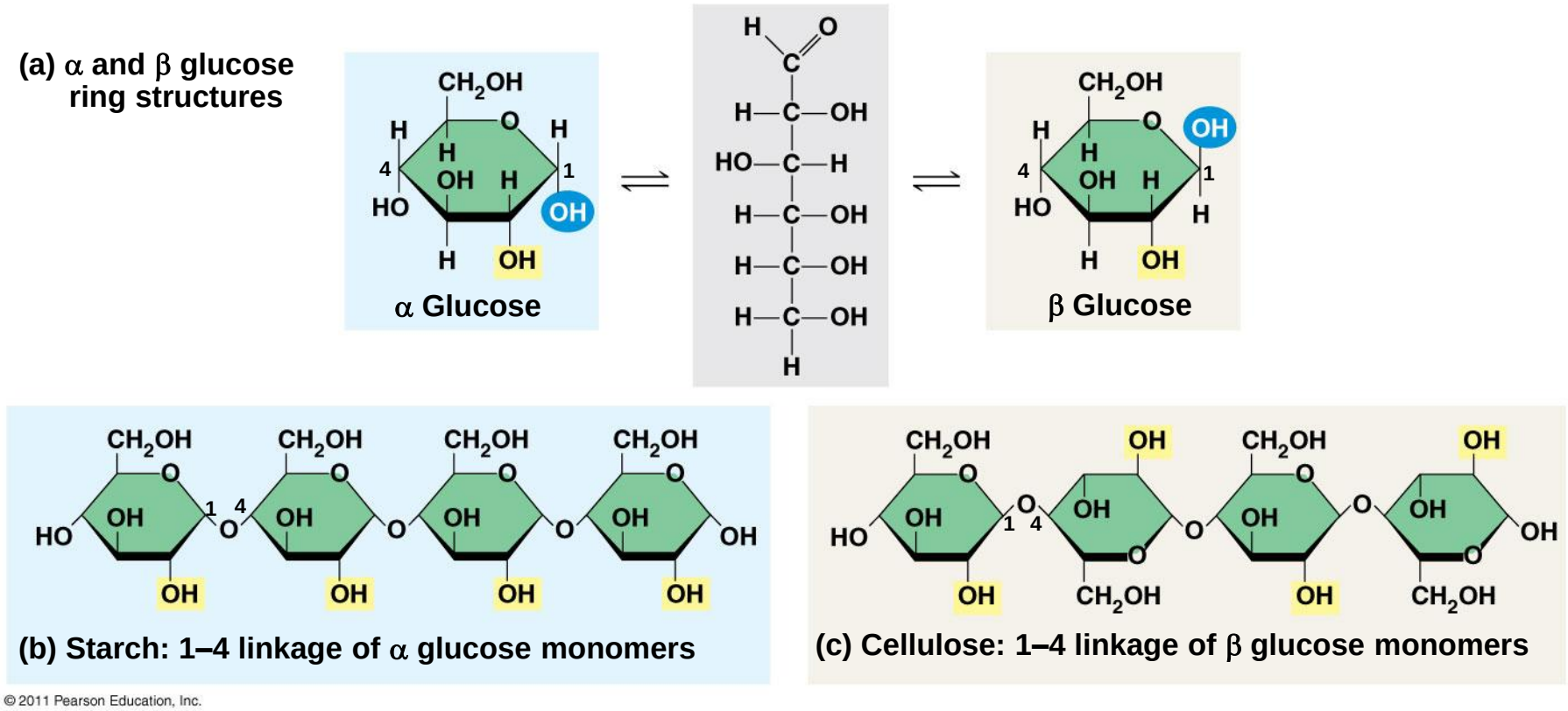
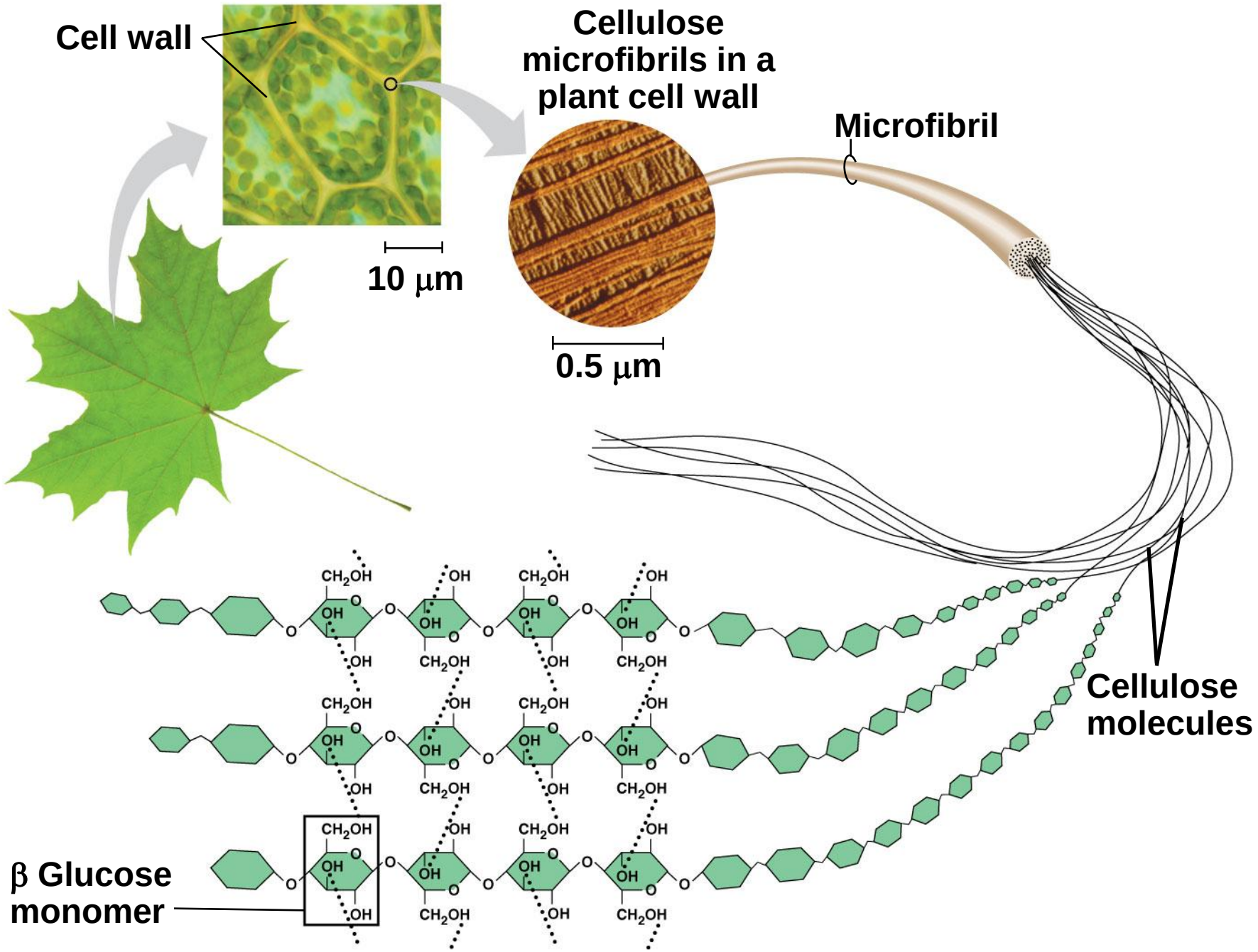


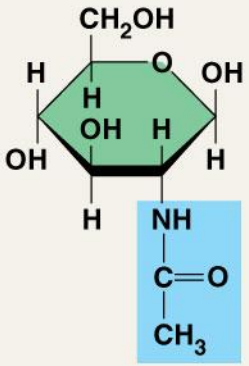
Figure 5.8



- Enzymes that digest starch by hydrolyzing α linkages can't hydrolyze β linkages in cellulose
- Cellulose in human food passes through the digestive tract as insoluble fiber
- Some microbes use enzymes to digest cellulose
- Many herbivores, from cows to termites, have symbiotic relationships with these microbes

- **Chitin**, another structural polysaccharide, is found in the exoskeleton of arthropods
- Chitin also provides structural support for the cell walls of many fungi

Figure 5.9



The structure of the chitin monomer

Chitin forms the exoskeleton of arthropods.

Chitin is used to make a strong and flexible surgical thread that decomposes after the wound or incision heals.

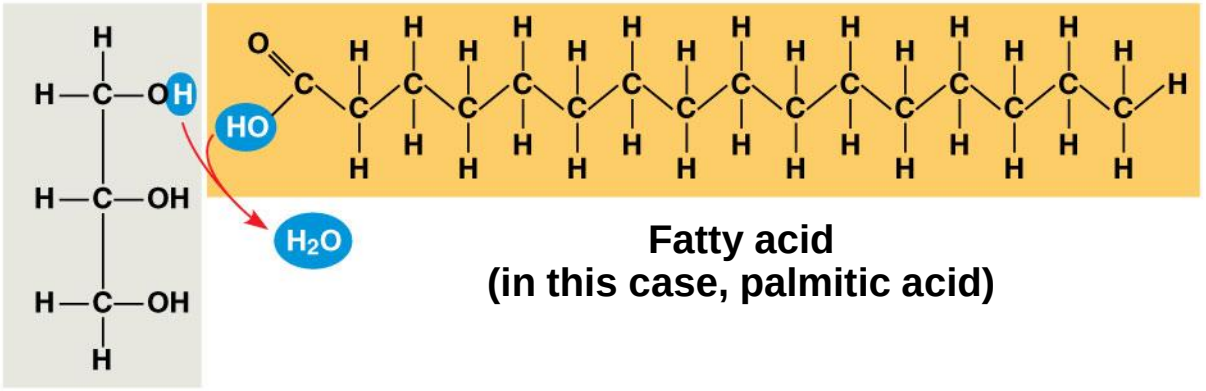
Concept 5.3: Lipids are a diverse group of hydrophobic molecules

