LECTURE PRESENTATIONS
For CAMPBELL BIOLOGY, NINTH EDITION
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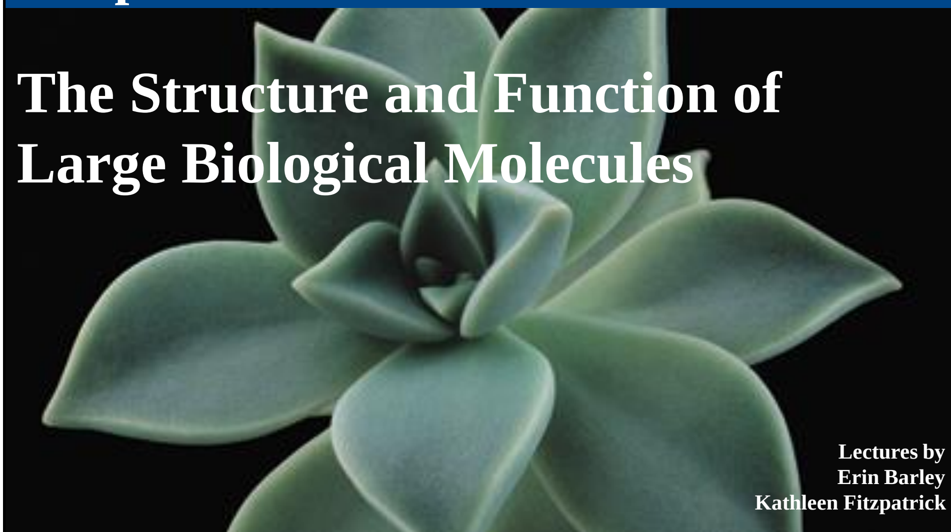
Chapter 5



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
- Within cells, small organic molecules are joined together to form larger molecules
- **Macromolecules** are large molecules composed of thousands of covalently connected atoms
- Molecular structure and function are inseparable

Fig. 5-1

Concept 5.1: Macromolecules are polymers, built from monomers

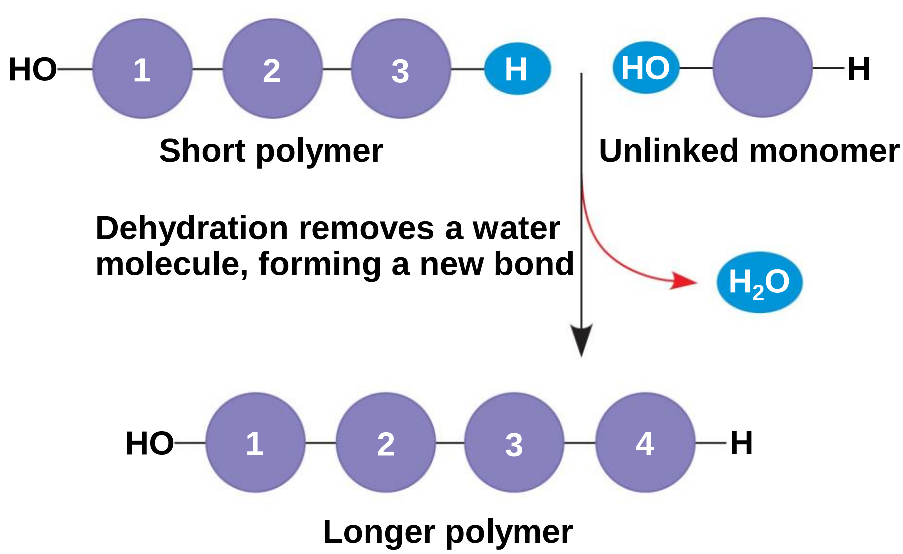
- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**
- Three of the **four classes** of life's organic molecules are **polymers**:
  - **Carbohydrates**
  - **Proteins**
  - **Nucleic acids**

The Synthesis and Breakdown of Polymers

- A **condensation reaction** or more specifically a **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule
- **Enzymes** are macromolecules that speed up the dehydration process
- Polymers are disassembled to monomers by **hydrolysis**, a reaction that is essentially the reverse of the dehydration reaction

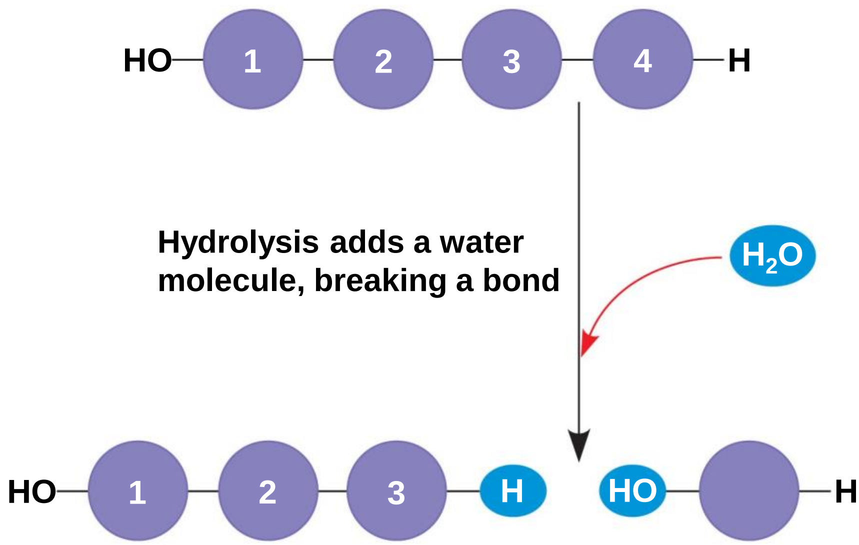
PLAY Animation: Polymers

Fig. 5-2a



(a) Dehydration reaction in the synthesis of a polymer

Fig. 5-2b



(b) Hydrolysis of a polymer

The Diversity of Polymers

- Each cell has thousands of different kinds of macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species
- What is the basis of this diversity??
- An immense variety of polymers can be built from a small set of monomers

Concept 5.2: Carbohydrates serve as fuel and building material

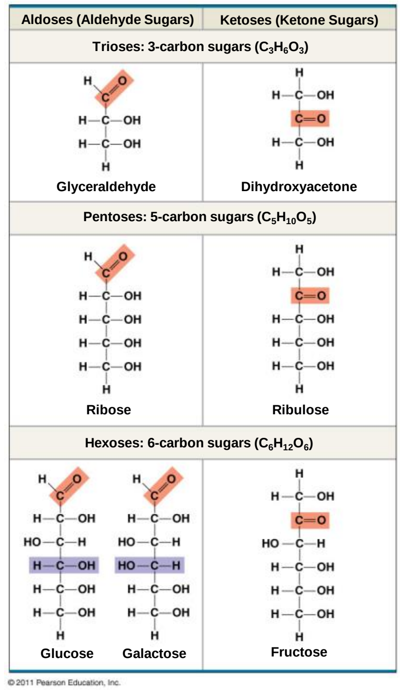
- **Carbohydrates** include sugars and the polymers of sugars
- The simplest carbohydrates are **monosaccharides**, or single sugars
- Carbohydrate macromolecules are **polysaccharides**, polymers composed of many sugar building blocks

Sugars

- **Monosaccharides** have molecular formulas that are usually multiples of $(CH_2O)n$
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Most names of sugars end in **-ose**
- 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

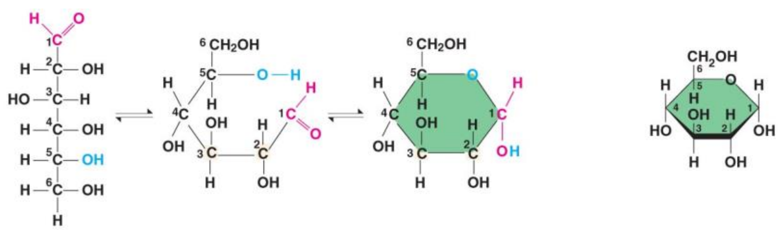
The structure and classification of some monosaccharides.



