LECTURE PRESENTATIONS
For CAMPBELL BIOLOGY, NINTH EDITION
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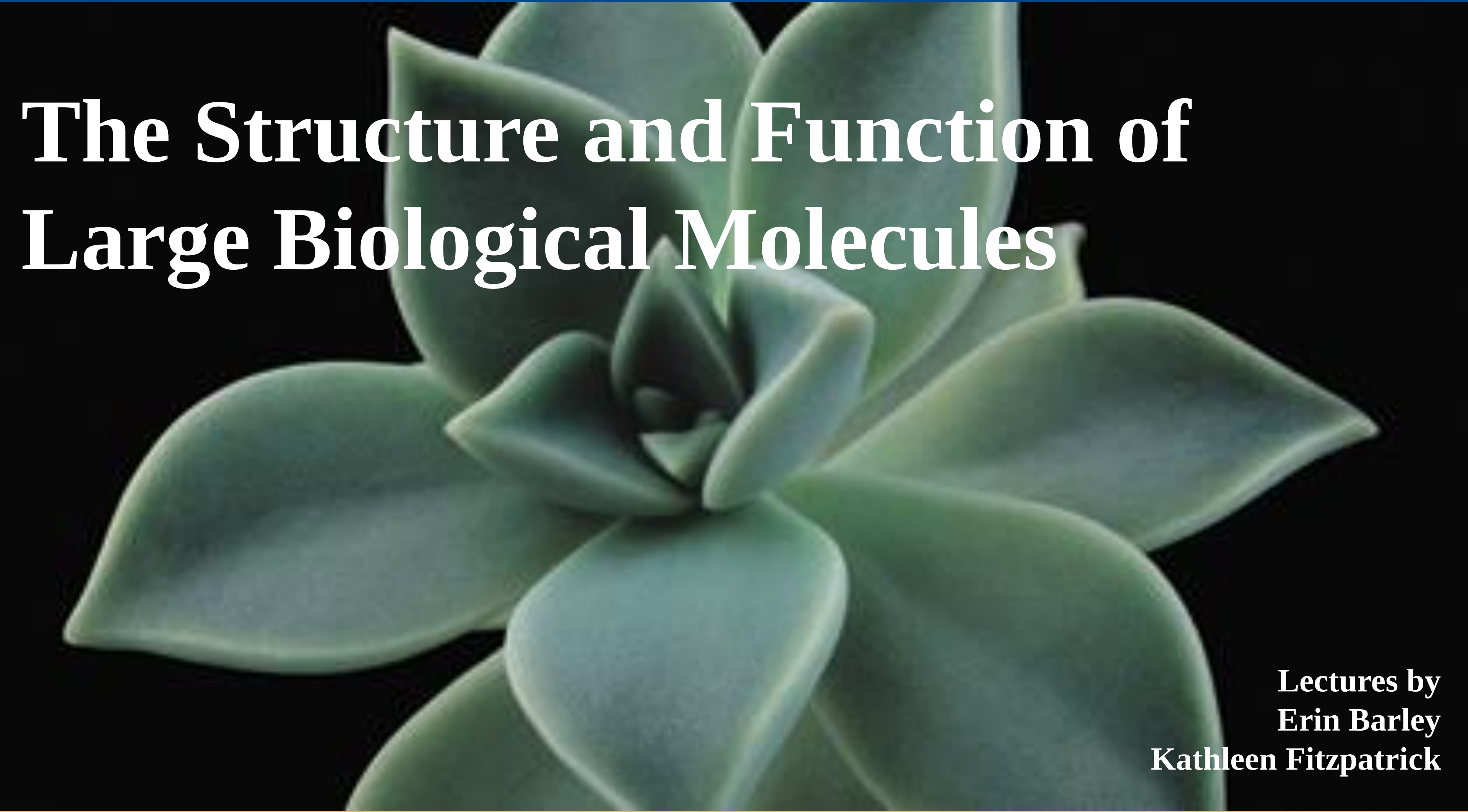
Chapter 5

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
- **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**
- Three of the four classes of life's organic molecules are polymers
  - Carbohydrates
  - Proteins
  - Nucleic acids

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

Figure 5.2

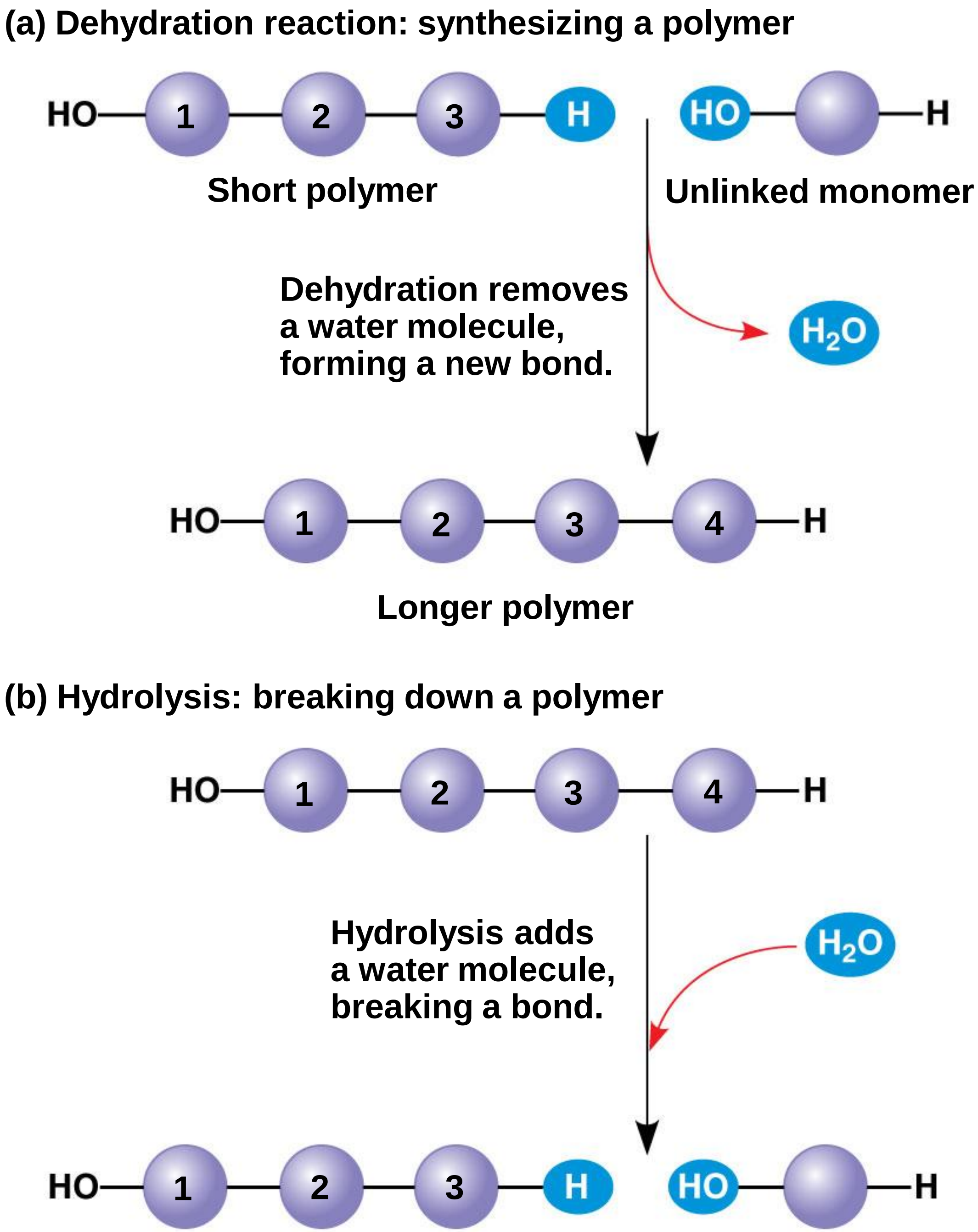

(a) Dehydration reaction: synthesizing a polymer
HO 1 2 3 H
HO H
Short polymer
Unlinked monomer
Dehydration removes a water molecule, forming a new bond.
H_2O
HO 1 2 3 4 H
Longer polymer
(b) Hydrolysis: breaking down a polymer
HO 1 2 3 4 H
Hydrolysis adds a water molecule, breaking a bond.
H_2O
HO 1 2 3 H
HO H

Figure 5.2a

(a) Dehydration reaction: synthesizing a polymer

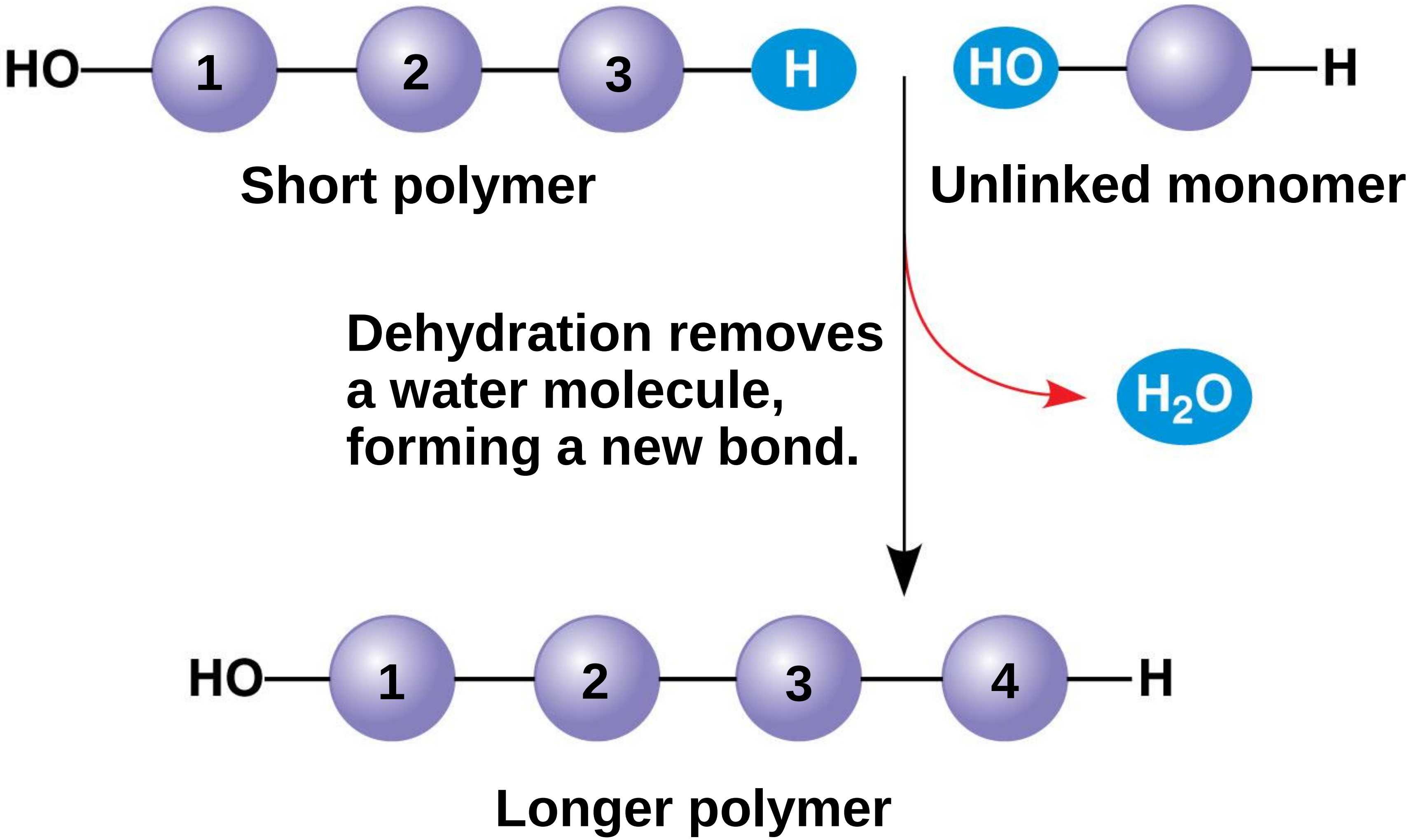
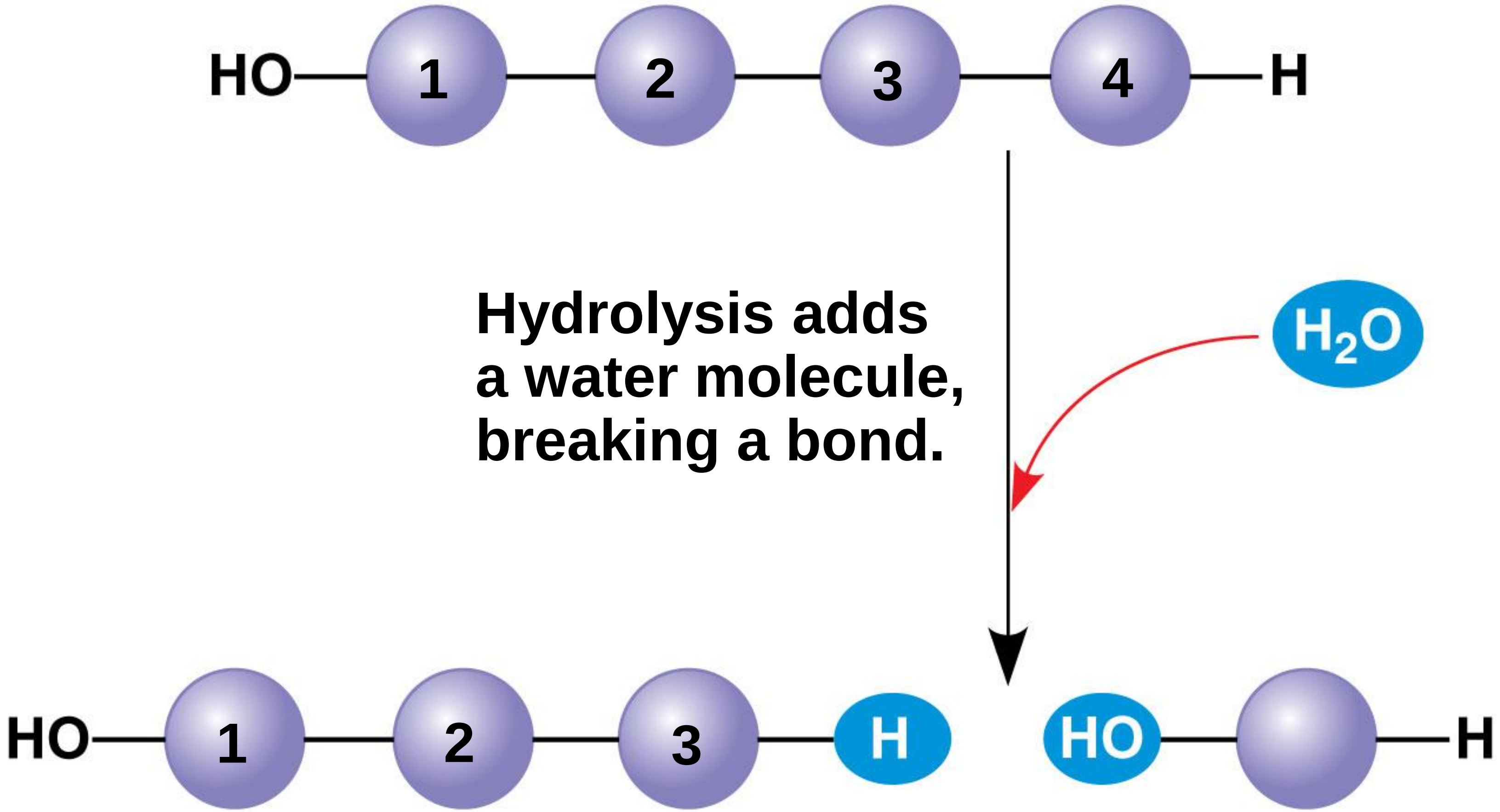


Figure 5.2b

(b) Hydrolysis: breaking down a polymer



The Diversity of Polymers

- Each cell has thousands of different macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species
- 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
- 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

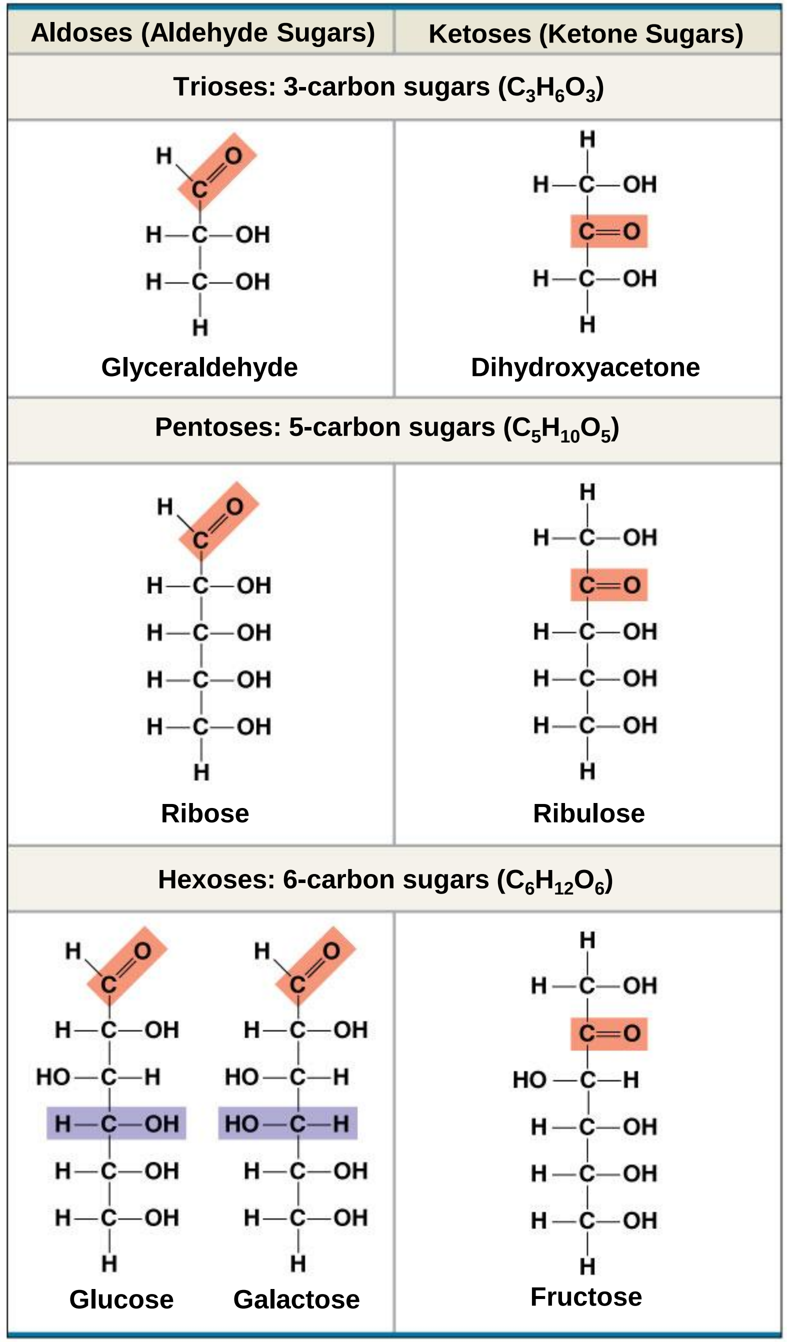

Aldoses (Aldehyde Sugars)
Ketoses (Ketone Sugars)
Trioses: 3-carbon sugars ($C_3H_6O_3$)
Glyceraldehyde
Dihydroxyacetone
Pentoses: 5-carbon sugars ($C_5H_{10}O_5$)
Ribose
Ribulose
Hexoses: 6-carbon sugars ($C_6H_{12}O_6$)
Glucose
Galactose
Fructose

Figure 5.3a

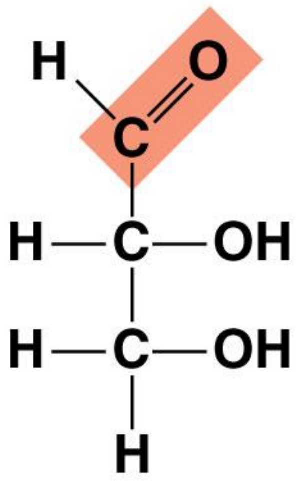
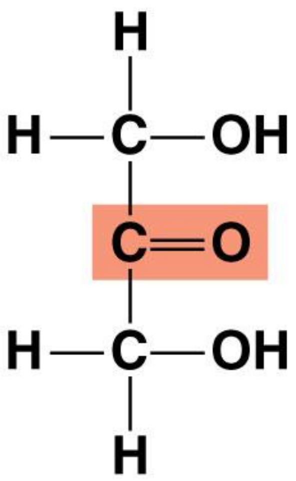
Aldose (Aldehyde Sugar)	Ketose (Ketone Sugar)
Trioses: 3-carbon sugars ($C_3H_6O_3$)	
 Glyceraldehyde	 Dihydroxyacetone

Figure 5.3b

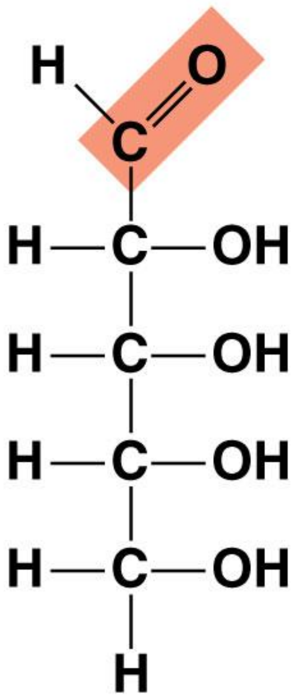
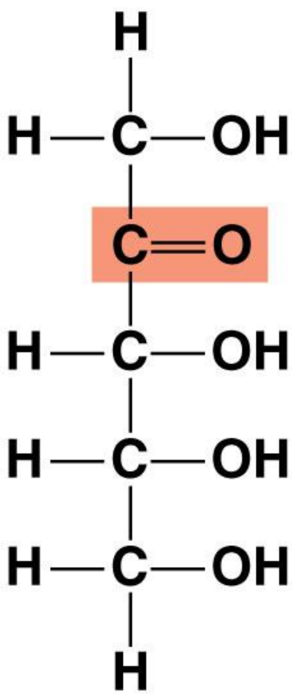
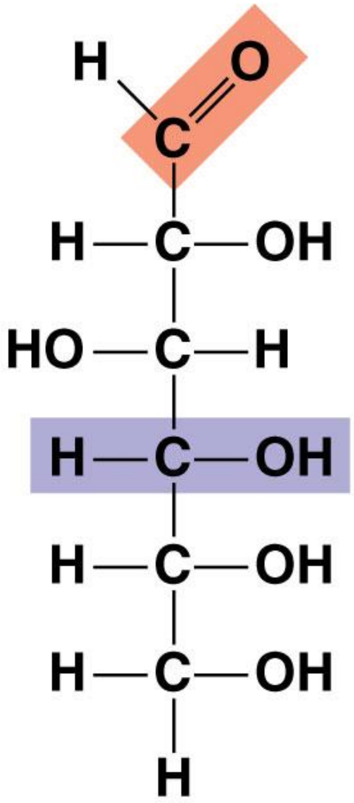
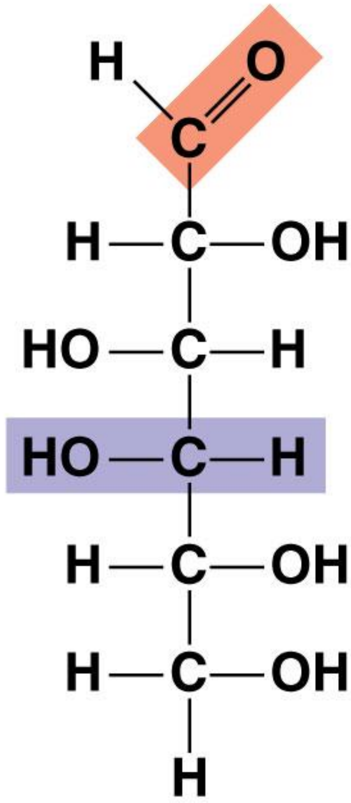
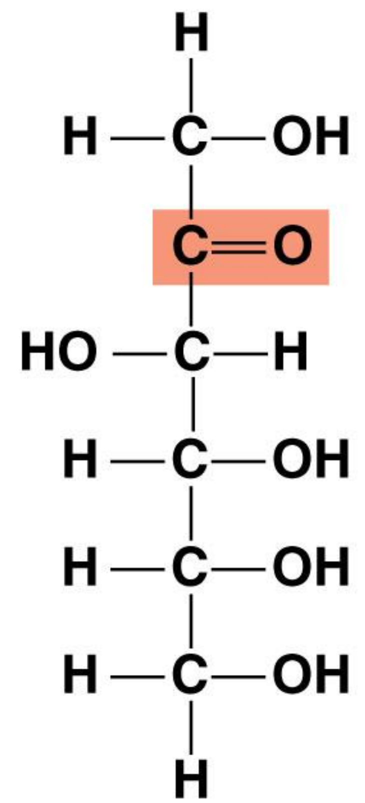
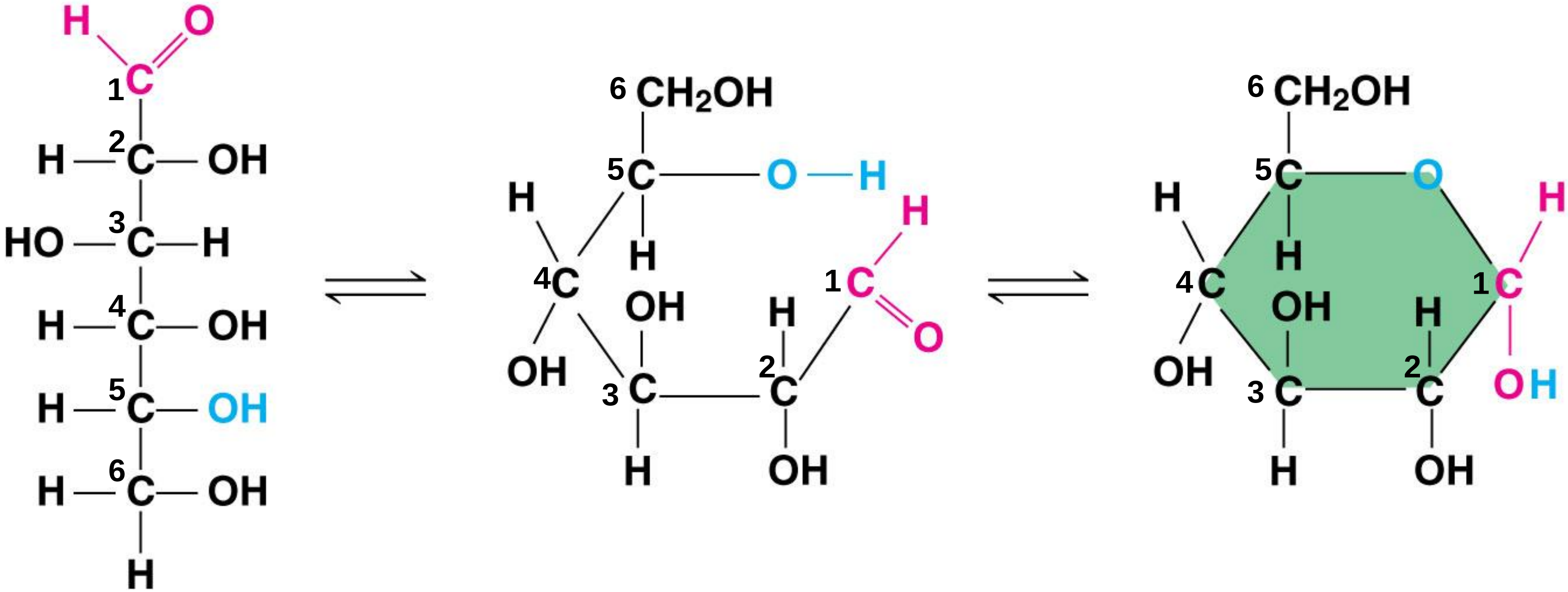
Aldose (Aldehyde Sugar)	Ketose (Ketone Sugar)
Pentoses: 5-carbon sugars ($C_5H_{10}O_5$)	
	