- **Lipids** are the one class of large biological molecules that do not form polymers
- The unifying feature of lipids is having little or no affinity for water
- Lipids are hydrophobic because they consist mostly of hydrocarbons, which form nonpolar covalent bonds
- The most biologically important lipids are fats, phospholipids, and steroids

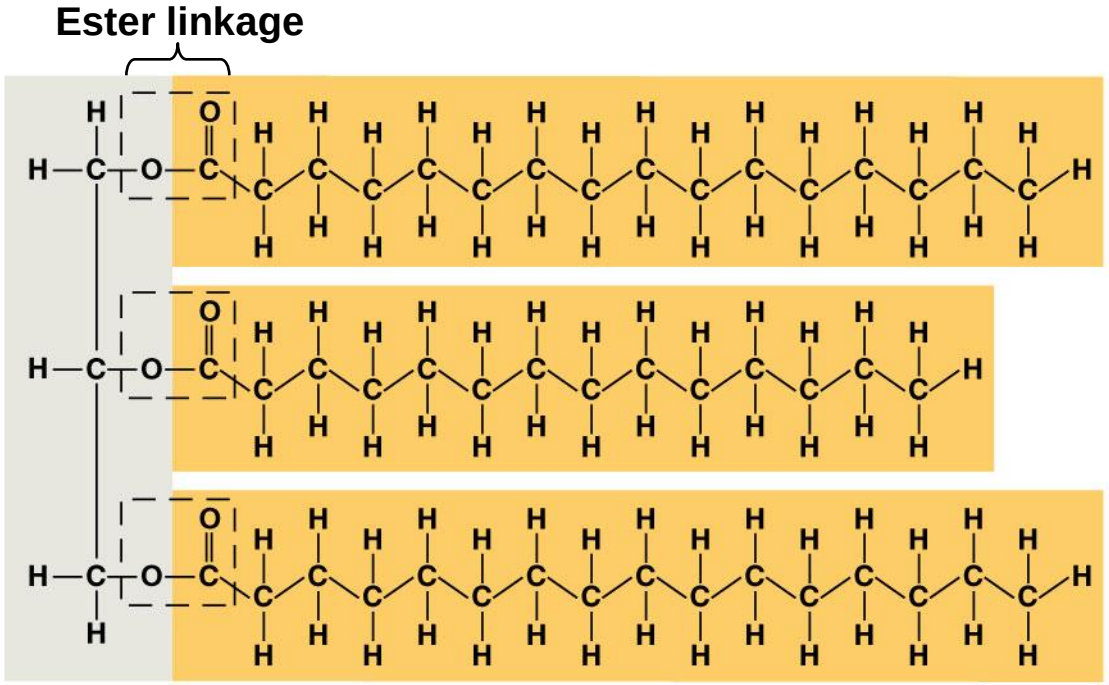
Fats

- **Fats** are constructed from two types of smaller molecules: glycerol and fatty acids
- Glycerol is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton

Figure 5.10



(a) One of three dehydration reactions in the synthesis of a fat

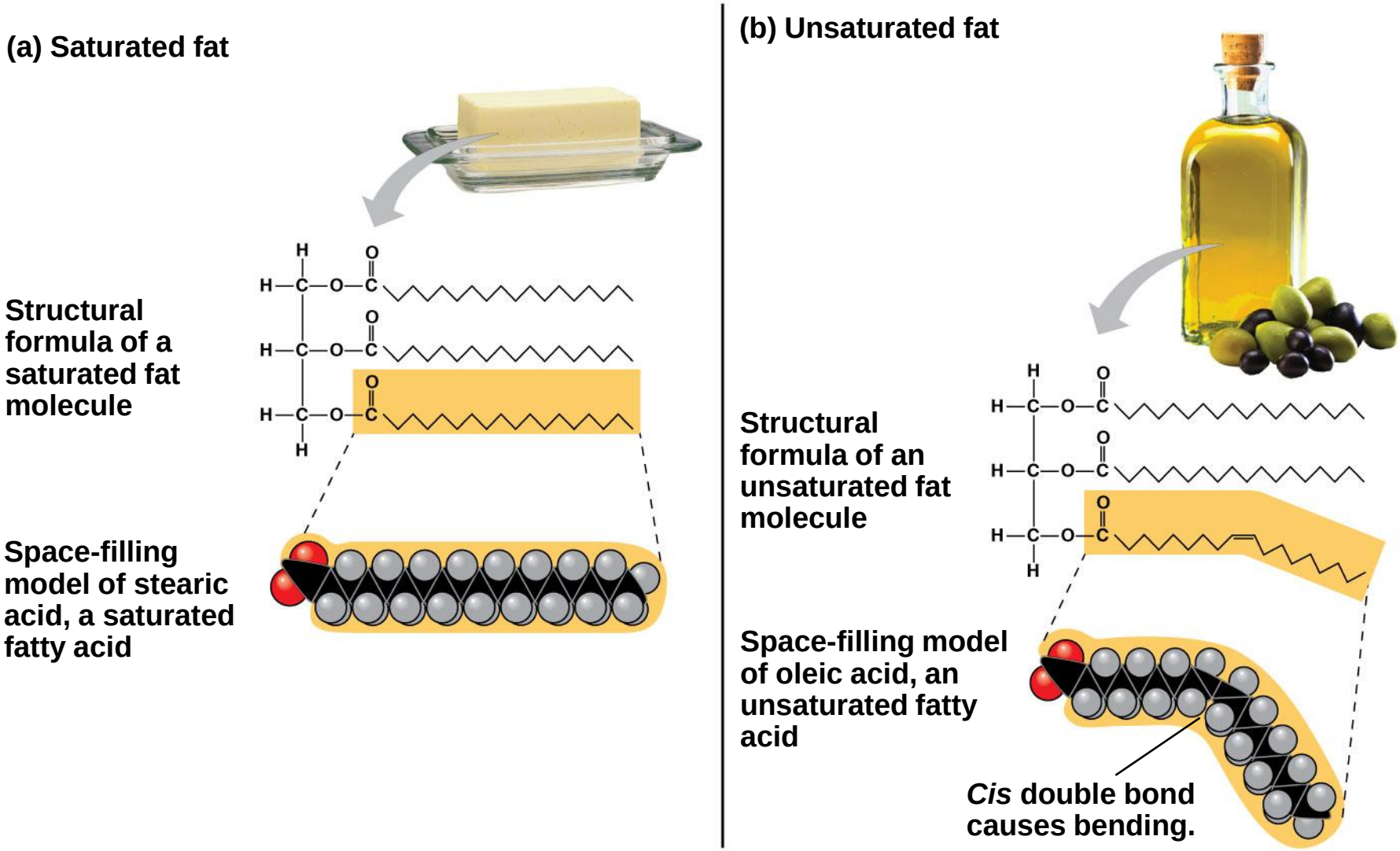


(b) Fat molecule (triacylglycerol)

- Fatty acids vary in length (number of carbons) and in the number and locations of double bonds
- **Saturated fatty acids** have the maximum number of hydrogen atoms possible and no double bonds
- **Unsaturated fatty acids** have one or more double bonds

Animation: Fats

Figure 5.11



- Fats made from saturated fatty acids are called saturated fats, and are solid at room temperature
- Most animal fats are saturated
- Fats made from unsaturated fatty acids are called unsaturated fats or oils, and are liquid at room temperature
- Plant fats and fish fats are usually unsaturated

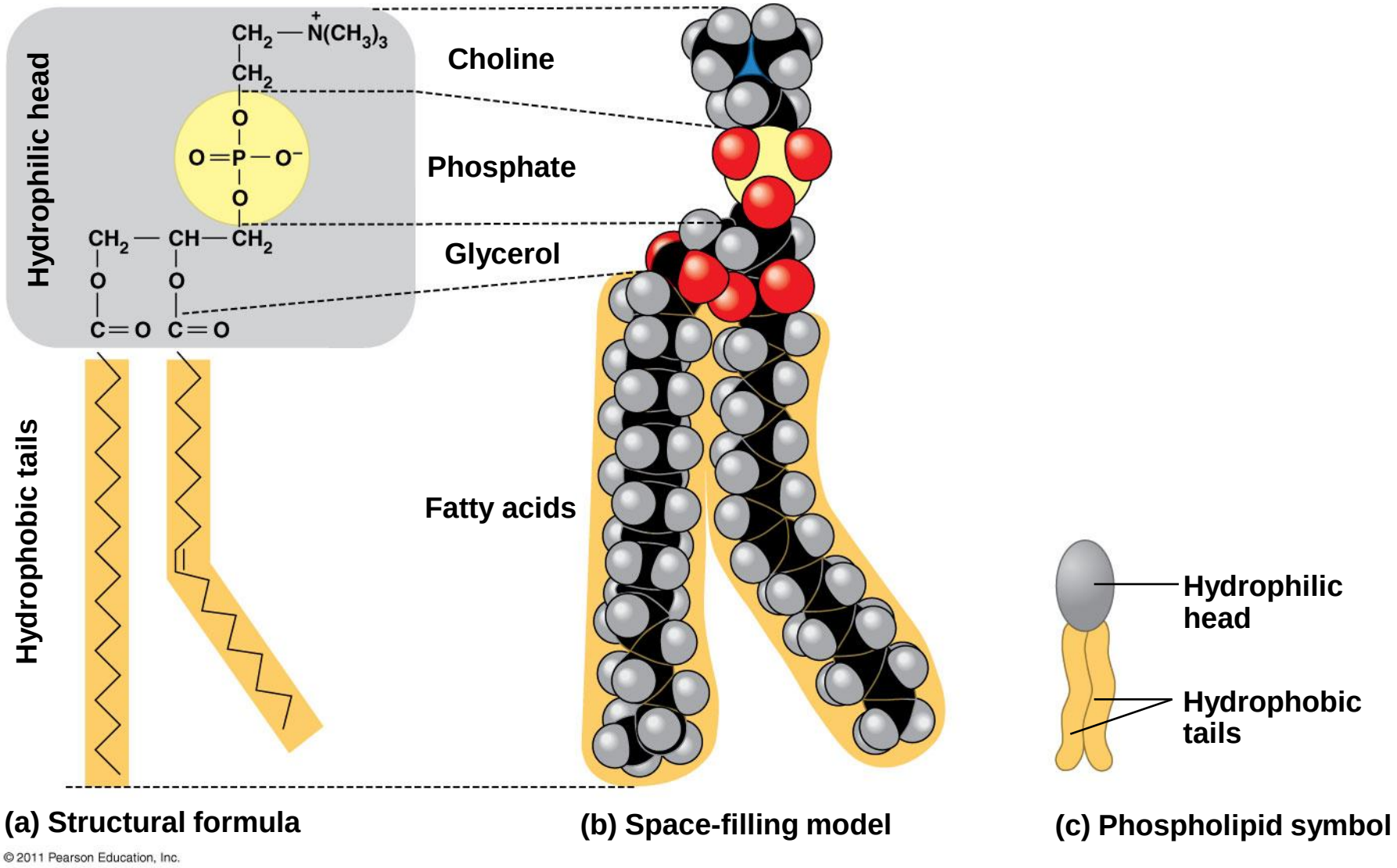
- A diet rich in saturated fats may contribute to cardiovascular disease through plaque deposits
- Hydrogenation is the process of converting unsaturated fats to saturated fats by adding hydrogen
- Hydrogenating vegetable oils also creates unsaturated fats with *trans* double bonds
- These ***trans* fats** may contribute more than saturated fats to cardiovascular disease