- Though often drawn as **linear skeletons**, in aqueous solutions many sugars **form rings**
- **Monosaccharides** serve as a **major fuel** for cells and as **raw material for building molecules**

Fig. 5-4

Linear and ring forms of glucose



(a) Linear and ring forms

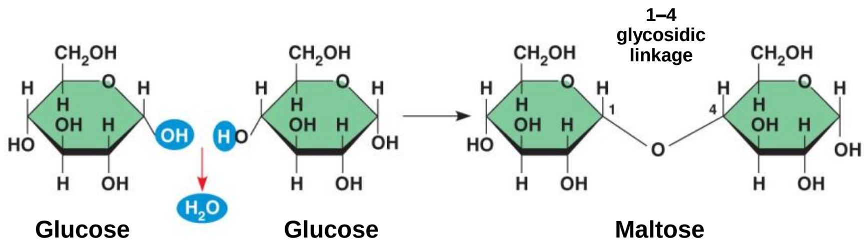
(b) Abbreviated ring structure

- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**
- **Examples of disaccharides:**
  - **Sucrose: Glucose + fructose**
  - **Maltose: glucose + glucose**
  - **Lactose: glucose + galactose**

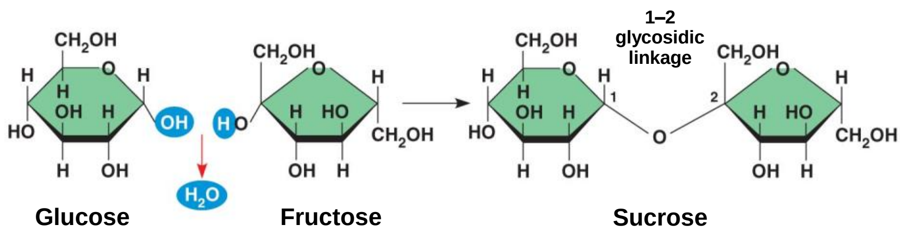
PLAY Animation: Disaccharides

Fig. 5-5

Examples of disaccharide synthesis



(a) Dehydration reaction in the synthesis of maltose



(b) Dehydration reaction in the synthesis of sucrose

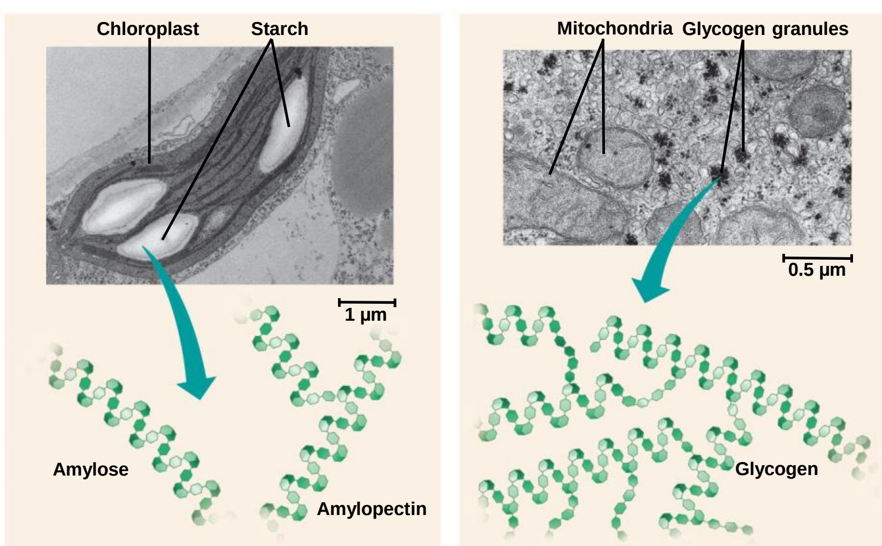
Polysaccharides

- **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 **α-glucose monomers**
- Plants store surplus starch as granules within **chloroplasts and other plastids**

Fig. 5-6



(a) Starch: a plant polysaccharide

(b) Glycogen: an animal polysaccharide

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

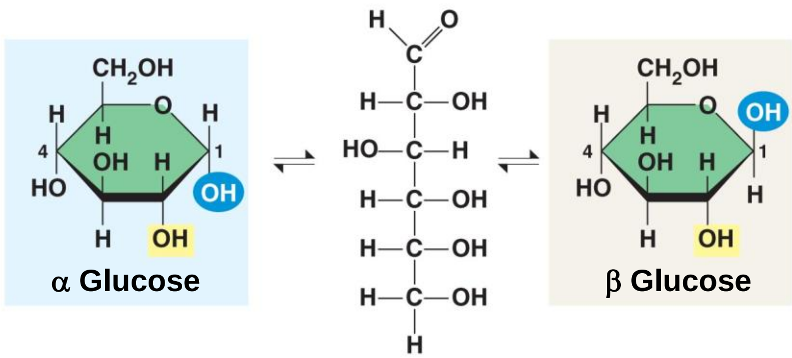
Structural Polysaccharides

- **Cellulose:**
- 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

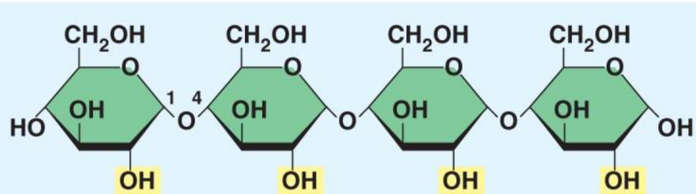
Fig. 5-7a

Starch and cellulose structures

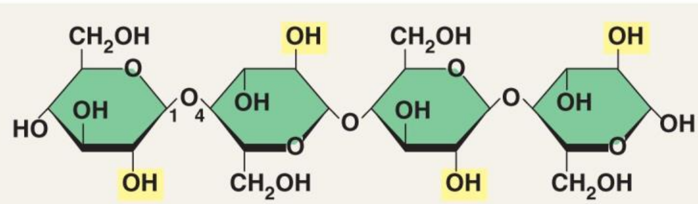


(a) α and β glucose ring structures

Fig. 5-7bc



(b) Starch: 1–4 linkage of α glucose monomers

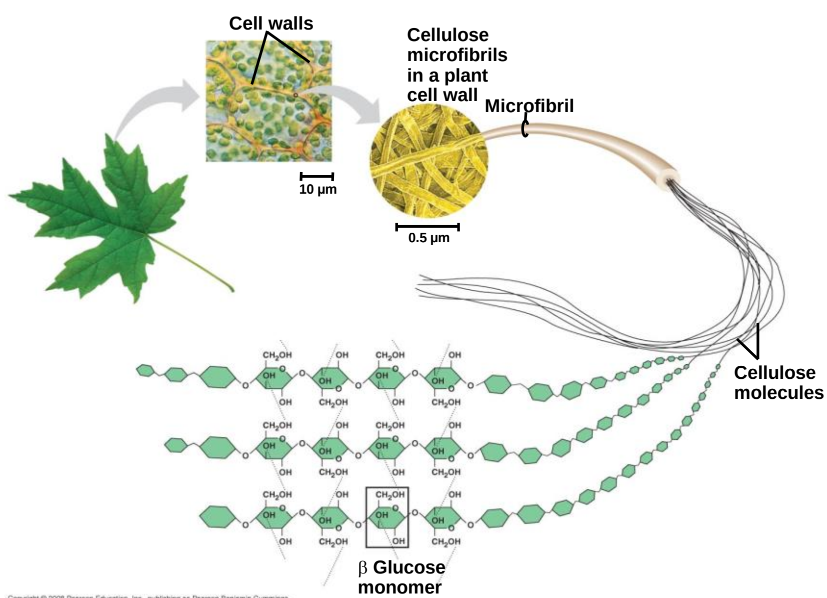


(c) Cellulose: 1–4 linkage of β glucose monomers

- Polymers with **α glucose are helical**
- Polymers with **β glucose are straight**
- In straight structures, H atoms on one strand can bond with OH groups on other strands
- Parallel cellulose molecules held together this way are grouped into **microfibrils**, which form strong building materials for plants

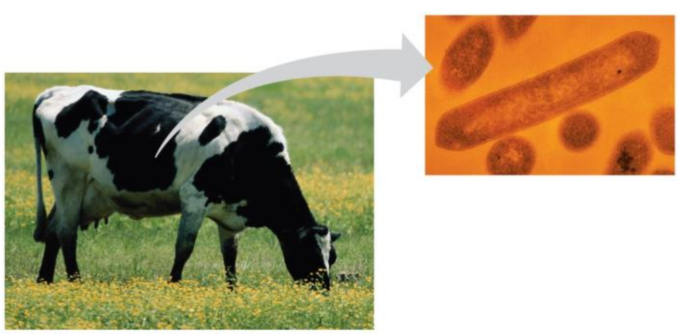
Fig. 5-8

The arrangement of cellulose in plant cell walls



- 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 secrete enzymes to digest cellulose
- Many herbivores, from cows to termites, have symbiotic relationships with these microbes

Fig. 5-9



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

Fig. 5-10

Chitin, a structural polysaccharide

(a) **The structure of the chitin monomer.**

(b) **Chitin forms the exoskeleton of arthropods.**

(c) **Chitin is used to make a strong and flexible surgical thread.**

N-acetyl-
Glucosamine

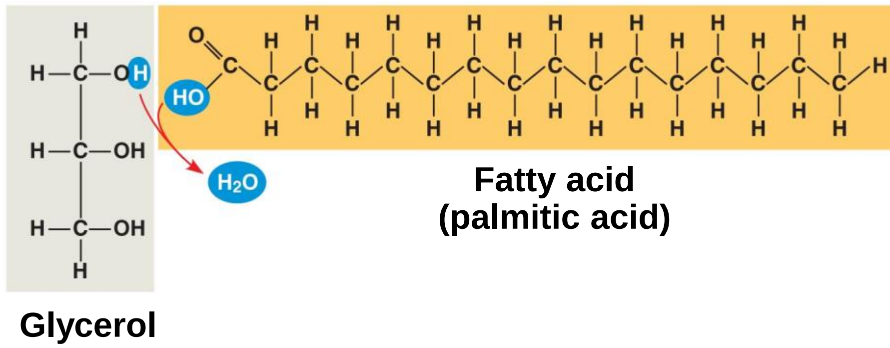
Concept 5.3: Lipids are a diverse group of hydrophobic molecules

