Chapter 5

The Structure and Function of Large Biological Molecules

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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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

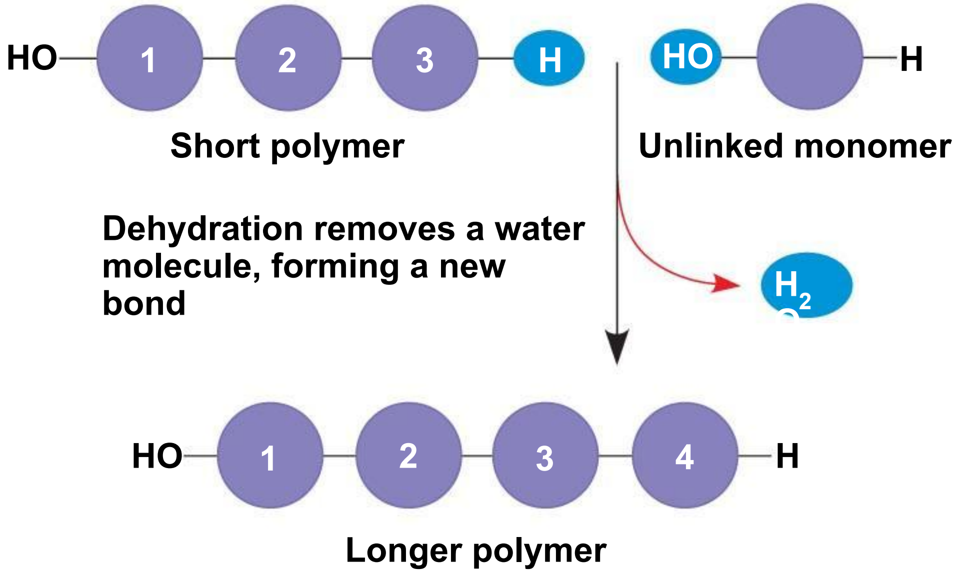
- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**
- Three of the four classes of life's organic molecules are polymers:
  - Carbohydrates
  - Proteins
  - Nucleic acids

The Synthesis and Breakdown of Polymers

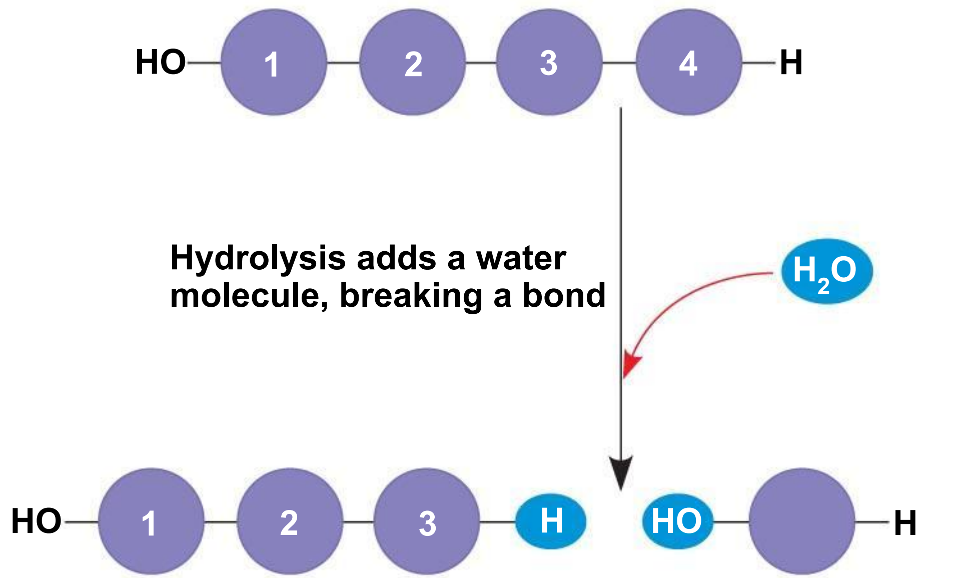
- A **condensation reaction** or more specifically a **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule
- **Enzymes** are macromolecules that speed up the dehydration process
- Polymers are disassembled to monomers by **hydrolysis**, a reaction that is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