Ribose	Ribulose

Figure 5.3c

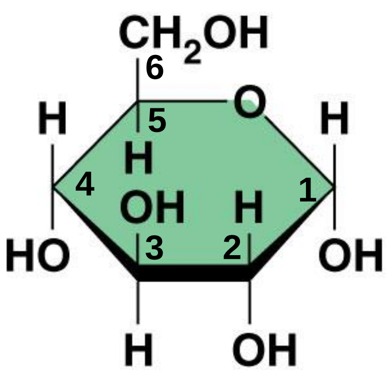
Aldose (Aldehyde Sugar)	**Ketose (Ketone Sugar)**
Hexoses: 6-carbon sugars ($C_6H_{12}O_6$)	
 **Glucose**  **Galactose**	 **Fructose**

- 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

Figure 5.4



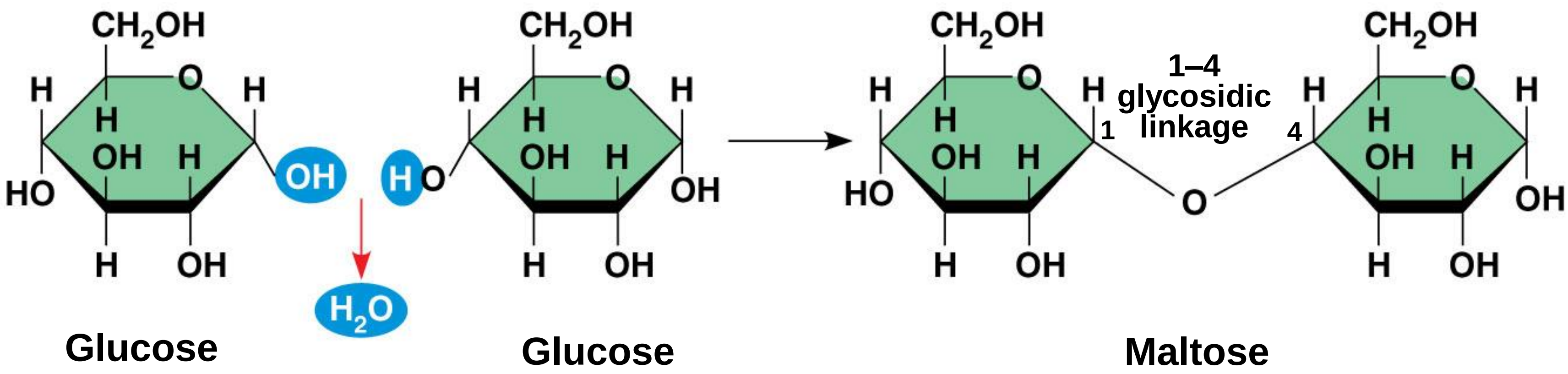
(a) Linear and ring forms



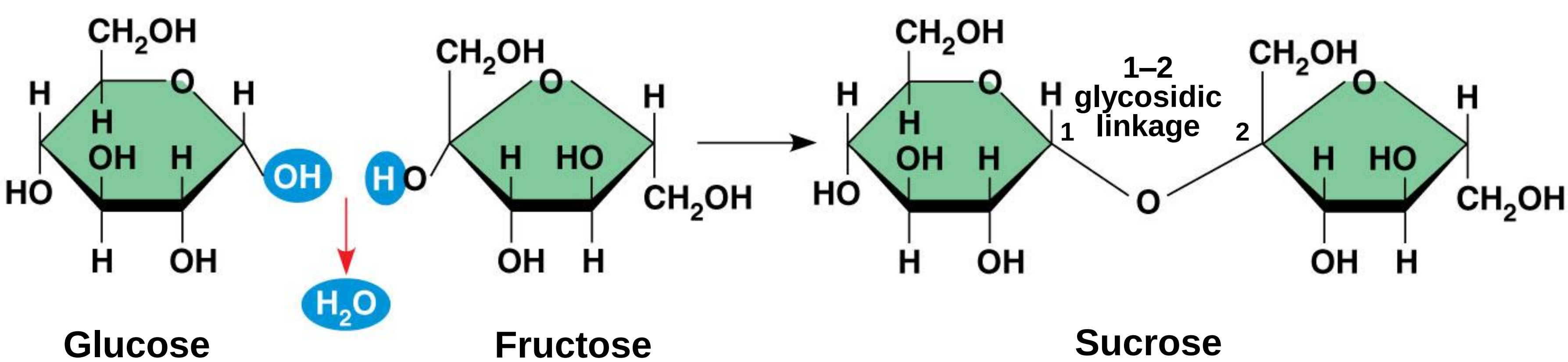
(b) Abbreviated ring structure

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

Figure 5.5



(a) Dehydration reaction in the synthesis of maltose



(b) Dehydration reaction in the synthesis of sucrose

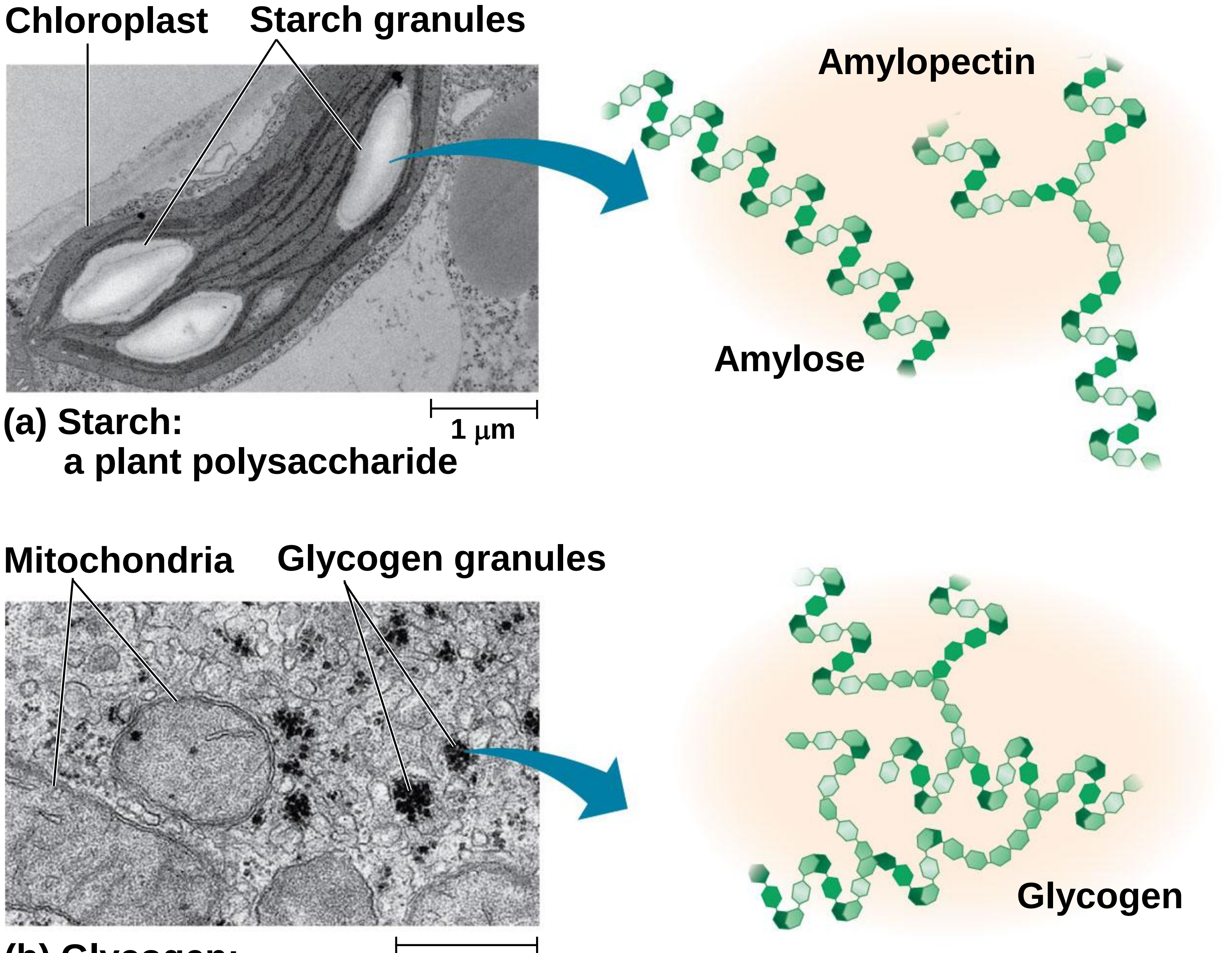
Polysaccharides

- **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

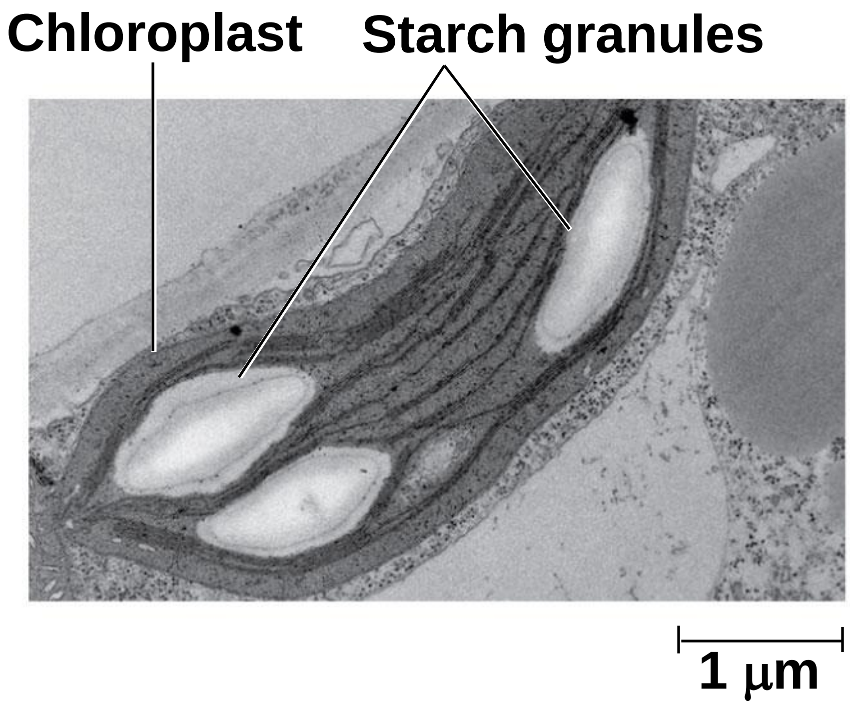
Figure 5.6



(a) Starch: a plant polysaccharide

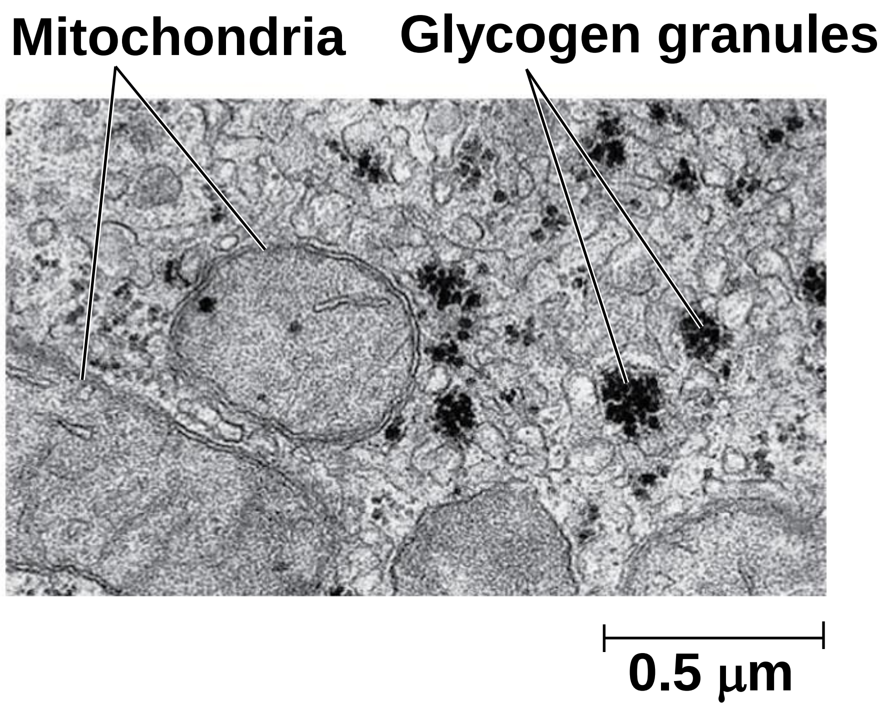
(b) Glycogen: an animal polysaccharide

Figure 5.6a



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

Figure 5.6b



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)

Figure 5.7

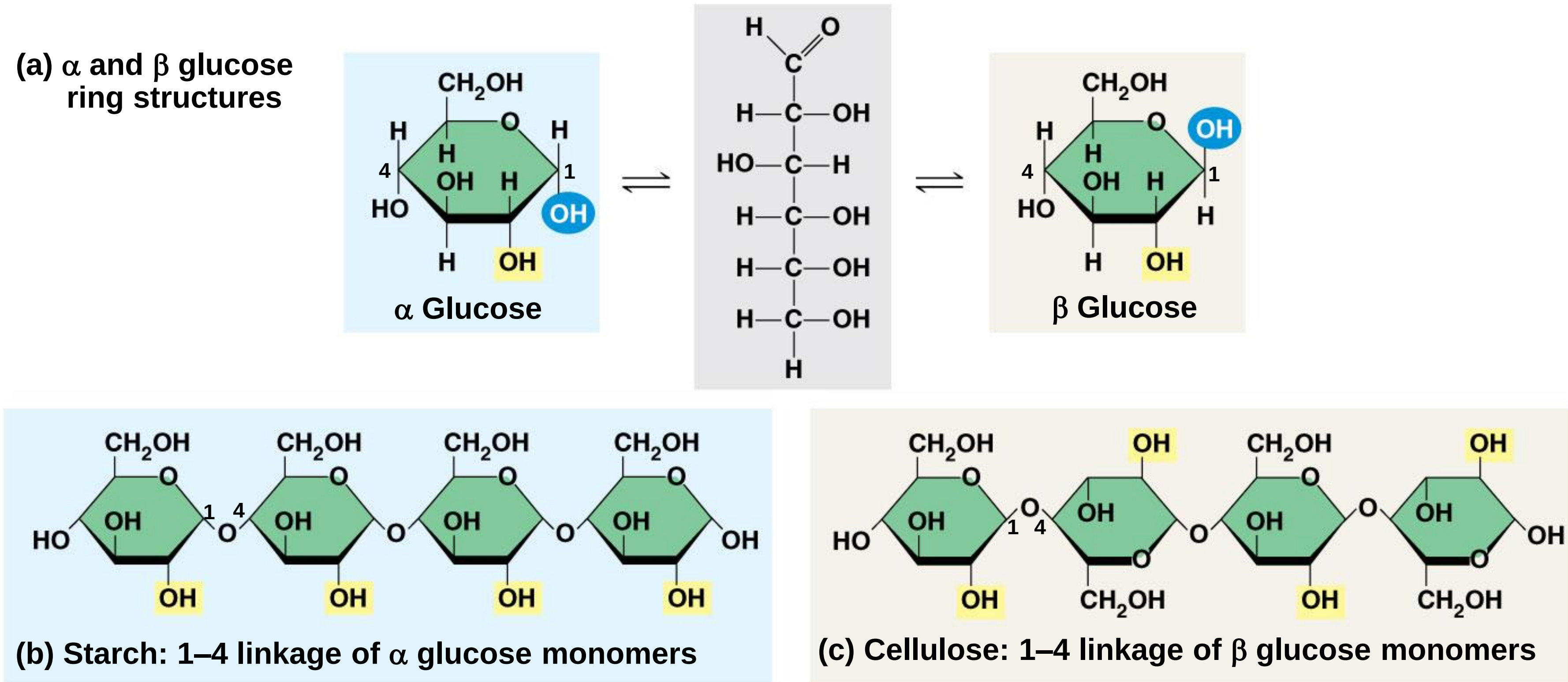
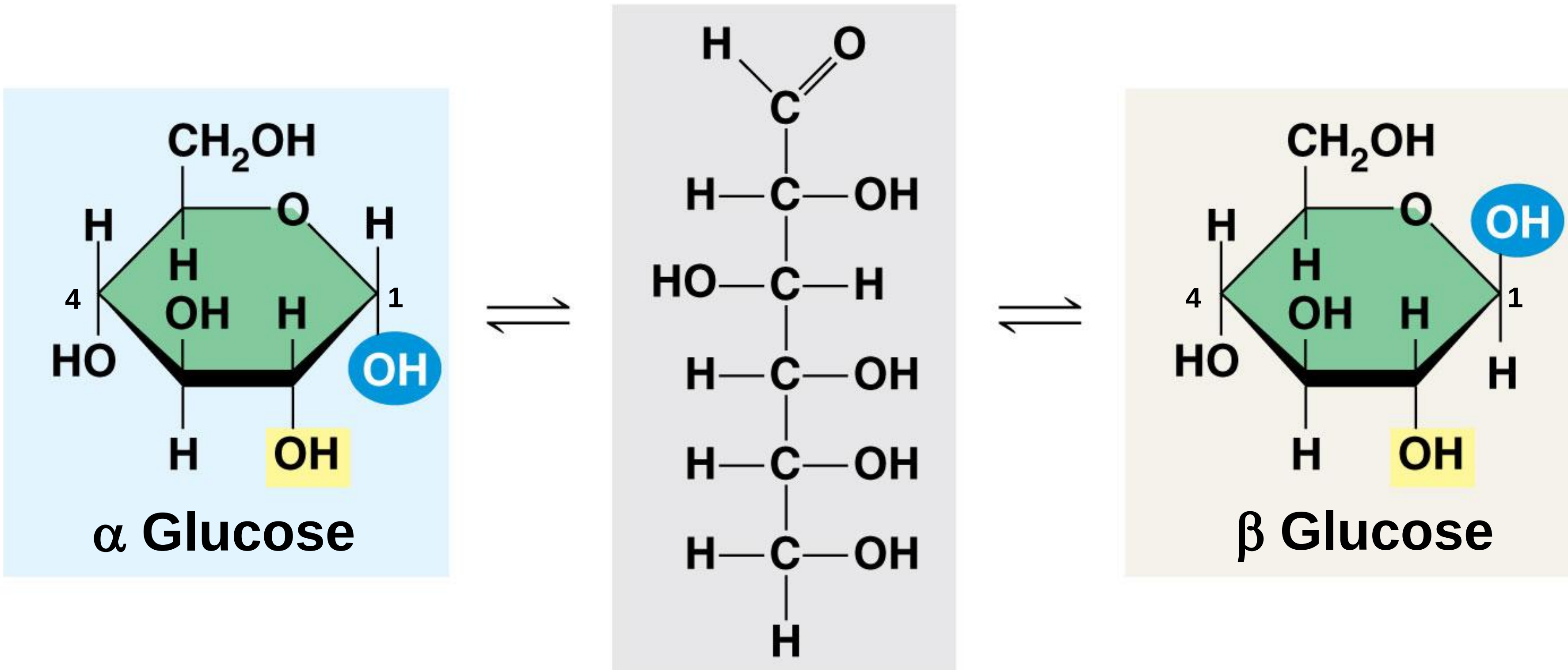
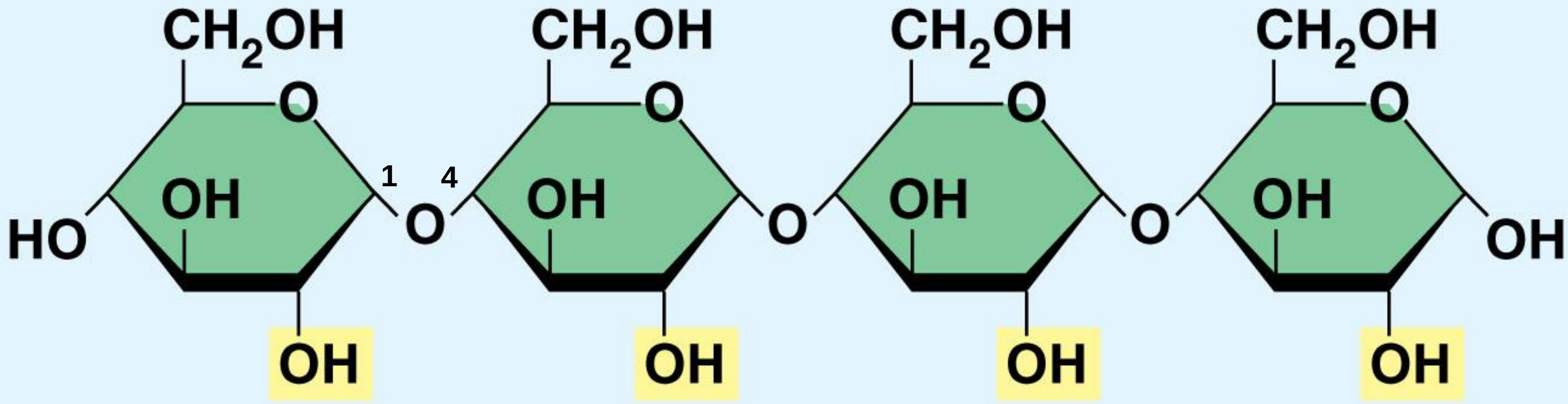

(a) α and β glucose ring structures
CH₂OH
O
H
H
4
1
H
OH
H
HO
OH
H
OH
α Glucose
H
O
C
H—C—OH
HO—C—H
H—C—OH
H—C—OH
H—C—OH
H
β Glucose
(b) Starch: 1–4 linkage of α glucose monomers
(c) Cellulose: 1–4 linkage of β glucose monomers

Figure 5.7a

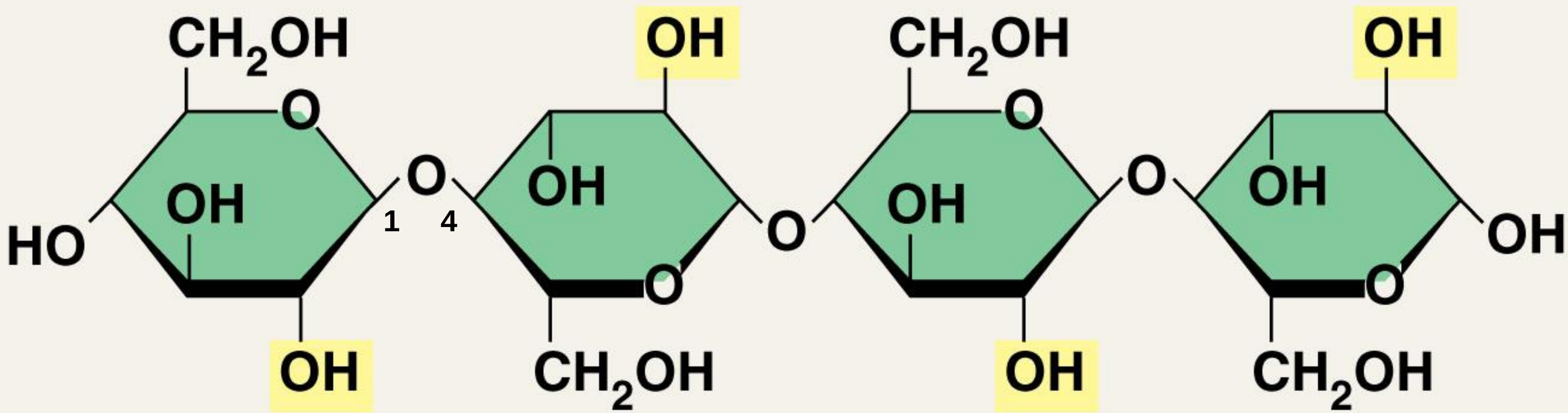


(a) α and β glucose ring structures

Figure 5.7b



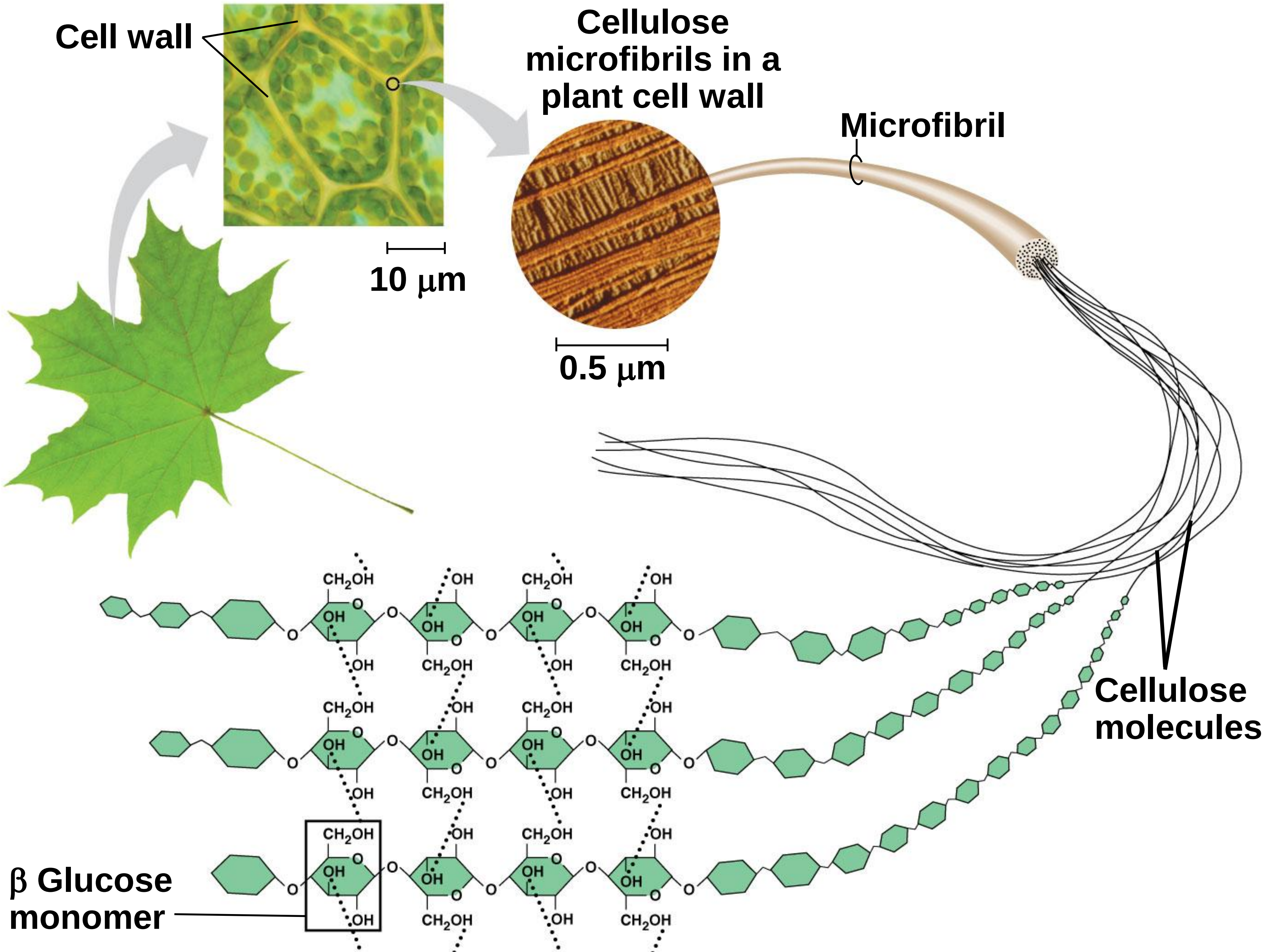
(b) Starch: 1–4 linkage of α glucose monomers



(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

Figure 5.8

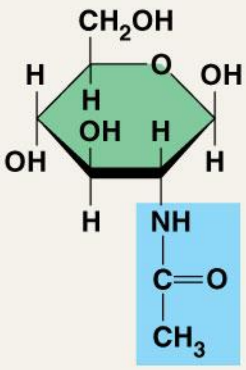


Cell wall
10 µm
Cellulose microfibrils in a plant cell wall
0.5 µm
Microfibril
Cellulose molecules
β Glucose monomer
CH₂OH
OH
O