- **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

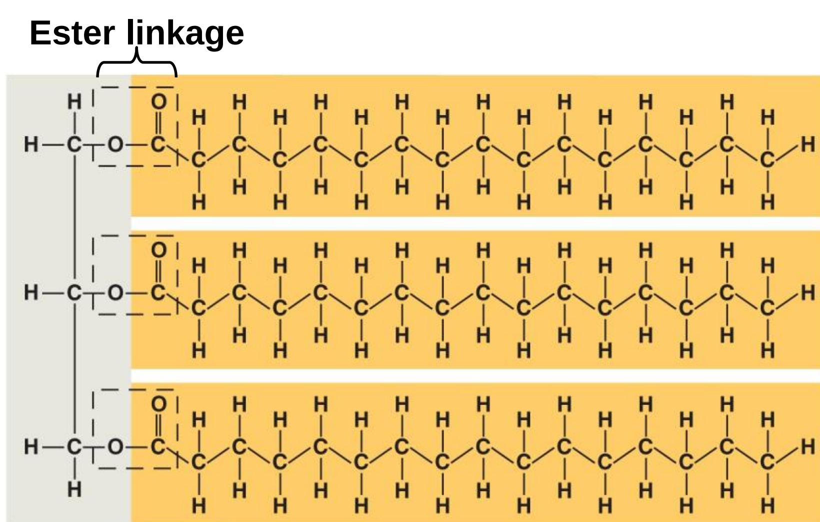
- **Fats** are constructed from two types of smaller molecules: glycerol and fatty acids
- **Glycerol** is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton

Fig. 5-11a



(a) Dehydration reaction in the synthesis of a fat

Fig. 5-11b



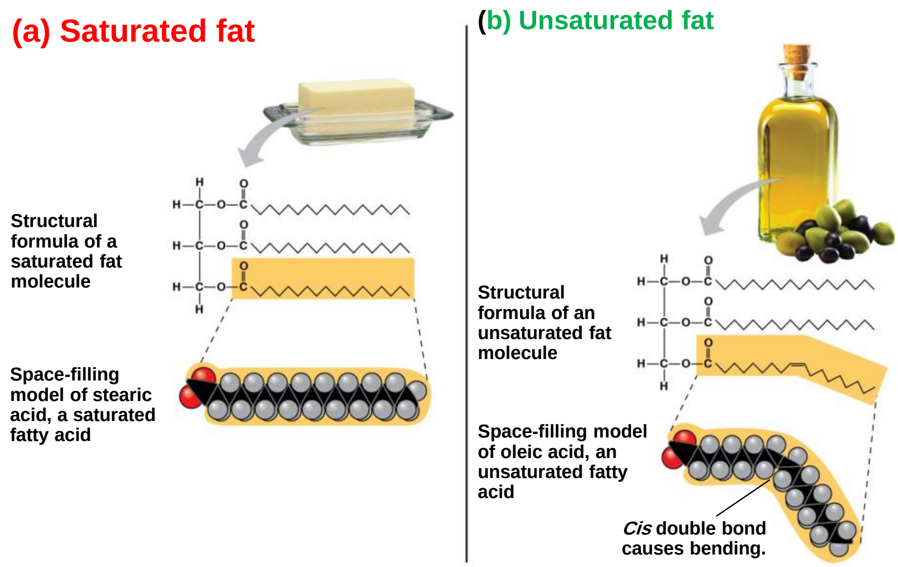
(b) Fat molecule (triacylglycerol)

- Fats **separate from water** because water molecules form hydrogen bonds with each other and **exclude the fats**
- **In a fat**, three fatty acids are joined to a glycerol by an **ester linkage**, creating a **triacylglycerol,** or **triglyceride**

- 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

PLAY 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

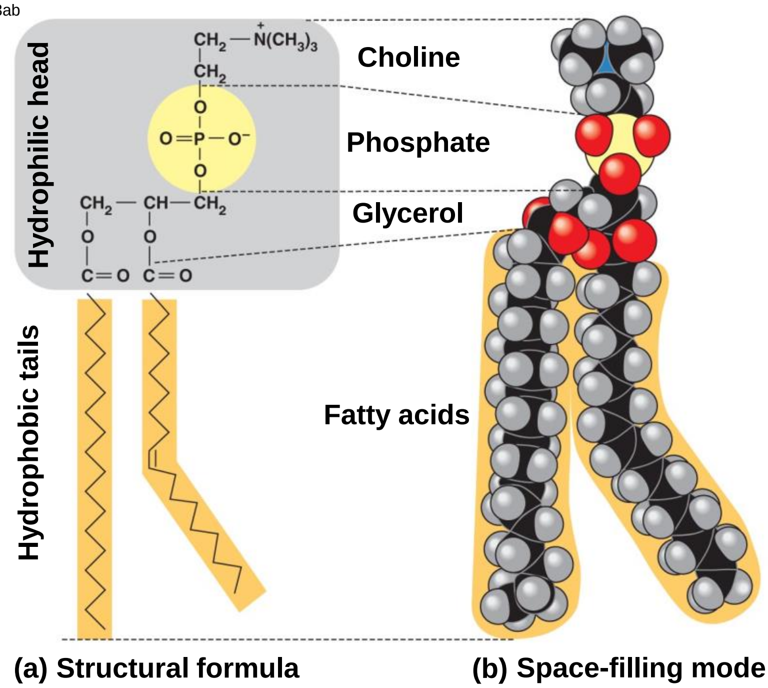
- A diet rich in **saturated fats** may contribute to **cardiovascular disease** through plaque deposits
- **Hydrogenation** is the process of converting unsaturated fats to saturated fats by adding hydrogen
- Hydrogenating vegetable oils also creates unsaturated fats with ***trans*** **double bonds**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

- The **major function of fats** is **energy storage**
- Humans and other mammals **store** their fat in **adipose cells**
- **Adipose tissue** also **cushions vital organs and insulates the body**

Phospholipids

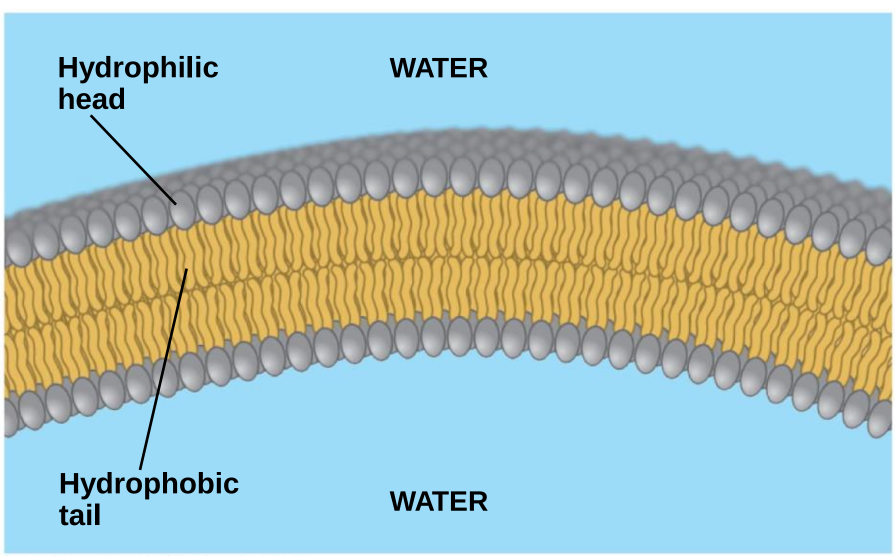
- In a **phospholipid**, **two fatty acids** and a **phosphate group** are attached to **glycerol**
- The two fatty acid tails are hydrophobic, but the **phosphate group** and its attachments form a **hydrophilic head**

Fig. 5-13ab



- 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***

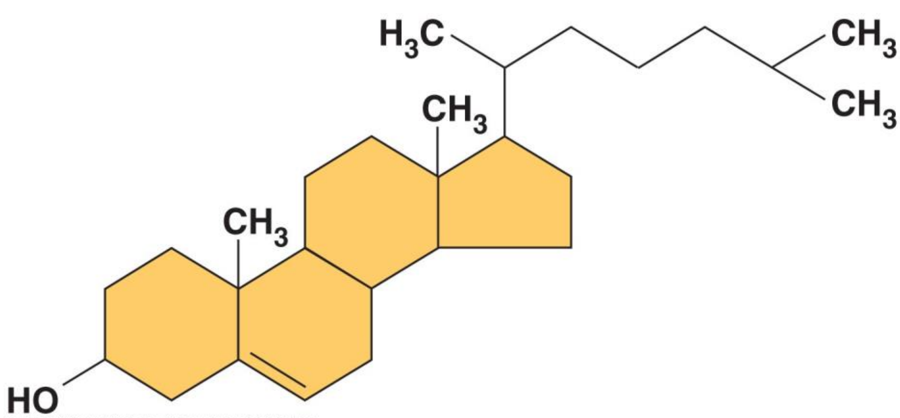
Fig. 5-14



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**

Fig. 5-15



Concept 5.4: Proteins have many 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

Table 5-1

Table 5.1 An Overview of Protein Functions

Type of Protein	Function	Examples
Enzymatic proteins	Selective acceleration of chemical reactions	Digestive enzymes
Structural proteins	Support	Silk fibers; collagen and elastin in animal connective tissues; keratin in hair, horns, feathers, and other skin appendages
Storage proteins	Storage of amino acids	Ovalbumin in egg white; casein, the protein of milk; storage proteins in plant seeds
Transport proteins	Transport of other substances	Hemoglobin, transport proteins
Hormonal proteins	Coordination of an organism's activities	Insulin, a hormone secreted by the pancreas
Receptor proteins	Response of cell to chemical stimuli	Receptors in nerve cell membranes
Contractile and motor proteins	Movement	Actin and myosin in muscles, proteins in cilia and flagella
Defensive proteins	Protection against disease	Antibodies combat bacteria and viruses.