PLAY Animation: Polymers

Fig. 5-2

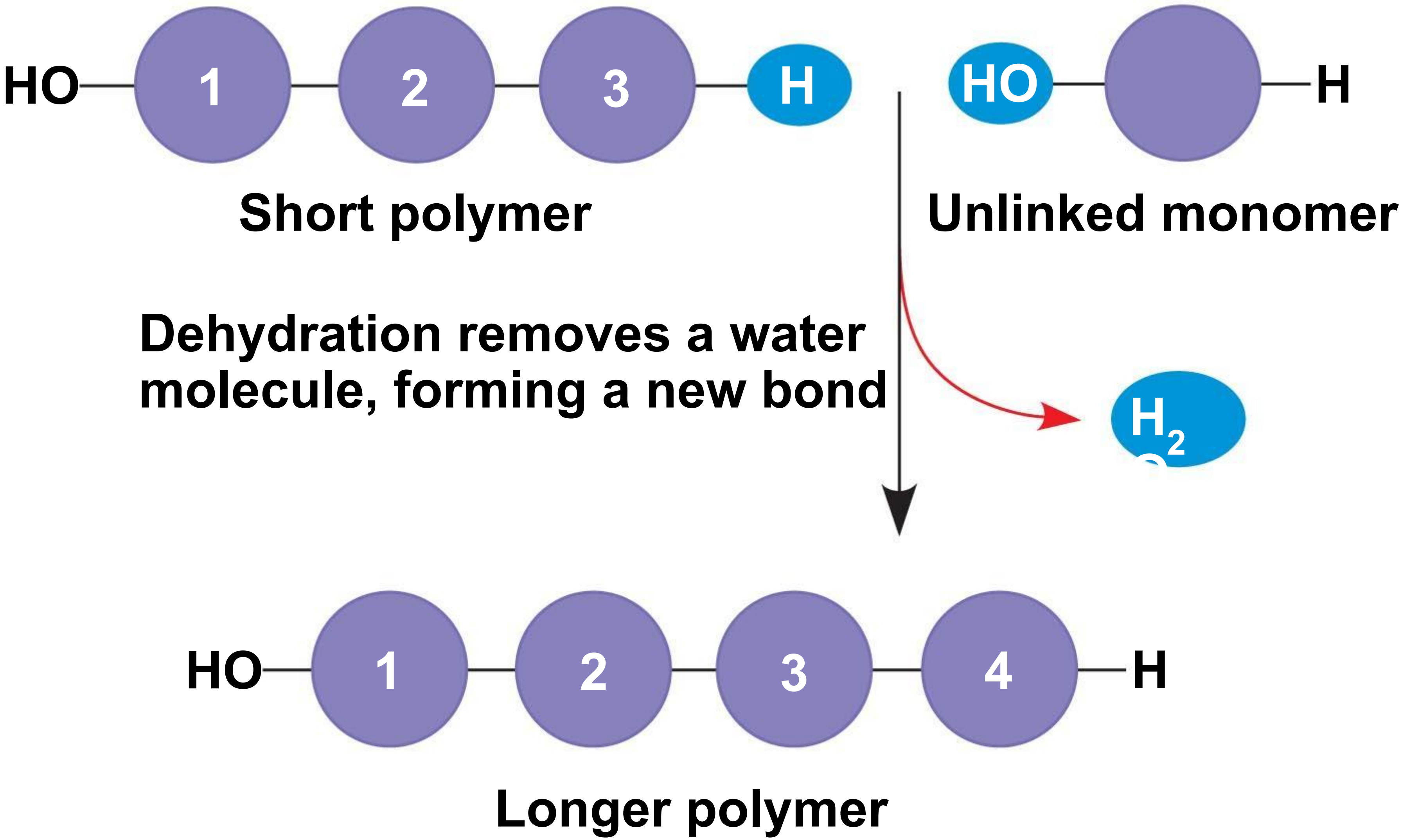


(a) Dehydration reaction in the synthesis of a polymer



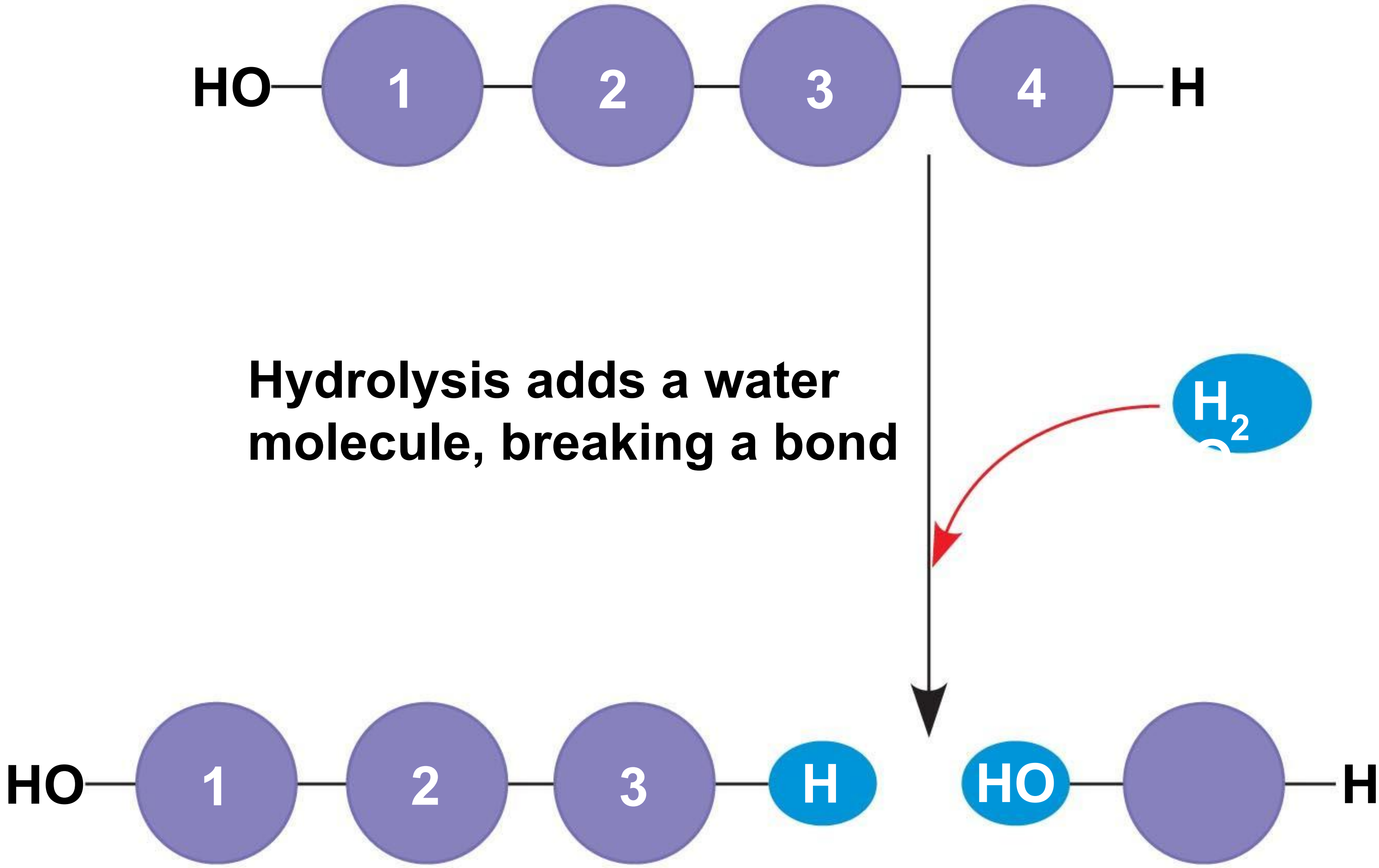
(b) Hydrolysis of a polymer

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
- An immense variety of polymers can be built from a small set of monomers

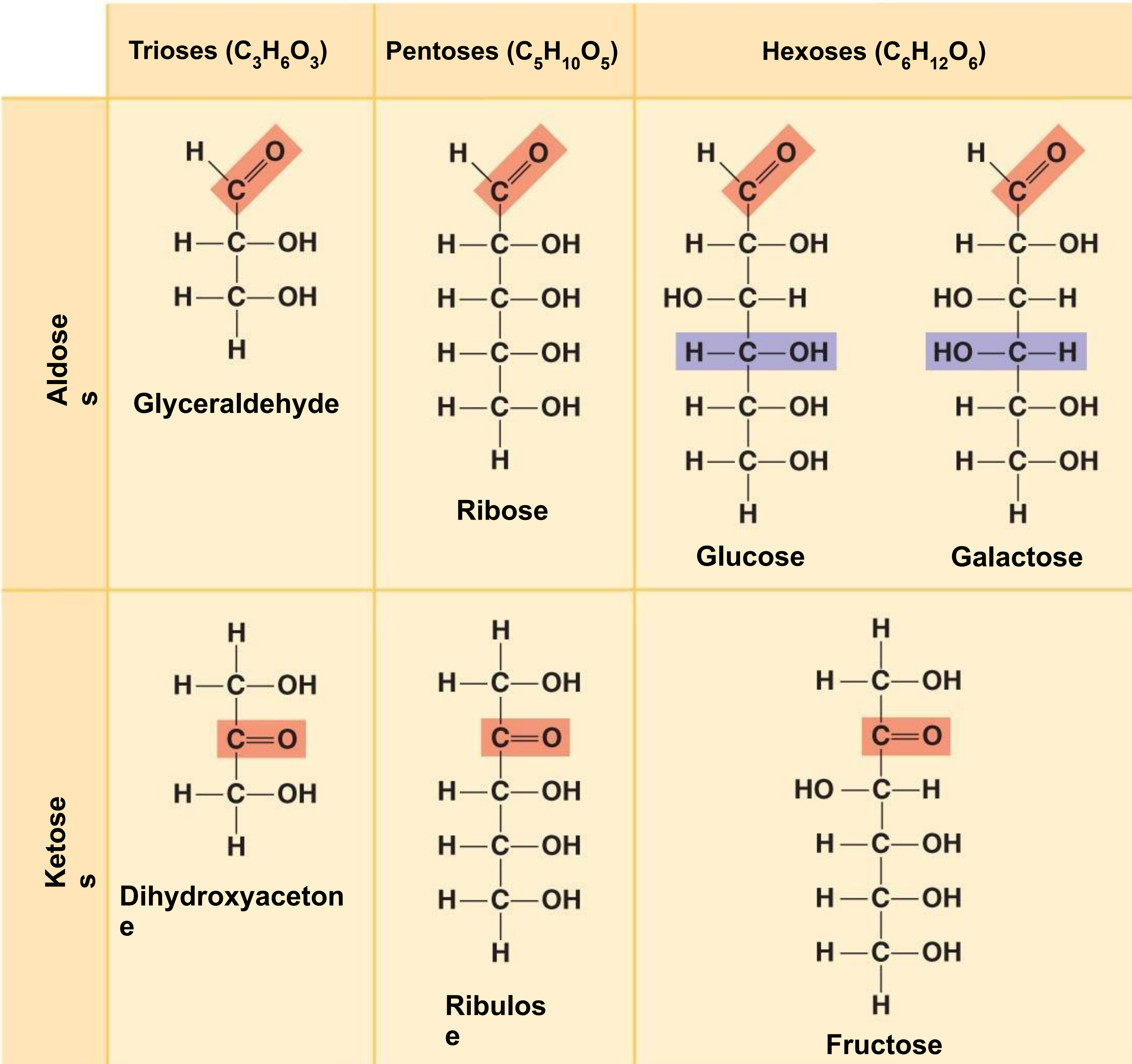
Concept 5.2: Carbohydrates serve as fuel and building material