- 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.**

Figure 5.9a

▲ **Chitin forms the exoskeleton of arthropods.**

Figure 5.9b

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

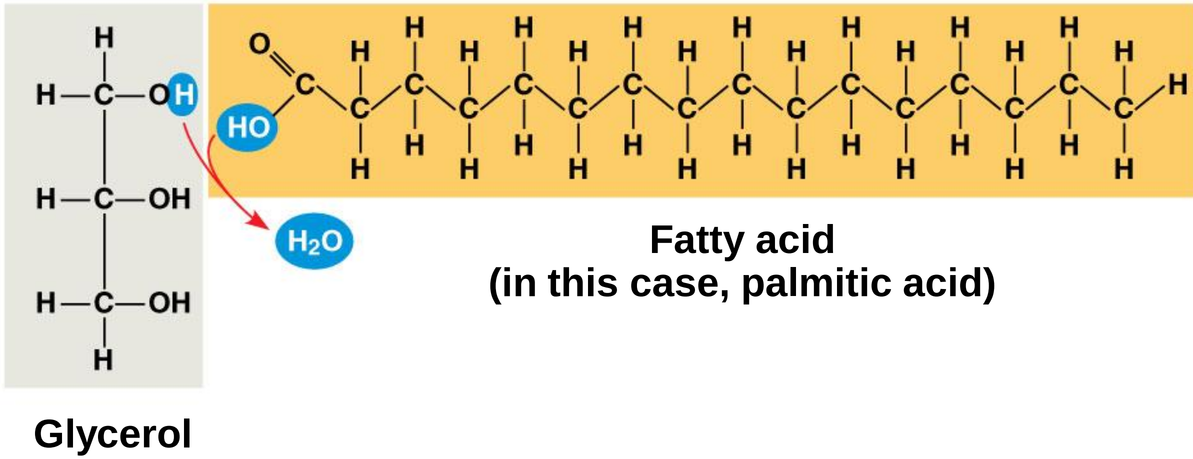
Concept 5.3: Lipids are a diverse group of hydrophobic molecules

- **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

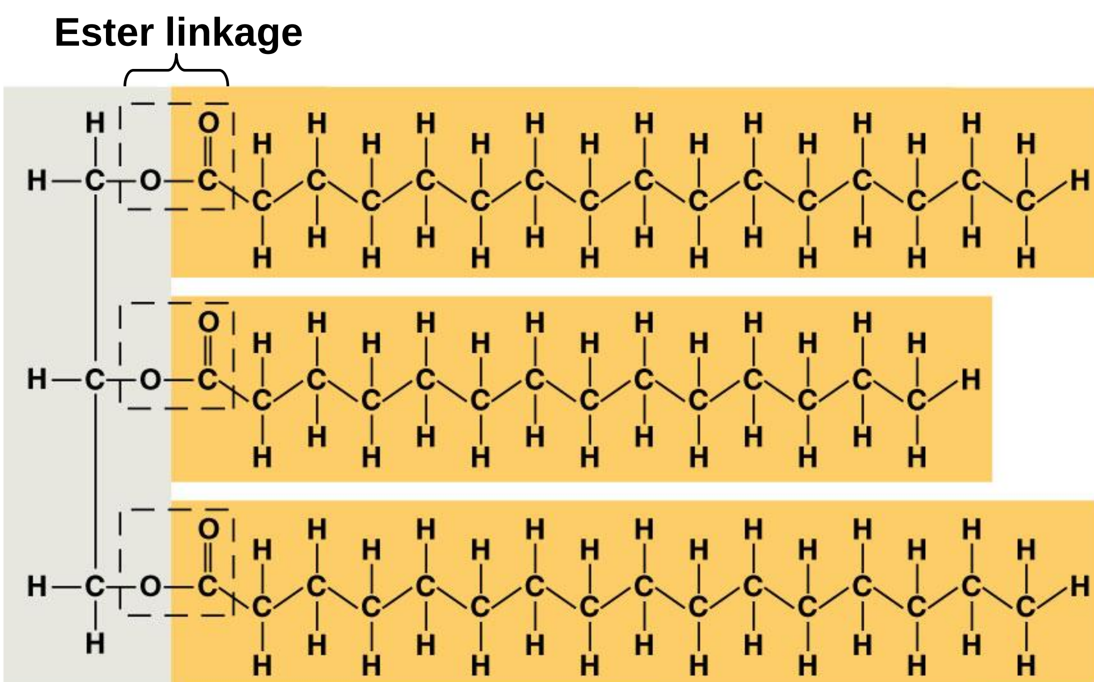
Fats

- **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

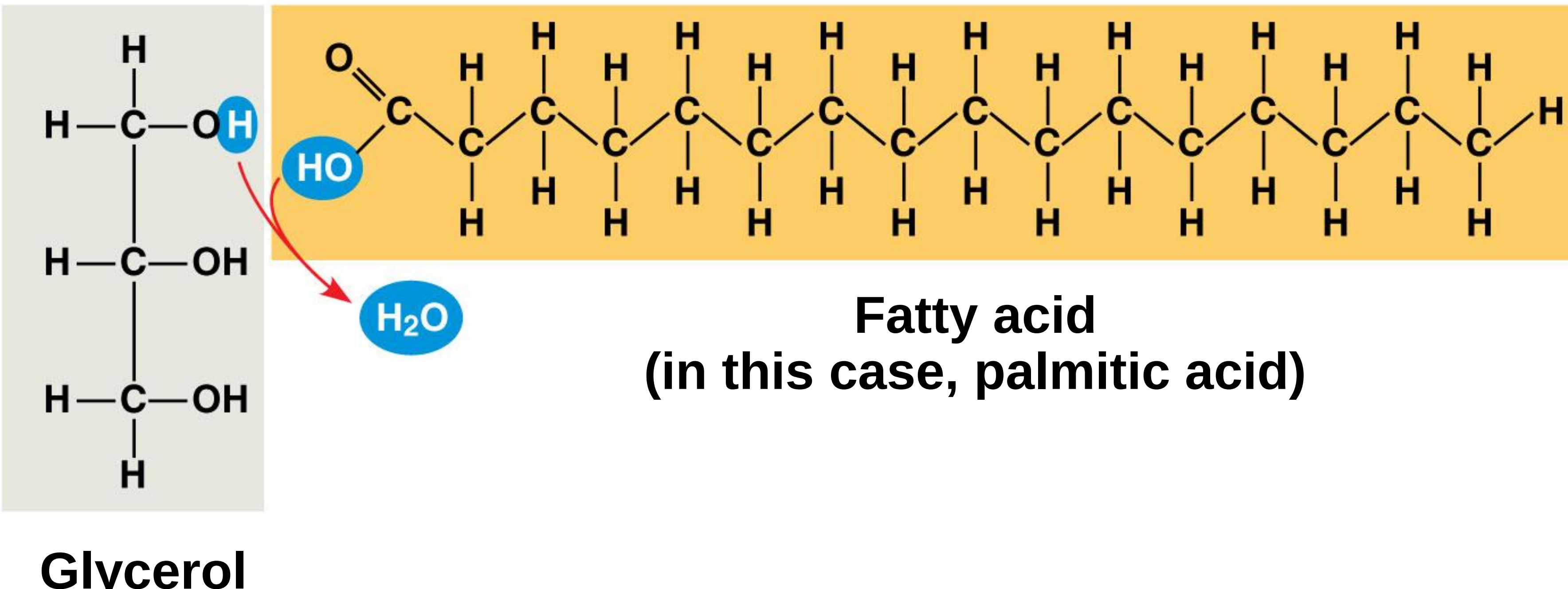


(a) One of three dehydration reactions in the synthesis of a fat



(b) Fat molecule (triacylglycerol)

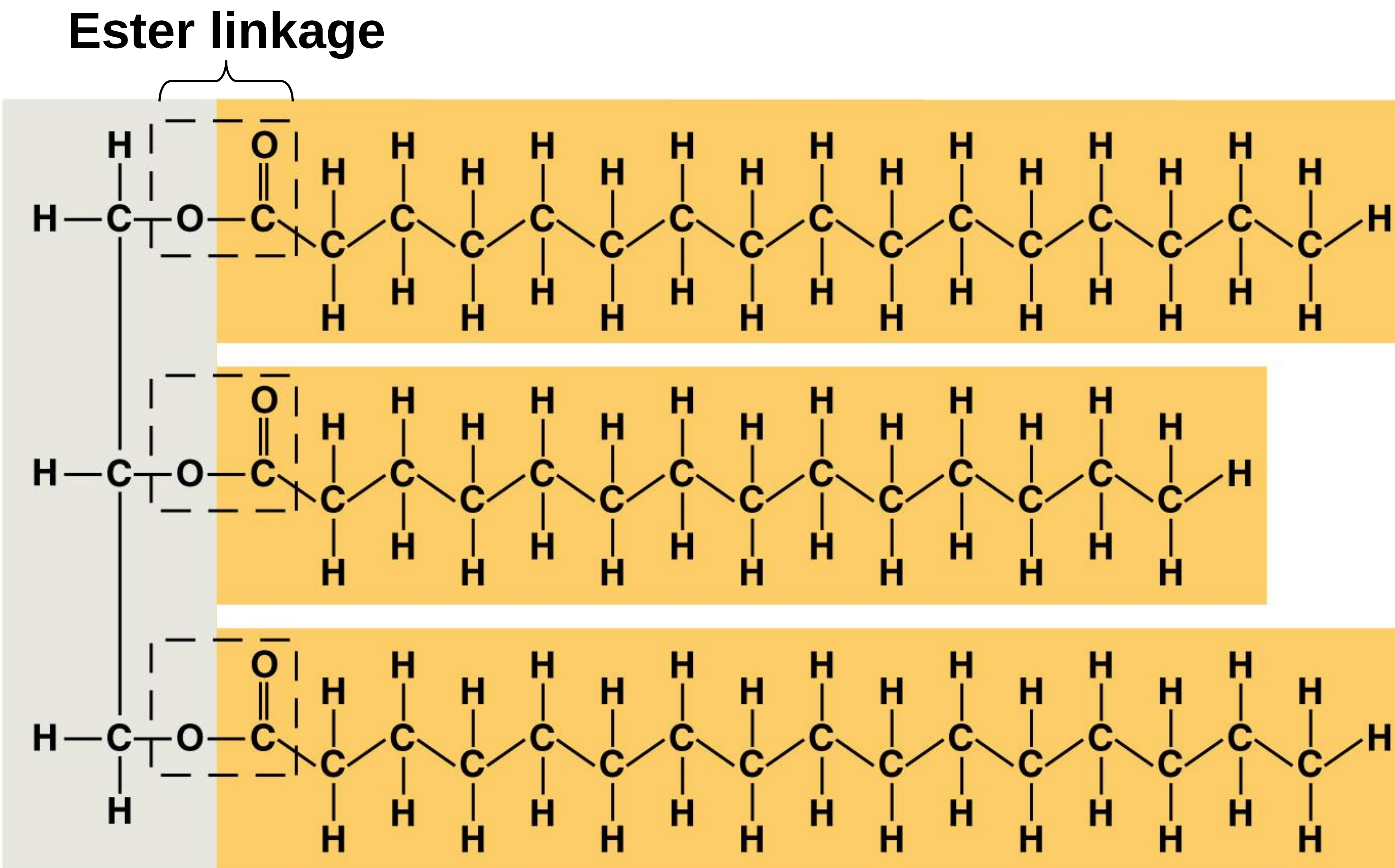
Figure 5.10a



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

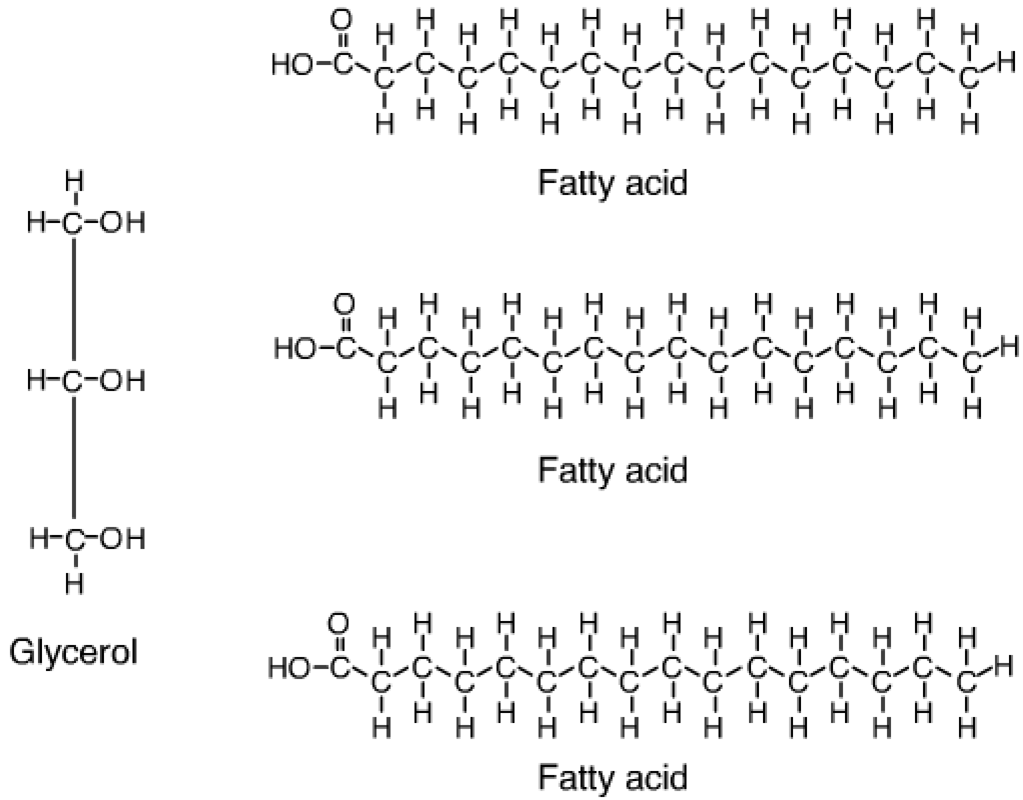
- Fats separate from water because water molecules form hydrogen bonds with each other and exclude the fats
- In a fat, three fatty acids are joined to glycerol by an ester linkage, creating a **triacylglycerol**, or triglyceride

Figure 5.10b



(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

Right-click slide / select “Play”

Figure 5.11

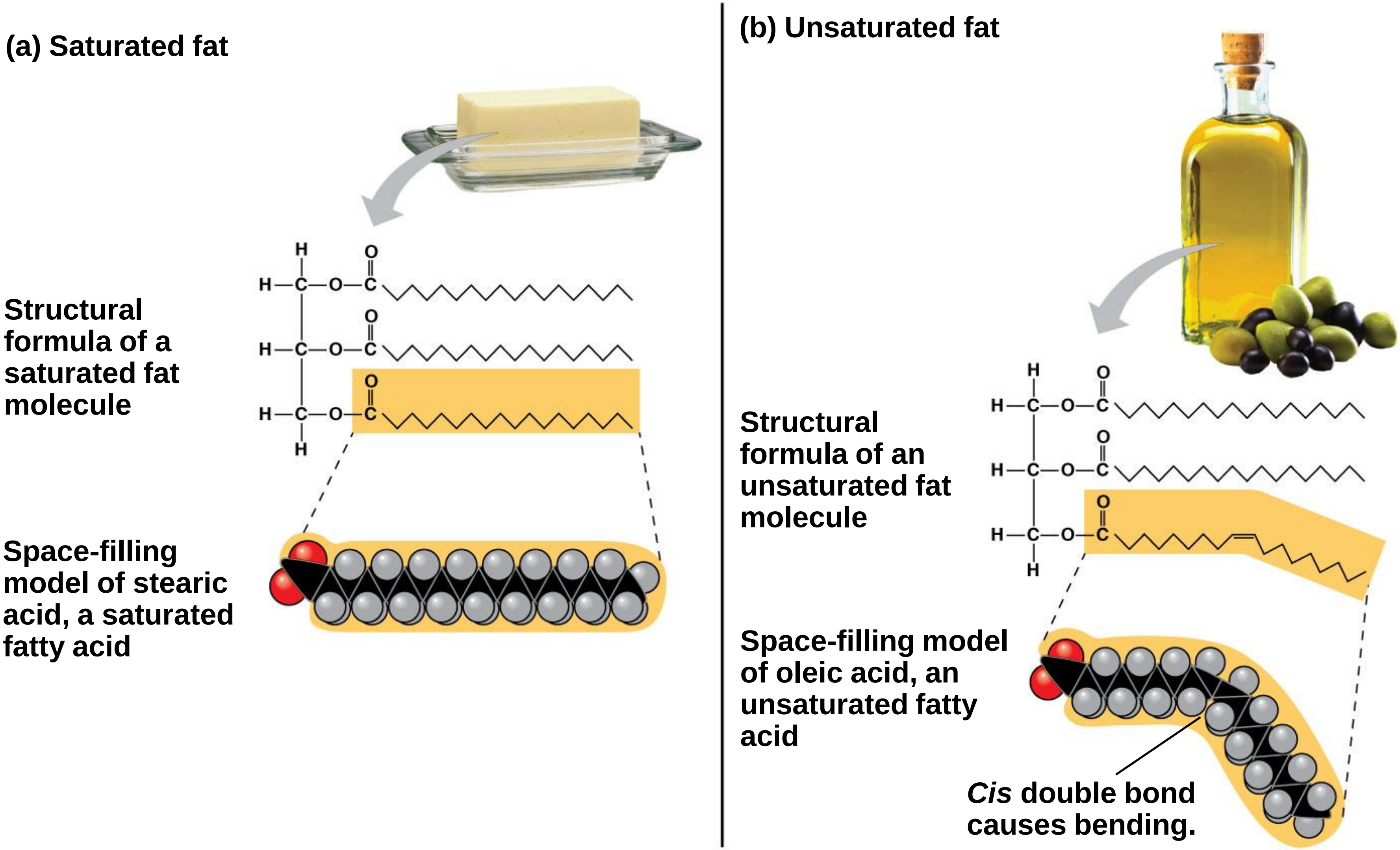
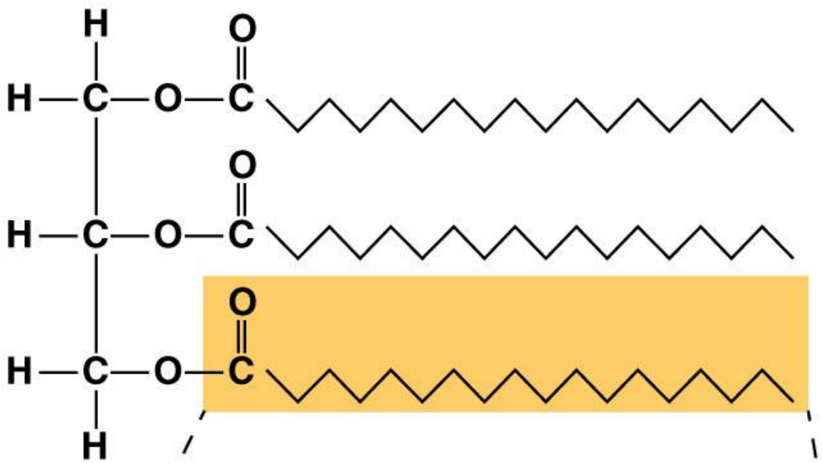

(a) Saturated fat
Structural formula of a saturated fat molecule
Space-filling model of stearic acid, a saturated fatty acid
(b) Unsaturated fat
Structural formula of an unsaturated fat molecule
Space-filling model of oleic acid, an unsaturated fatty acid
Cis double bond causes bending.

Figure 5.11a

(a) Saturated fat

Structural formula of a saturated fat molecule



Space-filling model of stearic acid, a saturated fatty acid

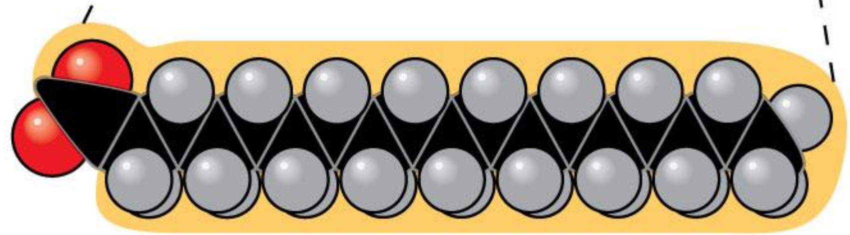
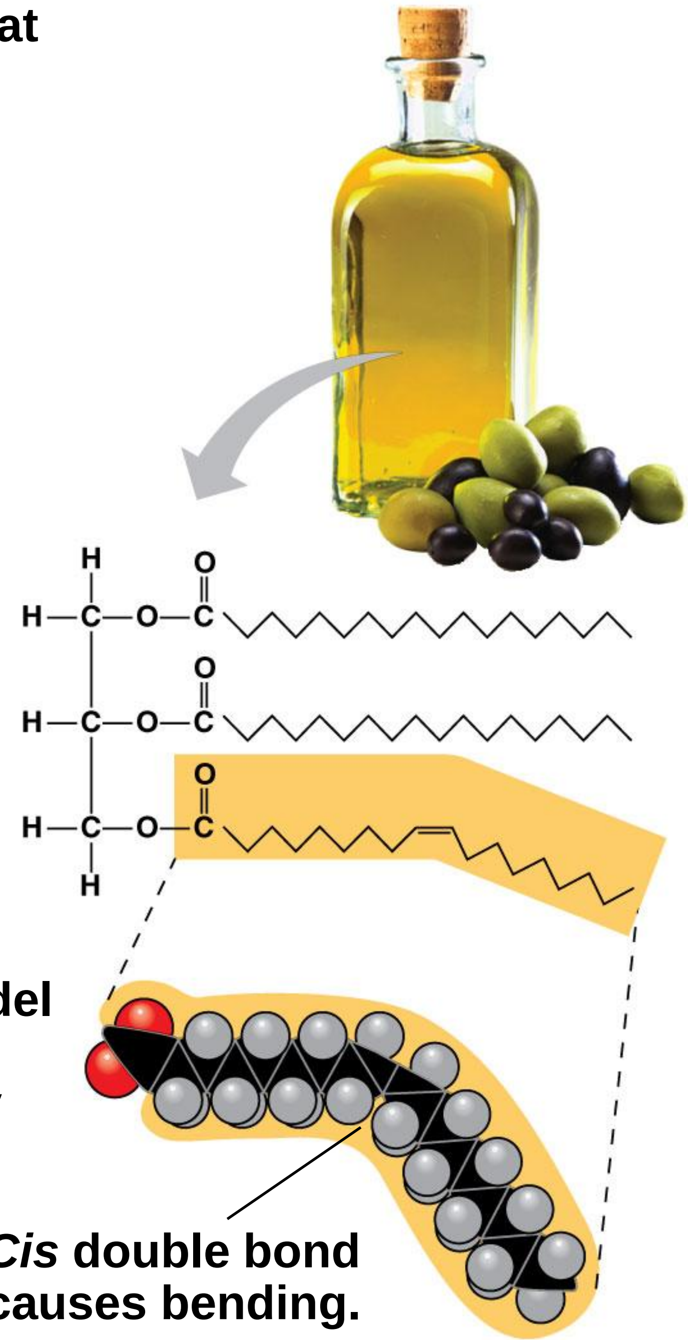


Figure 5.11b

(b) Unsaturated fat

Structural formula of an unsaturated fat molecule

Space-filling model of oleic acid, an unsaturated fatty acid



- 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

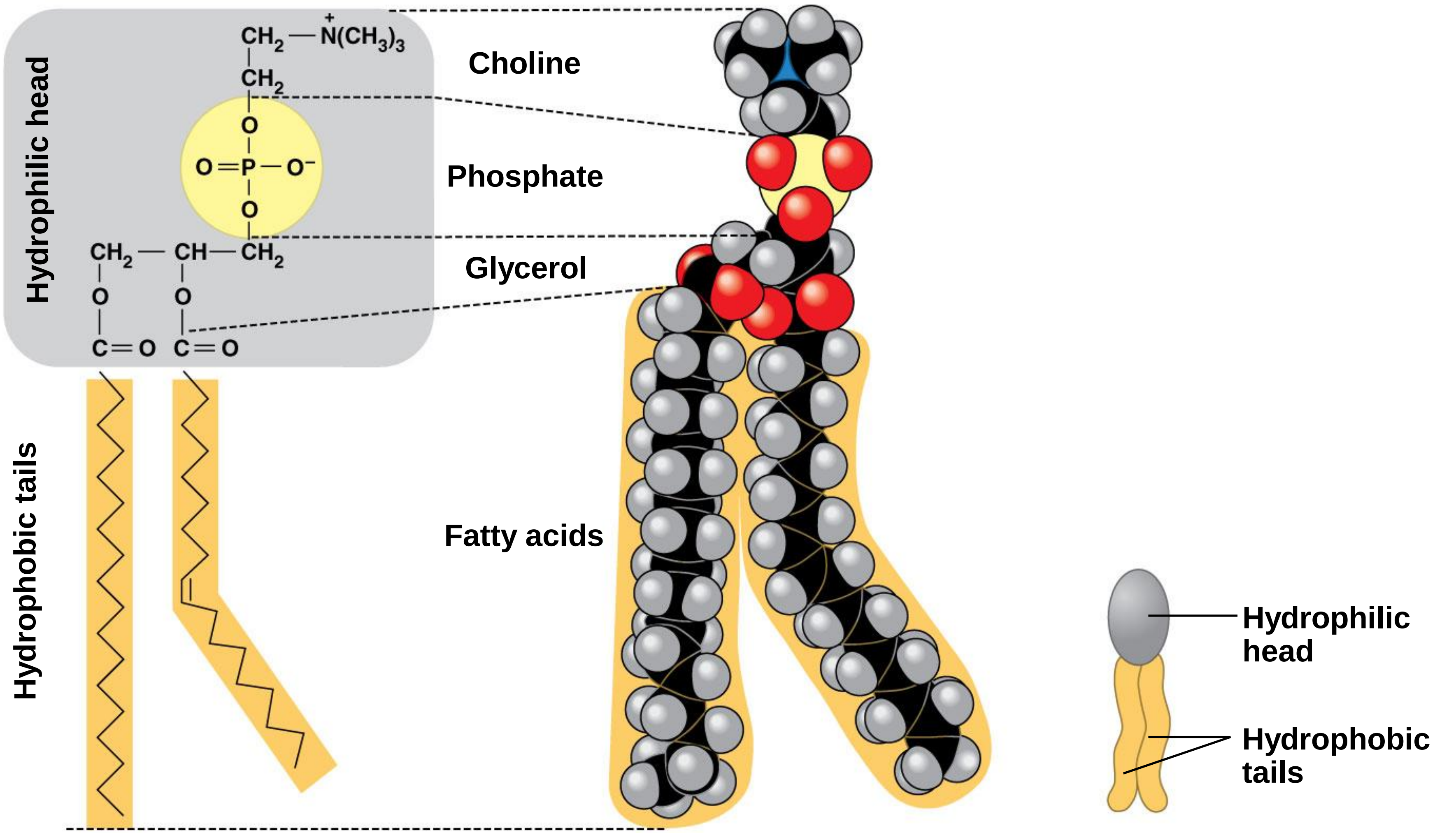
- Certain unsaturated fatty acids are not synthesized in the human body
- These must be supplied in the diet
- These essential fatty acids include the omega-3 fatty acids, required for normal growth, and thought to provide protection against cardiovascular disease