Figure 5.15-a

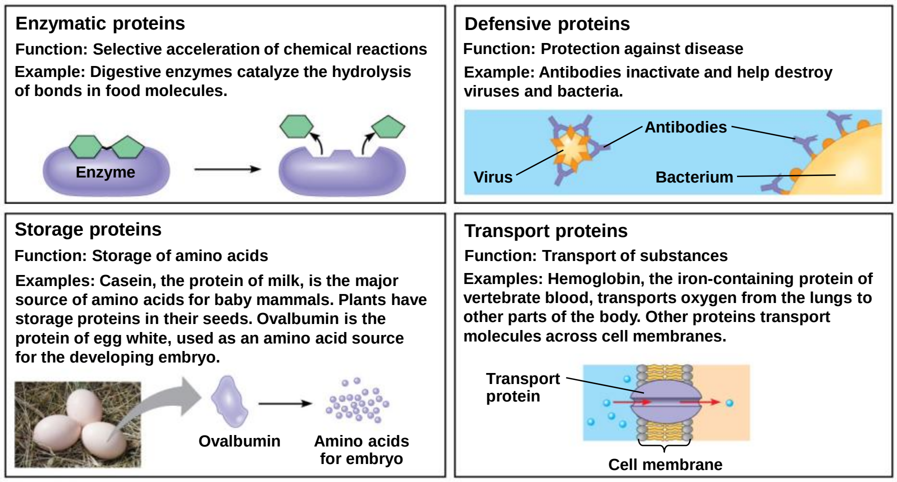


Figure 5.15-b

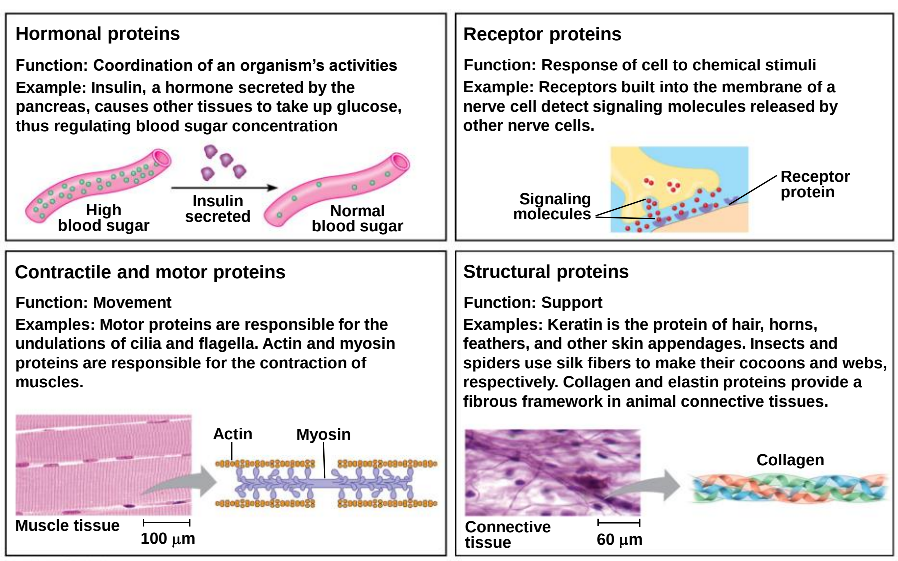


Figure 5.15a

Enzymatic proteins

Function: Selective acceleration of chemical reactions

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

Figure 5.15b

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.

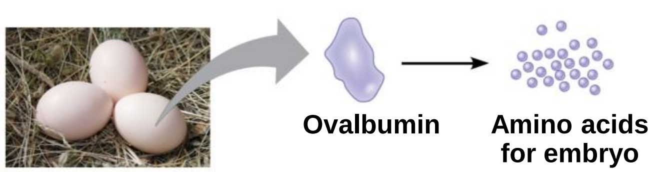


Figure 5.15c

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

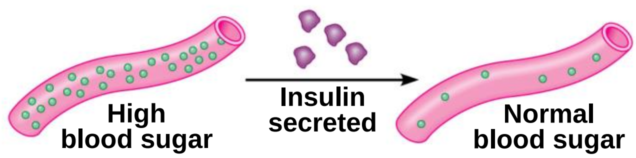


Figure 5.15d

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.

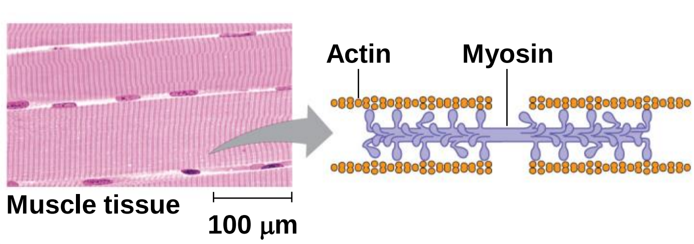


Figure 5.15e

Defensive proteins

Function: Protection against disease

Example: Antibodies inactivate and help destroy viruses and bacteria.

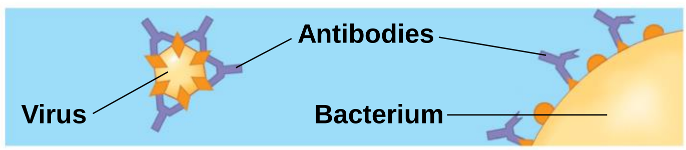


Figure 5.15f

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.

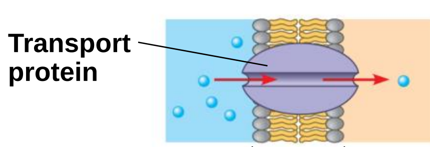


Figure 5.15g

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.

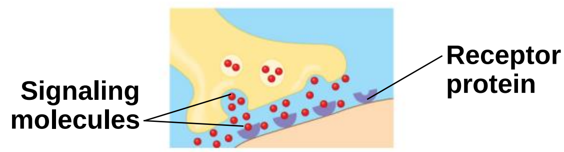
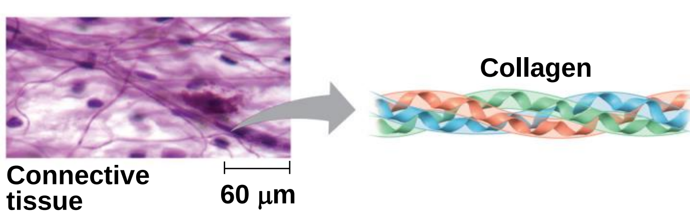


Figure 5.15h

Structural proteins

Function: Support

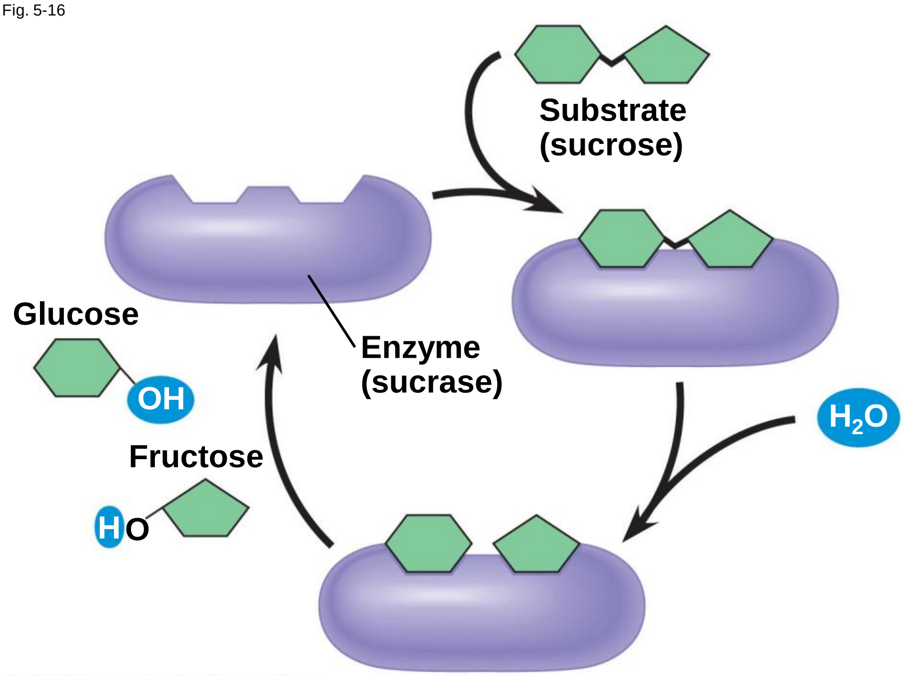
Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.