- The major function of fats is energy storage
- Fat also serves as insulation, vitamin carriers, and hunger suppressors.
- Humans and other mammals store their fat in adipose cells
- Adipose tissue also cushions vital organs and insulates the body

Phospholipids

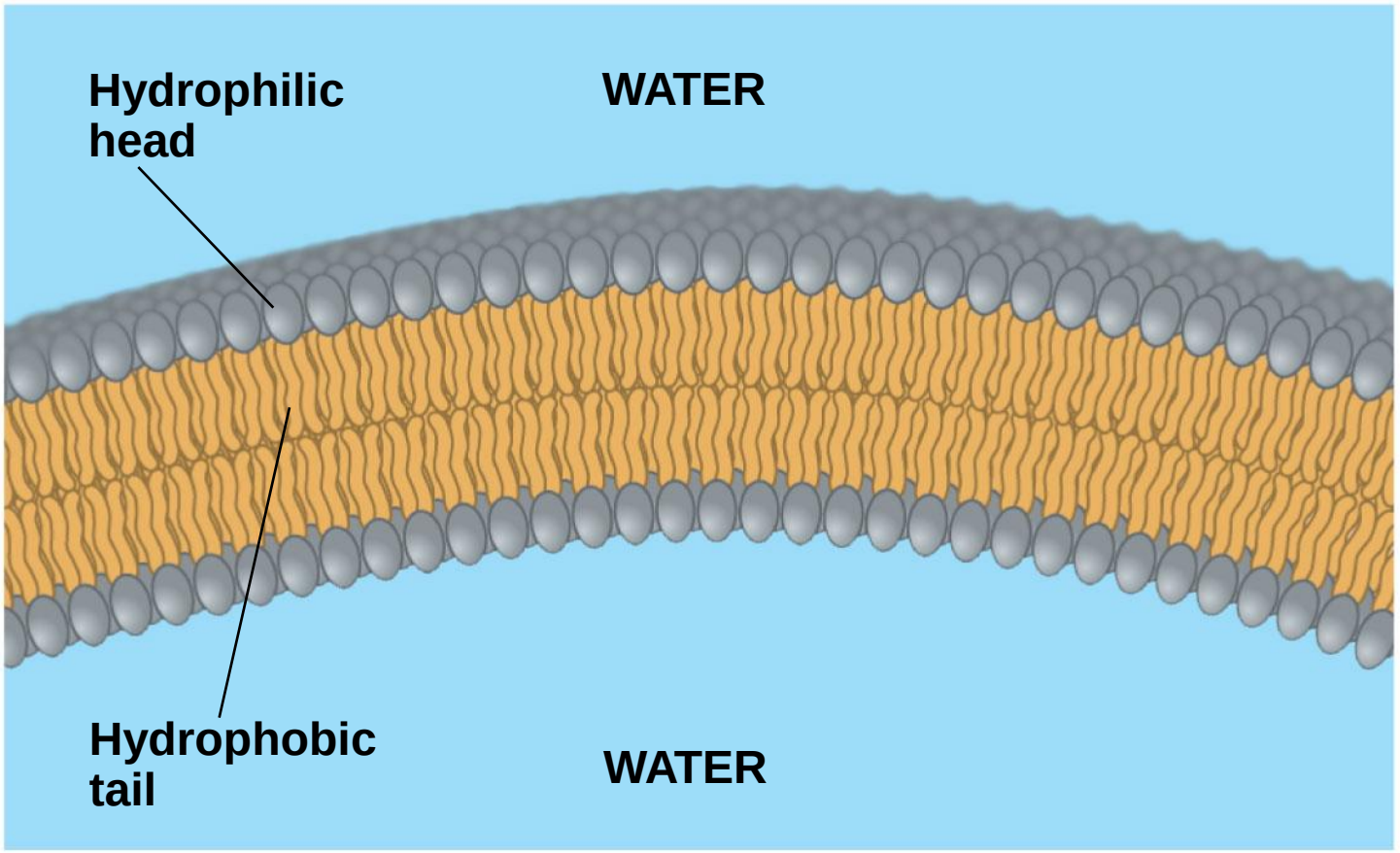
- In a **phospholipid**, two fatty acids and a phosphate group are attached to glycerol
- The two fatty acid tails are hydrophobic, but the phosphate group and its attachments form a hydrophilic head

Figure 5.12



- When phospholipids are added to water, they self-assemble into a bilayer, with the hydrophobic tails pointing toward the interior
- The structure of phospholipids results in a bilayer arrangement found in cell membranes
- Phospholipids are the major component of all cell membranes

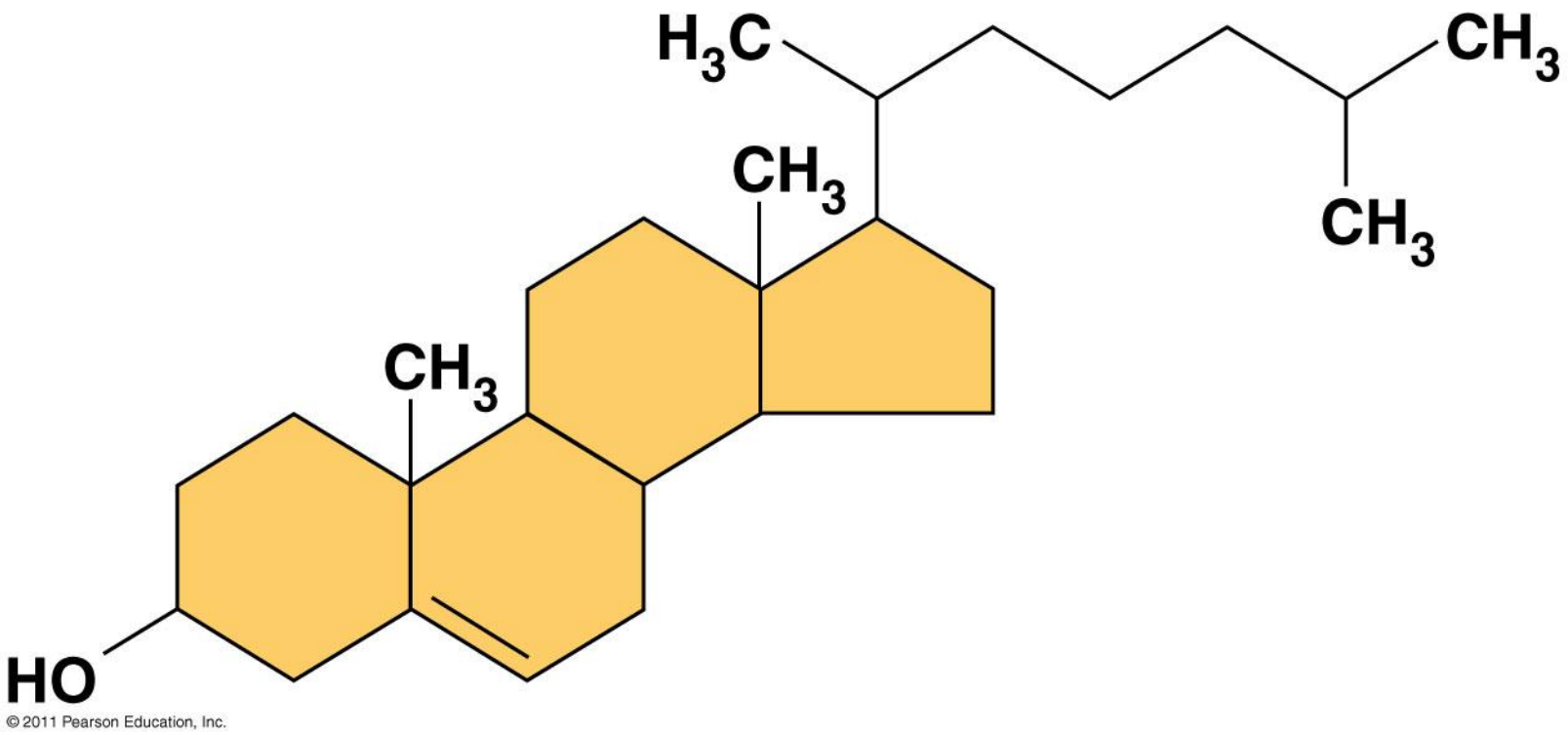
Figure 5.13



Steroids

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings
- **Cholesterol**, an important steroid, is a component in animal cell membranes
- Although cholesterol is essential in animals, high levels in the blood may contribute to cardiovascular disease