- **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

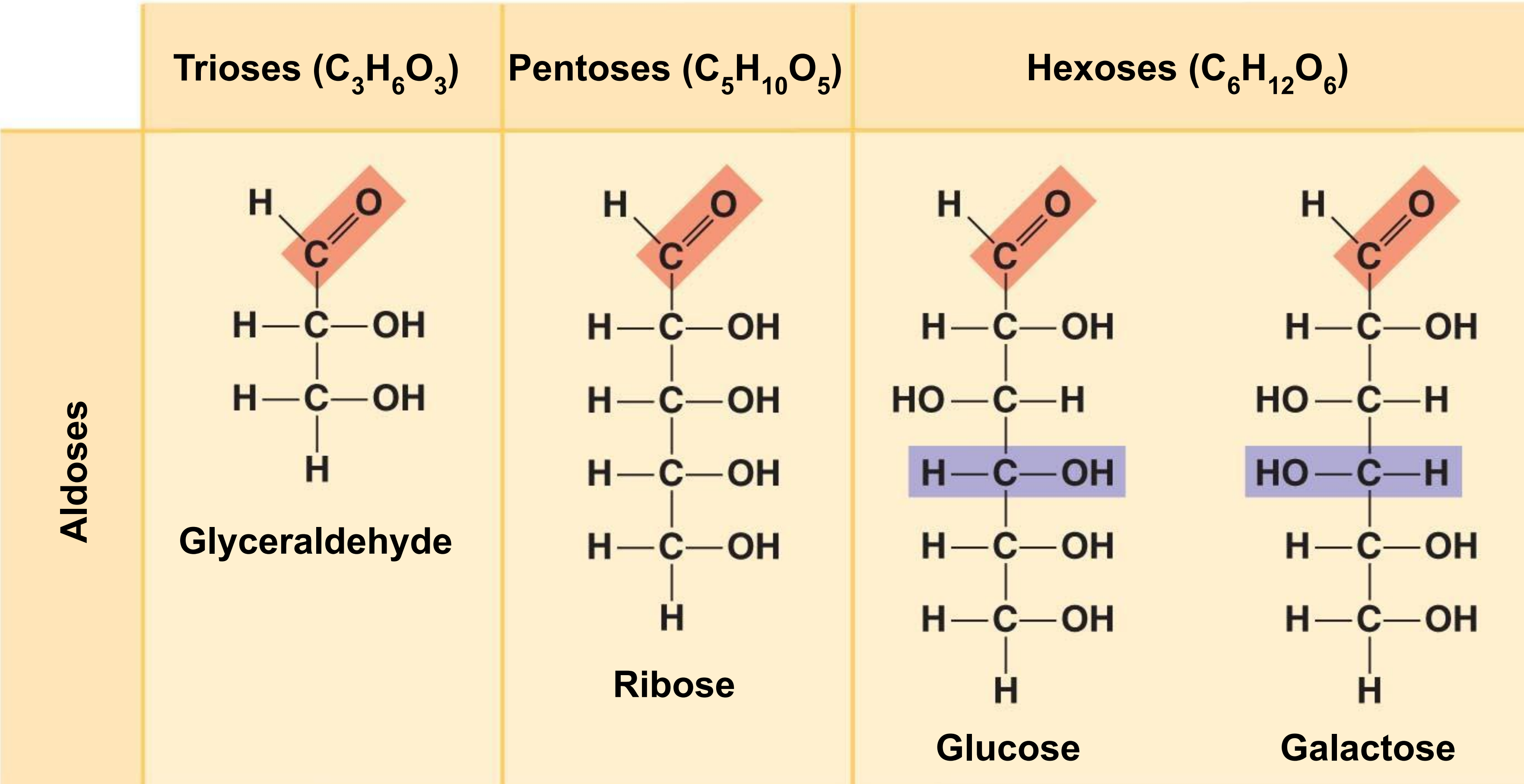
- **Monosaccharides** have molecular formulas that are usually multiples of CH_2O
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Monosaccharides are classified by
  - The location of the carbonyl group (as aldose or ketose)
  - The number of carbons in the carbon skeleton

Fig. 5-3



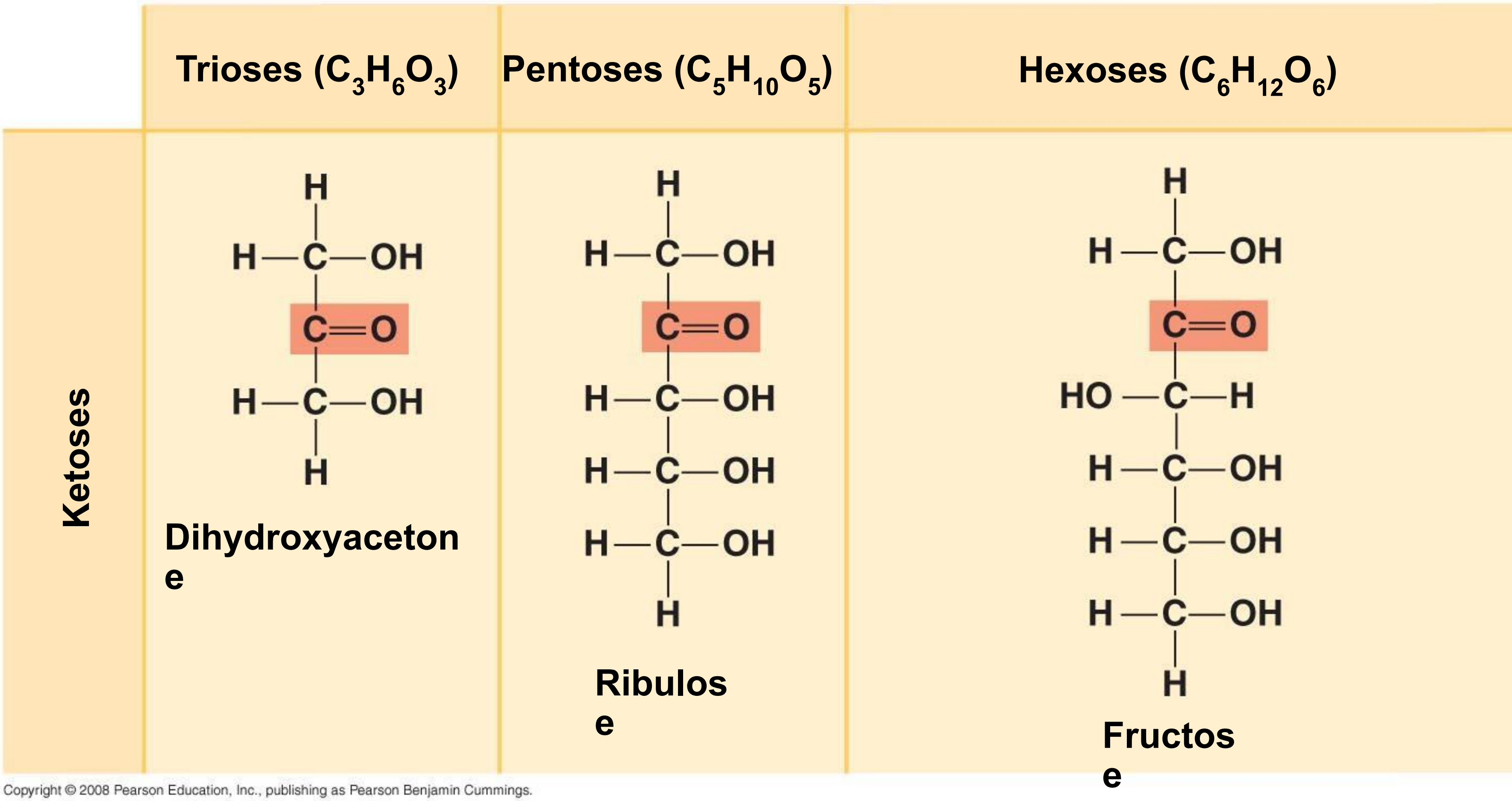
Trioses ($C_3H_6O_3$)
Pentoses ($C_5H_{10}O_5$)
Hexoses ($C_6H_{12}O_6$)
Aldose
s
Glyceraldehyde
Ribose
Glucose
Galactose
Ketose
s
Dihydroxyaceton
e
Ribulos
e
Fructose