- **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

PLAY Animation: Enzymes

Fig. 5-16



Polypeptides

- **Polypeptides** are polymers built from the same set of 20 amino acids
- A **protein** consists of one or more polypeptides

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

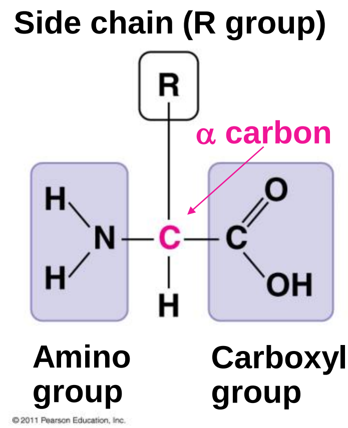
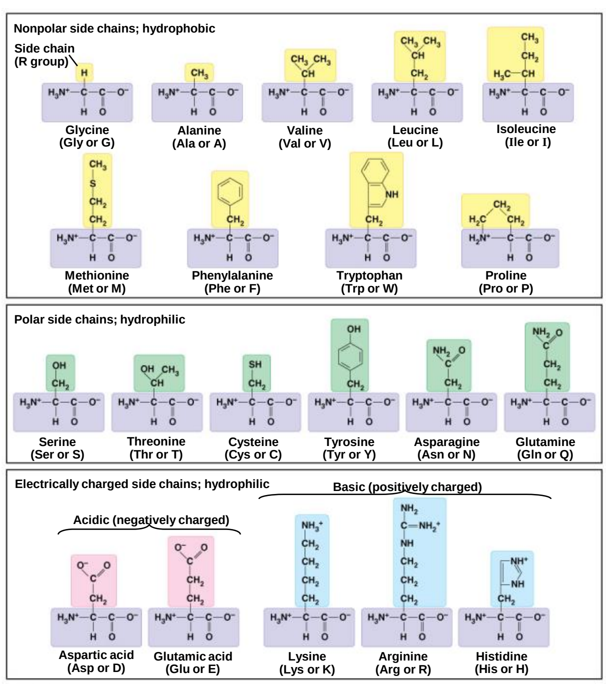


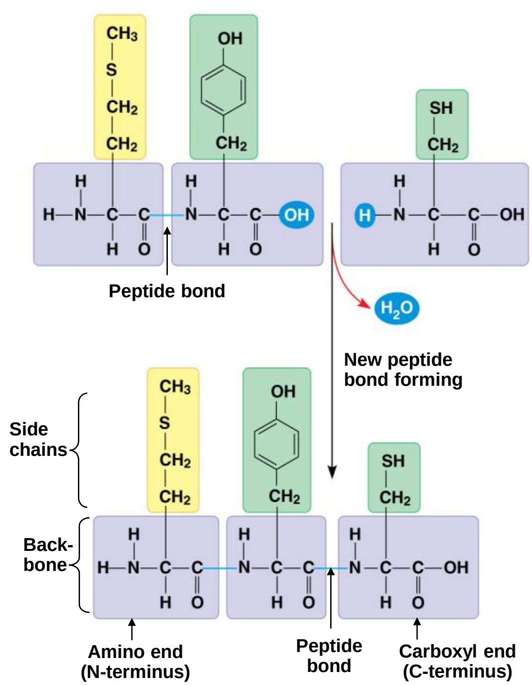
Figure 5.16



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**

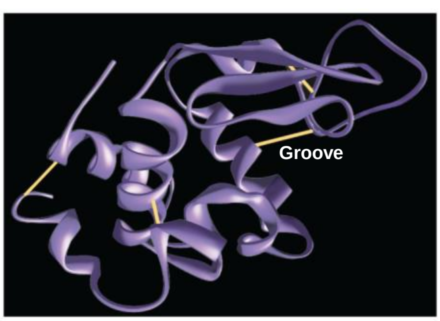
Figure 5.17



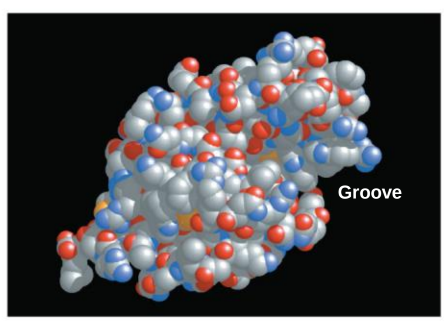
Protein Structure and Function

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

Figure 5.18



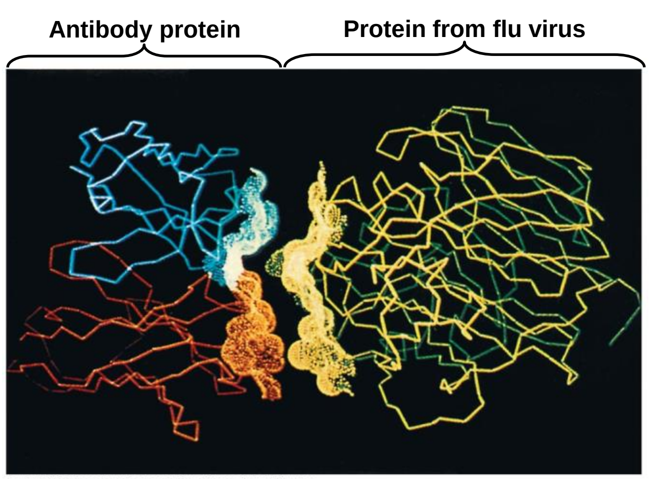
(a) A ribbon model



(b) A space-filling model

- The <u>sequence</u> of amino acids determines a protein's three-dimensional structure
- A protein's structure determines its function

Fig. 5-20



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*

PLAY Animation: Protein Structure Introduction

Figure 5.20a

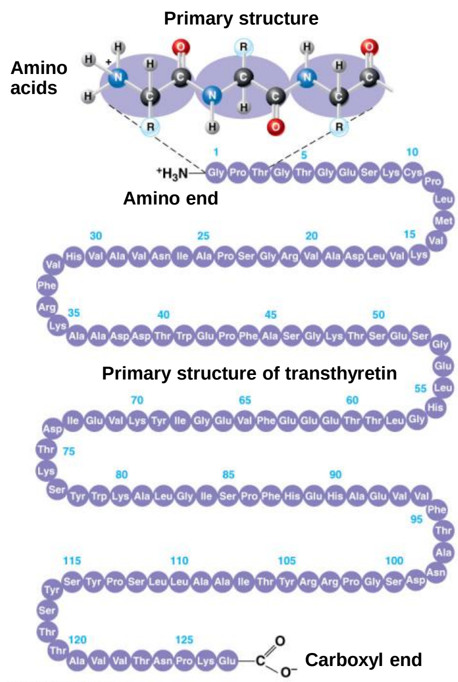
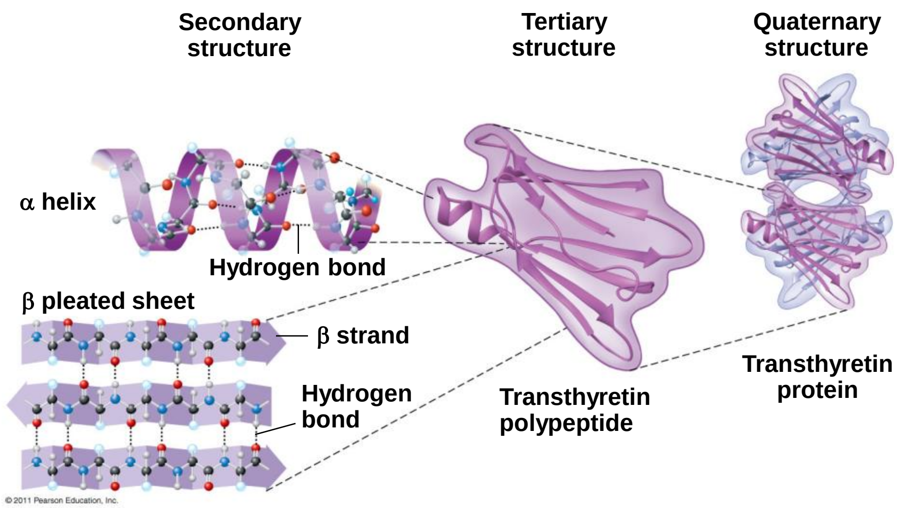