Figure 5.14



Concept 5.4: Proteins include a diversity of structures, resulting in a wide range of functions

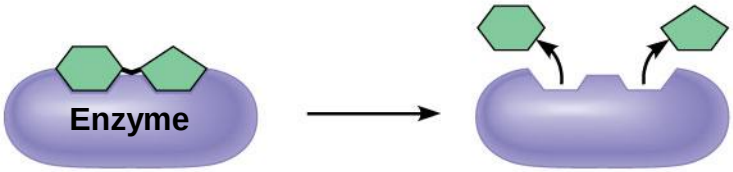
- Proteins account for more than 50% of the dry mass of most cells
- Protein functions include structural support, storage, transport, cellular communications, movement, and defense against foreign substances

Figure 5.15-a

Enzymatic proteins

Function: Selective acceleration of chemical reactions

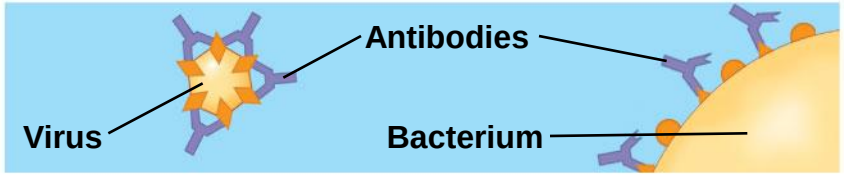
Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.



Defensive proteins

Function: Protection against disease

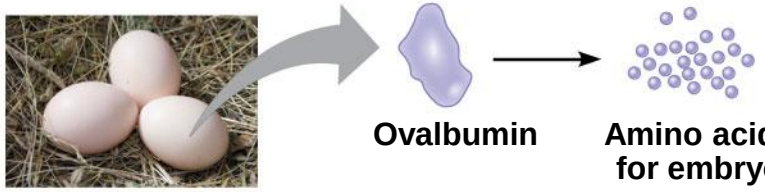
Example: Antibodies inactivate and help destroy viruses and bacteria.



Storage proteins

Function: Storage of amino acids

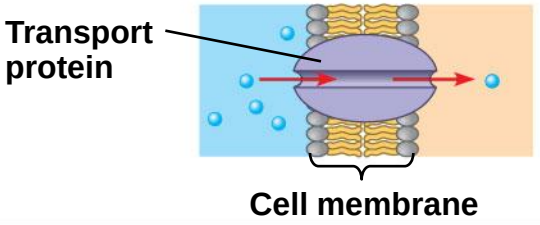
Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.



Transport proteins

Function: Transport of substances

Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.



- **Enzymes** are a type of protein that acts as a **catalyst** to speed up chemical reactions
- Enzymes can perform their functions repeatedly, functioning as workhorses that carry out the processes of life

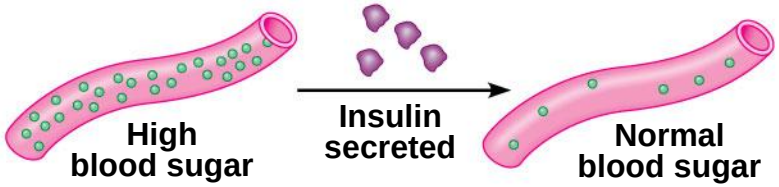
Animation: Enzymes

Figure 5.15-b

Hormonal proteins

Function: Coordination of an organism's activities

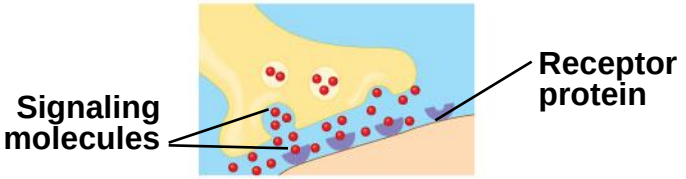
Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration



Receptor proteins

Function: Response of cell to chemical stimuli

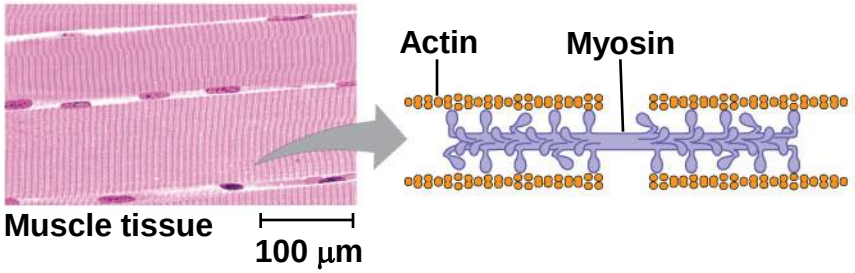
Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



Contractile and motor proteins

Function: Movement

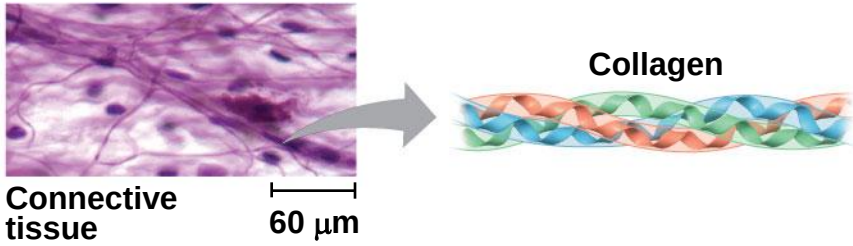
Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.



Animation: Structural Proteins

Animation: Storage Proteins

Animation: Transport Proteins

Animation: Receptor Proteins

Animation: Contractile Proteins

Animation: Defensive Proteins

Animation: Hormonal Proteins

Animation: Sensory Proteins

Animation: Gene Regulatory Proteins

Amino Acid Monomers

- **Amino acids** are organic molecules with carboxyl and amino groups
- Amino acids differ in their properties due to differing side chains, called R groups

Figure 5.UN01

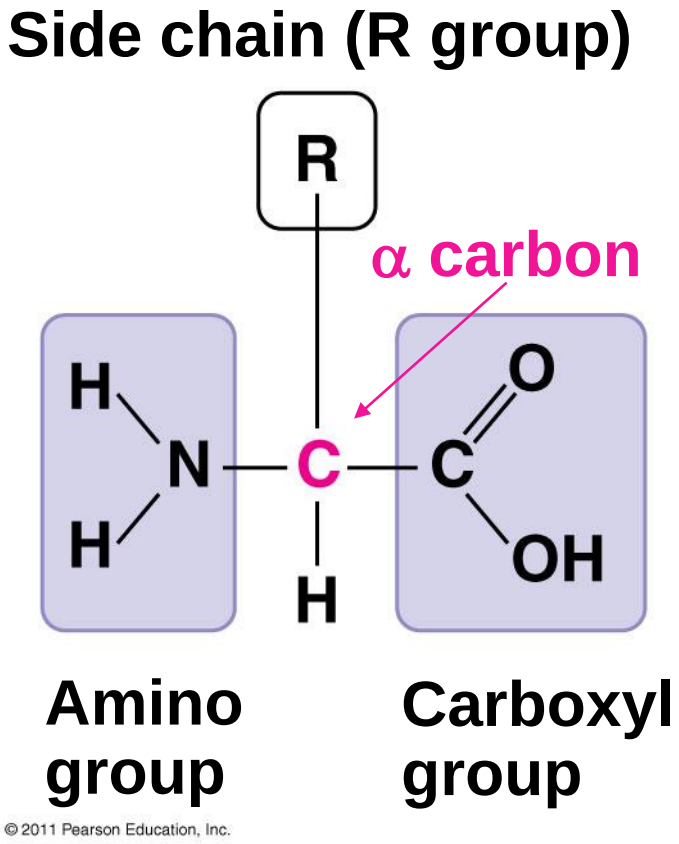
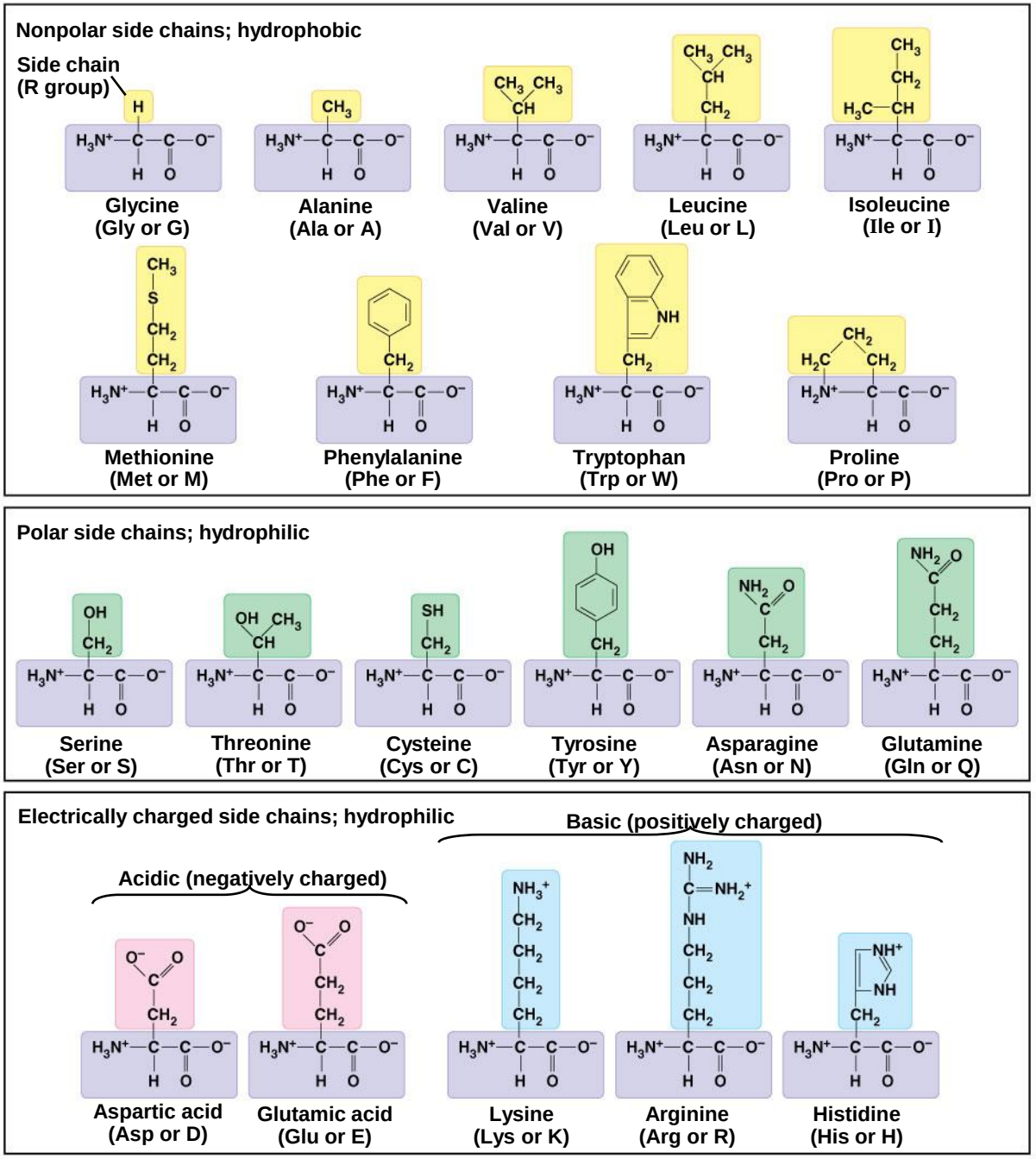