Fig. 5-3a



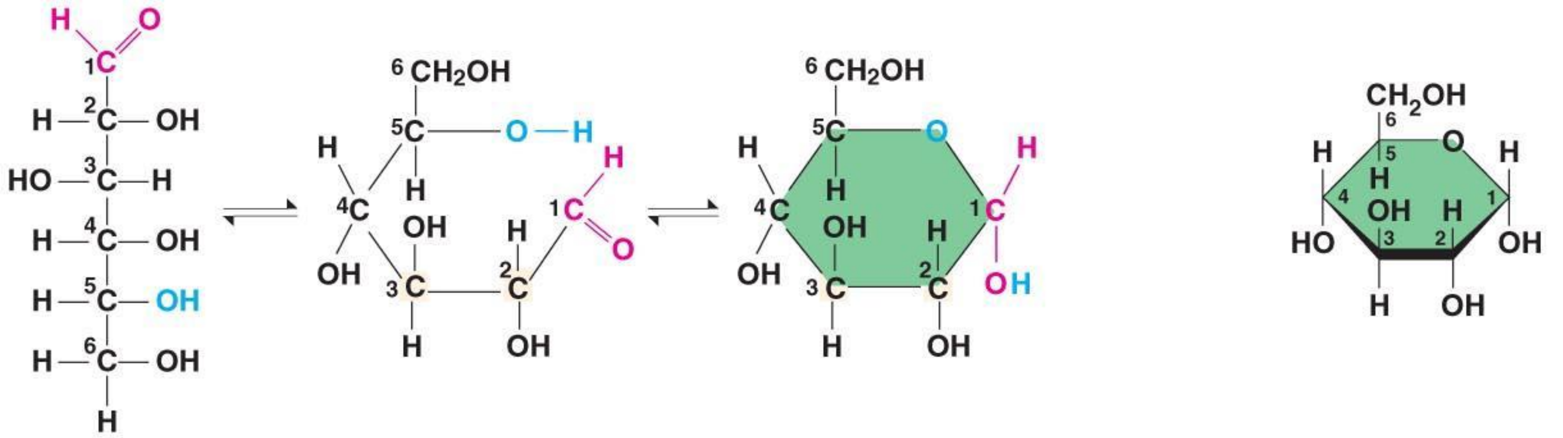
Trioses ($C_3H_6O_3$)
Pentoses ($C_5H_{10}O_5$)
Hexoses ($C_6H_{12}O_6$)
Aldoses
Glyceraldehyde
Ribose
Glucose
Galactose

Fig. 5-3b


Trioses ($C_3H_6O_3$)
Pentoses ($C_5H_{10}O_5$)
Hexoses ($C_6H_{12}O_6$)
Ketoses
Dihydroxyaceton
e
Ribulos
e
Fructos
e