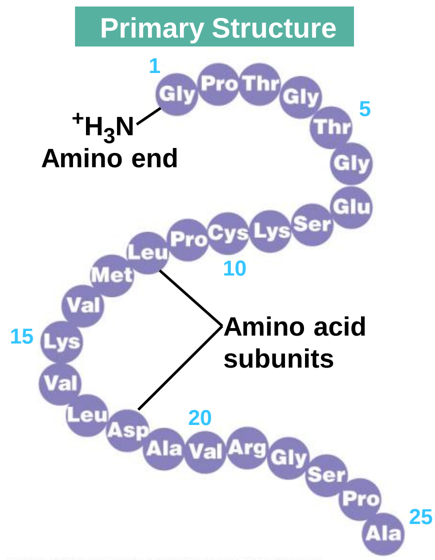
Figure 5.20b



- **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**

PLAY Animation: Primary Protein Structure

Fig. 5-21a



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

PLAY Animation: Secondary Protein Structure

Figure 5.20c

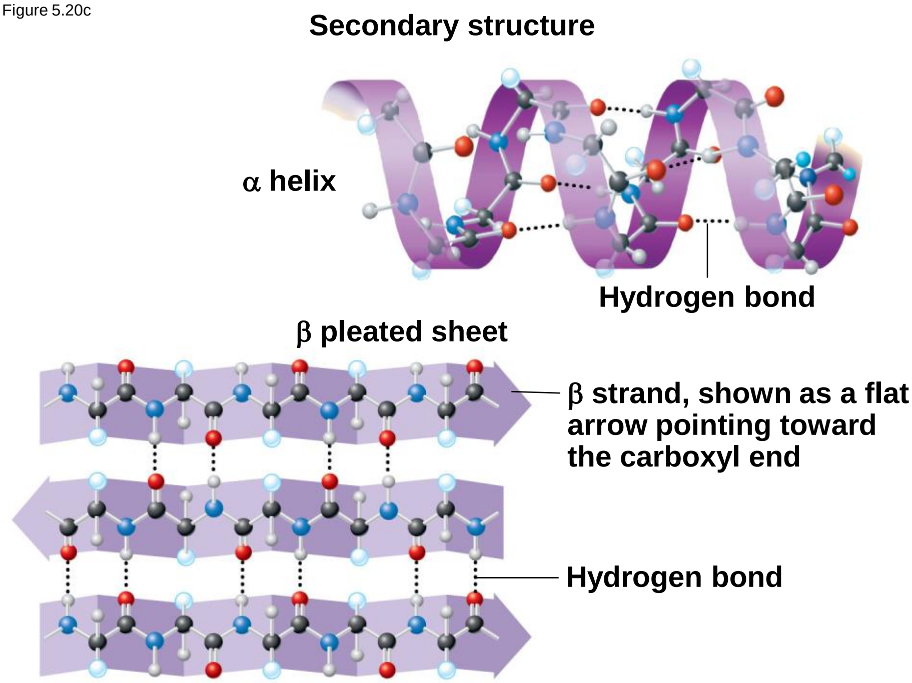
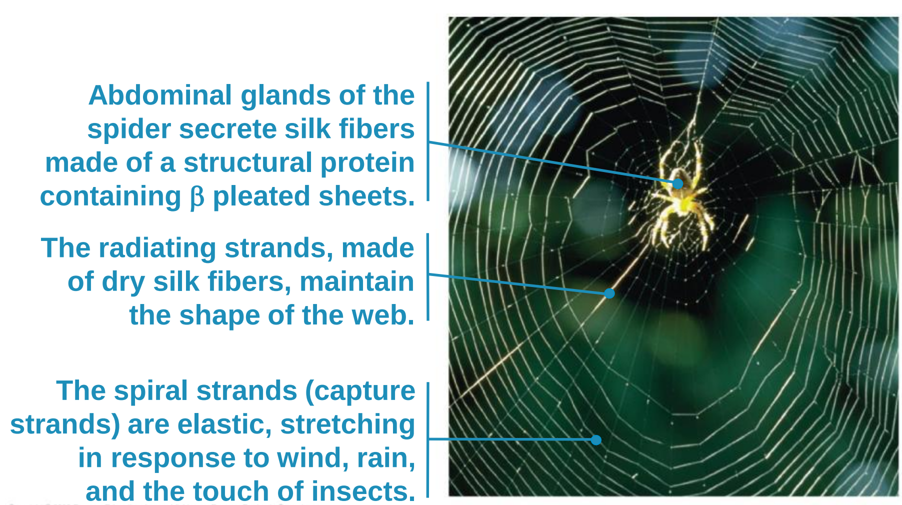


Fig. 5-21d



- **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

PLAY Animation: Tertiary Protein Structure

Figure 5.20e

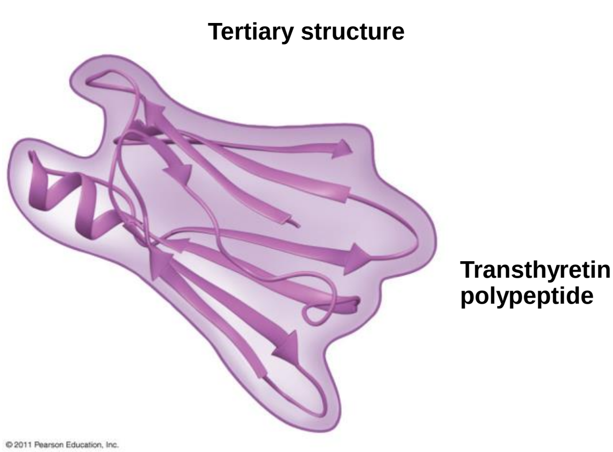
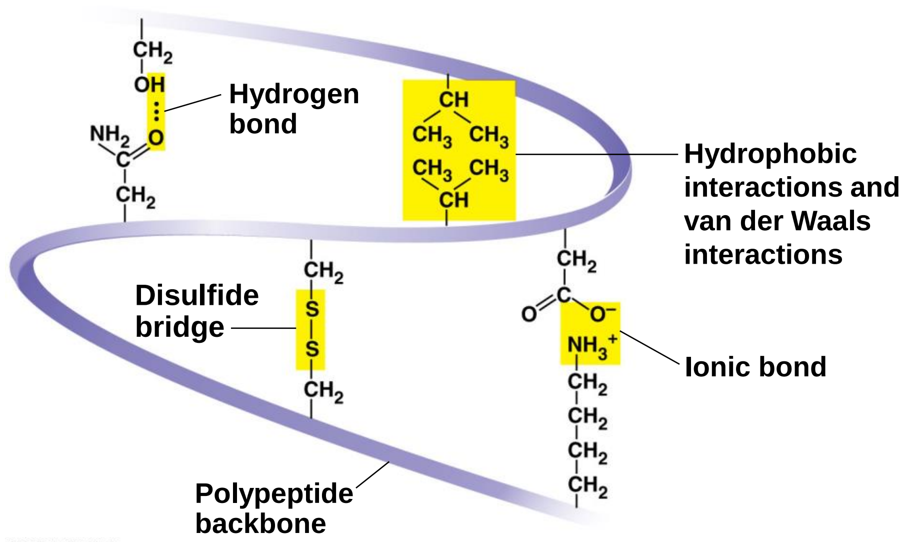


Figure 5.20f

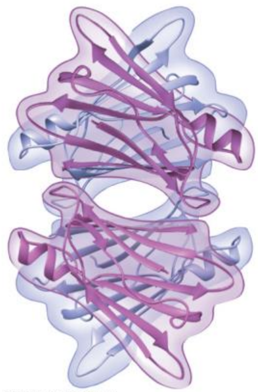


- **Quaternary structure** results when two or more polypeptide chains form one macromolecule
- **Collagen** is a fibrous protein consisting of three polypeptides coiled like a rope
- **Hemoglobin** is a globular protein consisting of four polypeptides: two alpha and two beta chains

PLAY Animation: Quaternary Protein Structure

Figure 5.20g

Quaternary structure



Transthyretin protein (four identical polypeptides)

Figure 5.20h

Collagen

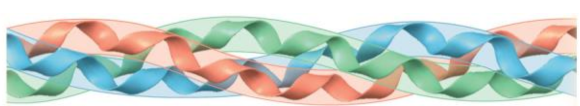
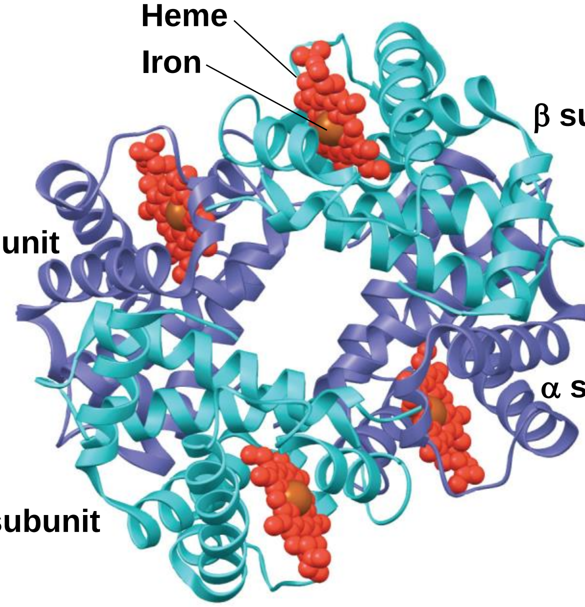