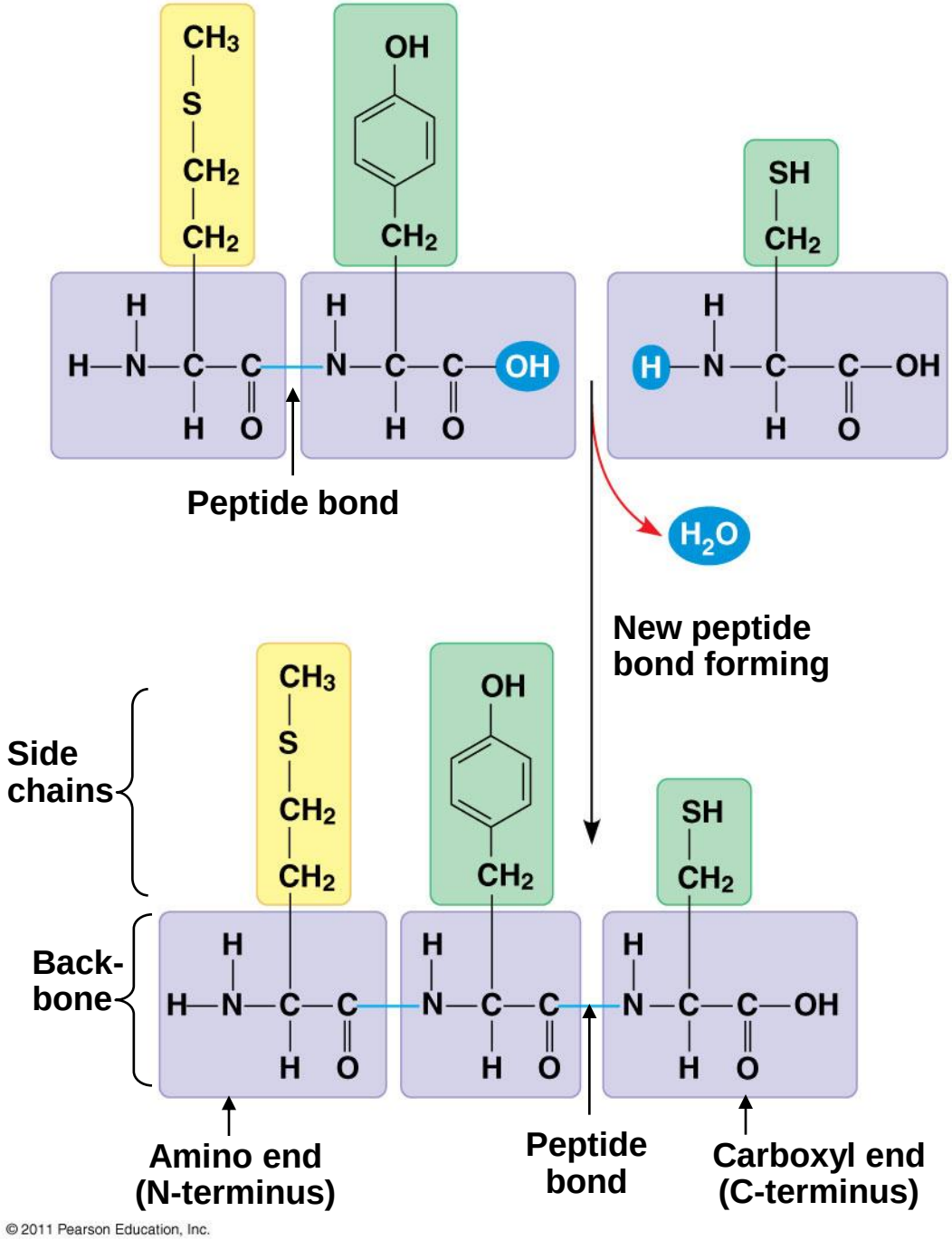
Figure 5.16



Amino Acid Polymers

- Amino acids are linked by **peptide bonds**
- A polypeptide is a polymer of amino acids
- Polypeptides range in length from a few to more than a thousand monomers
- Each polypeptide has a unique linear sequence of amino acids, with a carboxyl end (C-terminus) and an amino end (N-terminus)

Figure 5.17



Protein Structure and Function

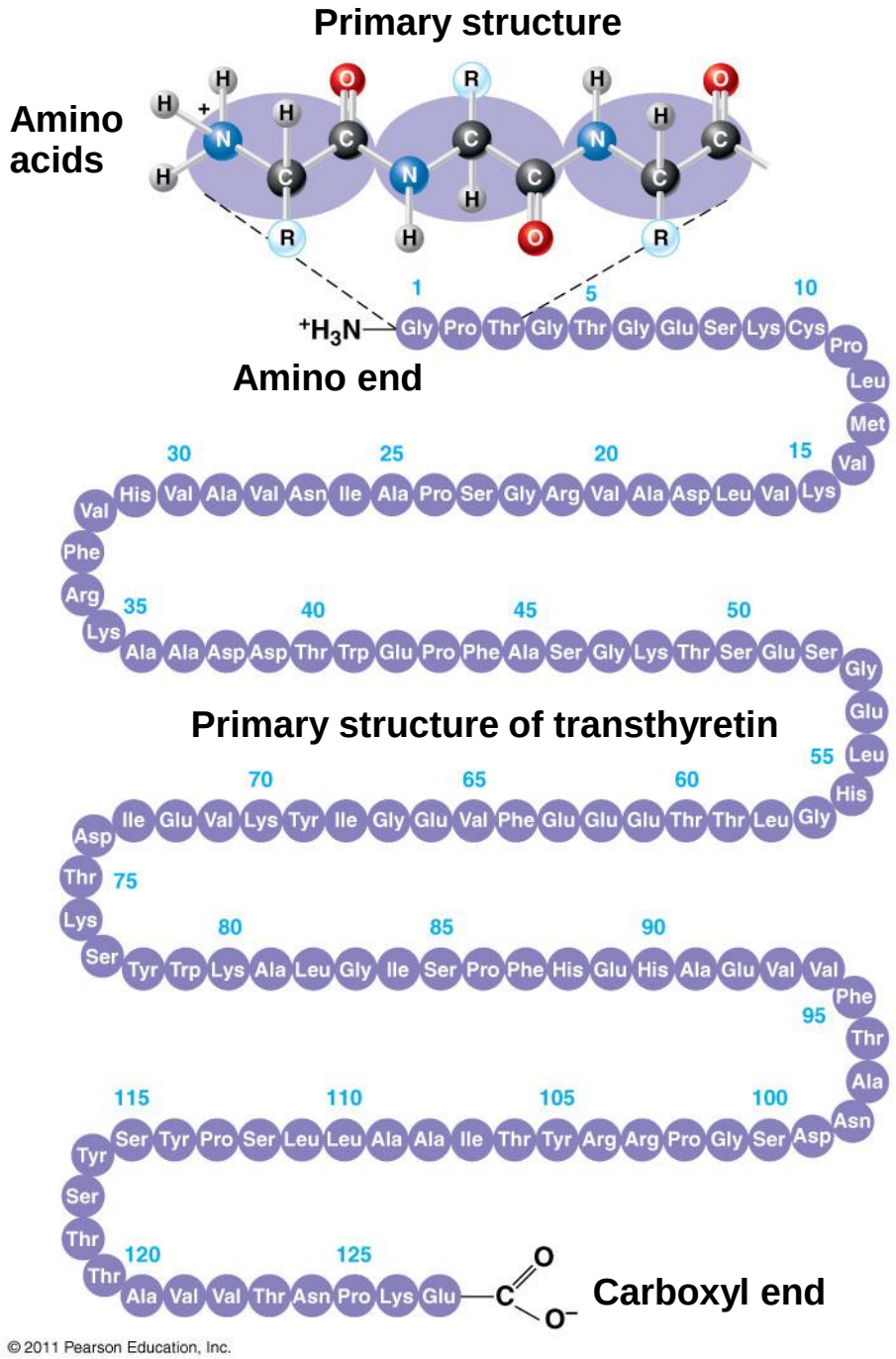
- A functional protein consists of one or more polypeptides precisely twisted, folded, and coiled into a unique shape