- 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

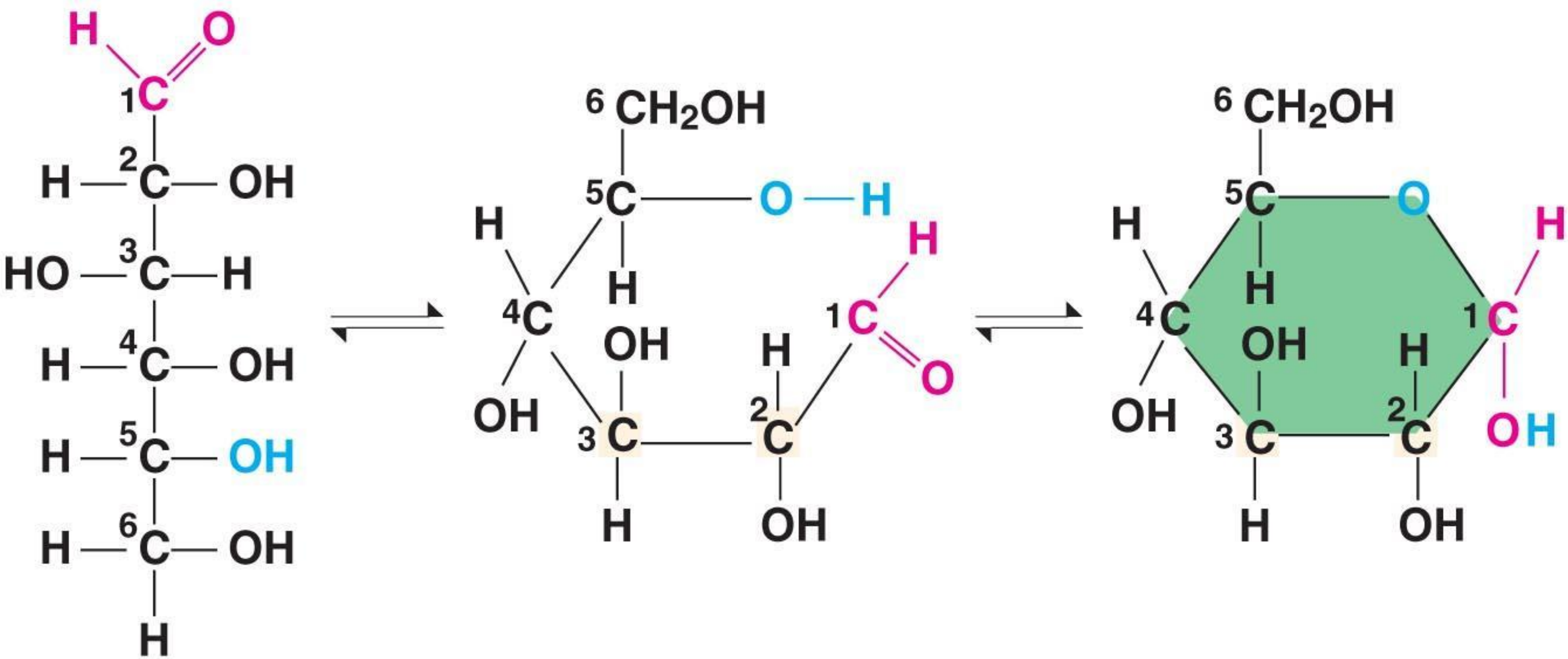
Fig. 5-4



(a) Linear and ring forms

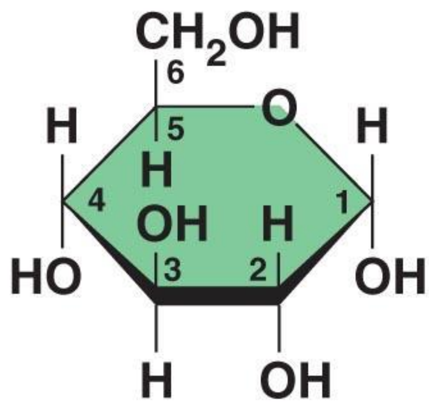
(b) Abbreviated ring structure

Fig. 5-4a



(a) Linear and ring forms

Fig. 5-4b

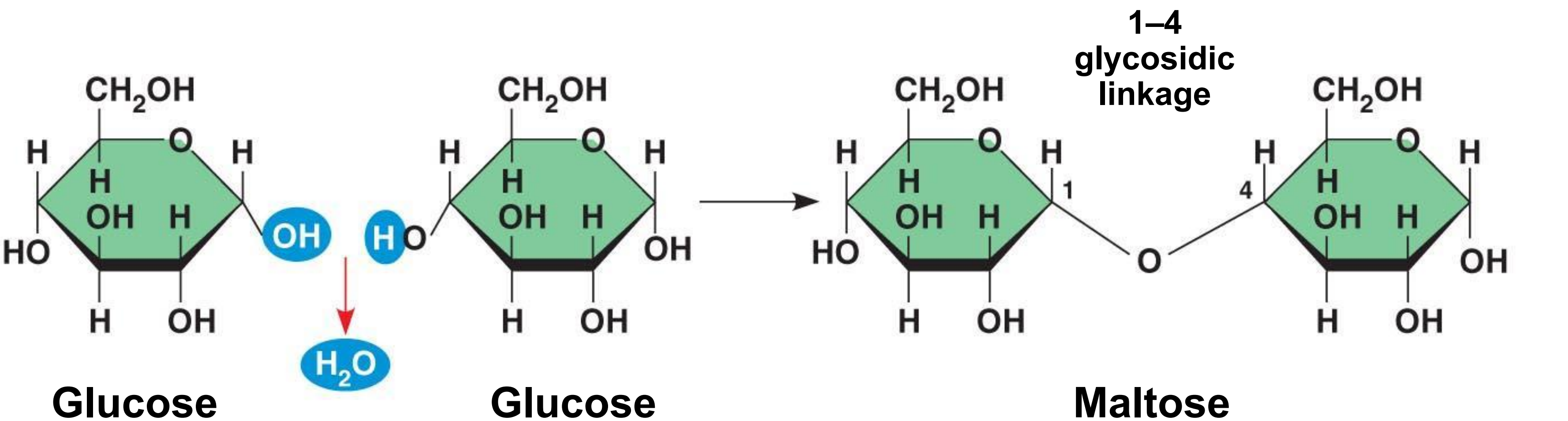


(b) Abbreviated ring structure

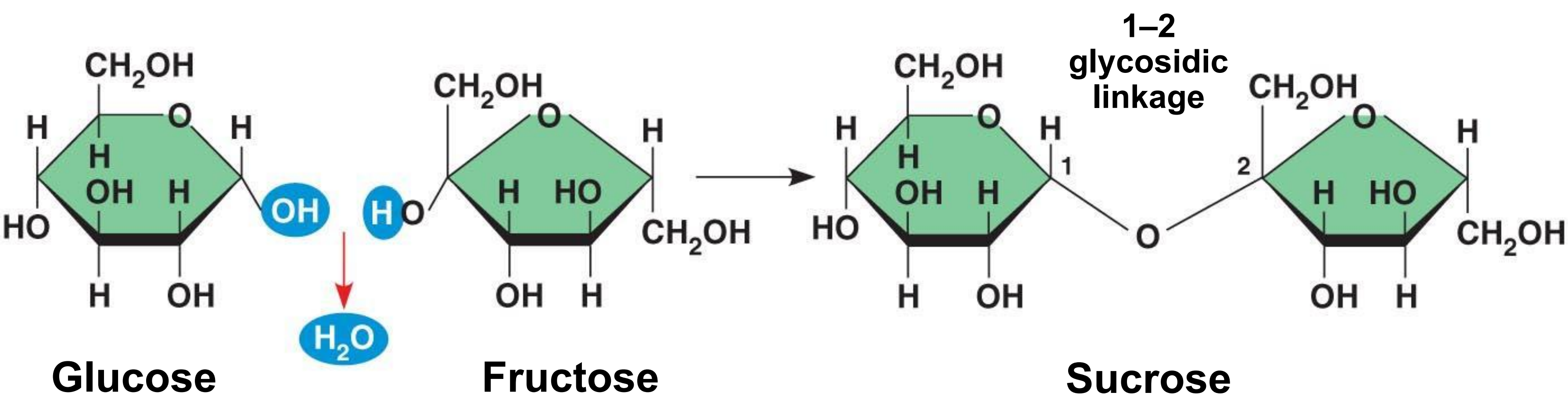
- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**