- 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

Figure 5.12

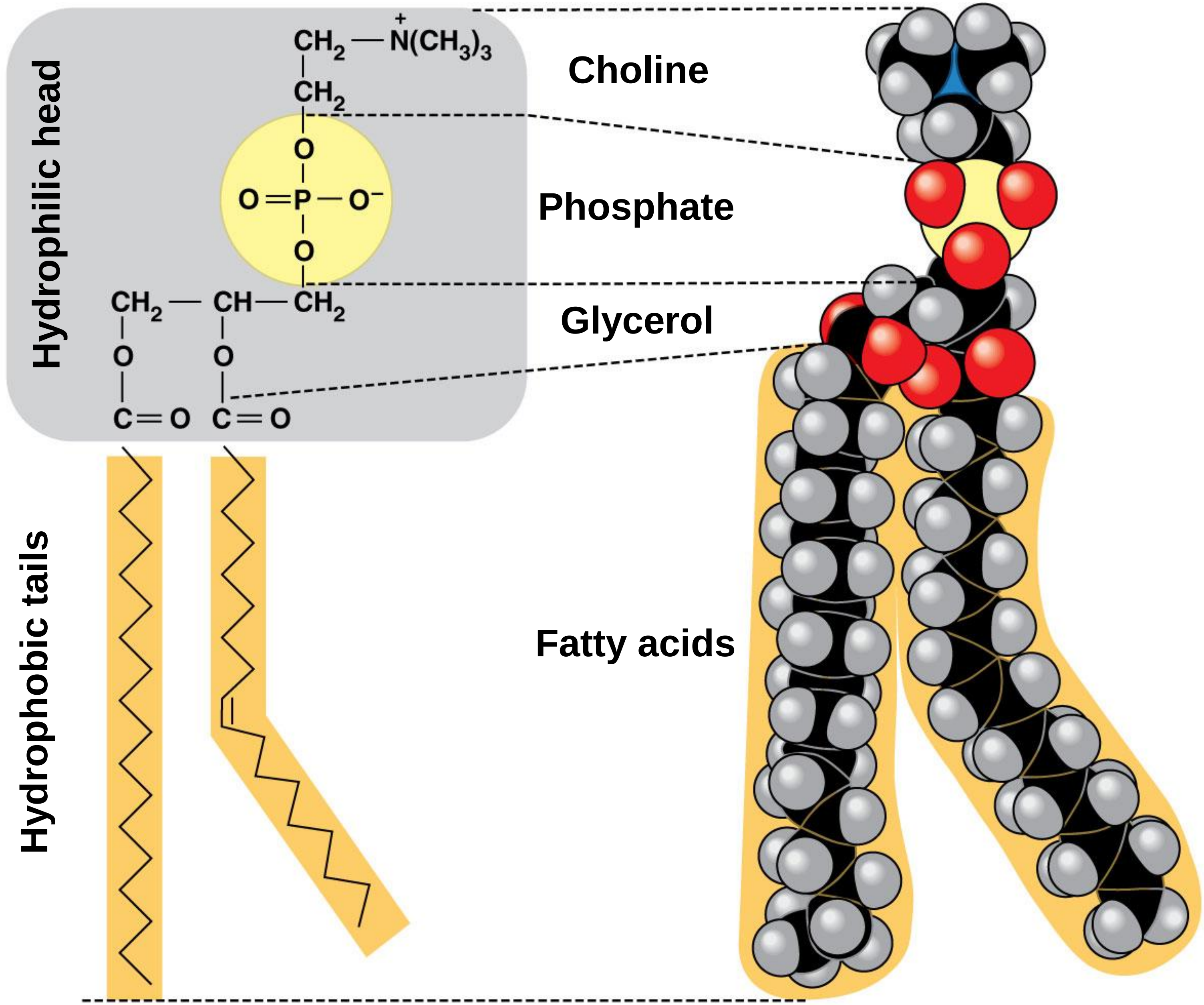


(a) Structural formula

(b) Space-filling model

(c) Phospholipid symbol

Figure 5.12a

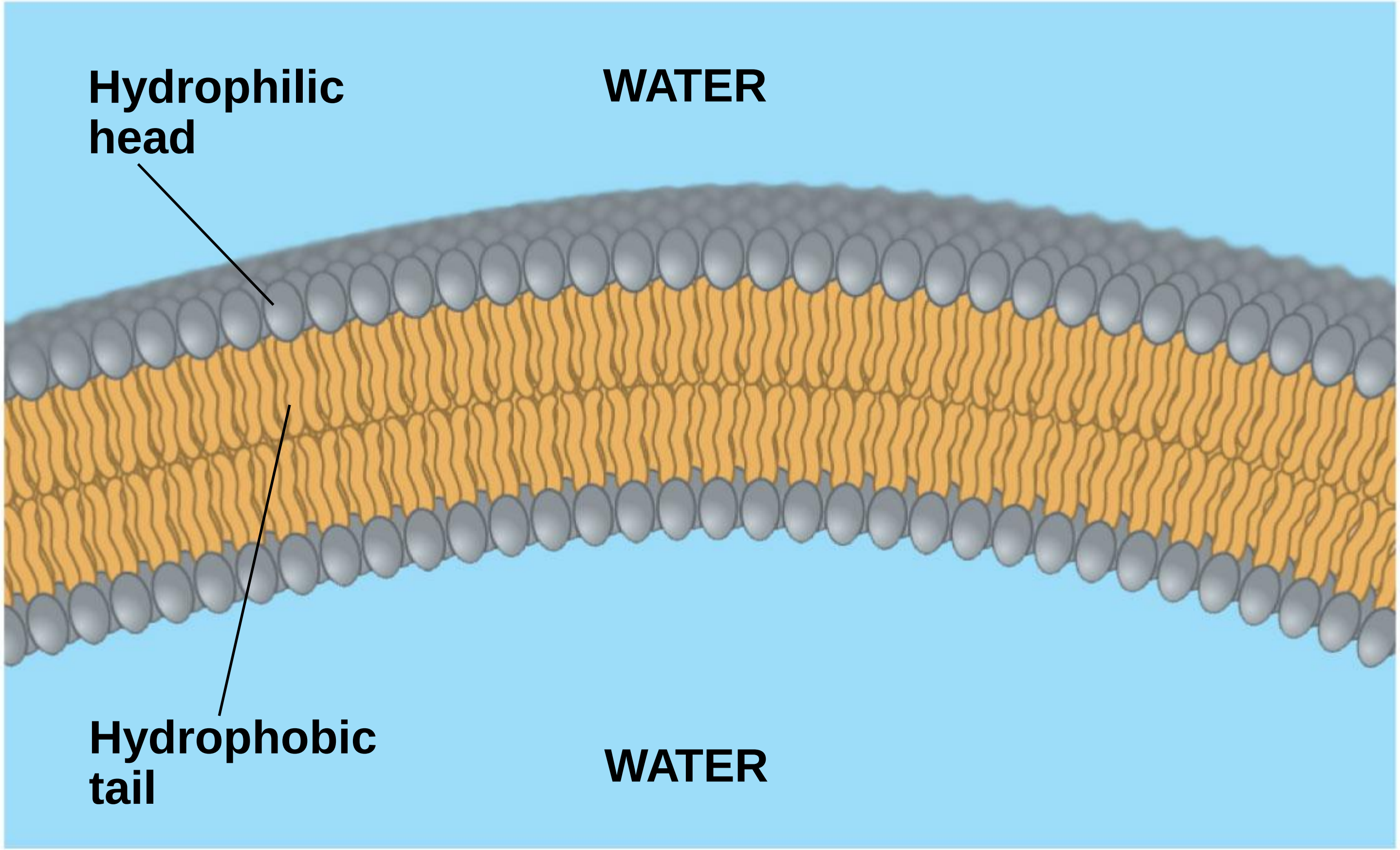


(a) Structural formula

(b) Space-filling model

- 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

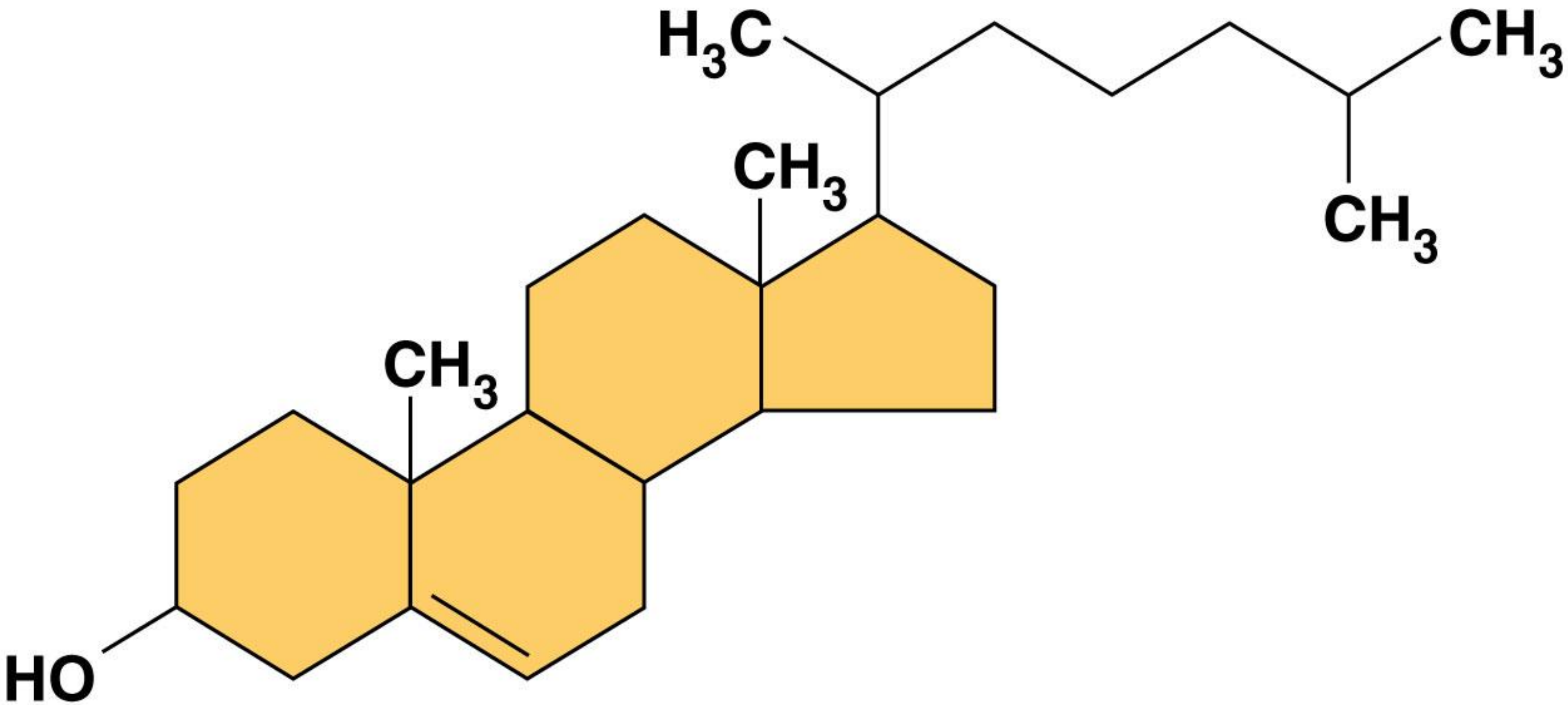
Figure 5.13



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

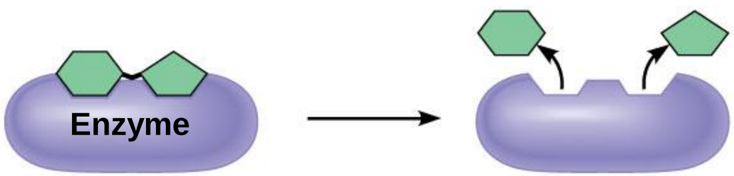
- Proteins account for more than 50% of the dry mass of most cells
- Protein functions include structural support, storage, transport, cellular communications, movement, and defense against foreign substances

Figure 5.15-a

Enzymatic proteins

Function: Selective acceleration of chemical reactions

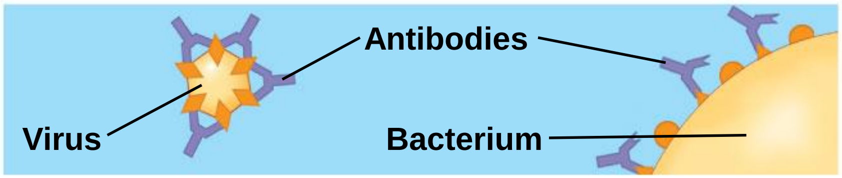
Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.



Defensive proteins

Function: Protection against disease

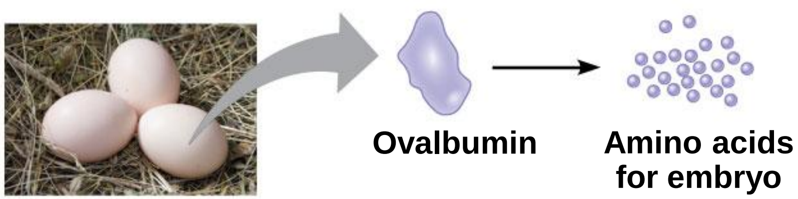
Example: Antibodies inactivate and help destroy viruses and bacteria.



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.

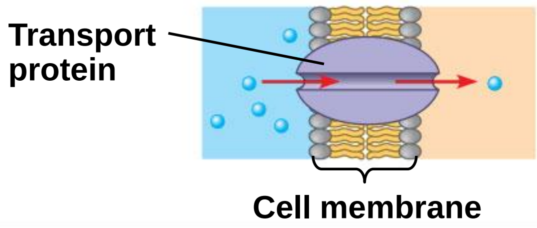
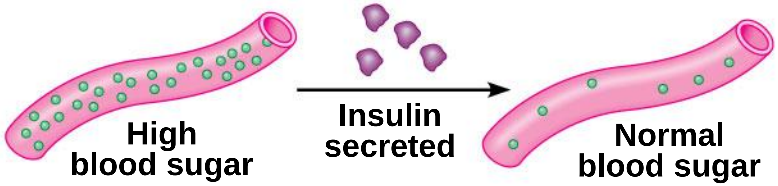


Figure 5.15-b

Hormonal proteins

Function: Coordination of an organism's activities

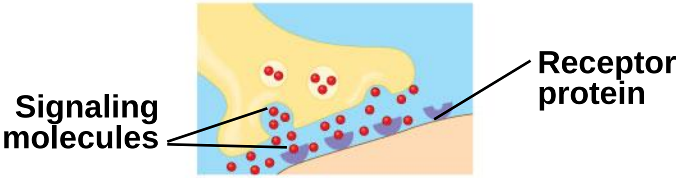
Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration



Receptor proteins

Function: Response of cell to chemical stimuli

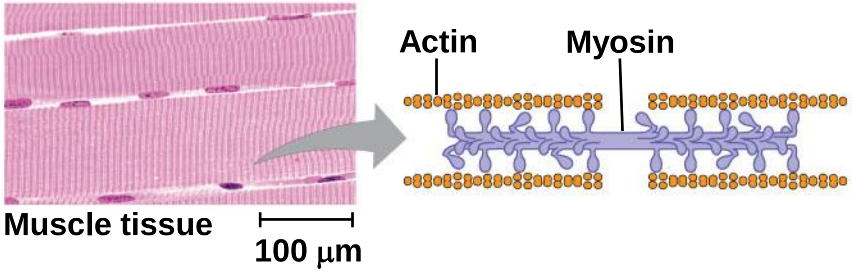
Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



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.

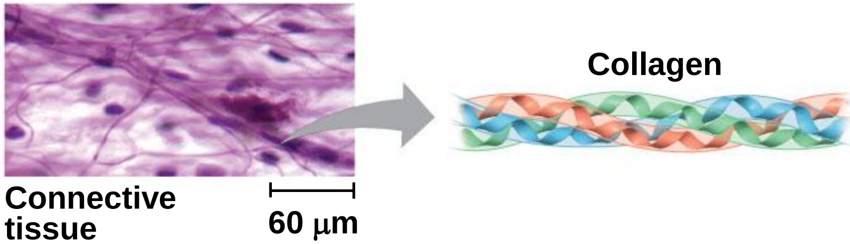


Figure 5.15a

Enzymatic proteins

Function: Selective acceleration of chemical reactions

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

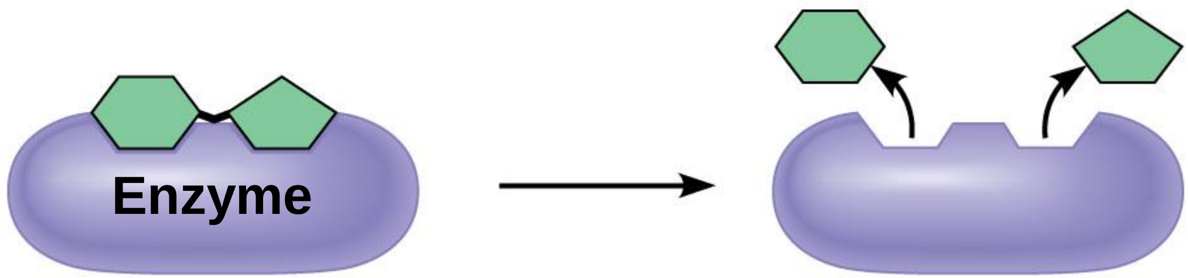


Figure 5.15b

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.

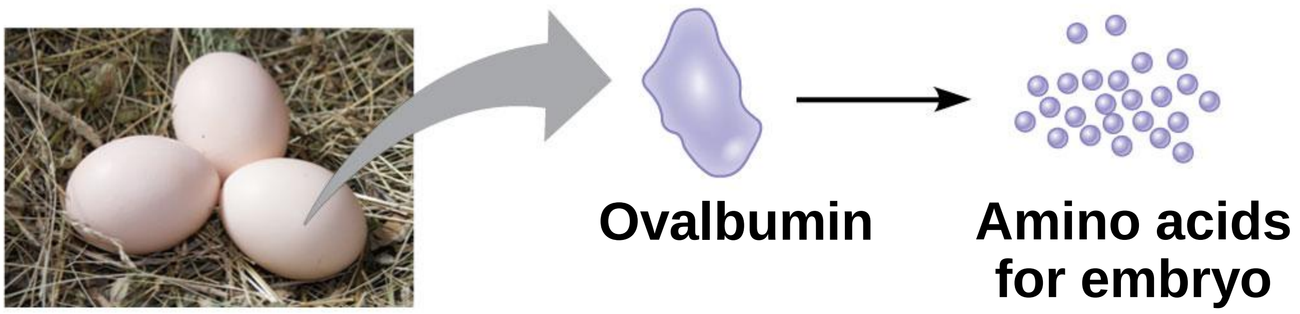


Figure 5.15c

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

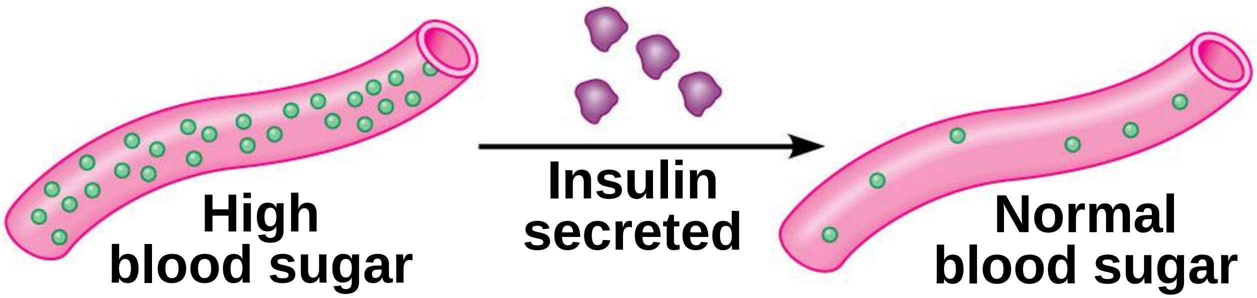


Figure 5.15d

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.

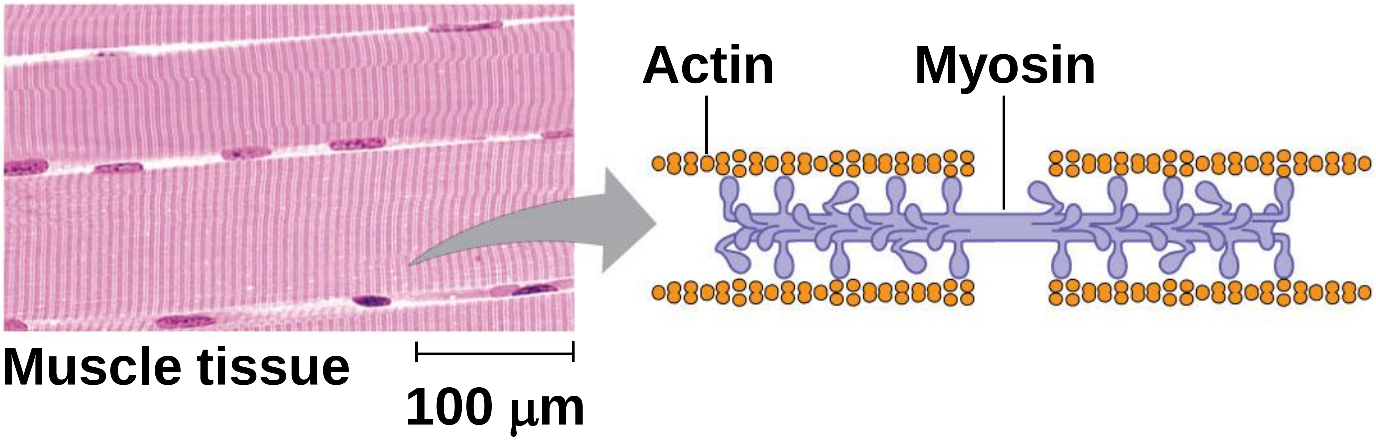
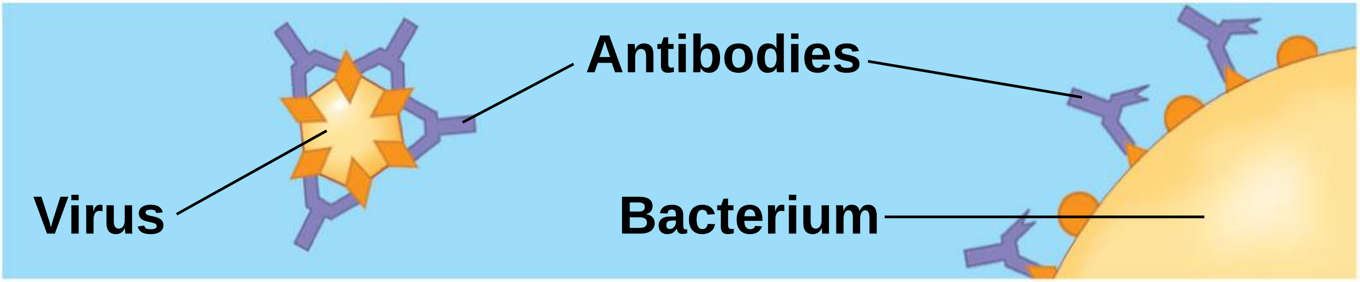


Figure 5.15e

Defensive proteins

Function: Protection against disease

Example: Antibodies inactivate and help destroy viruses and bacteria.



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.

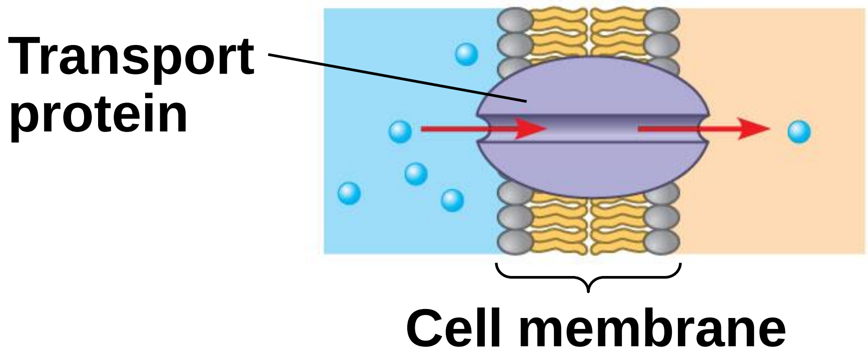


Figure 5.15g

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.

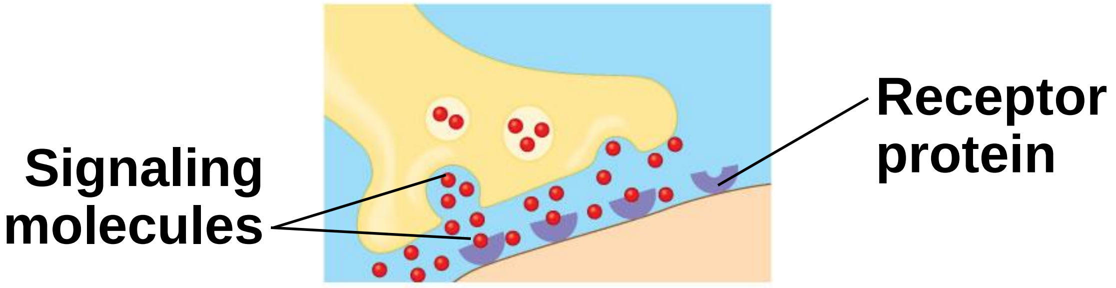
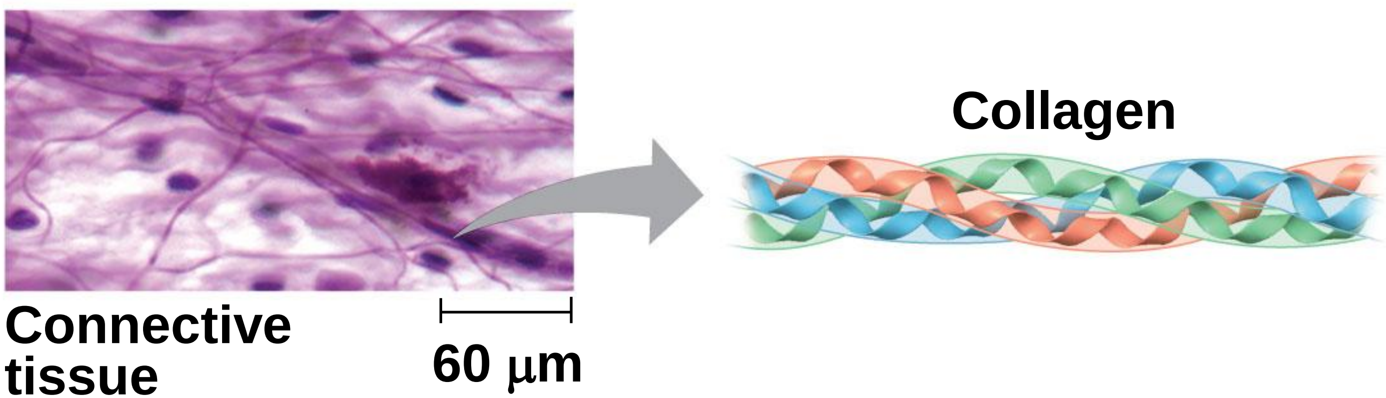


Figure 5.15h

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

Polypeptides

- **Polypeptides** are unbranched polymers built from the same set of 20 amino acids
- A **protein** is a biologically functional molecule that 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

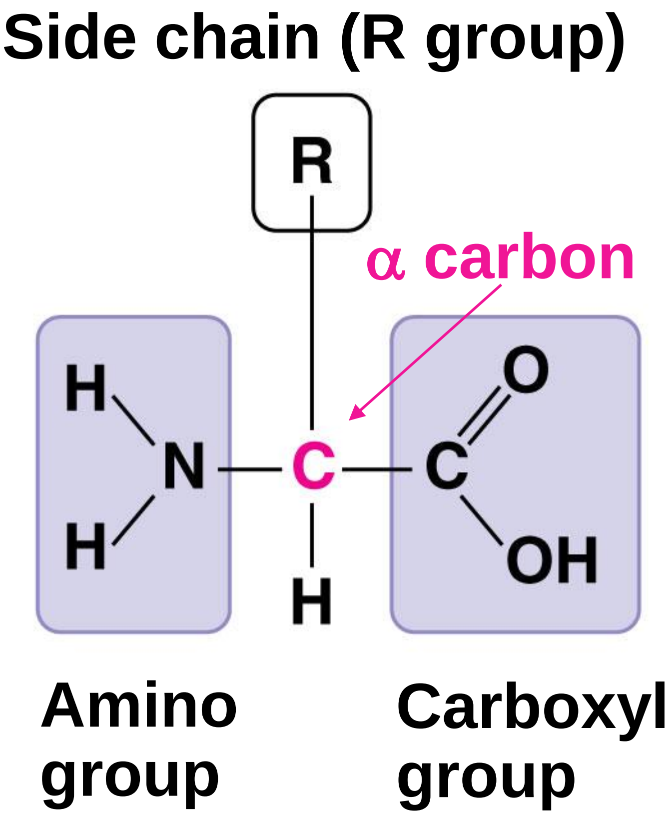
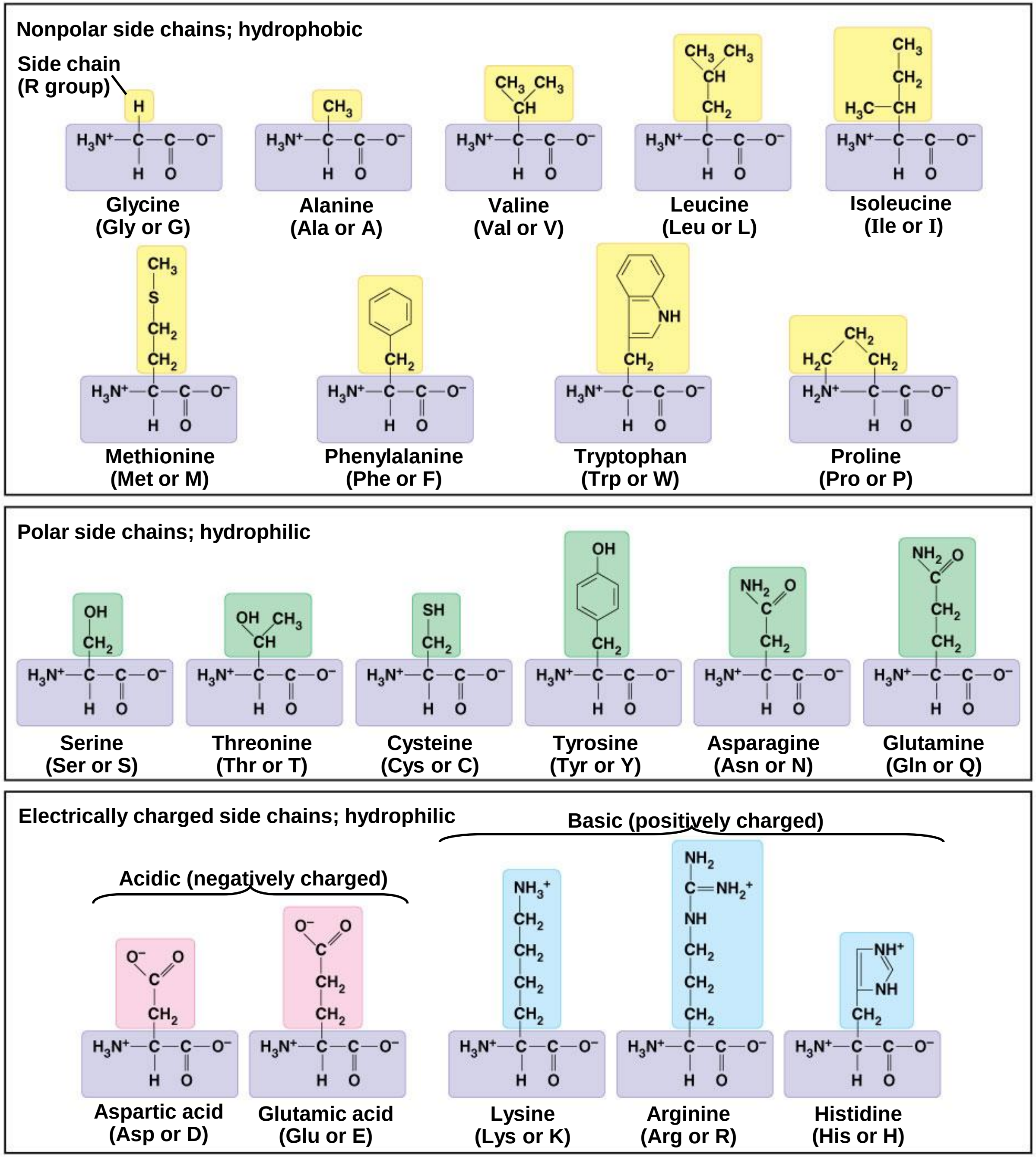