Four Levels of Protein Structure

- The primary structure of a protein is its unique sequence of amino acids
- Secondary structure, found in most proteins, consists of coils and folds in the polypeptide chain
- Tertiary structure is determined by interactions among various side chains (R groups)
- Quaternary structure results when a protein consists of multiple polypeptide chains

Animation: Protein Structure Introduction

Figure 5.20a



- **Primary structure**, the sequence of amino acids in a protein, is like the order of letters in a long word
- Primary structure is determined by inherited genetic information

Animation: Primary Protein Structure

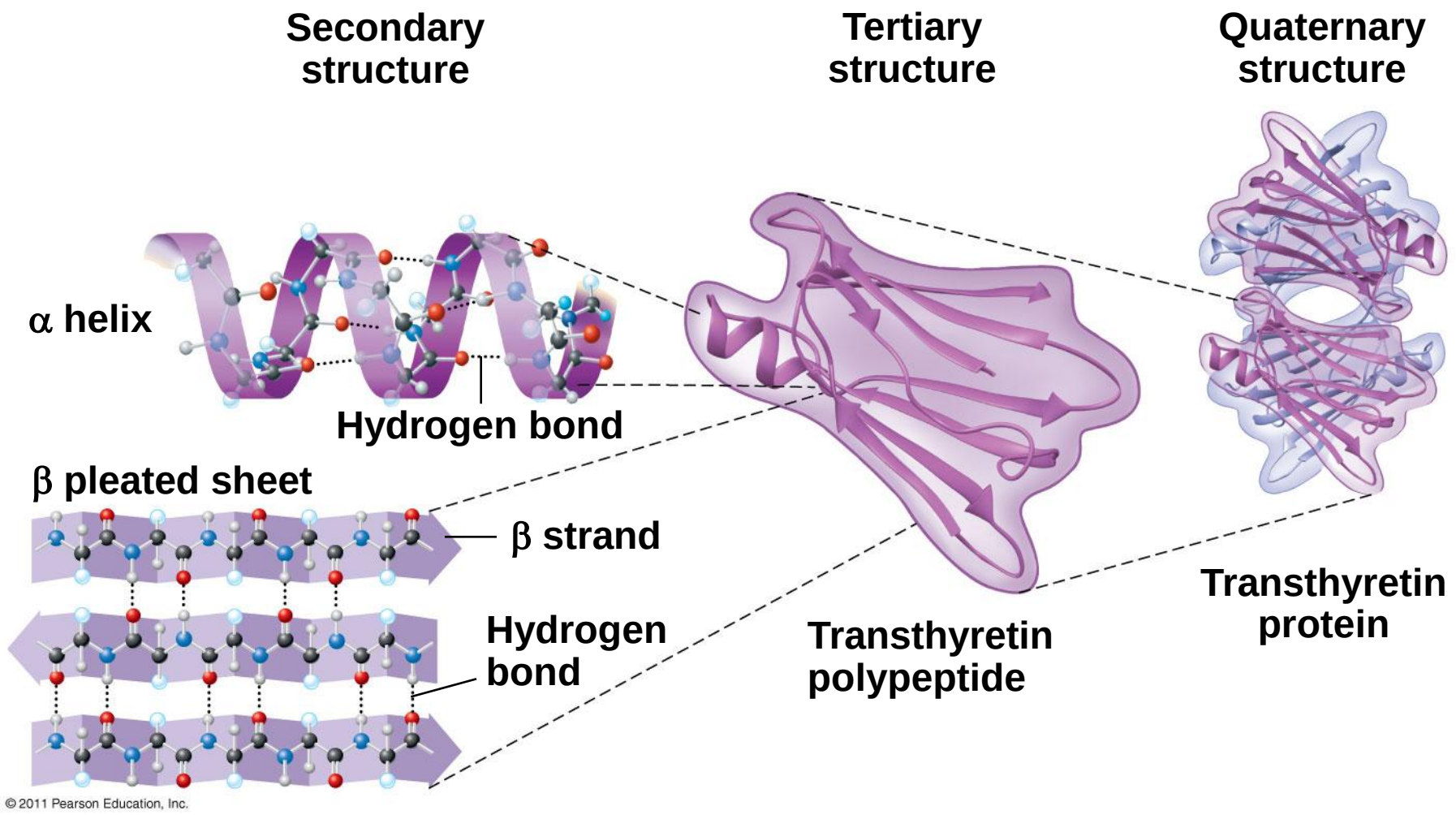
- The coils and folds of **secondary structure** result from hydrogen bonds between repeating constituents of the polypeptide backbone
- Typical secondary structures are a coil called an α **helix** and a folded structure called a β **pleated sheet**

Animation: Secondary Protein Structure

- **Tertiary structure** is determined by interactions between R groups, rather than interactions between backbone constituents
- These interactions between R groups include hydrogen bonds, ionic bonds, **hydrophobic interactions**, and van der Waals interactions
- Strong covalent bonds called **disulfide bridges** may reinforce the protein's structure

Animation: Tertiary Protein Structure

Figure 5.20b


Secondary structure
Tertiary structure
Quaternary structure
α helix
Hydrogen bond
β pleated sheet
β strand
Hydrogen bond
Transthyretin polypeptide
Transthyretin protein
© 2011 Pearson Education, Inc.

- **Quaternary structure** results when two or more polypeptide chains form one macromolecule
- Collagen is a fibrous protein consisting of three polypeptides coiled like a rope
- Hemoglobin is a globular protein consisting of four polypeptides: two alpha and two beta chains

Animation: Quaternary Protein Structure

Sickle-Cell Disease: A Change in Primary Structure

- A slight change in primary structure can affect a protein's structure and ability to function
- **Sickle-cell disease**, an inherited blood disorder, results from a single amino acid substitution in the protein hemoglobin

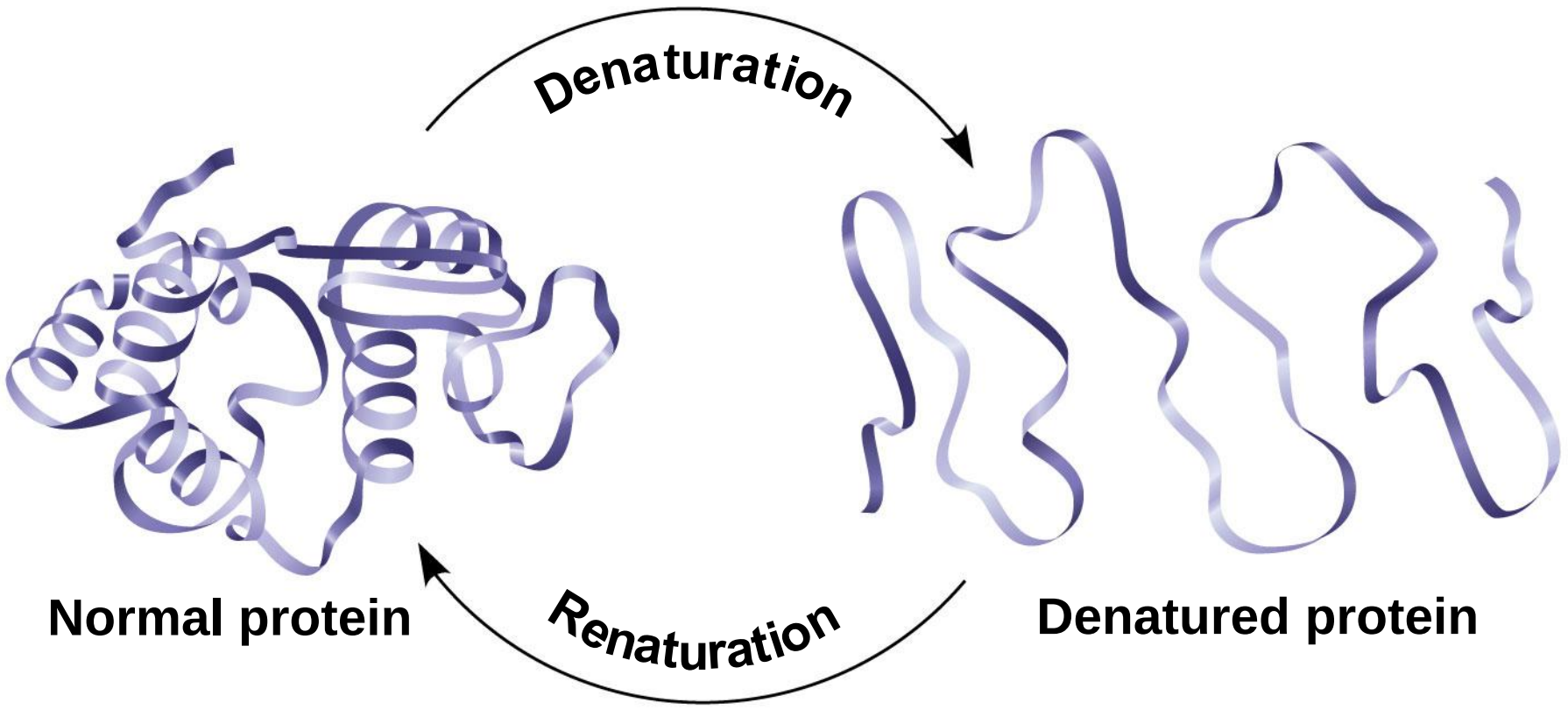
Figure 5.21

	Primary Structure	Secondary and Tertiary Structures	Quaternary Structure	Function	Red Blood Cell Shape
Normal hemoglobin	1 Val 2 His 3 Leu 4 Thr 5 Pro 6 Glu 7 Glu	β subunit	Normal hemoglobin α β α β	Molecules do not associate with one another; each carries oxygen.	10 μm
Sickle-cell hemoglobin	1 Val 2 His 3 Leu 4 Thr 5 Pro 6 Val 7 Glu	Exposed hydrophobic region β subunit	Sickle-cell hemoglobin α β α β	Molecules crystallize into a fiber; capacity to carry oxygen is reduced.	10 μm

What Determines Protein Structure?