PLAY Animation: Disaccharides

Fig. 5-5



(a) Dehydration reaction in the synthesis of maltose



(b) Dehydration reaction in the synthesis of sucrose

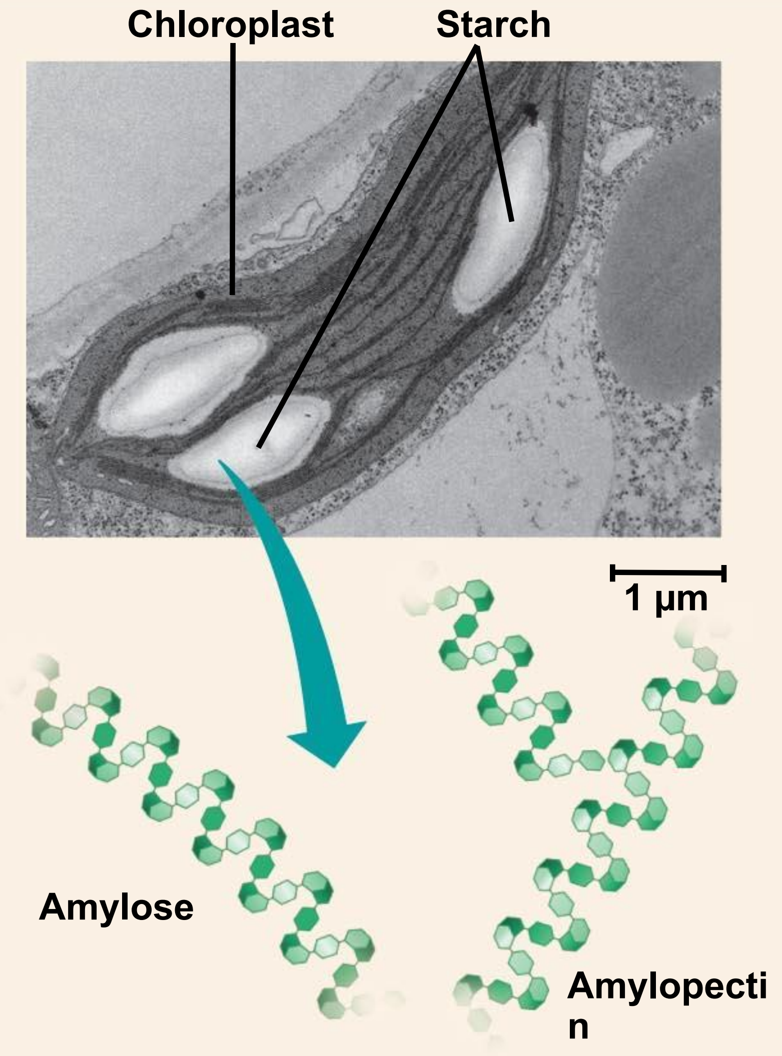
Polysaccharides

- **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

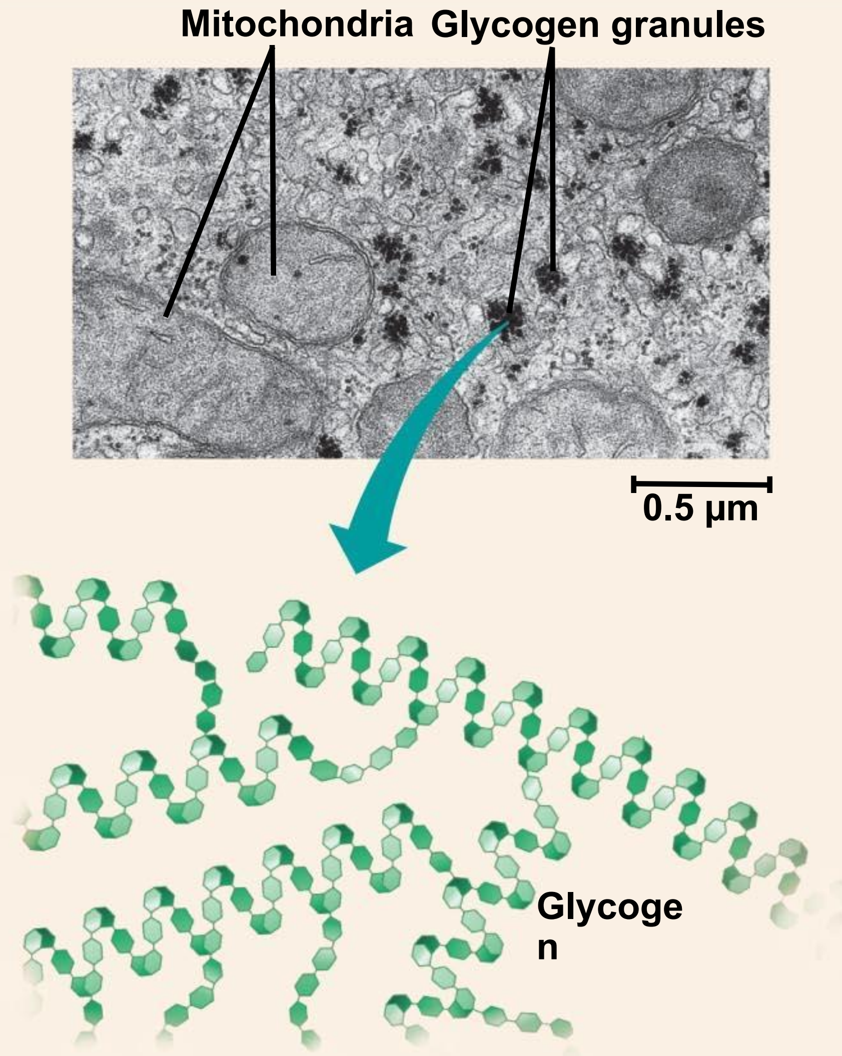
Storage Polysaccharides

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

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

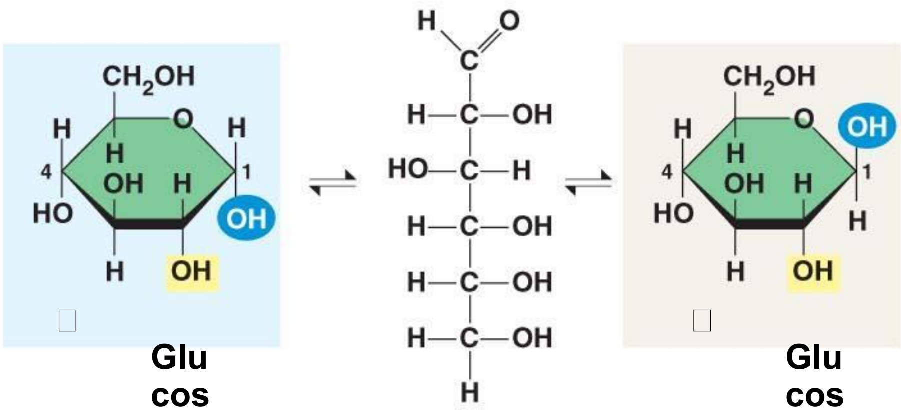
Structural Polysaccharides

- 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

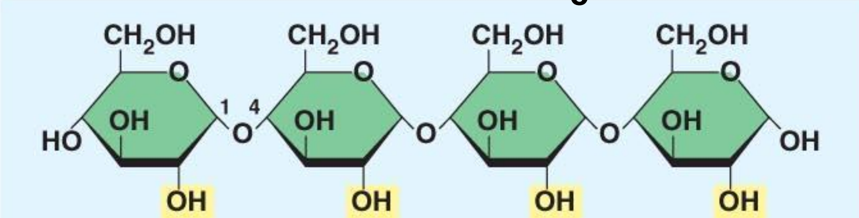
Fig. 5-7

(a) □ and □ glucose ring structures

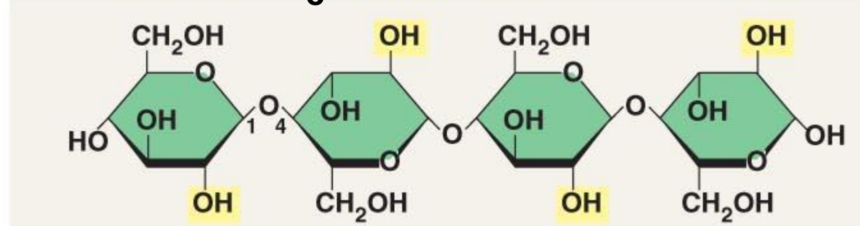


□ Glucose

□ Glucose

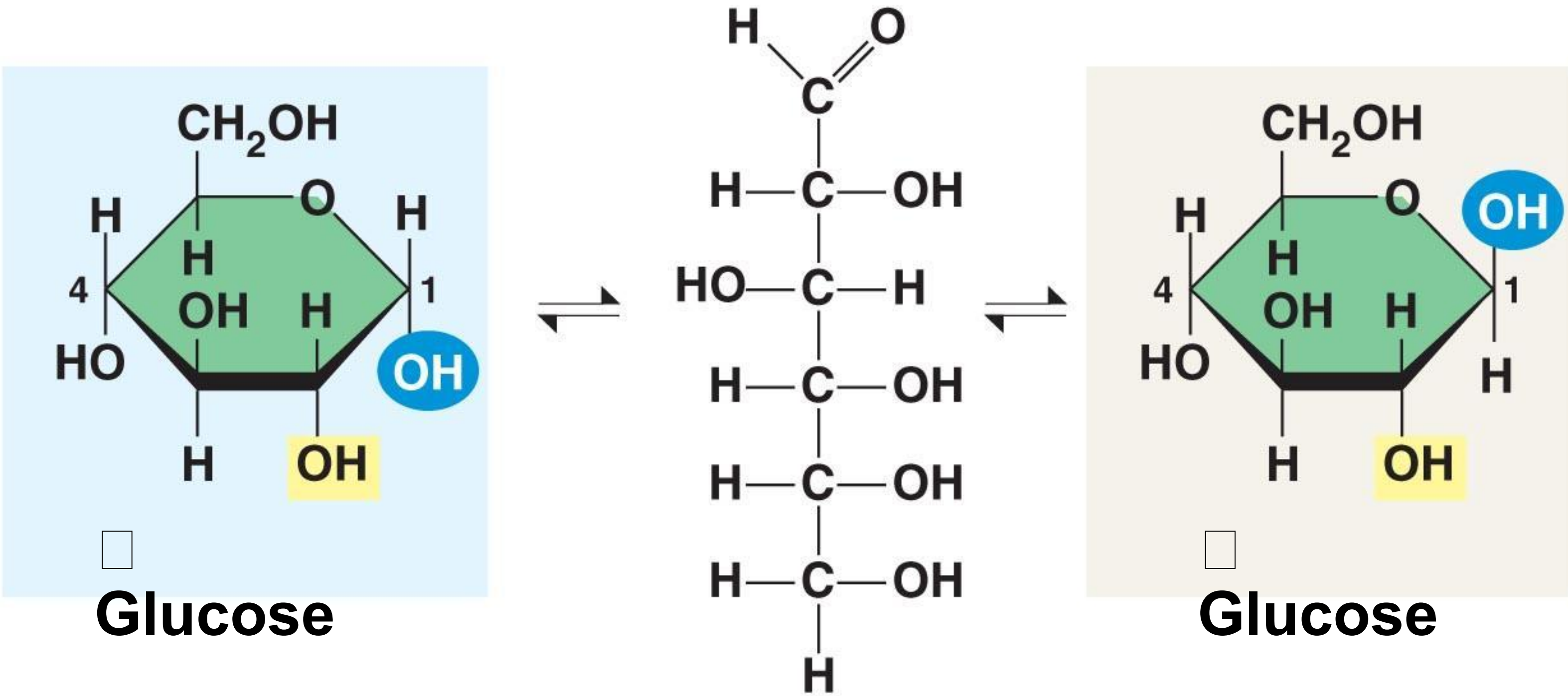


(b) Starch: 1–4 linkage of □ glucose monomers



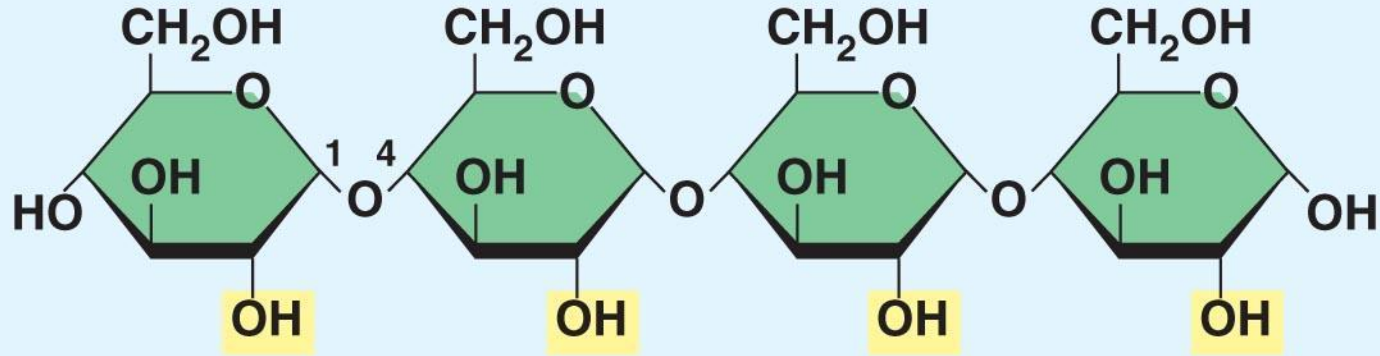
(b) Cellulose: 1–4 linkage of □ glucose monomers