Figure 5.16



Nonpolar side chains; hydrophobic
Side chain (R group)
Glycine (Gly or G)
Alanine (Ala or A)
Valine (Val or V)
Leucine (Leu or L)
Isoleucine (Ile or I)
Methionine (Met or M)
Phenylalanine (Phe or F)
Tryptophan (Trp or W)
Proline (Pro or P)
Polar side chains; hydrophilic
Serine (Ser or S)
Threonine (Thr or T)
Cysteine (Cys or C)
Tyrosine (Tyr or Y)
Asparagine (Asn or N)
Glutamine (Gln or Q)
Electrically charged side chains; hydrophilic
Acidic (negatively charged)
Basic (positively charged)
Aspartic acid (Asp or D)
Glutamic acid (Glu or E)
Lysine (Lys or K)
Arginine (Arg or R)
Histidine (His or H)

Figure 5.16a

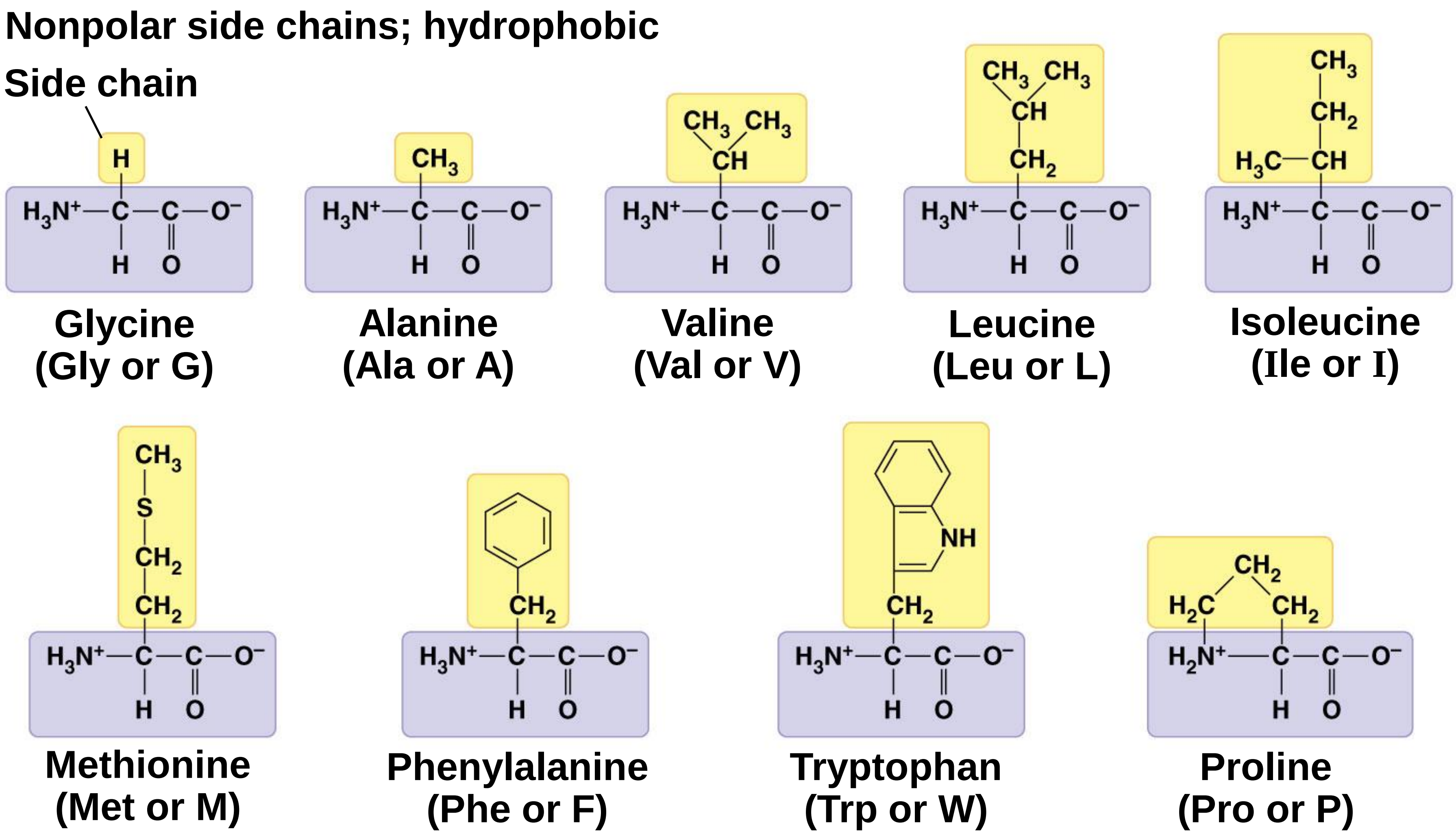
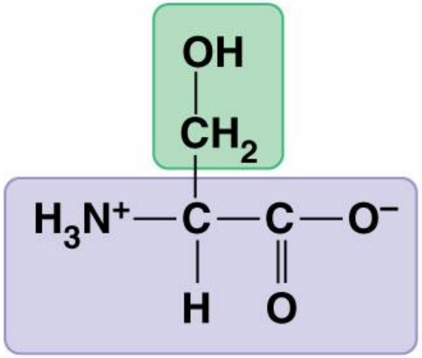
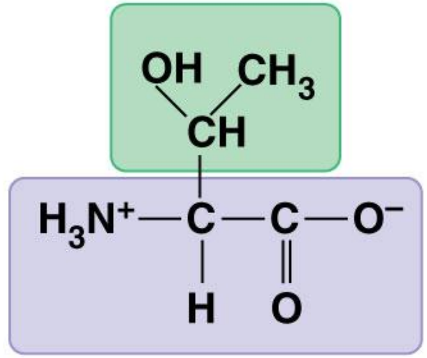

Nonpolar side chains; hydrophobic
Side chain
Glycine
(Gly or G)
Alanine
(Ala or A)
Valine
(Val or V)
Leucine
(Leu or L)
Isoleucine
(Ile or I)
Methionine
(Met or M)
Phenylalanine
(Phe or F)
Tryptophan
(Trp or W)
Proline
(Pro or P)

Figure 5.16b

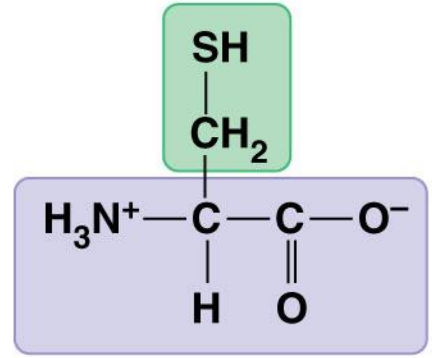
Polar side chains; hydrophilic



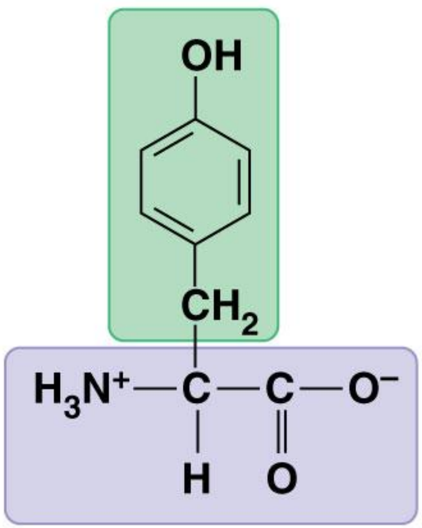
Serine
(Ser or S)



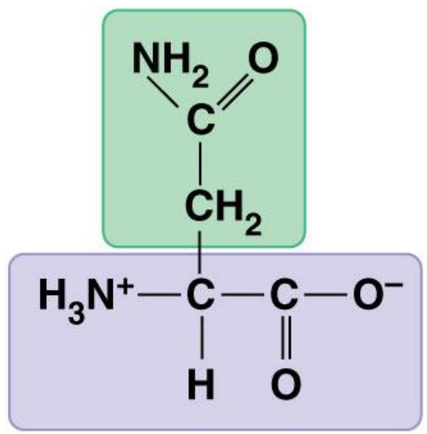
Threonine
(Thr or T)



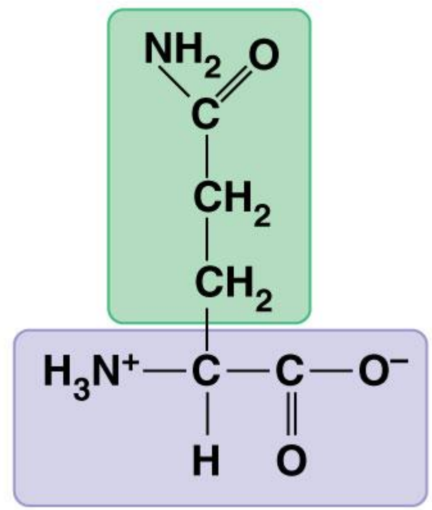
Cysteine
(Cys or C)



Tyrosine
(Tyr or Y)

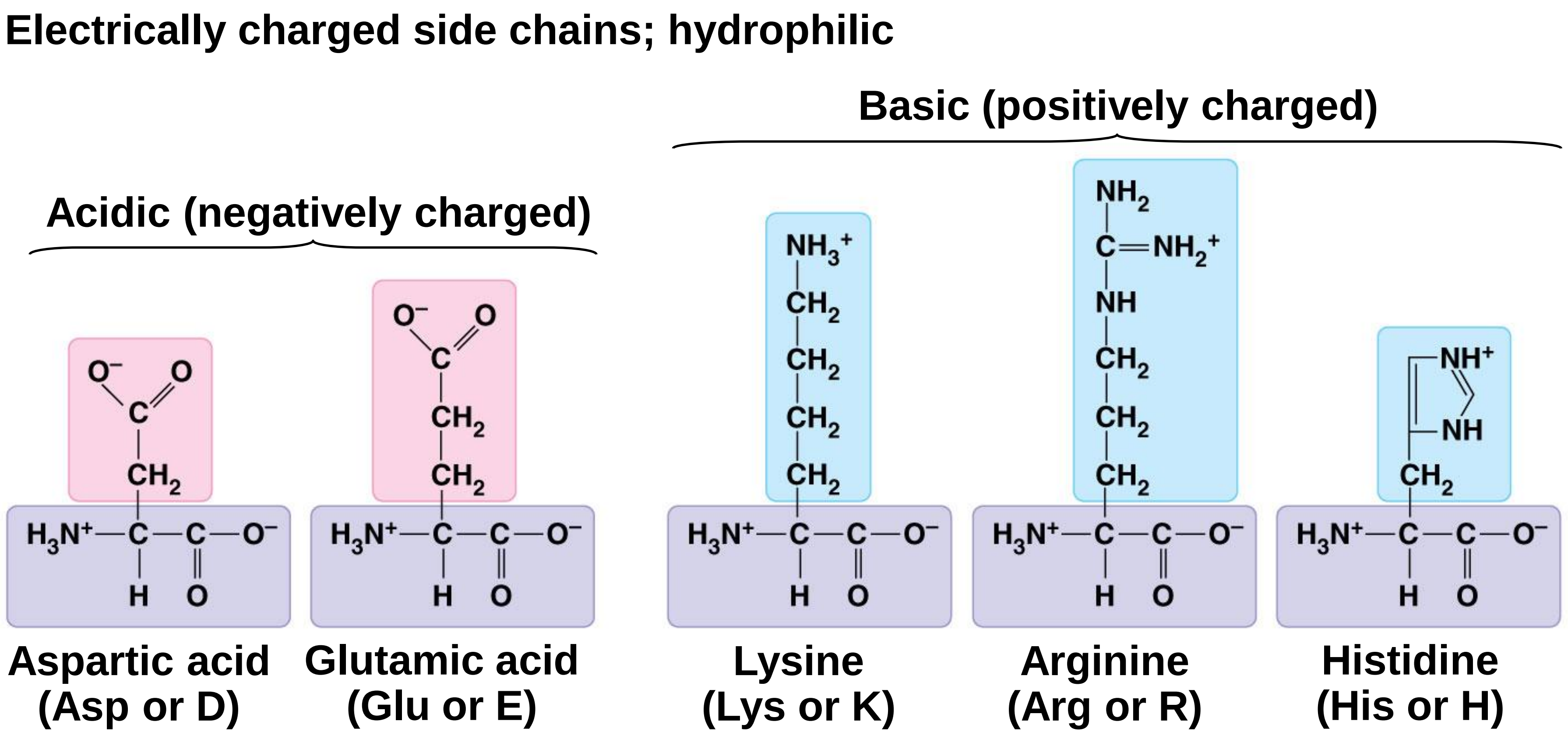


Asparagine
(Asn or N)



Glutamine
(Gln or Q)

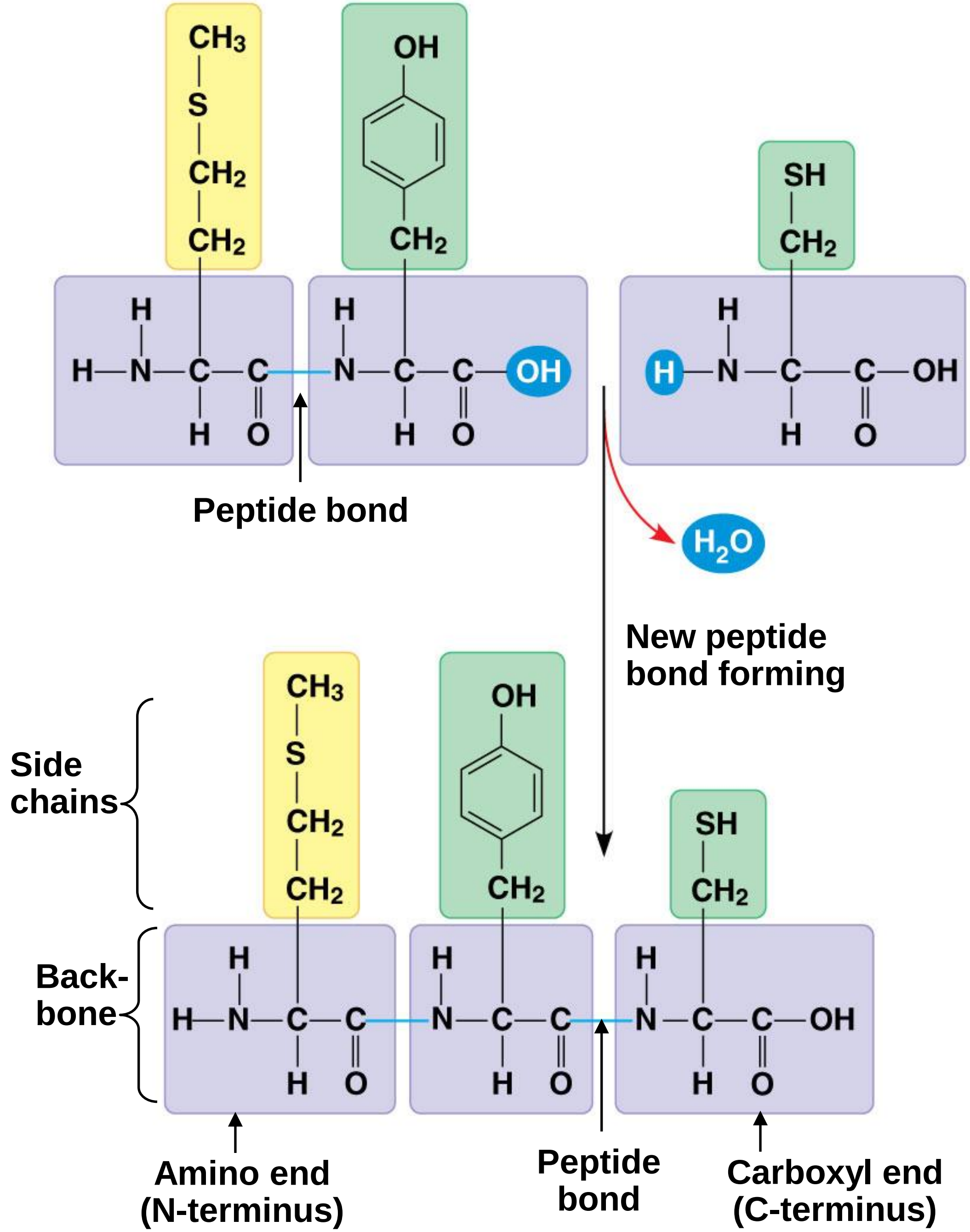
Figure 5.16c


Electrically charged side chains; hydrophilic
Basic (positively charged)
Acidic (negatively charged)
Aspartic acid (Asp or D)
Glutamic acid (Glu or E)
Lysine (Lys or K)
Arginine (Arg or R)
Histidine (His or H)

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



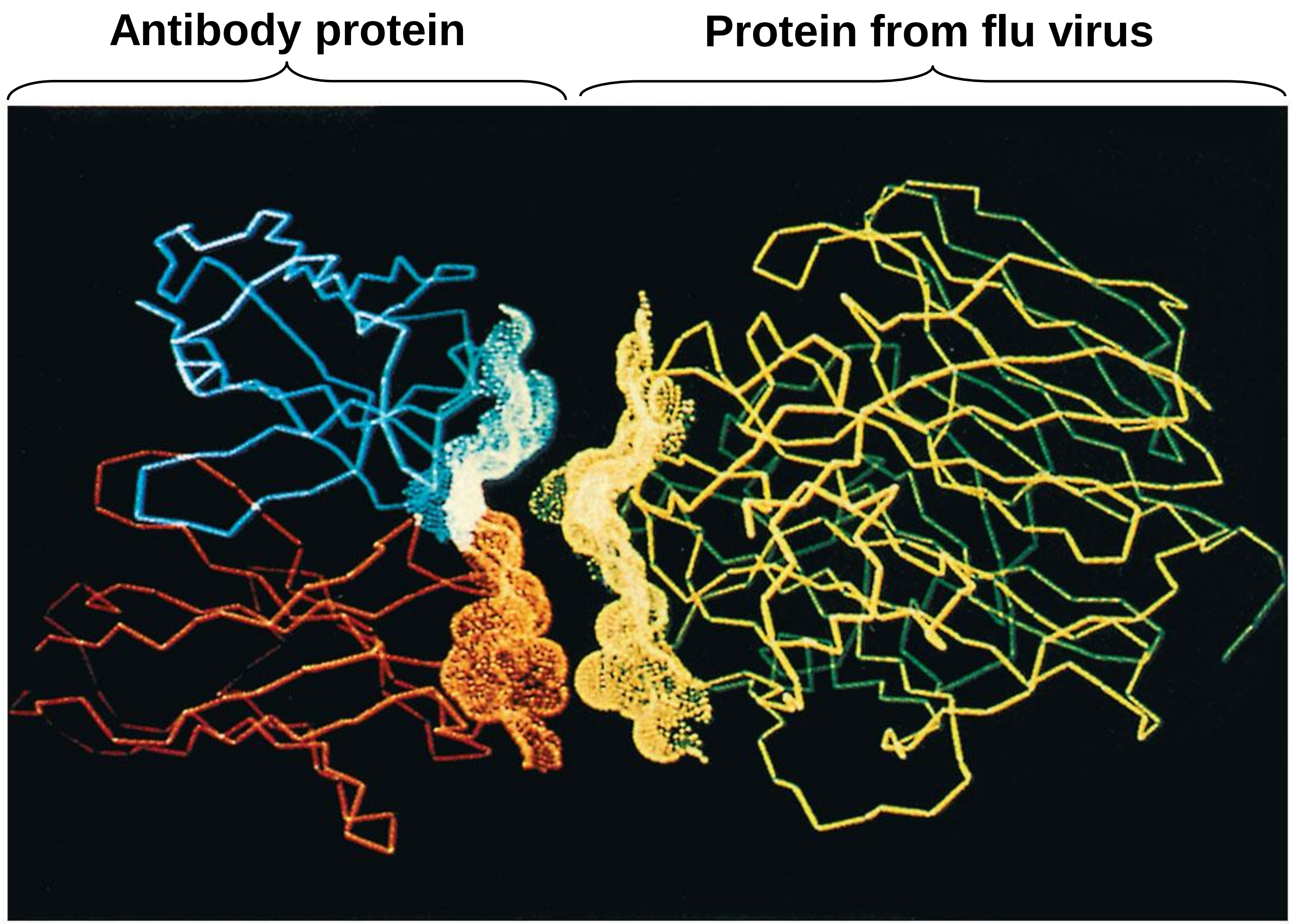
Peptide bond
New peptide
bond forming
Side
chains
Back-
bone
Amino end
(N-terminus)
Peptide
bond
Carboxyl end
(C-terminus)

Protein Structure and Function

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

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

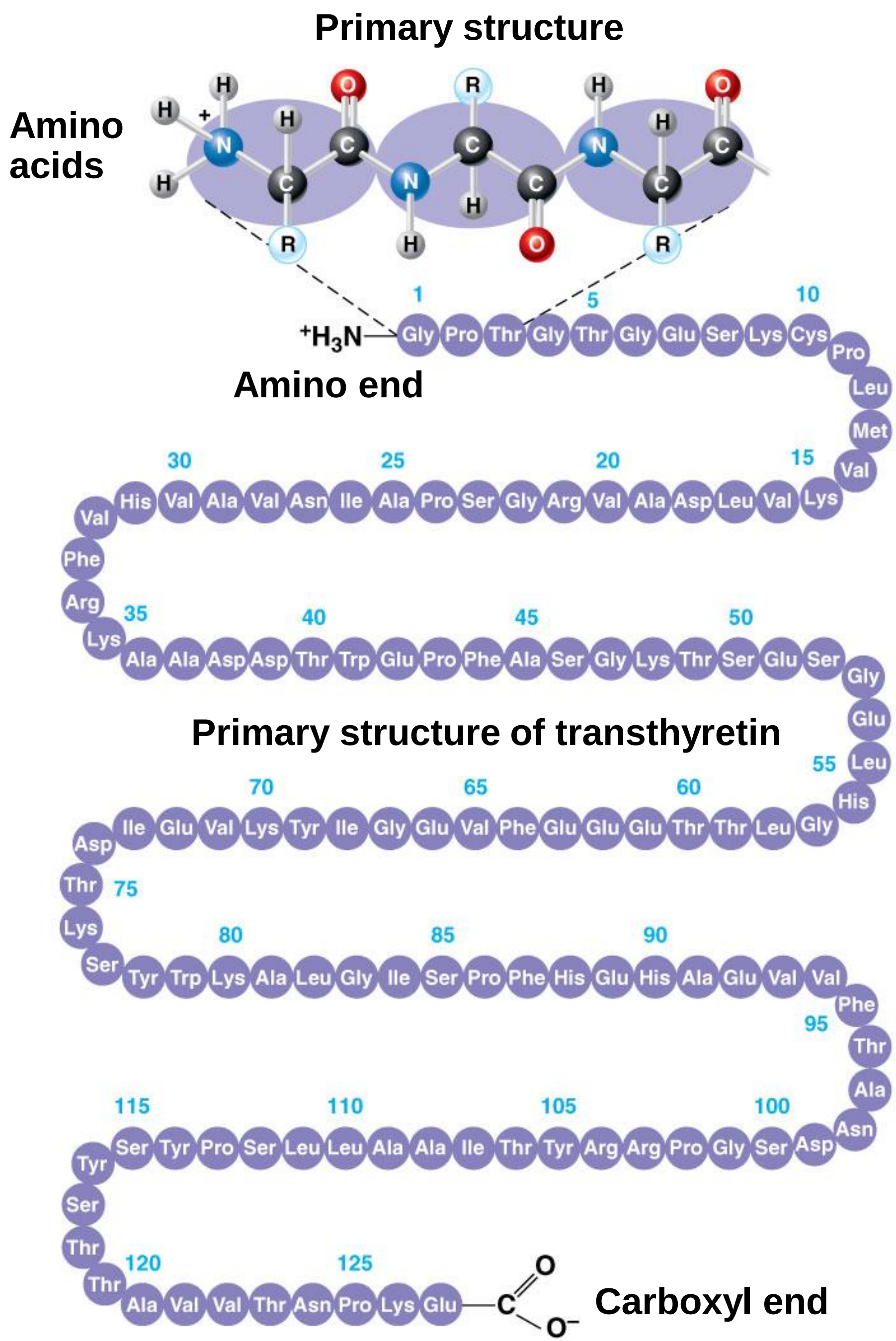
Figure 5.19



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

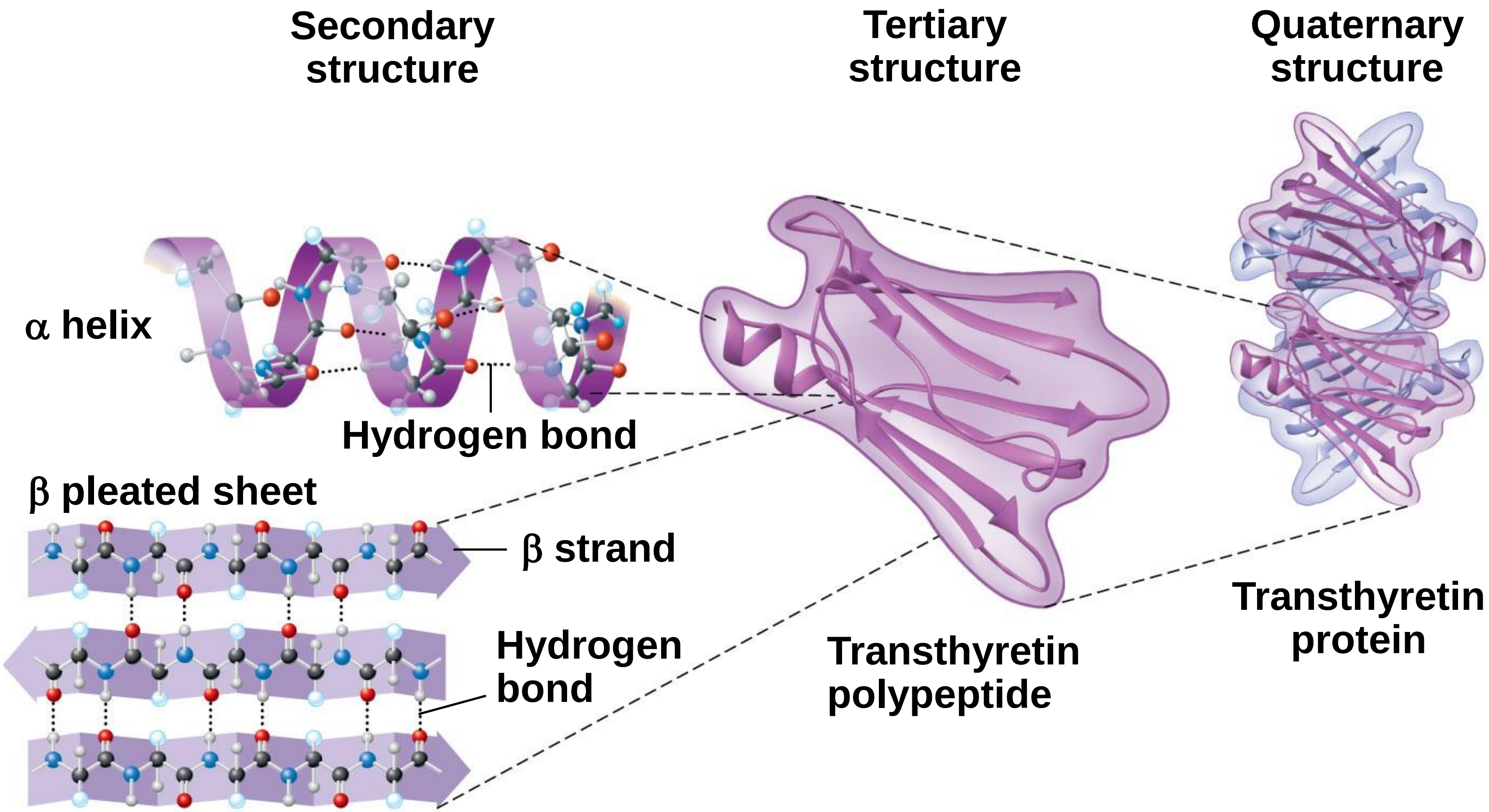
Figure 5.20a



Primary structure
Amino acids
H H + N H C H R C O N H H C R H C O N H H C R C O
1 5 10
^+H_3N
Gly Pro Thr Gly Thr Gly Glu Ser Lys Cys
Pro Leu Met Val
Amino end
30 25 20 15
His Val Ala Val Asn Ile Ala Pro Ser Gly Arg Val Ala Asp Leu Val Lys
Val Phe Arg Lys
35 40 45 50
Ala Ala Asp Asp Thr Trp Glu Pro Phe Ala Ser Gly Lys Thr Ser Glu Ser
Gly Glu Leu His
Primary structure of transthyretin
55
70 65 60
Ile Glu Val Lys Tyr Ile Gly Glu Val Phe Glu Glu Glu Thr Thr Leu Gly
Asp Thr Lys Ser
75
80 85 90
Tyr Trp Lys Ala Leu Gly Ile Ser Pro Phe His Glu His Ala Glu Val Val
Phe Thr Ala Asn
95
115 110 105 100
Ser Tyr Pro Ser Leu Leu Ala Ala Ile Thr Tyr Arg Arg Pro Gly Ser Asp
Tyr Ser Thr Thr
120 125
Ala Val Val Thr Asn Pro Lys Glu
C O O^-
Carboxyl end