Figure 5.20i



Hemoglobin

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

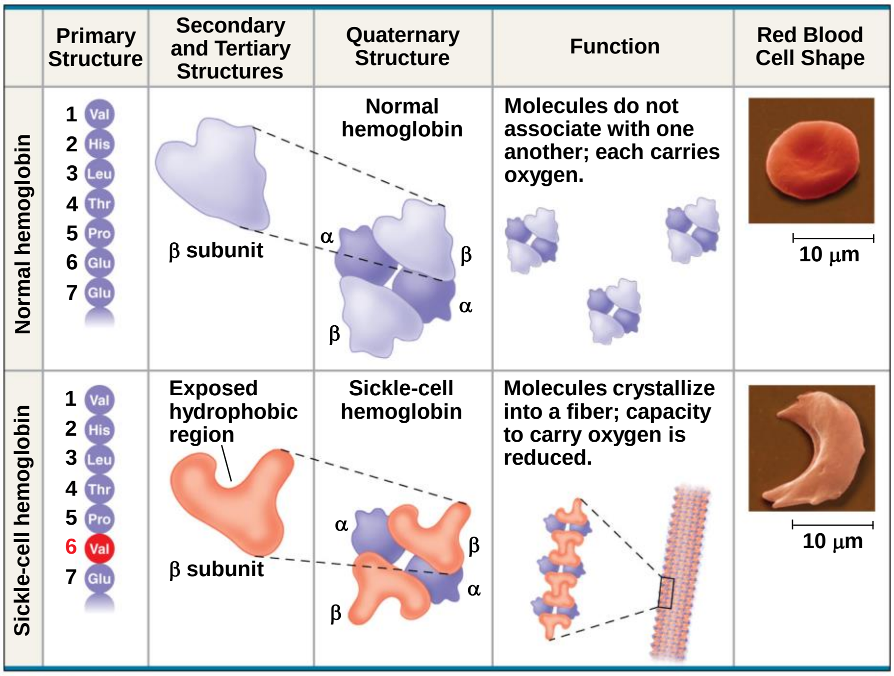
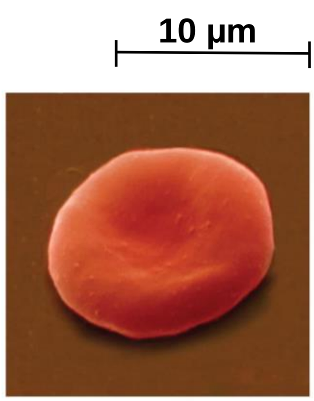
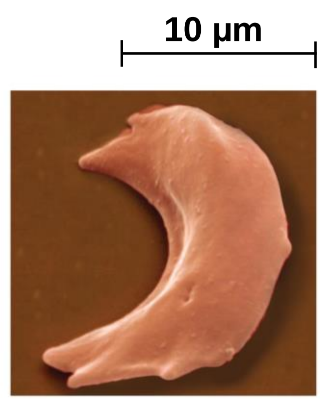


Fig. 5-22c



Normal red blood cells are full of individual hemoglobin molecules, each carrying oxygen.

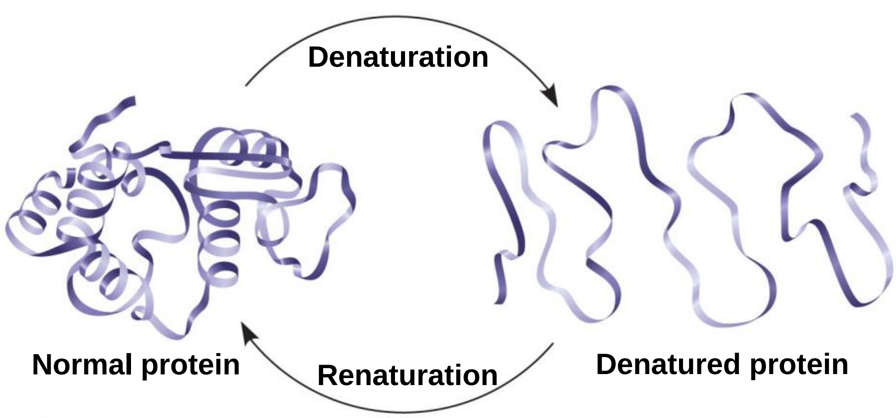


Fibers of abnormal hemoglobin deform red blood cell into sickle shape.

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**

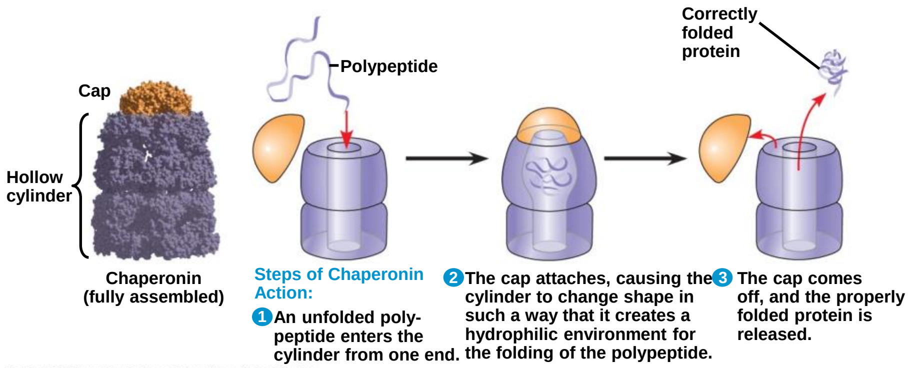
Fig. 5-23



Protein Folding in the Cell

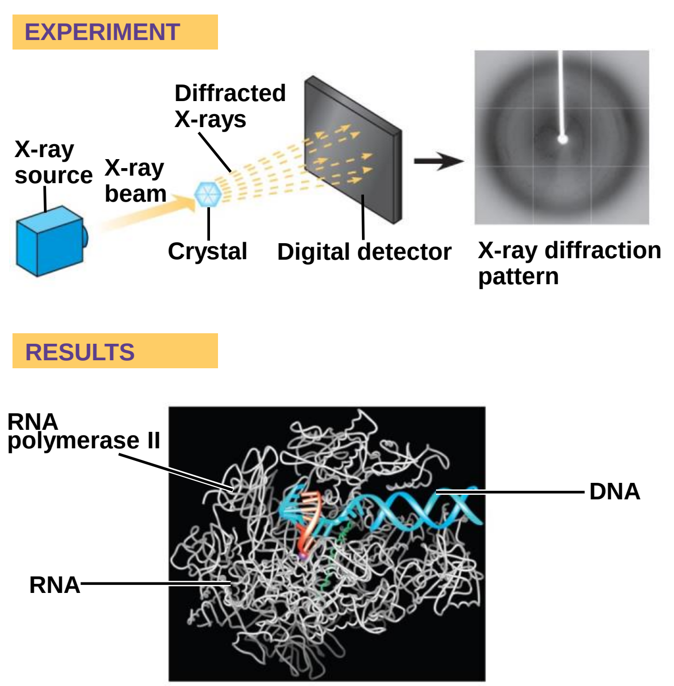
- It is hard to predict a protein's structure from its primary structure
- Most proteins probably go through several states on their way to a stable structure
- **Chaperonins** *are protein molecules that assist the proper folding of other proteins*

Fig. 5-24



- Scientists use **X-ray crystallography** to determine a protein's structure
- Another method is **nuclear magnetic resonance (NMR) spectroscopy**, which does not require protein crystallization
- **Bioinformatics** uses computer programs to predict protein structure from amino acid sequences

Fig. 5-25



Concept 5.5: Nucleic acids store and transmit 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**

The Roles of Nucleic Acids

- There are two types of nucleic acids:
  - **Deoxyribonucleic acid (DNA)**
  - **Ribonucleic acid (RNA)**
- DNA provides directions for its own replication
- DNA directs synthesis of messenger RNA (mRNA) and, through mRNA, controls protein synthesis
- Protein synthesis occurs in ribosomes

Fig. 5-26-1

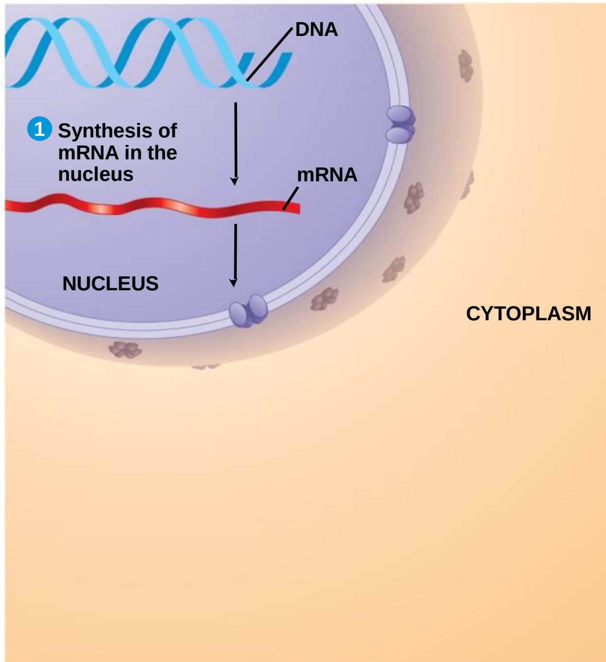


Fig. 5-26-2

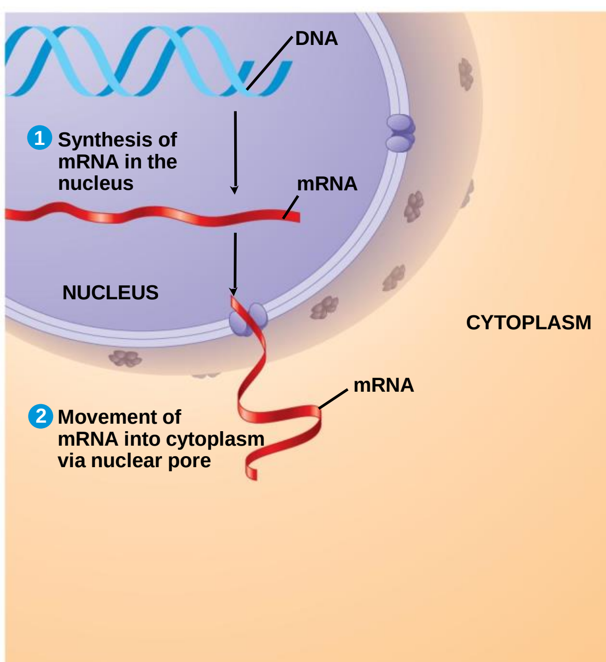
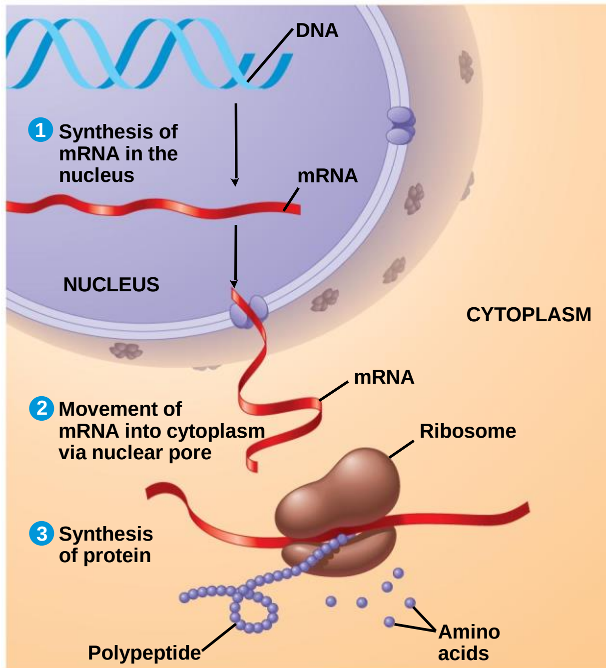