Fig. 5-7a

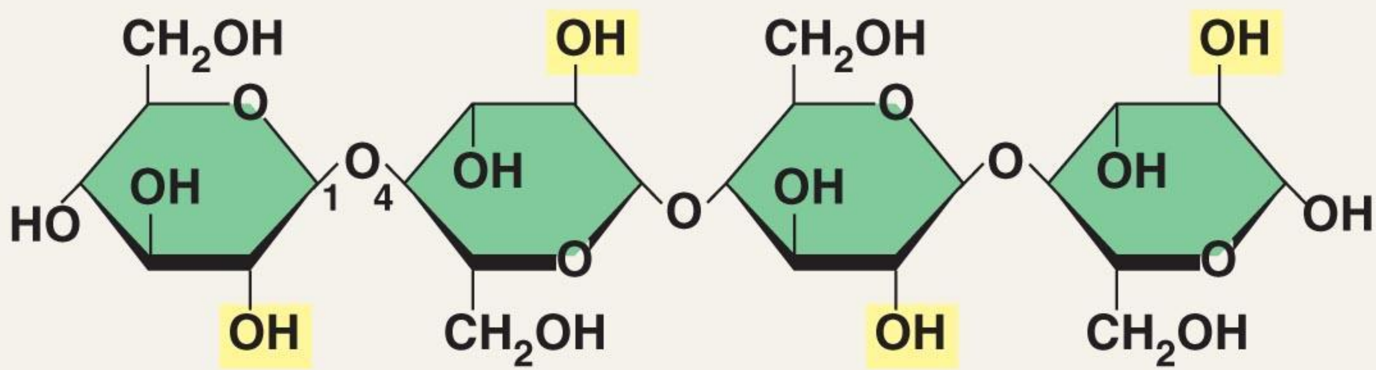


(a) □ and □ glucose ring structures

Fig. 5-7bc



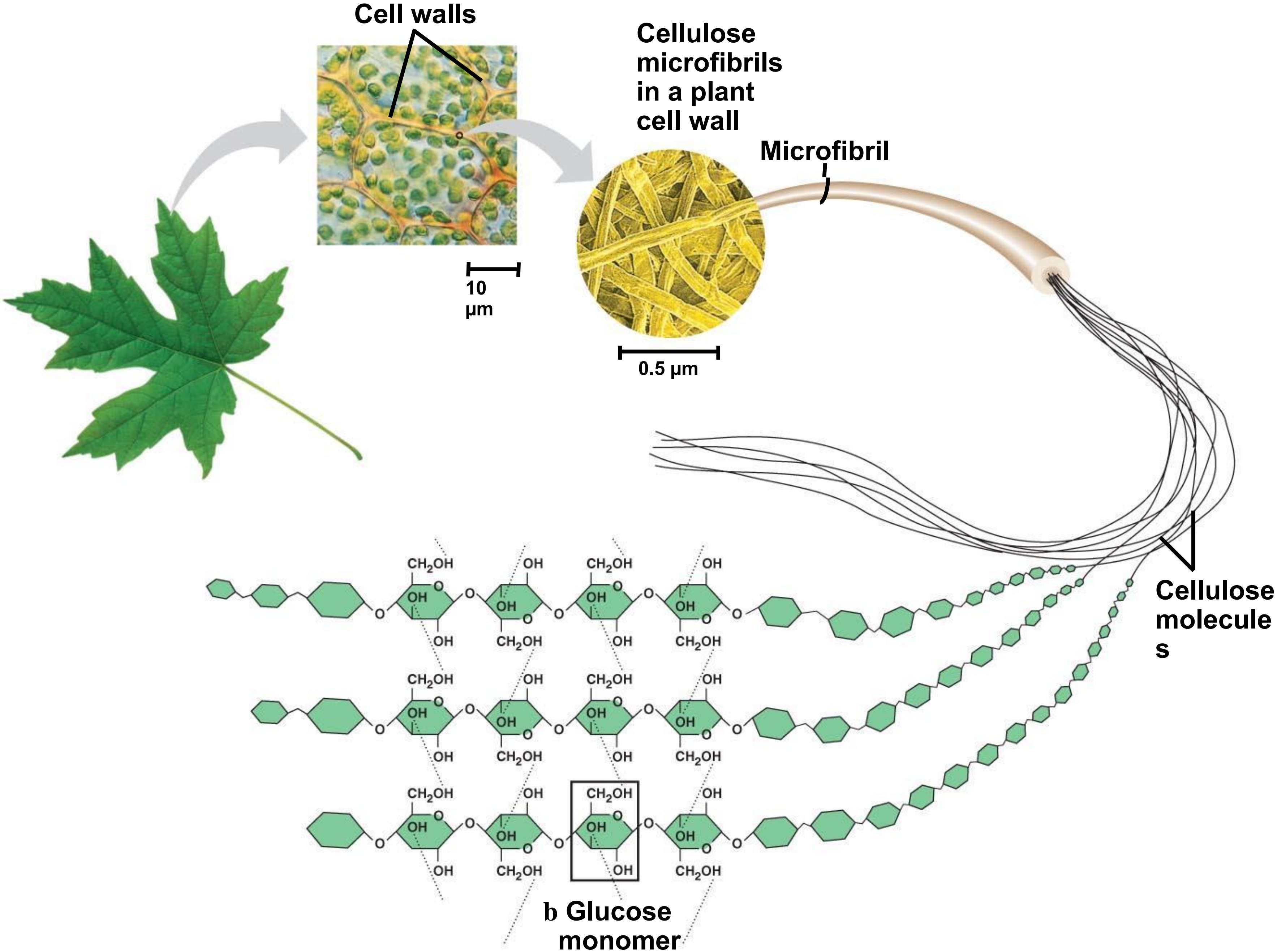
(b) Starch: 1–4 linkage of glucose monomers



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

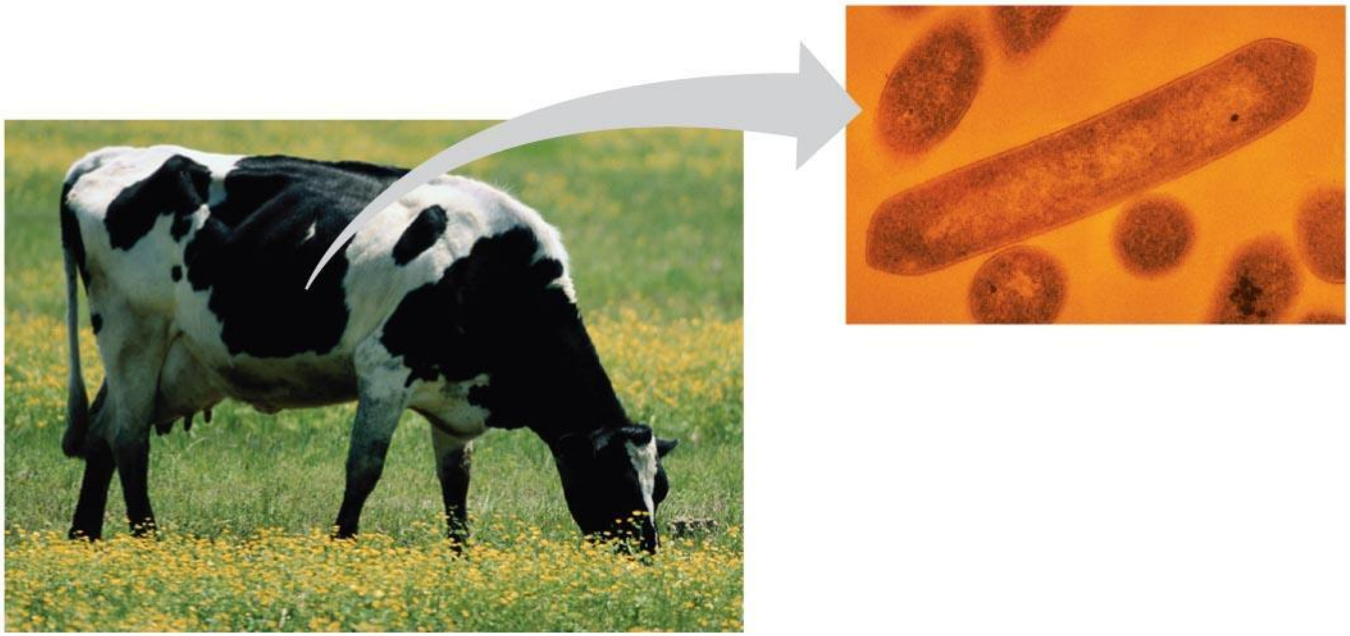
- Polymers with α glucose are helical
- Polymers with β glucose are straight
- In straight structures, H atoms on one strand can bond with OH groups on other strands
- Parallel cellulose molecules held together this way are grouped into microfibrils, which form strong building materials for plants

Fig. 5-8


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

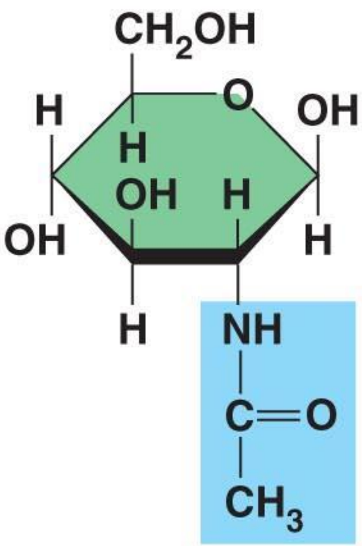
- Enzymes that digest starch by hydrolyzing α linkages can’t hydrolyze β linkages in cellulose
- Cellulose in human food passes through the digestive tract as insoluble fiber
- Some microbes use enzymes to digest cellulose
- Many herbivores, from cows to termites, have symbiotic relationships with these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