- In addition to primary structure, physical and chemical conditions can affect structure
- Alterations in pH, salt concentration, temperature, or other environmental factors can cause a protein to unravel
- This loss of a protein's native structure is called **denaturation**
- A denatured protein is biologically inactive

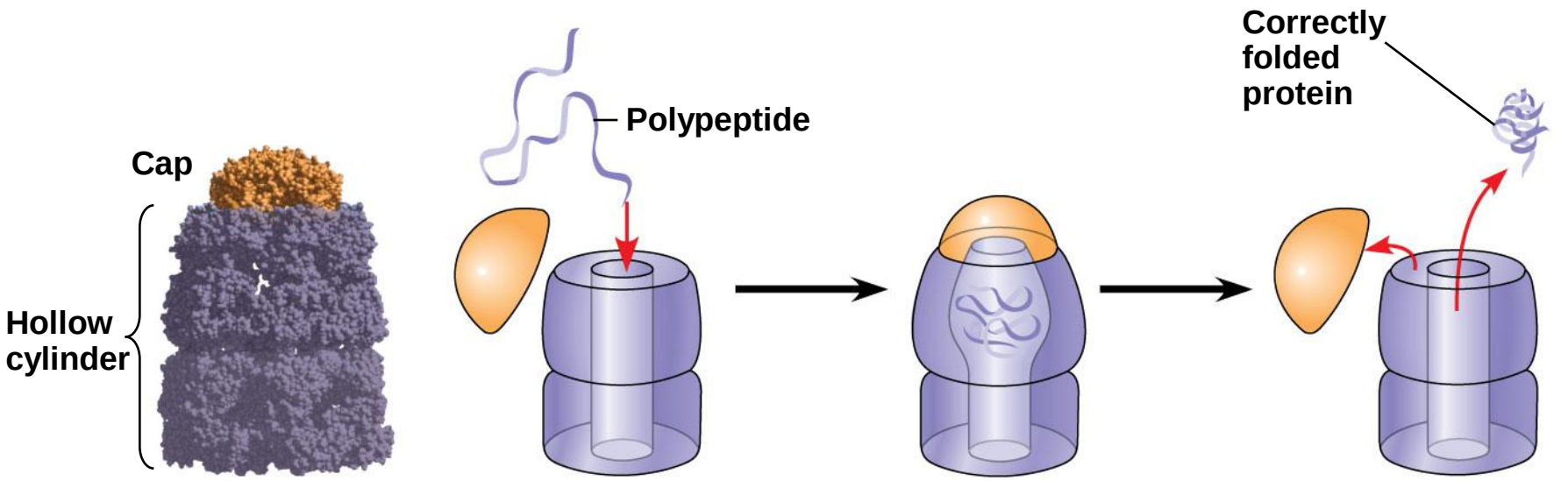
Figure 5.22



Protein Folding in the Cell

- It is hard to predict a protein's structure from its primary structure
- Most proteins probably go through several stages on their way to a stable structure
- **Chaperonins** are protein molecules that assist the proper folding of other proteins
- Diseases such as Alzheimer's, Parkinson's, and mad cow disease are associated with misfolded proteins

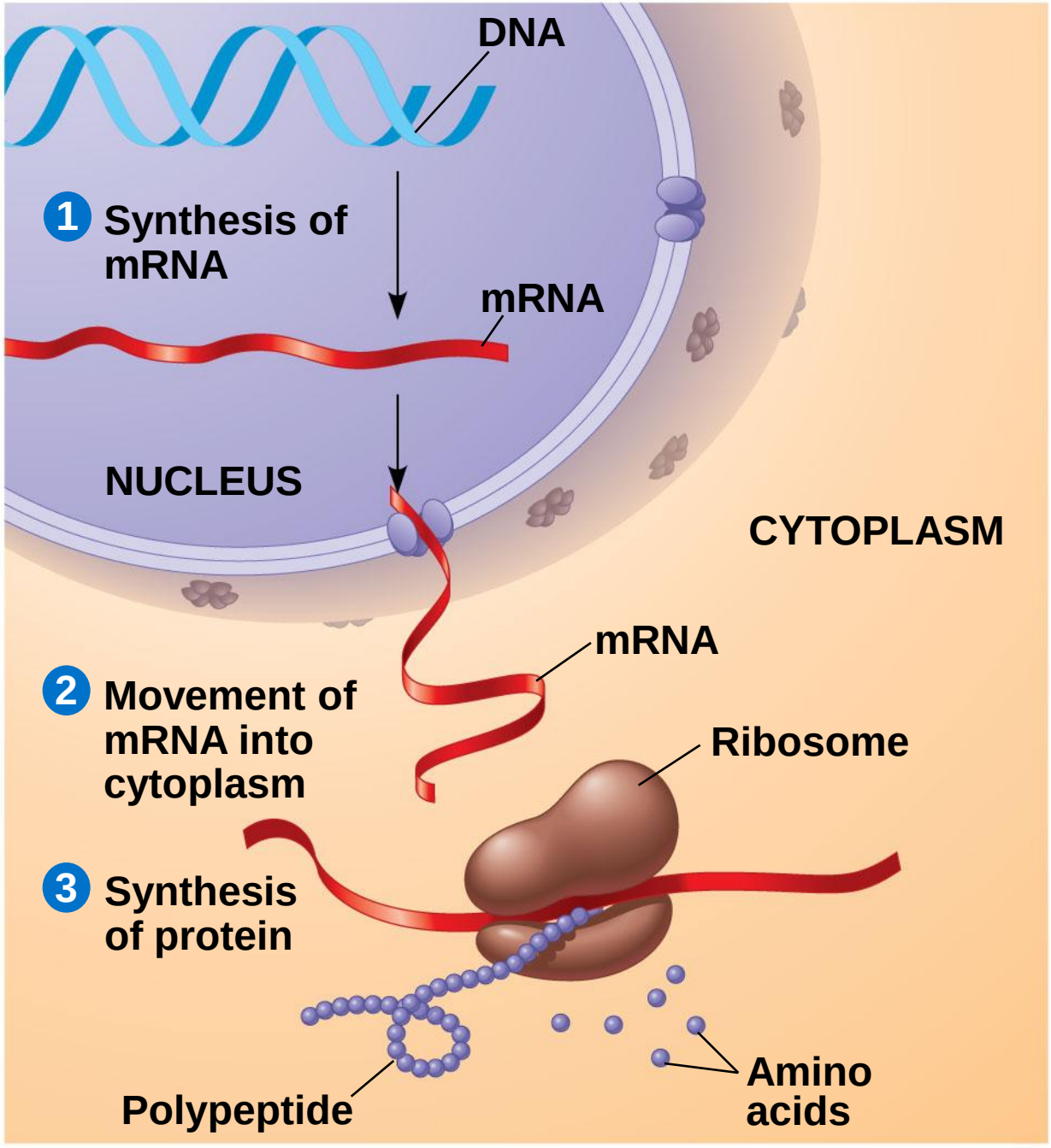
Figure 5.23



Concept 5.5: Nucleic acids store, transmit, and help express hereditary information

- The amino acid sequence of a polypeptide is programmed by a unit of inheritance called a **gene**
- Genes are made of DNA, a **nucleic acid** made of monomers called nucleotides