- **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

Figure 5.20b



Secondary structure
Tertiary structure
Quaternary structure
α helix
Hydrogen bond
β pleated sheet
β strand
Hydrogen bond
Transthyretin polypeptide
Transthyretin protein

- 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**

Figure 5.20c

Secondary structure

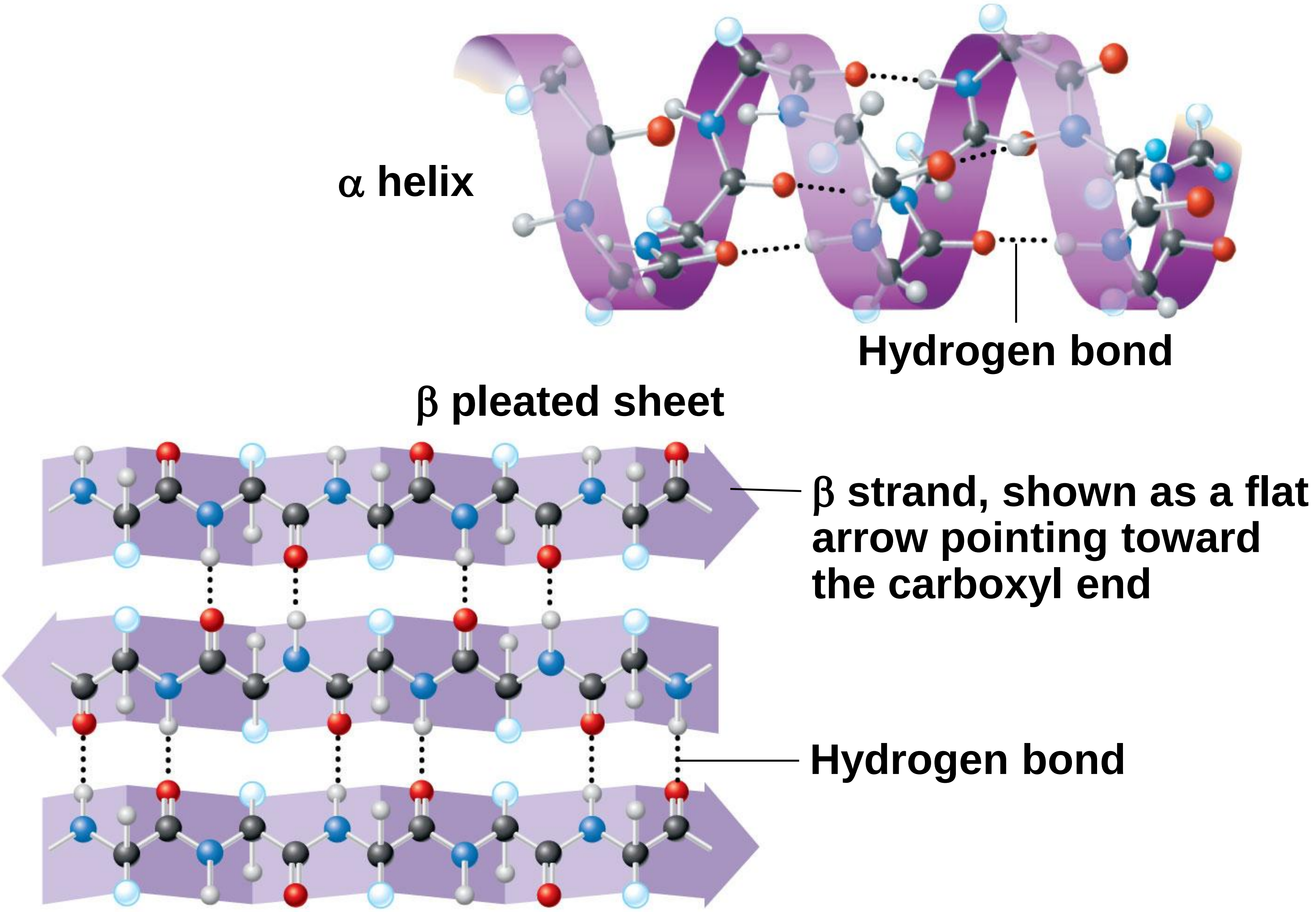
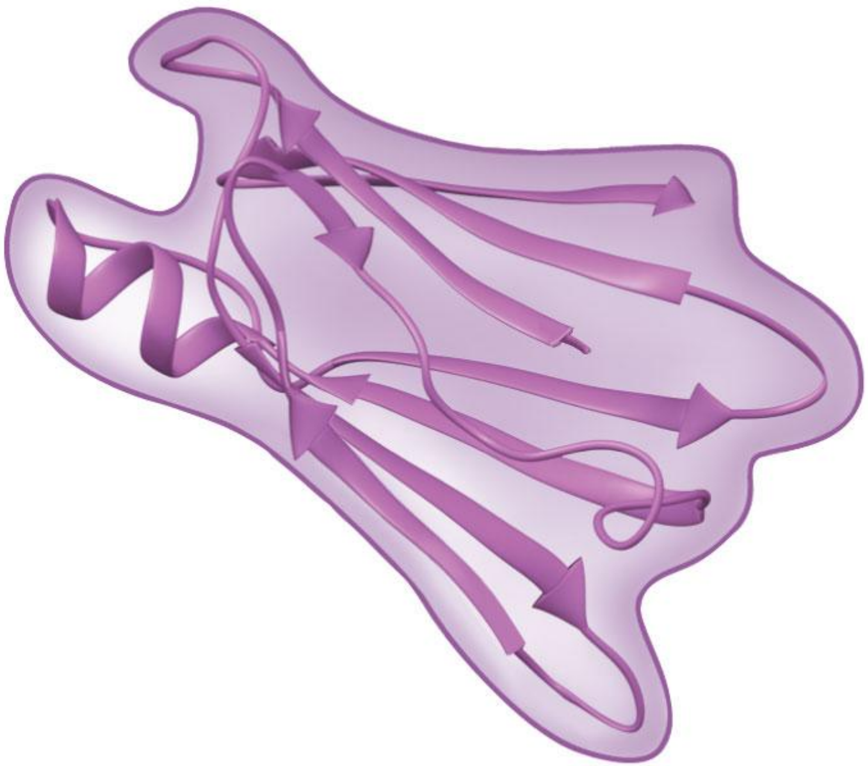


Figure 5.20d

- **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

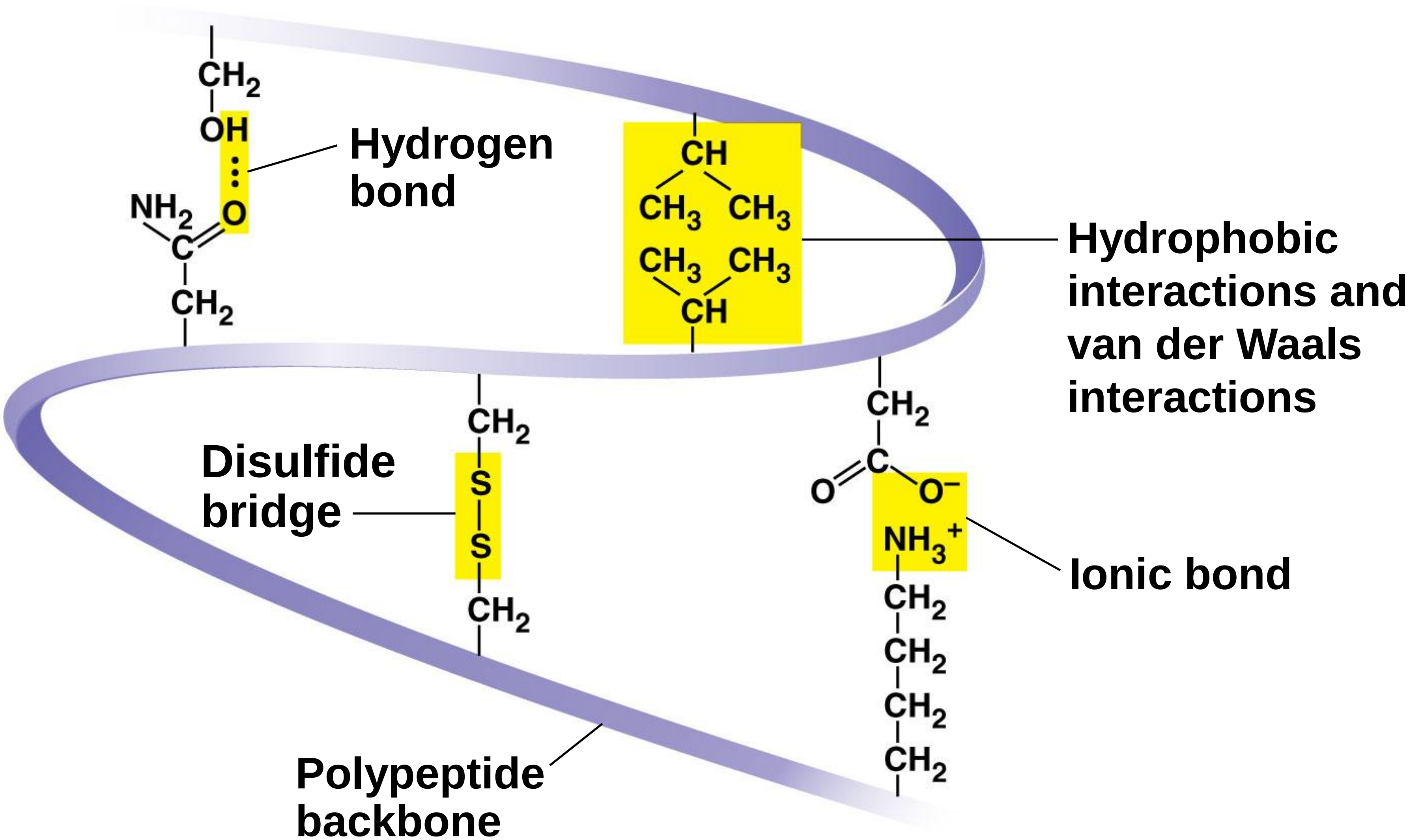
Figure 5.20e

Tertiary structure



Transthyretin
polypeptide

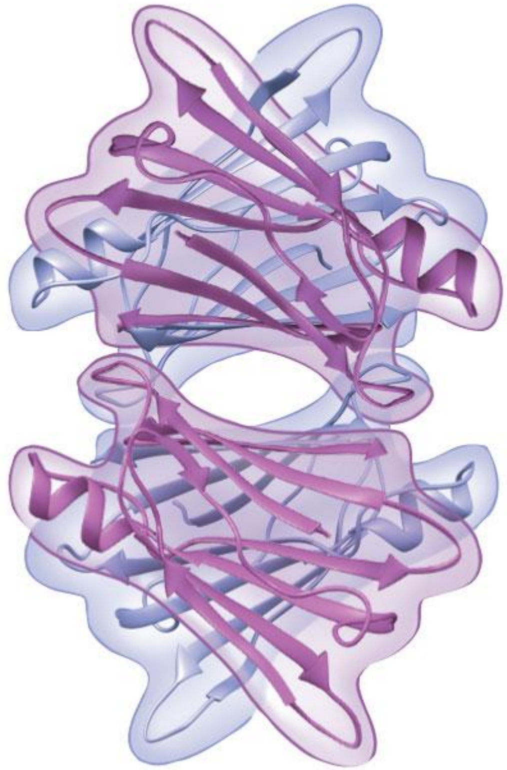
Figure 5.20f



CH2
OH
O
NH2
C
CH2
Hydrogen bond
CH
CH3 CH3
CH3 CH3
CH
Hydrophobic interactions and van der Waals interactions
CH2
S
S
CH2
Disulfide bridge
CH2
C
O
O−
NH3+
CH2
CH2
CH2
CH2
Ionic bond
Polypeptide backbone

Figure 5.20g

Quaternary structure



Transthyretin protein (four identical polypeptides)

Figure 5.20h

Collagen

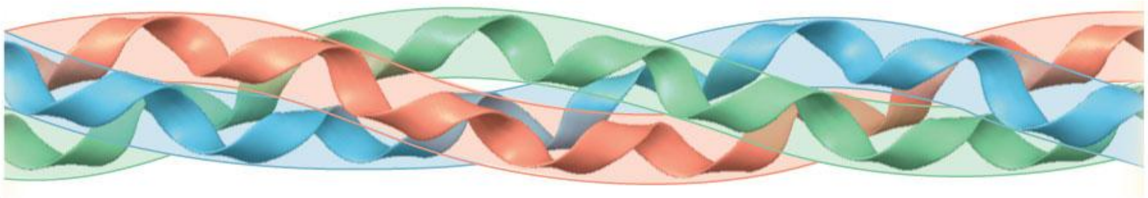
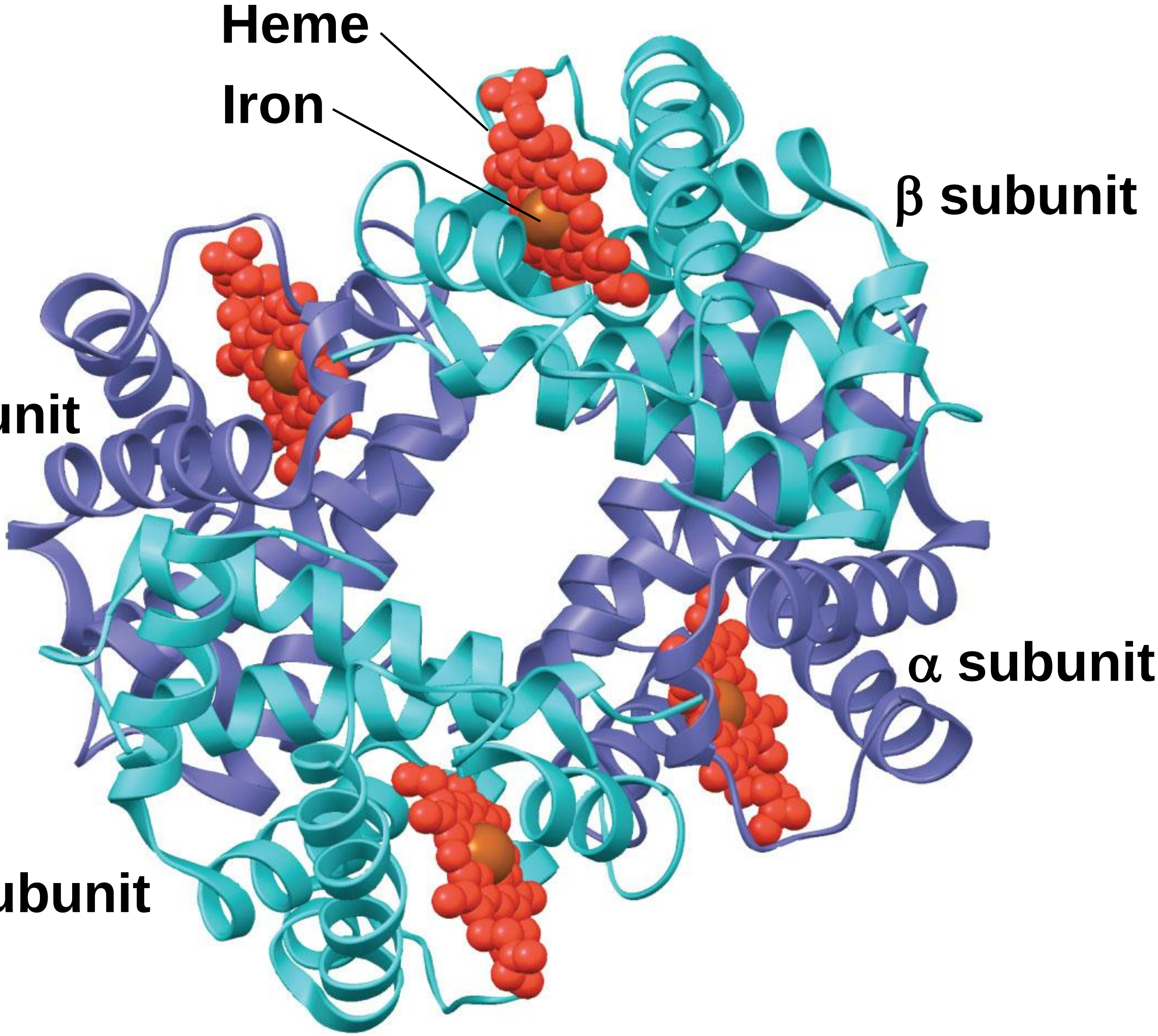


Figure 5.20i



Hemoglobin

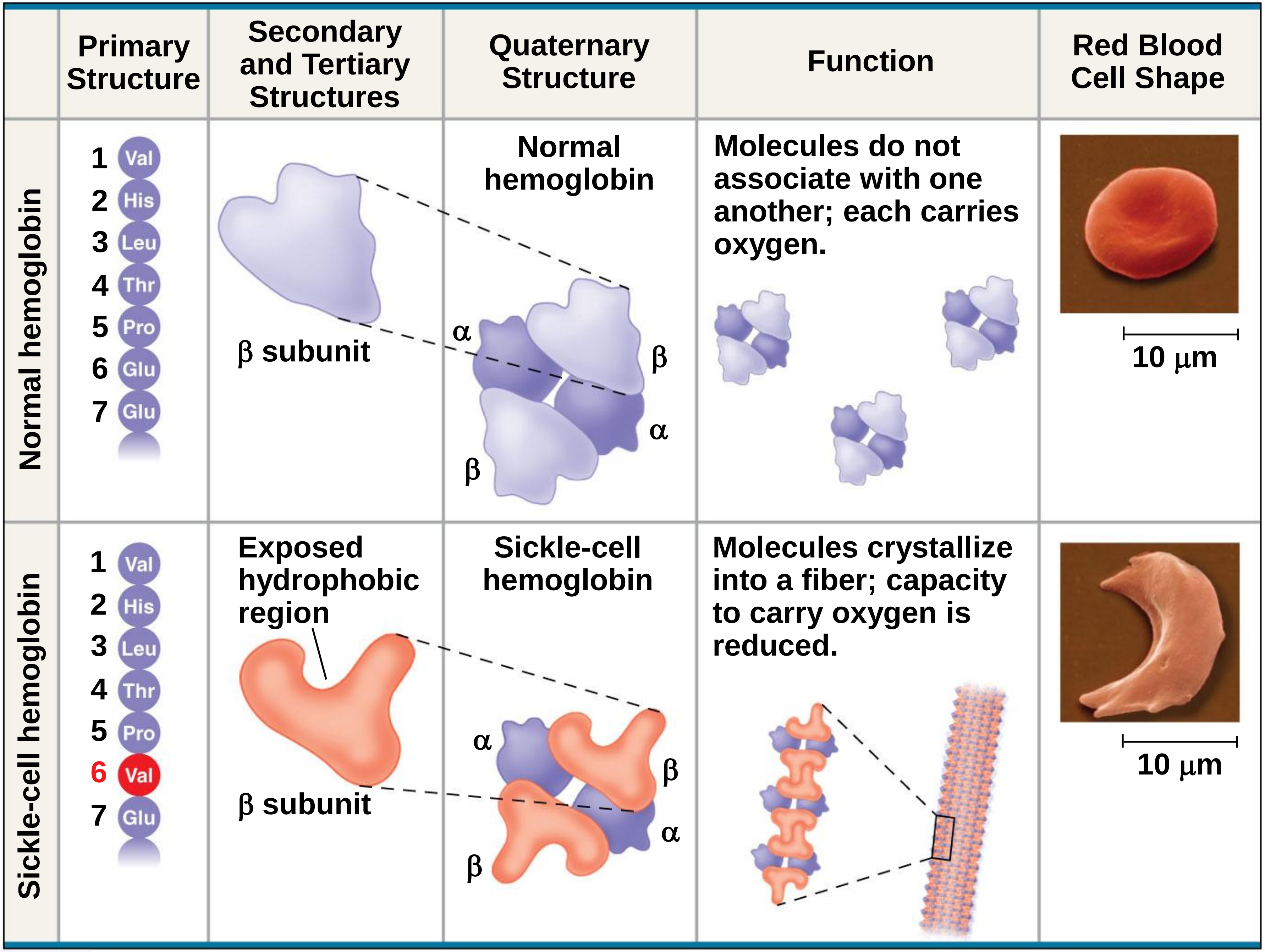
Figure 5.20j

- **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

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

Figure 5.21a

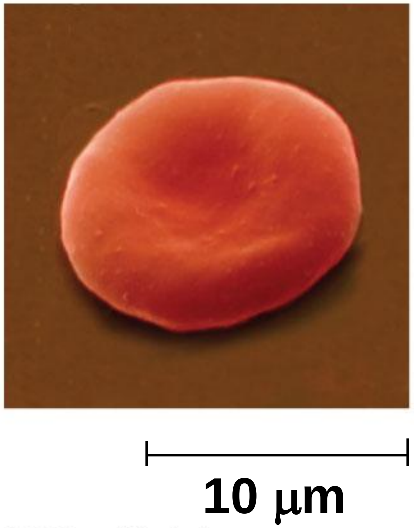
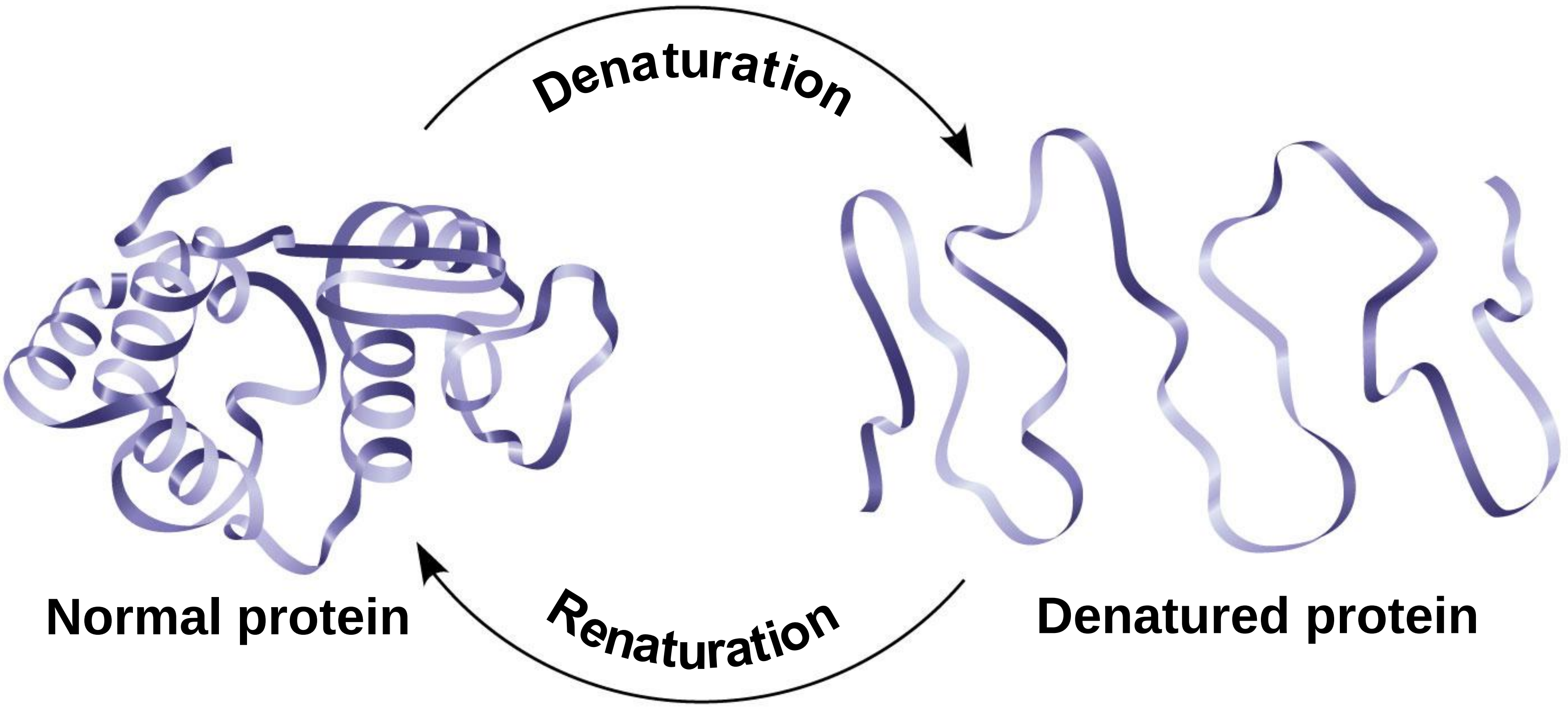


Figure 5.21b

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

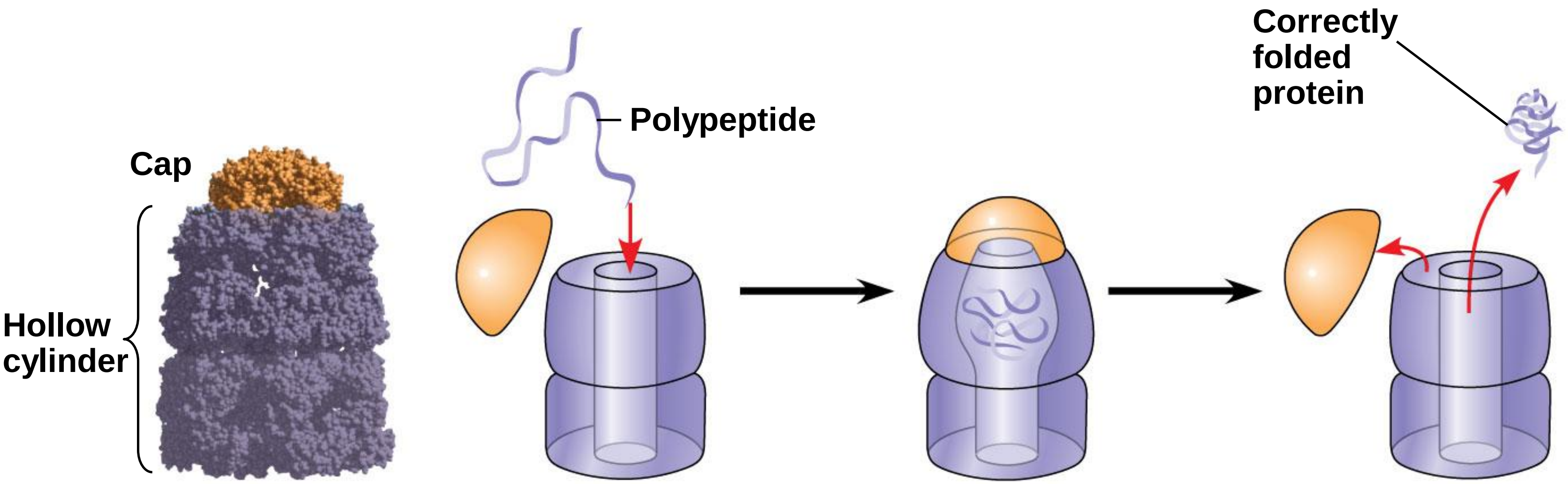
Figure 5.22


Denaturation
Renaturation
Normal protein
Denatured protein

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



Chaperonin (fully assembled)

Steps of Chaperonin Action:

1. An unfolded polypeptide enters the cylinder from one end.
2. The cap attaches, causing the cylinder to change shape in such a way that it creates a hydrophilic environment for the folding of the polypeptide.
3. The cap comes off, and the properly folded protein is released.