Fig. 5-26-3



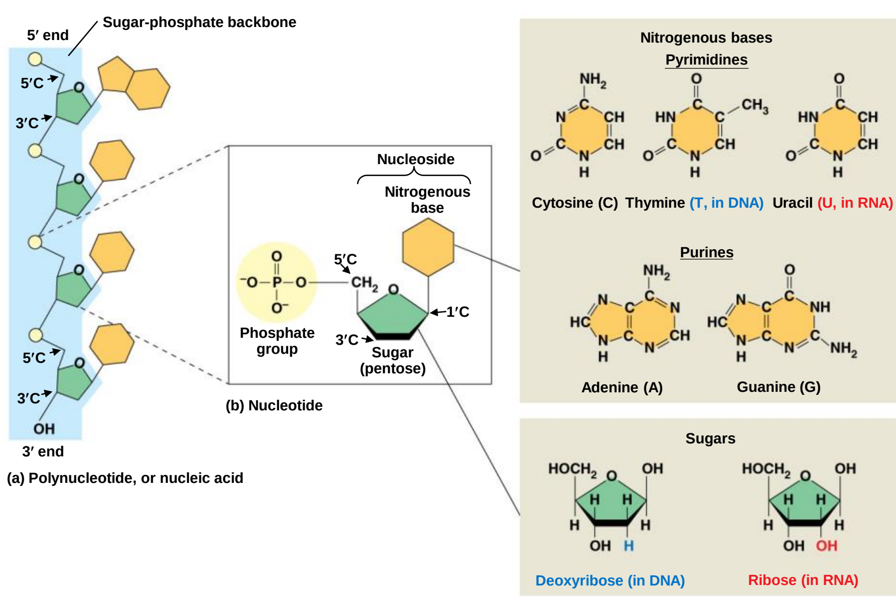
The Structure of Nucleic Acids

- 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 a phosphate group
- The portion of a nucleotide without the phosphate group is called a ***nucleoside***

Nucleotide Monomers

- 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

Figure 5.26



(a) Polynucleotide, or nucleic acid

(b) Nucleotide

(c) Nucleoside components

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 DNA Double Helix

- A **DNA molecule has 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**
- The nitrogenous bases in DNA pair up and form hydrogen bonds: **adenine (A) always with thymine (T),** and guanine (G) always with cytosine (C)

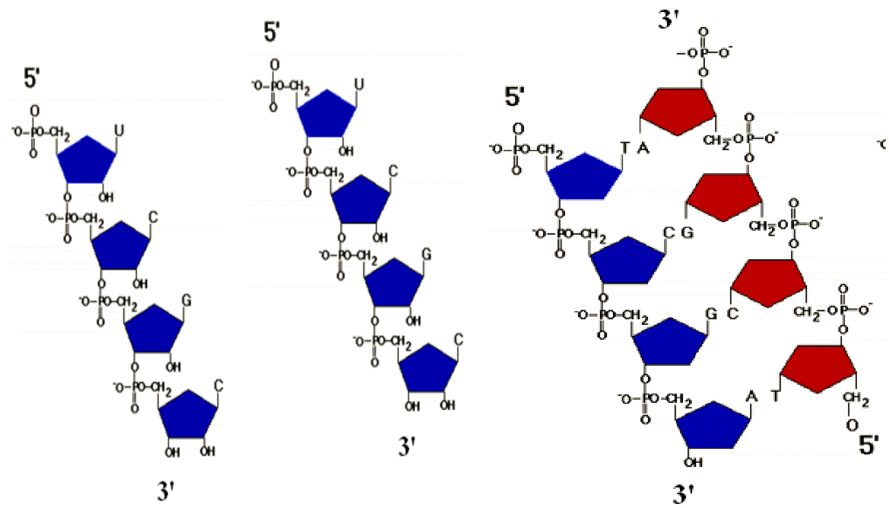
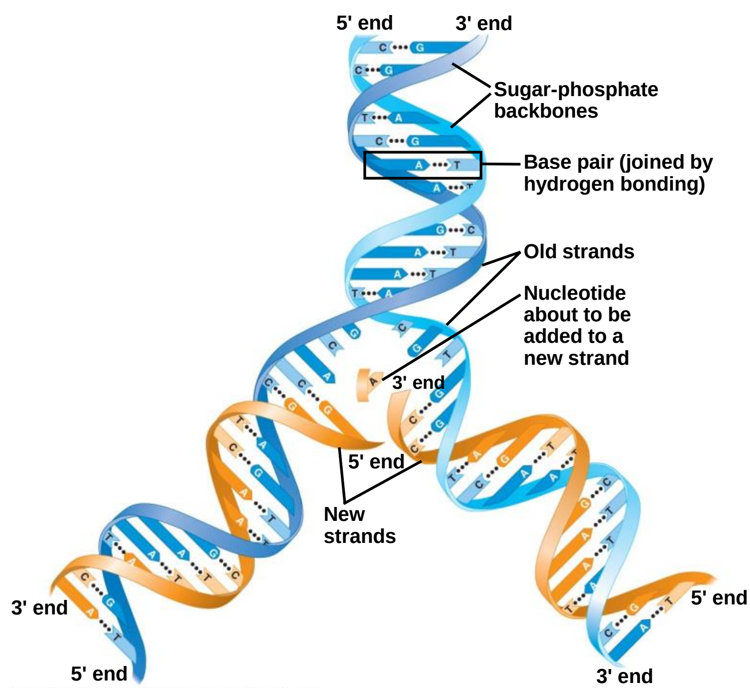

5'
3'
5'
3'
3'
5'
3'
5'
U
C
G
T A
C G
G C
A T

Fig. 5-28


5' end
3' end
Sugar-phosphate backbones
Base pair (joined by hydrogen bonding)
Old strands
Nucleotide about to be added to a new strand
3' end
5' end
New strands
3' end
5' end
5' end
3' end
Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings.

DNA and Proteins as Tape Measures of Evolution

- The linear sequences of nucleotides in DNA molecules are passed from parents to offspring
- Two closely related species are more similar in DNA than are more distantly related species
- Molecular biology can be used to **assess evolutionary kinship**

Figure 5.UN02

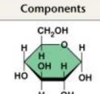
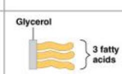
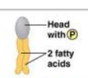
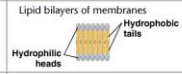
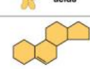
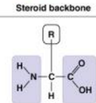
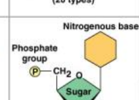
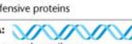
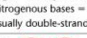
Large Biological Molecules	Components	Examples	Functions
CONCEPT 5.2 Carbohydrates serve as fuel and building material	 Monosaccharide monomer	**Monosaccharides:** glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Disaccharides: lactose, sucrose	
		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

Figure 5.UN02a

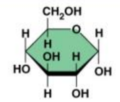
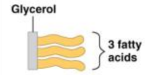
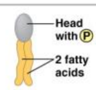
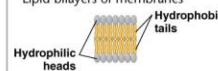
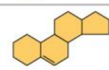
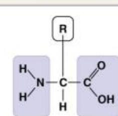
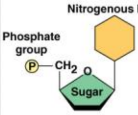
Large Biological Molecules	Components	Examples	Functions
CONCEPT 5.2 Carbohydrates serve as fuel and building material	 CH_2OH, H, O, H, H, OH, H, HO, OH, H, OH Monosaccharide monomer	**Monosaccharides:** glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into 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	 Glycerol, 3 fatty acids	**Triacylglycerols** (fats or oils): glycerol + 3 fatty acids	Important energy source 
	 Head with Ⓟ, 2 fatty acids	**Phospholipids:** phosphate group + 2 fatty acids	Lipid bilayers of membranes  Hydrophobic tails, Hydrophilic heads
	 Steroid backbone	**Steroids:** four fused rings with attached chemical groups	• Component of cell membranes (cholesterol) • Signaling molecules that travel through the body (hormones)

Figure 5.UN02b

Large Biological Molecules	Components	Examples	Functions
CONCEPT 5.4 Proteins include a diversity of structures, resulting in a wide range of functions	 R, H, N, C, C, O, H, H, OH 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	 Nitrogenous base, Phosphate group, Ⓟ—CH_2, O, Sugar 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