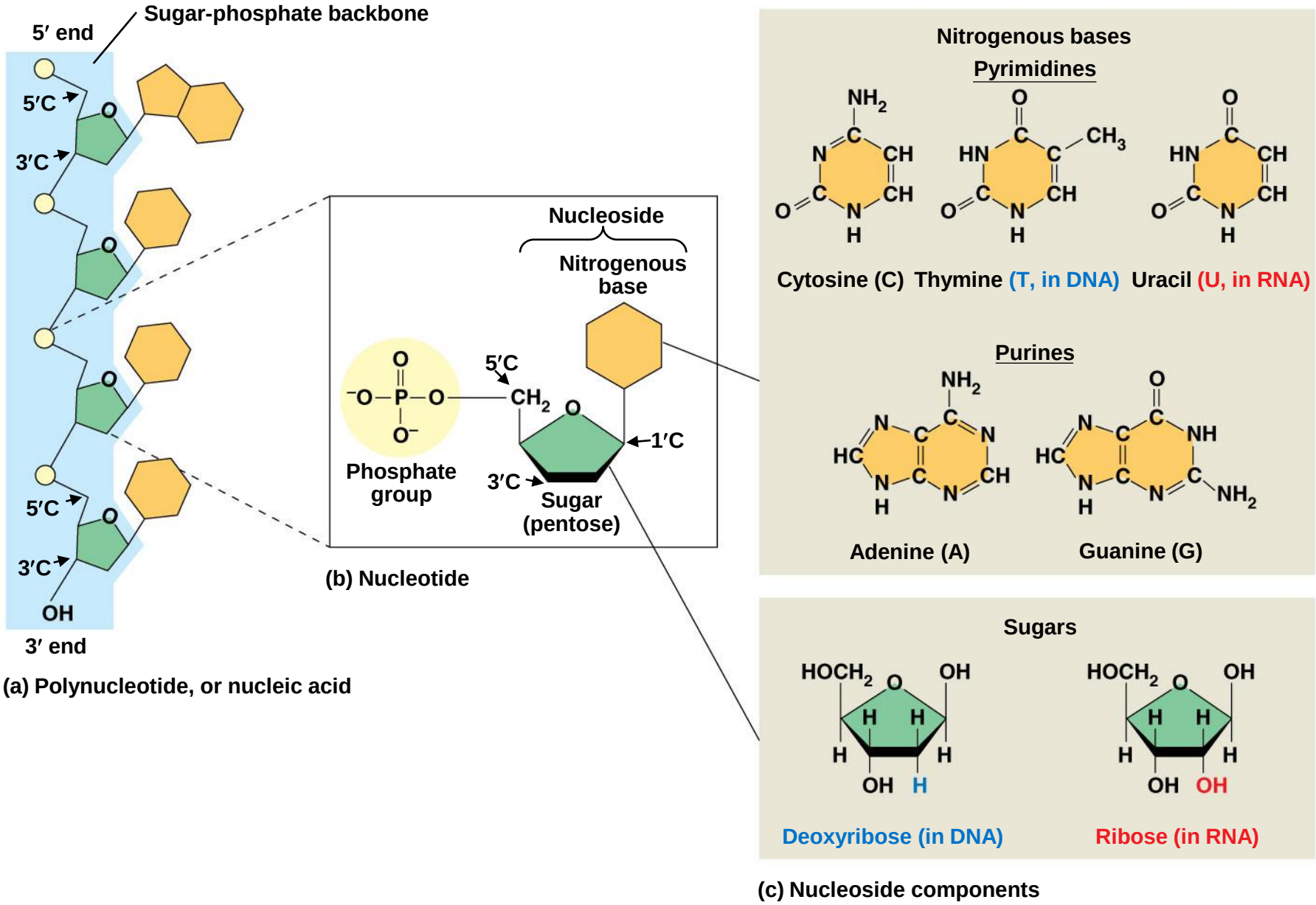
Figure 5.25-3



The Components of Nucleic Acids

- Nucleic acids are polymers called **polynucleotides**
- Each polynucleotide is made of monomers called **nucleotides**
- Each nucleotide consists of a nitrogenous base, a pentose sugar, and one or more phosphate groups
- The portion of a nucleotide without the phosphate group is called a nucleoside

Figure 5.26



- Nucleoside = nitrogenous base + sugar
- There are two families of nitrogenous bases
  - **Pyrimidines** (cytosine, thymine, and uracil) have a single six-membered ring
  - **Purines** (adenine and guanine) have a six-membered ring fused to a five-membered ring
- In DNA, the sugar is **deoxyribose**; in RNA, the sugar is **ribose**
- Nucleotide = nucleoside + phosphate group

Nucleotide Polymers

- Nucleotide polymers are linked together to build a polynucleotide
- Adjacent nucleotides are joined by covalent bonds that form between the –OH group on the 3′ carbon of one nucleotide and the phosphate on the 5′ carbon on the next
- These links create a backbone of sugar-phosphate units with nitrogenous bases as appendages
- The sequence of bases along a DNA or mRNA polymer is unique for each gene

The Structures of DNA and RNA Molecules

- RNA molecules usually exist as single polypeptide chains
- DNA molecules have two polynucleotides spiraling around an imaginary axis, forming a **double helix**
- In the DNA double helix, the two backbones run in opposite 5′→ 3′ directions from each other, an arrangement referred to as **antiparallel**
- One DNA molecule includes many genes

Figure 5.27

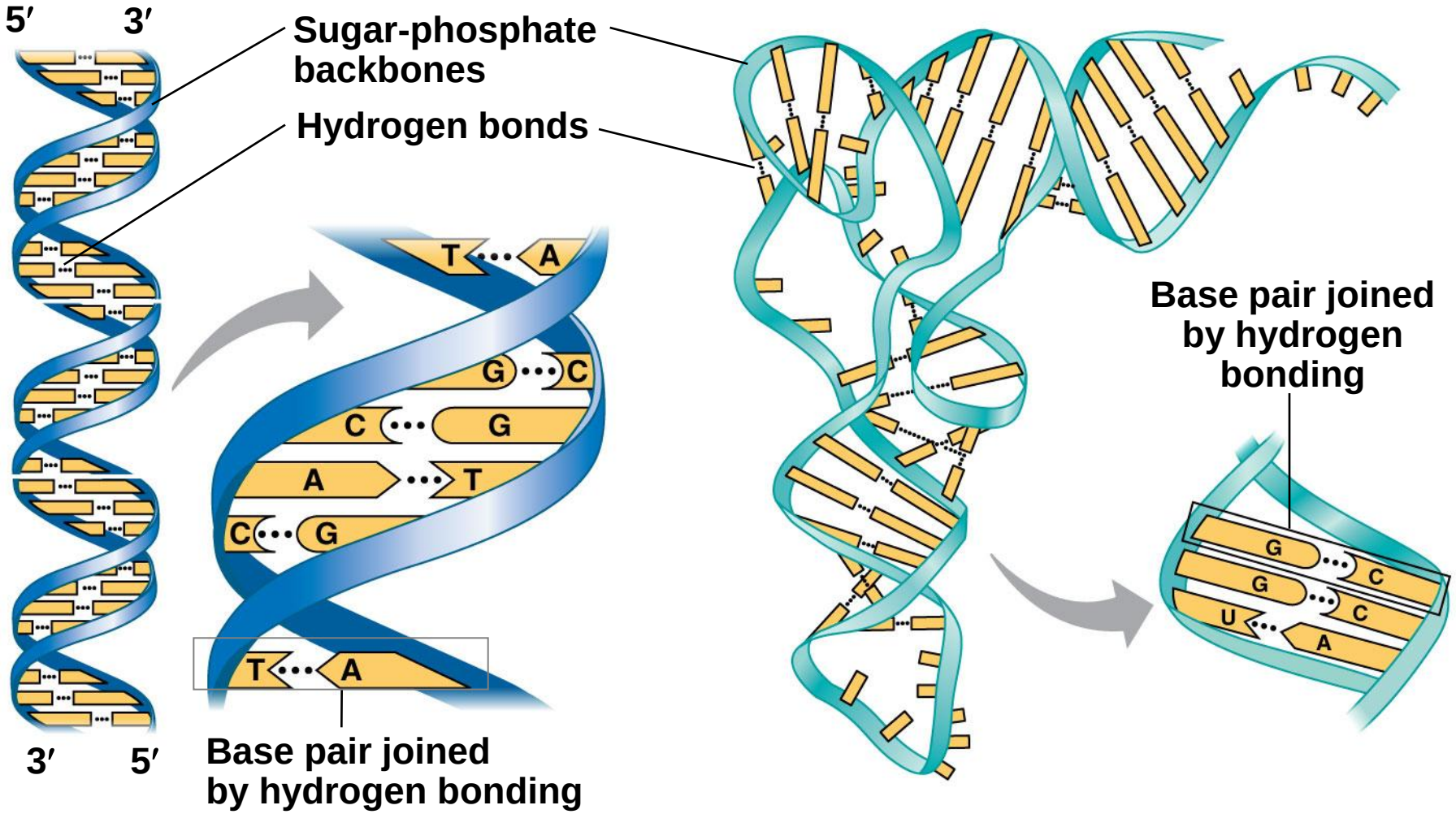
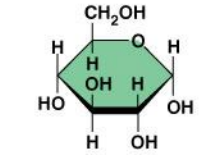
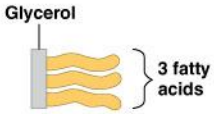
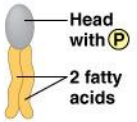
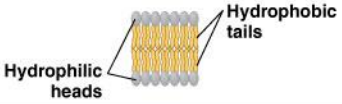
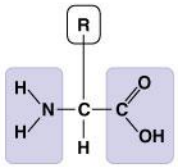
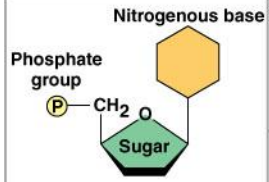


Figure 5.UN02

Large Biological Molecules	Components	Examples	Functions
CONCEPT 5.2 Carbohydrates serve as fuel and building material	 Monosaccharide monomer	**Monosaccharides:** glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Disaccharides: lactose, sucrose	
		Polysaccharides: • Cellulose (plants) • Starch (plants) • Glycogen (animals) • Chitin (animals and fungi)	• Strengthens plant cell walls • Stores glucose for energy • Stores glucose for energy • Strengthens exoskeletons and fungal cell walls
CONCEPT 5.3 Lipids are a diverse group of hydrophobic molecules		**Triacylglycerols** (fats or oils): glycerol + 3 fatty acids	Important energy source 
		**Phospholipids:** phosphate group + 2 fatty acids	Lipid bilayers of membranes 
	 Steroid backbone	**Steroids:** four fused rings with attached chemical groups	• Component of cell membranes (cholesterol) • Signaling molecules that travel through the body (hormones)
CONCEPT 5.4 Proteins include a diversity of structures, resulting in a wide range of functions	 Amino acid monomer (20 types)	• Enzymes • Structural proteins • Storage proteins • Transport proteins • Hormones • Receptor proteins • Motor proteins • Defensive proteins	• Catalyze chemical reactions • Provide structural support • Store amino acids • Transport substances • Coordinate organismal responses • Receive signals from outside cell • Function in cell movement • Protect against disease
CONCEPT 5.5 Nucleic acids store, transmit, and help express hereditary information	 Nucleotide monomer	**DNA:**  • Sugar = deoxyribose • Nitrogenous bases = C, G, A, T • Usually double-stranded	Stores hereditary information
		RNA:  • Sugar = ribose • Nitrogenous bases = C, G, A, U • Usually single-stranded	Various functions during gene expression, including carrying instructions from DNA to ribosomes