Figure 5.23a

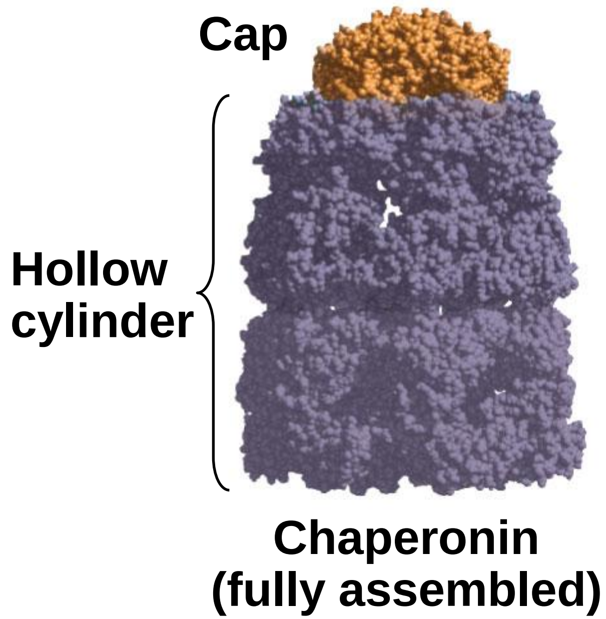
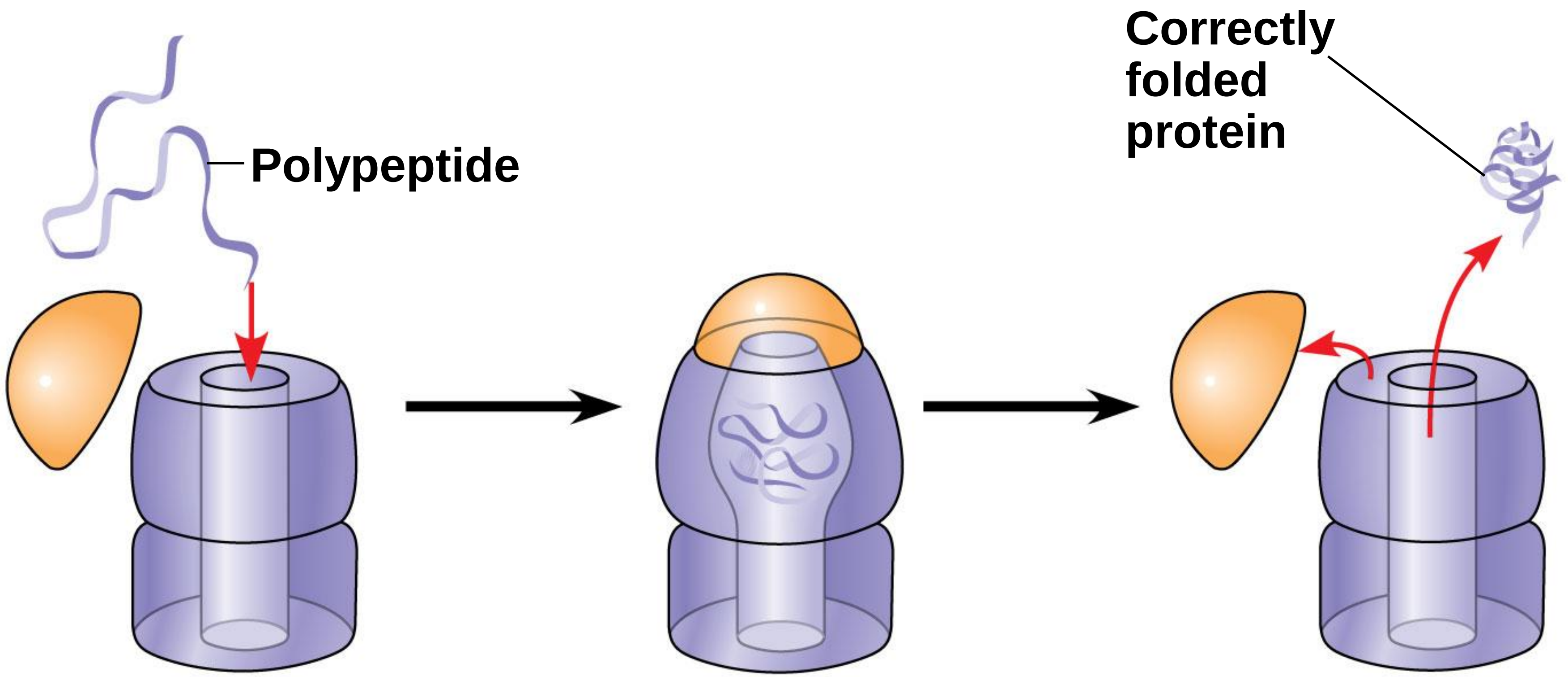


Figure 5.23b



Steps of Chaperonin Action:

1 An unfolded polypeptide enters the cylinder from one end.

2 The cap attaches, causing the cylinder to change shape in such a way that it creates a hydrophilic environment for the folding of the polypeptide.

3 The cap comes off, and the properly folded protein is released.

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

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 on ribosomes

Figure 5.25-1

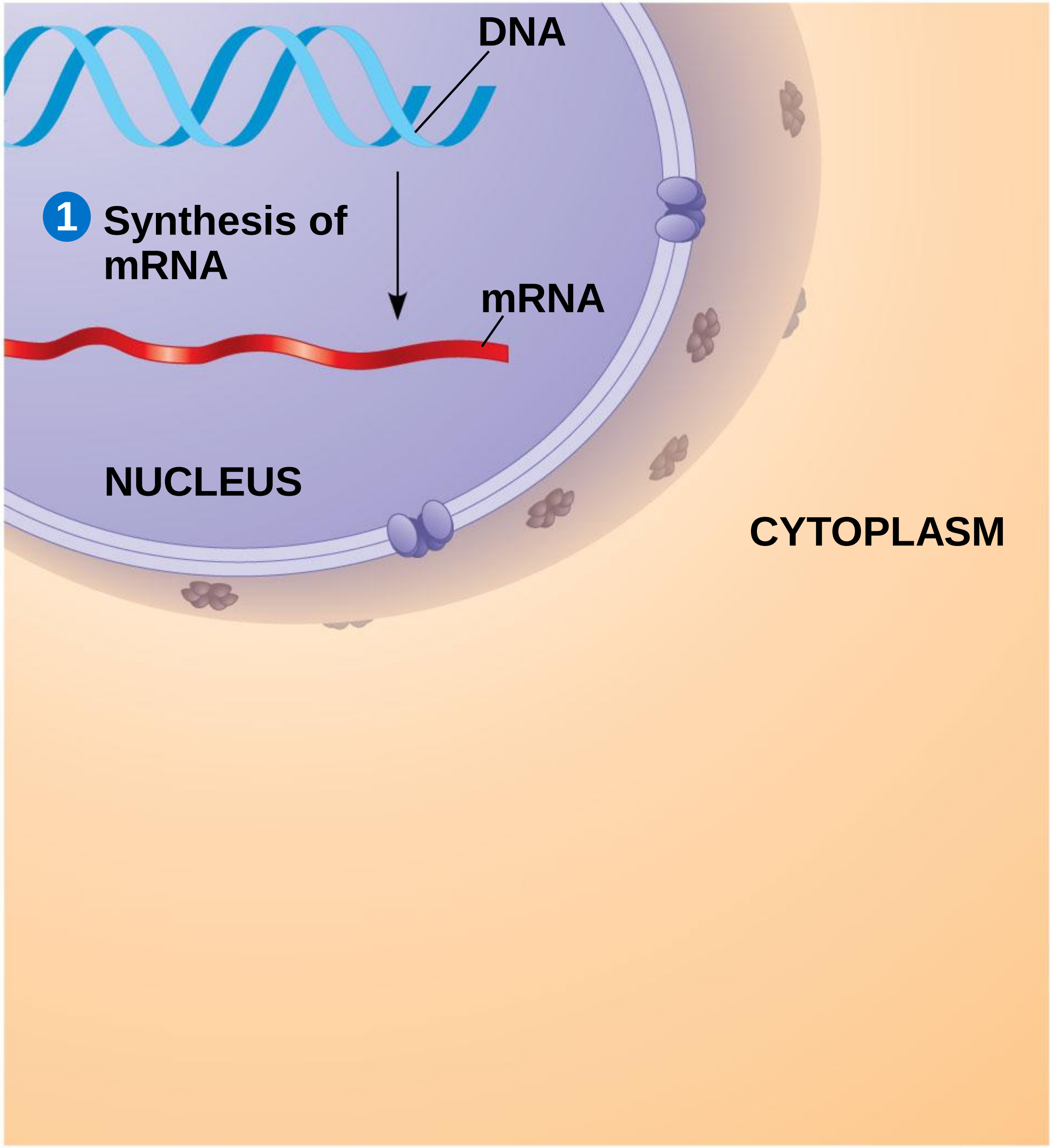


Figure 5.25-2

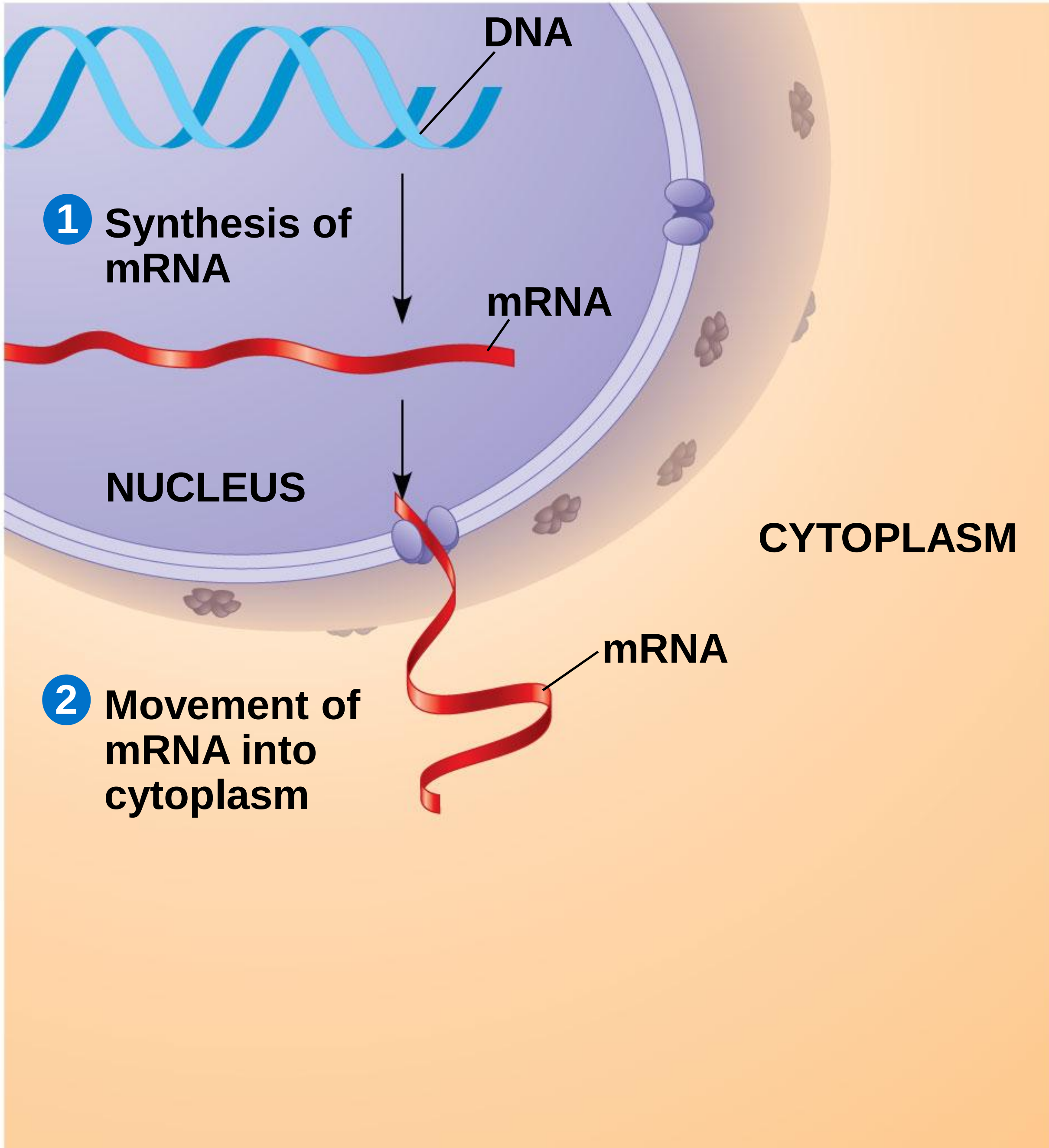
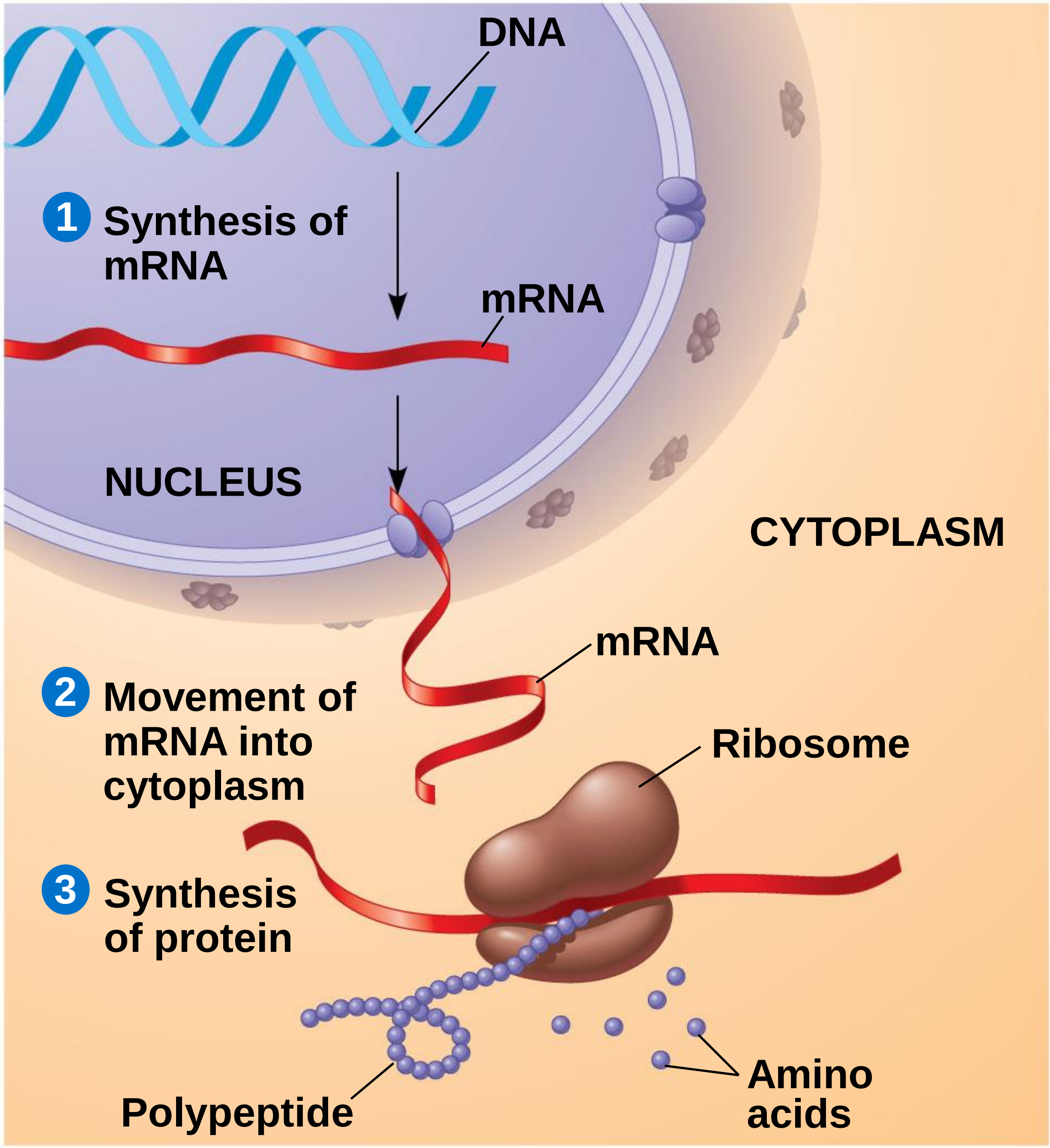

DNA
1 Synthesis of mRNA
mRNA
NUCLEUS
CYTOPLASM
mRNA
2 Movement of mRNA into cytoplasm

Figure 5.25-3


DNA
1 Synthesis of mRNA
mRNA
NUCLEUS
CYTOPLASM
mRNA
2 Movement of mRNA into cytoplasm
Ribosome
3 Synthesis of protein
Polypeptide
Amino acids

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

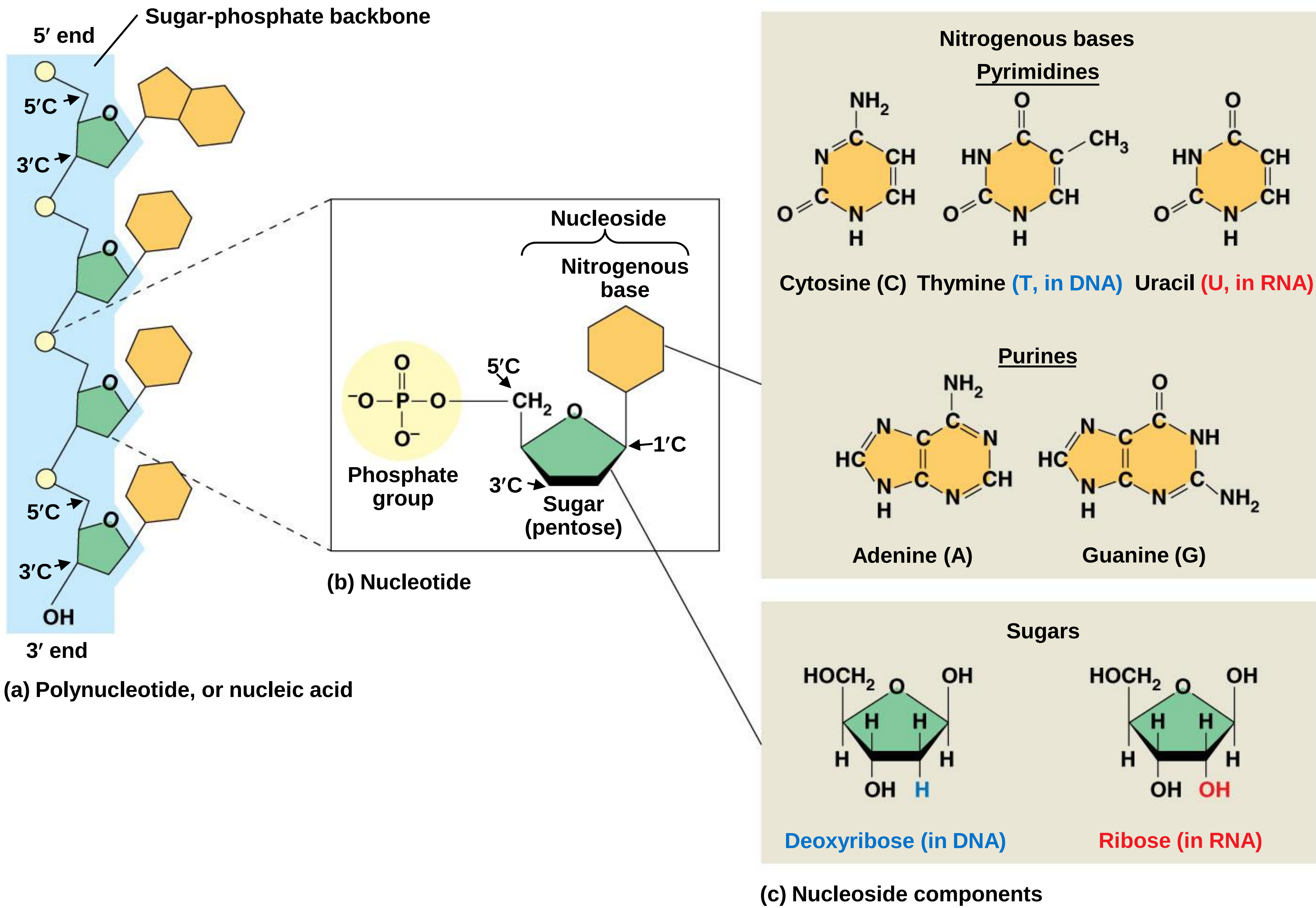
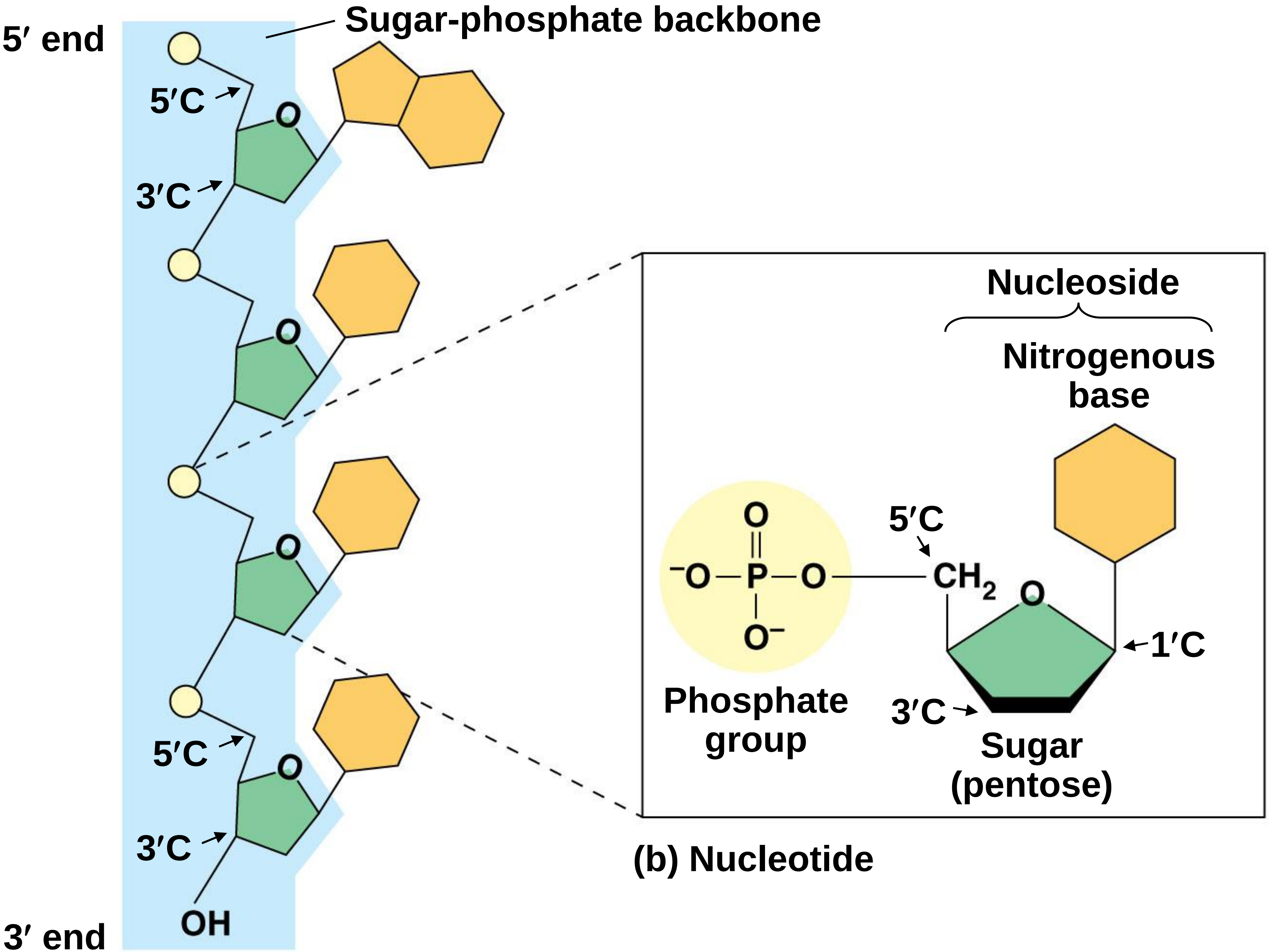

Sugar-phosphate backbone
5′ end
5′C
3′C
OH
3′ end
(a) Polynucleotide, or nucleic acid
Nucleoside
Nitrogenous base
Phosphate group
5′C
3′C
1′C
Sugar (pentose)
(b) Nucleotide
Nitrogenous bases
Pyrimidines
Cytosine (C)
Thymine (T, in DNA)
Uracil (U, in RNA)
Purines
Adenine (A)
Guanine (G)
Sugars
Deoxyribose (in DNA)
Ribose (in RNA)
(c) Nucleoside components

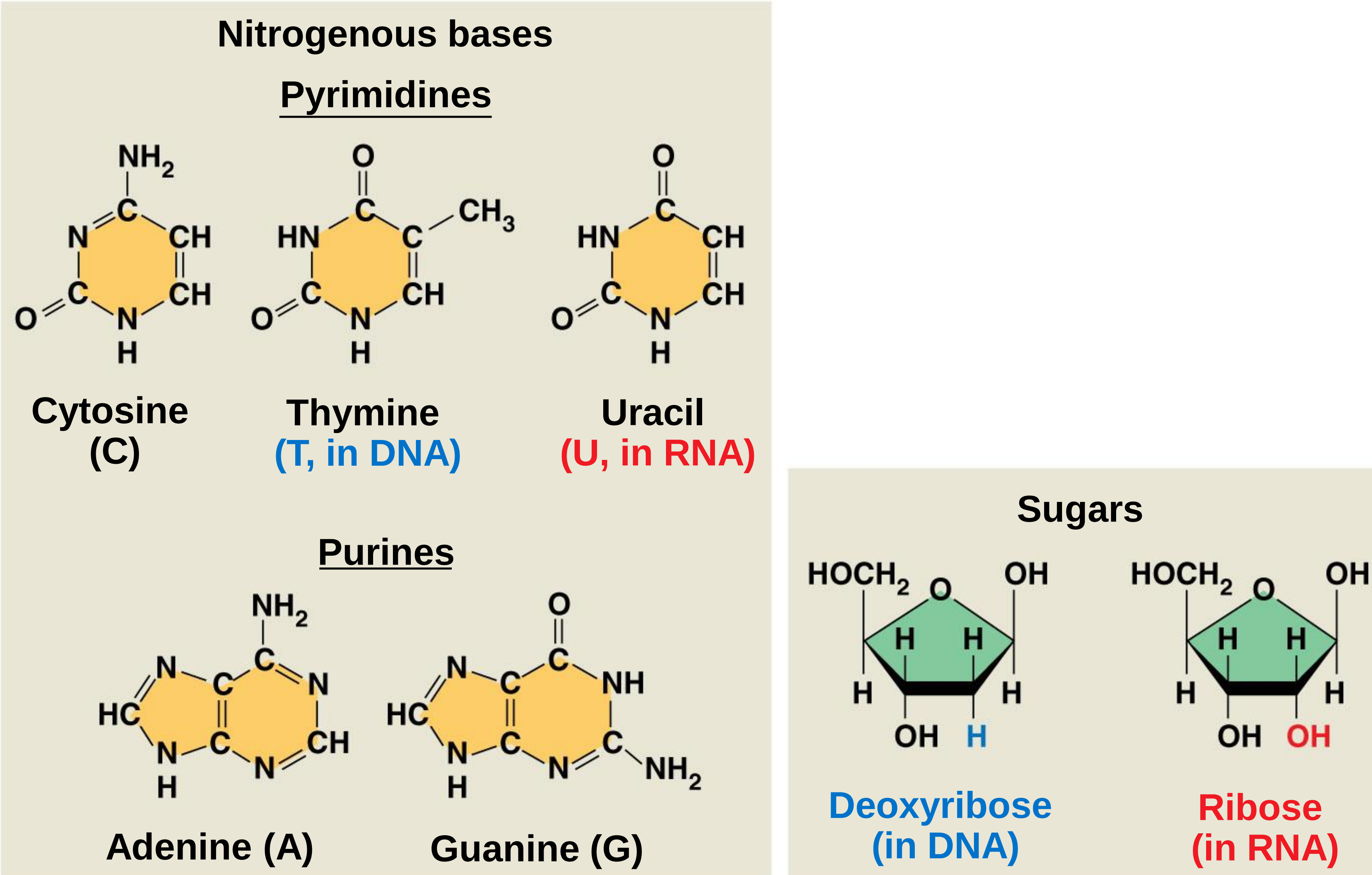
Figure 5.26ab



(a) Polynucleotide, or nucleic acid

(b) Nucleotide

Figure 5.26c



(c) Nucleoside components

- 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

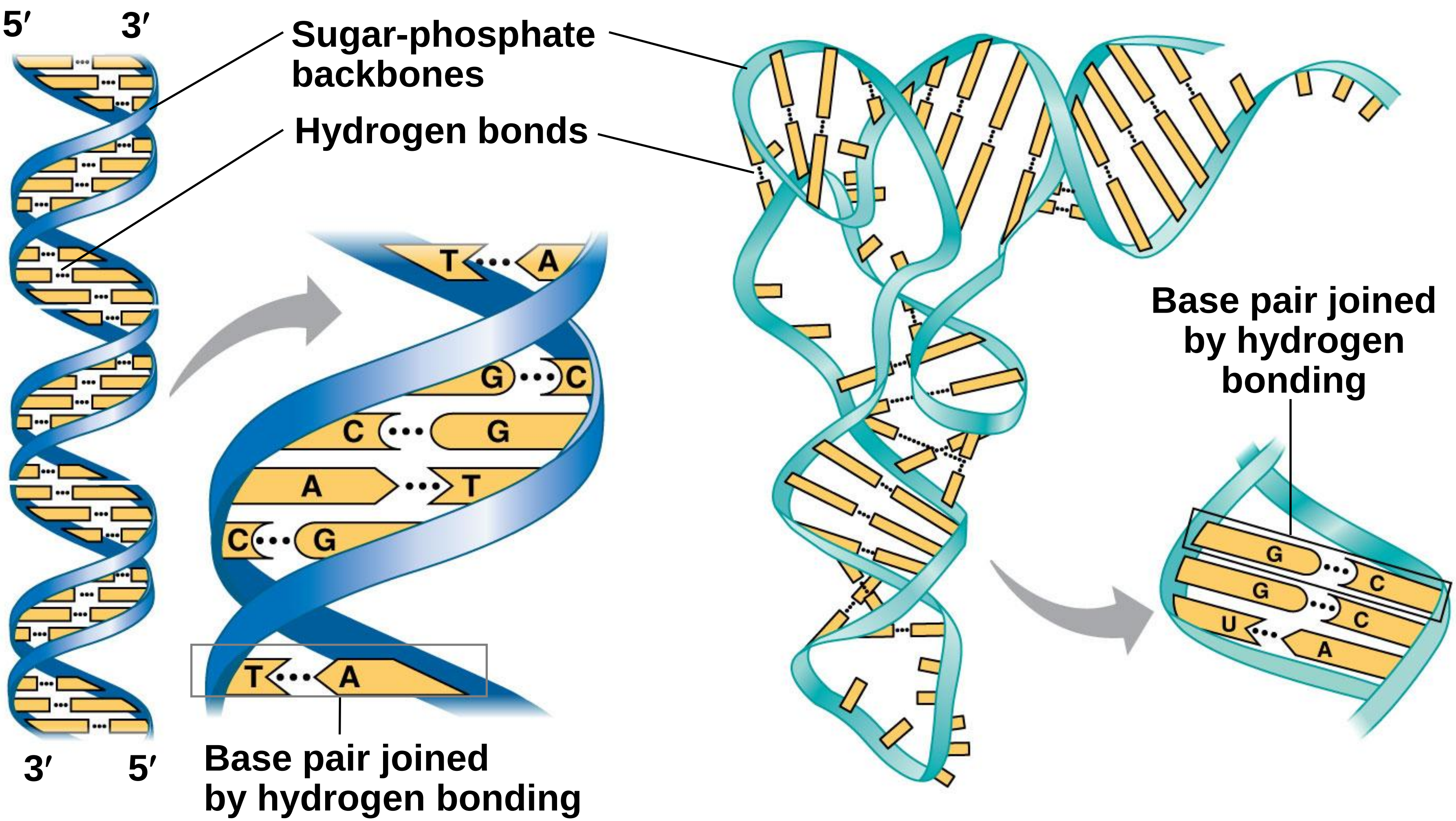
- Nucleotide polymers are linked together to build a polynucleotide
- Adjacent nucleotides are joined by covalent bonds that form between the —OH group on the 3′ carbon of one nucleotide and the phosphate on the 5′ carbon on the next
- These links create a backbone of sugar-phosphate units with nitrogenous 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 $5' \rightarrow 3'$ directions from each other, an arrangement referred to as **antiparallel**
- One DNA molecule includes many genes

- The nitrogenous bases in DNA pair up and form hydrogen bonds: adenine (A) always with thymine (T), and guanine (G) always with cytosine (C)
- Called complementary base pairing
- Complementary pairing can also occur between two RNA molecules or between parts of the same molecule
- In RNA, thymine is replaced by uracil (U) so A and U pair

Figure 5.27



(a) DNA

(b) Transfer RNA

The Theme of Emergent Properties in the Chemistry of Life: *A Review*

- Higher levels of organization result in the emergence of new properties
- Organization is the key to the chemistry of life

Figure 5.UN02

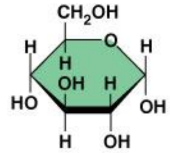
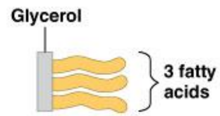
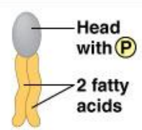
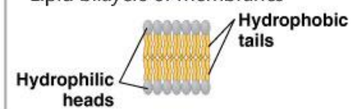
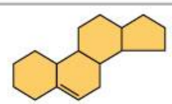
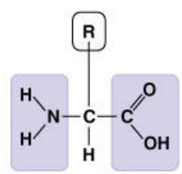
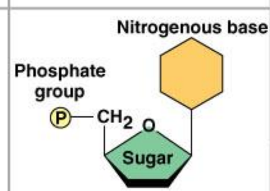
Large Biological Molecules	Components	Examples	Functions
CONCEPT 5.2 Carbohydrates serve as fuel and building material	 Monosaccharide monomer	**Monosaccharides:** glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Disaccharides: lactose, sucrose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

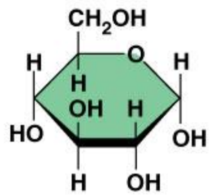
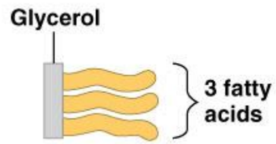
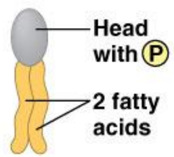
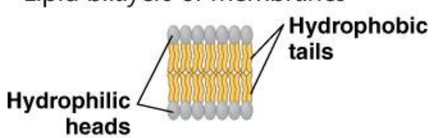
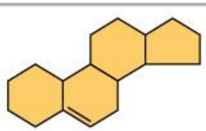
Large Biological Molecules	Components	Examples	Functions
CONCEPT 5.2 Carbohydrates serve as fuel and building material	 Monosaccharide monomer	**Monosaccharides:** glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Disaccharides: lactose, sucrose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

Figure 5.UN02b

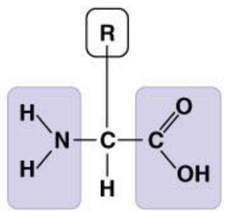
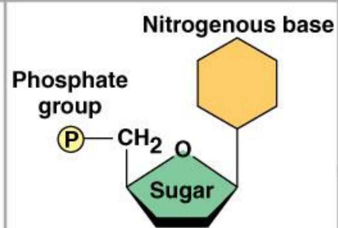
Large Biological Molecules	Components	Examples	Functions
CONCEPT 5.4 Proteins include a diversity of structures, resulting in a wide range of functions	 **Amino acid monomer (20 types)**	• Enzymes • Structural proteins • Storage proteins • Transport proteins • Hormones • Receptor proteins • Motor proteins • 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. UN03

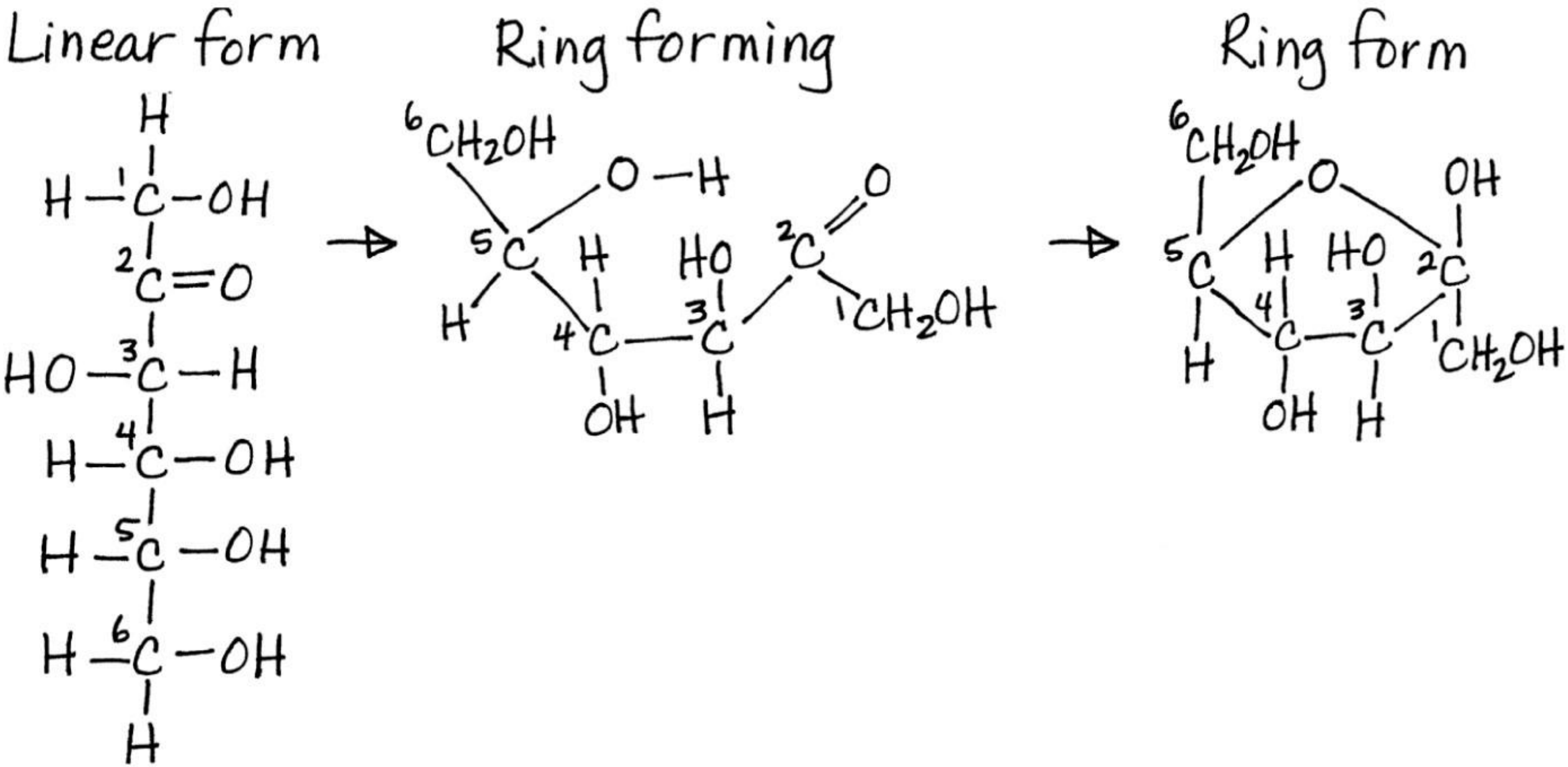


Figure 5. UN04

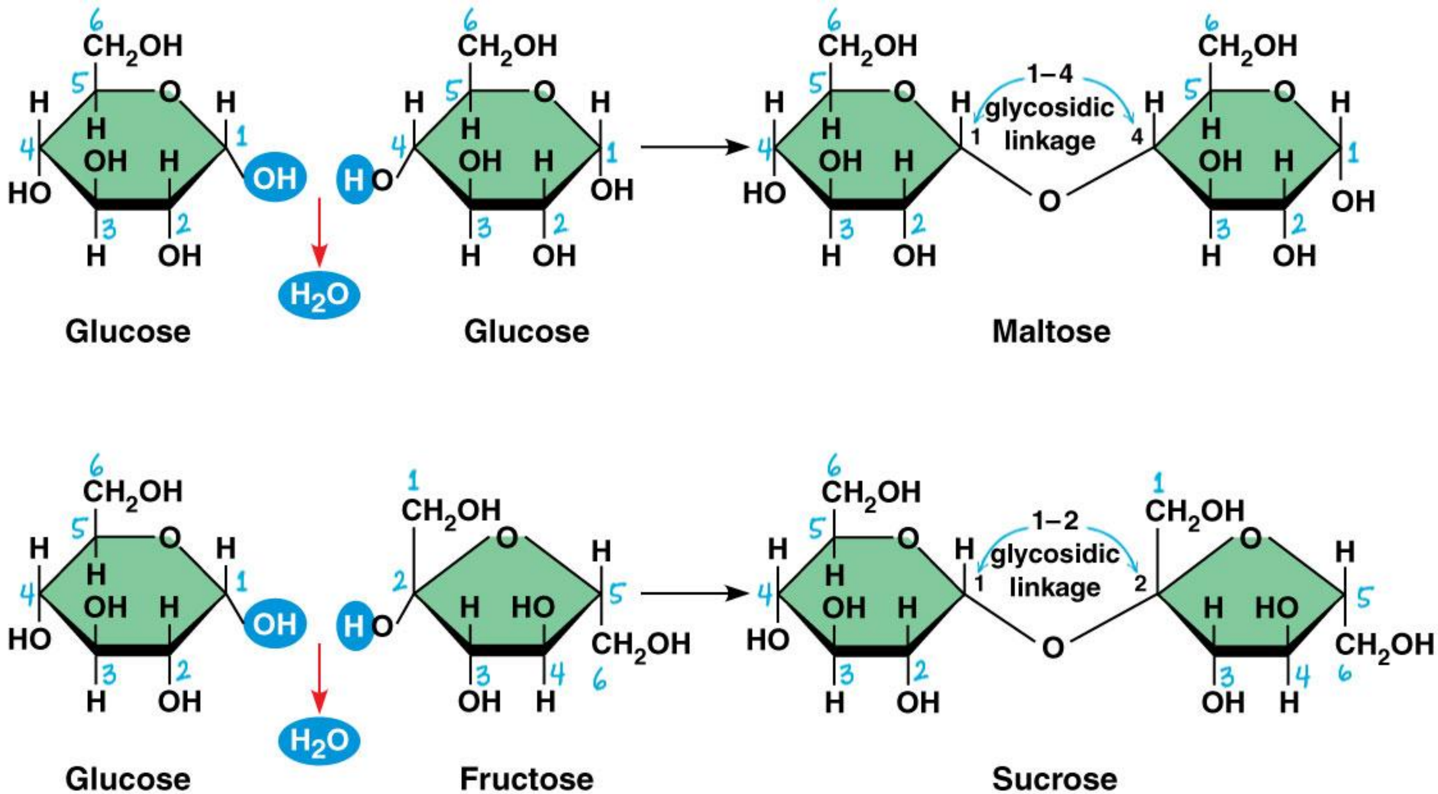


Figure 5. UN05

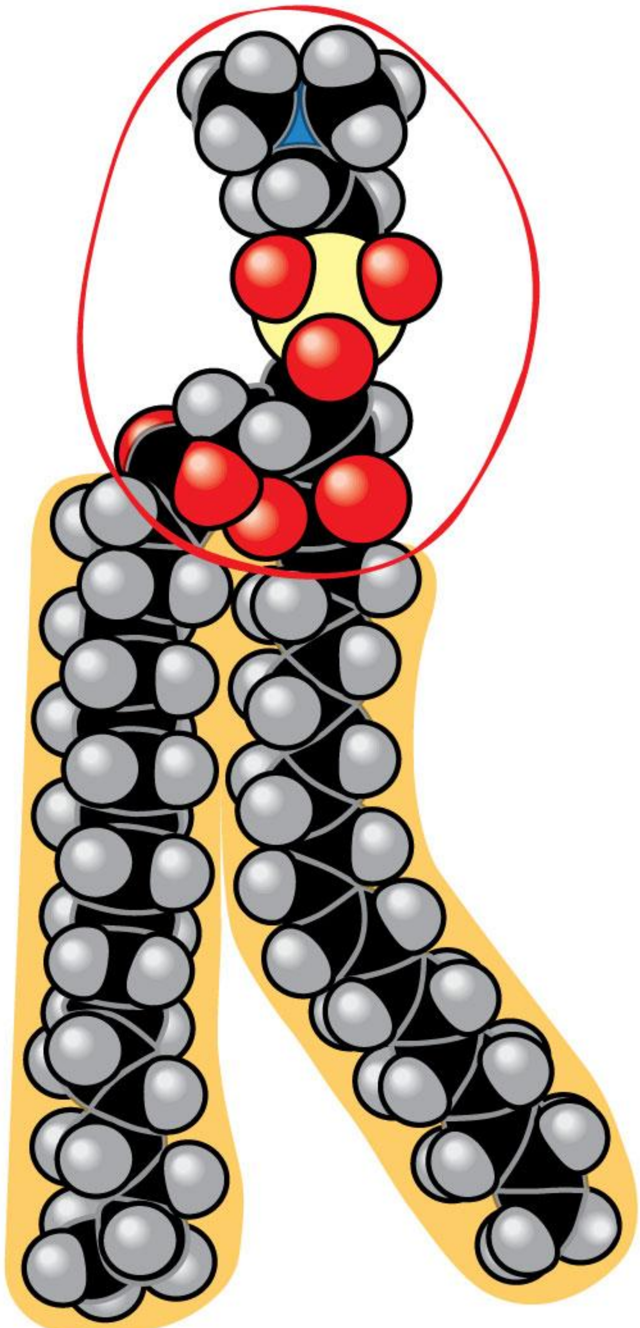


Figure 5. UN06

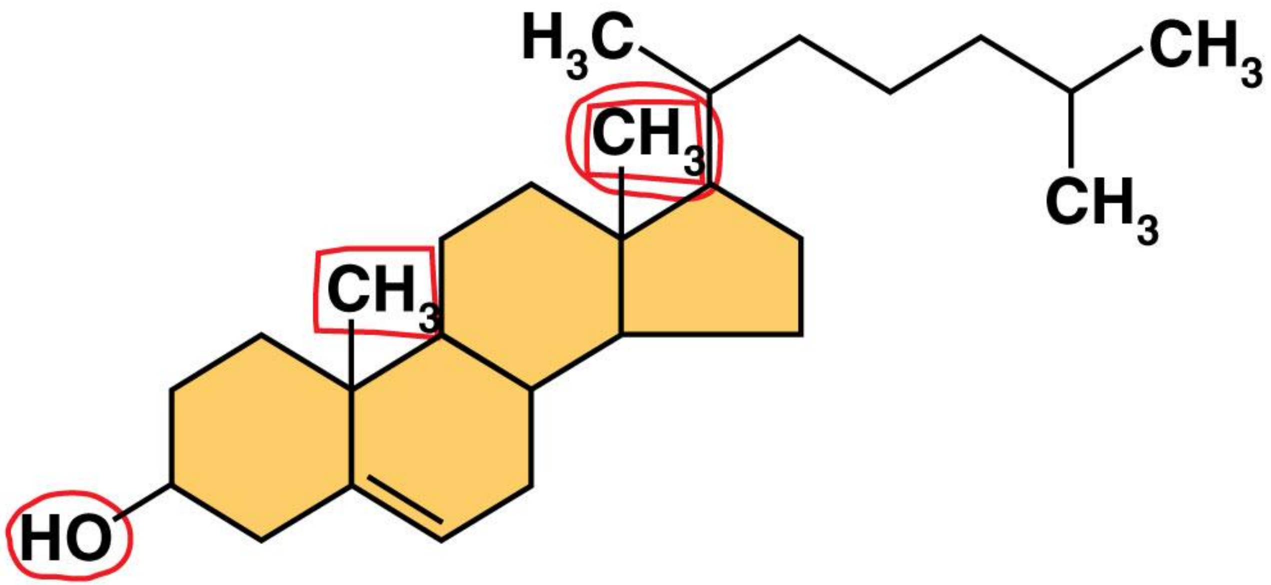


Figure 5. UN07

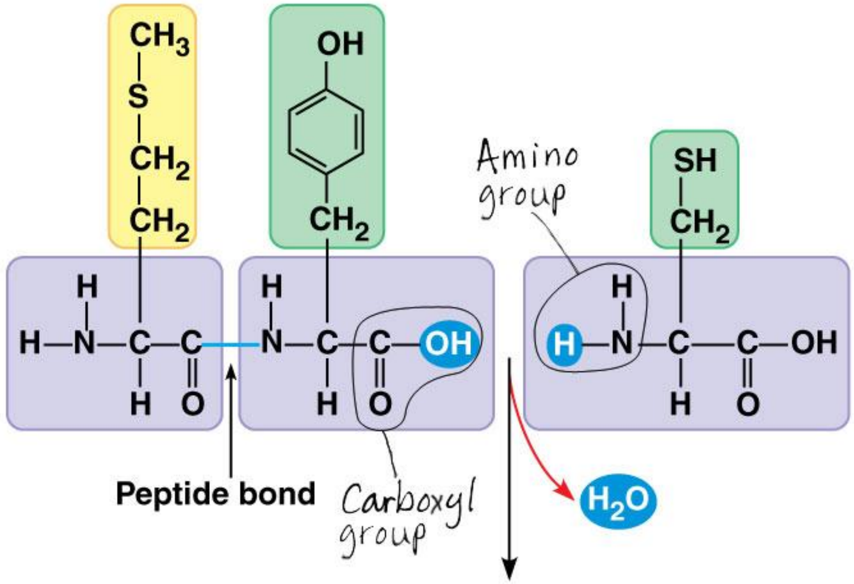


Figure 5. UN08

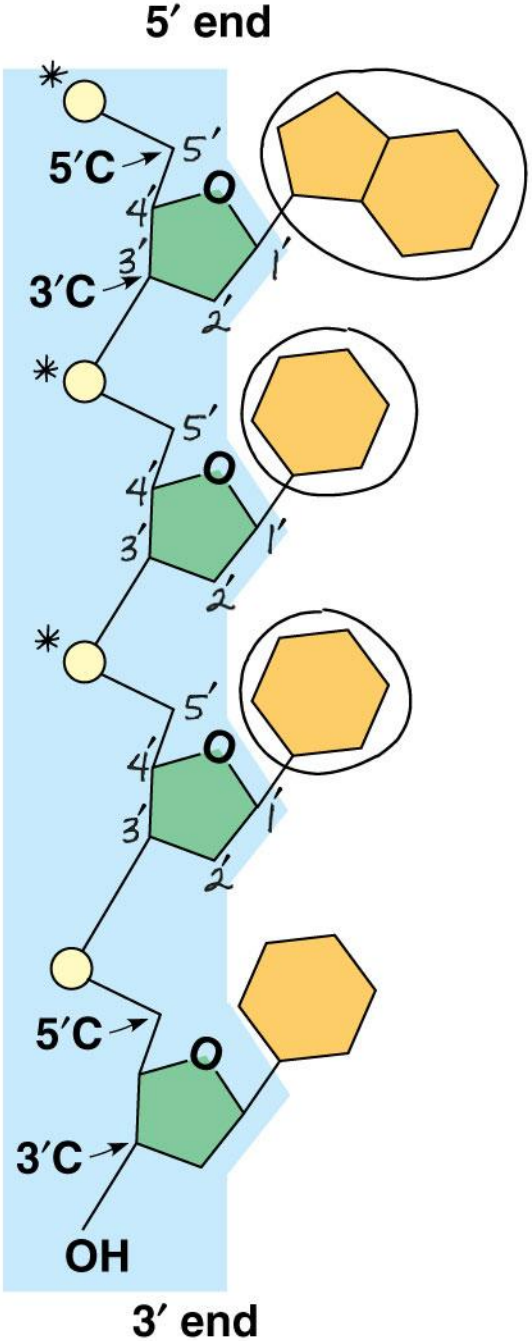


Figure 5. UN09

5′-T A G G C C T-3′

3′-A T C C G G A-5′

Figure 5. UN10

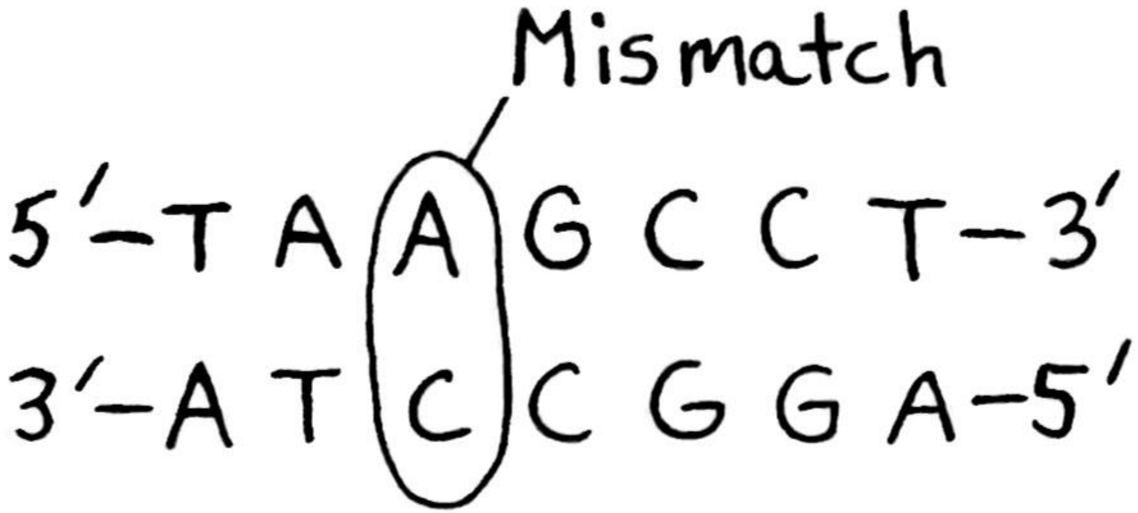


Figure 5. UN11

3′-A T T C G G A-5′

Figure 5. UN12

	Monomers or Components	Polymer or larger molecule	Type of linkage
Carbohydrates	Monosaccharides	Polysaccharides	Glycosidic linkages
Lipids	Fatty acids	Triacylglycerols	Ester linkages
Proteins	Amino acids	Polypeptides	Peptide bonds
Nucleic acids	Nucleotides	Polynucleotides	Phosphodiester linkages

Figure 5. UN13