Fig. 5-9



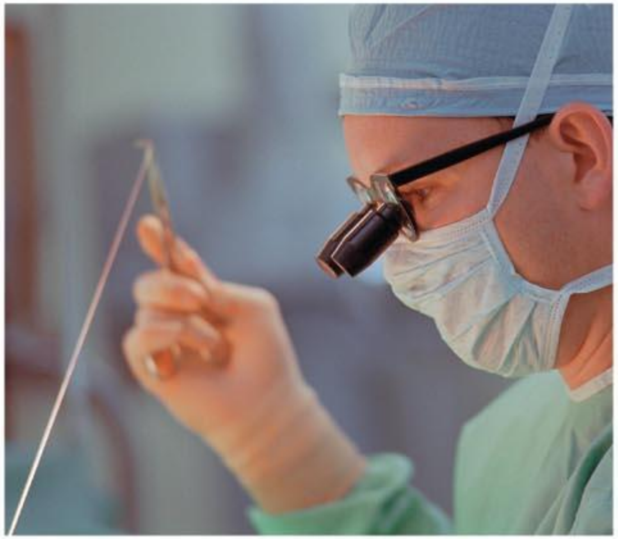
- **Chitin**, another structural polysaccharide, is found in the exoskeleton of arthropods
- Chitin also provides structural support for the cell walls of many fungi

Fig. 5-10



(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.

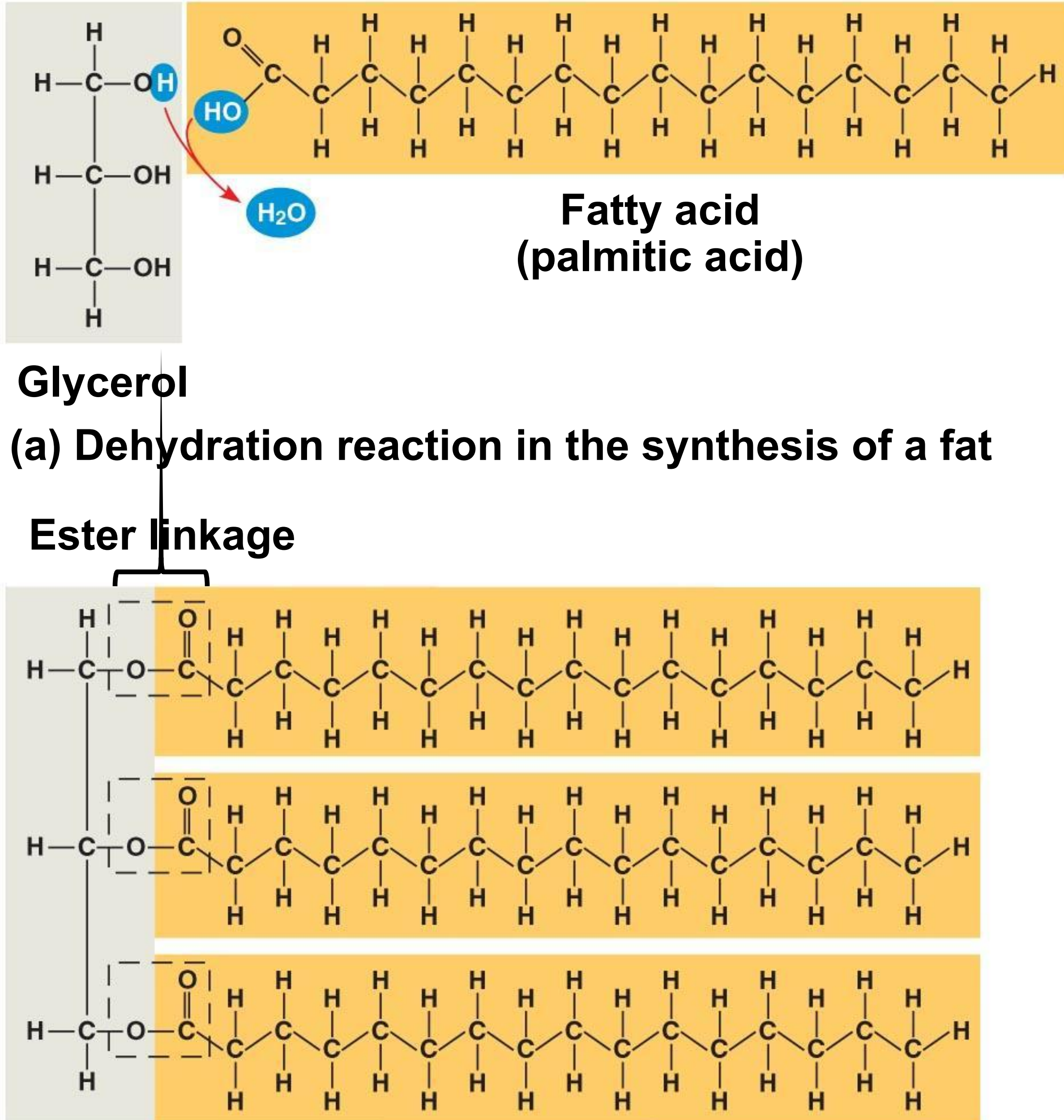
Concept 5.3: Lipids are a diverse group of hydrophobic molecules

- **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

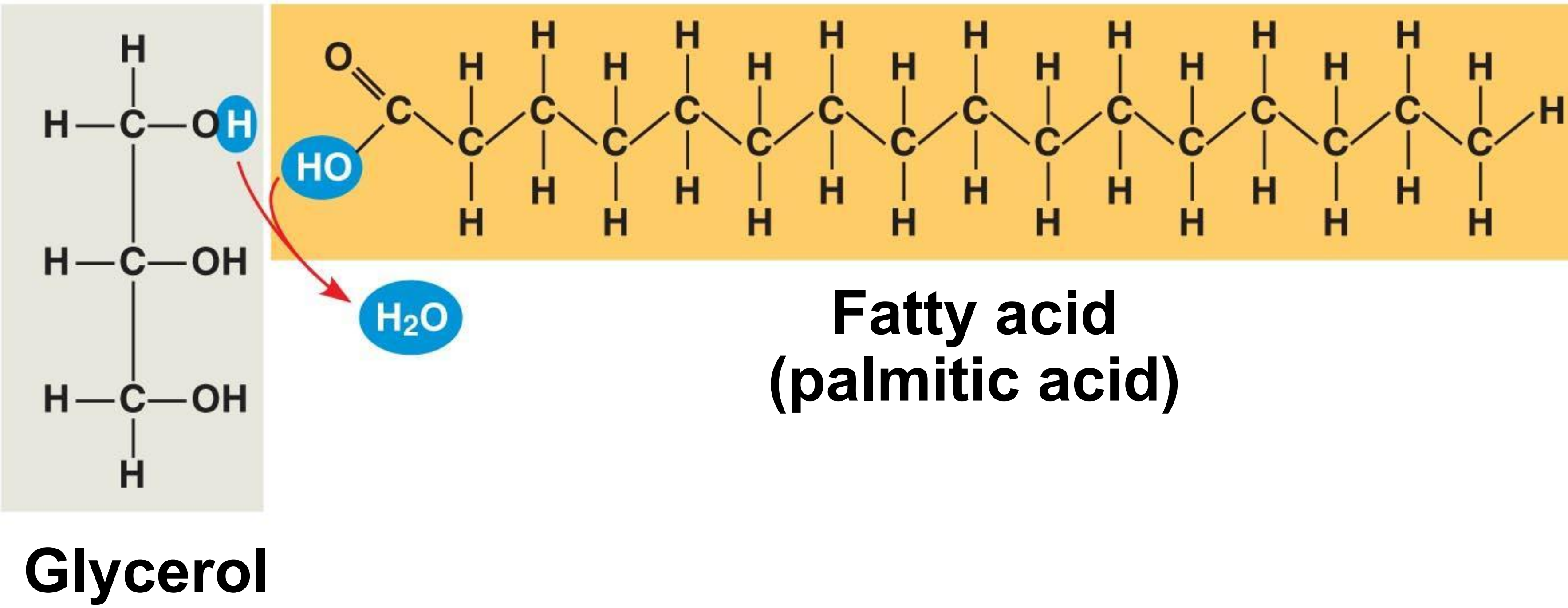
Fig. 5-11



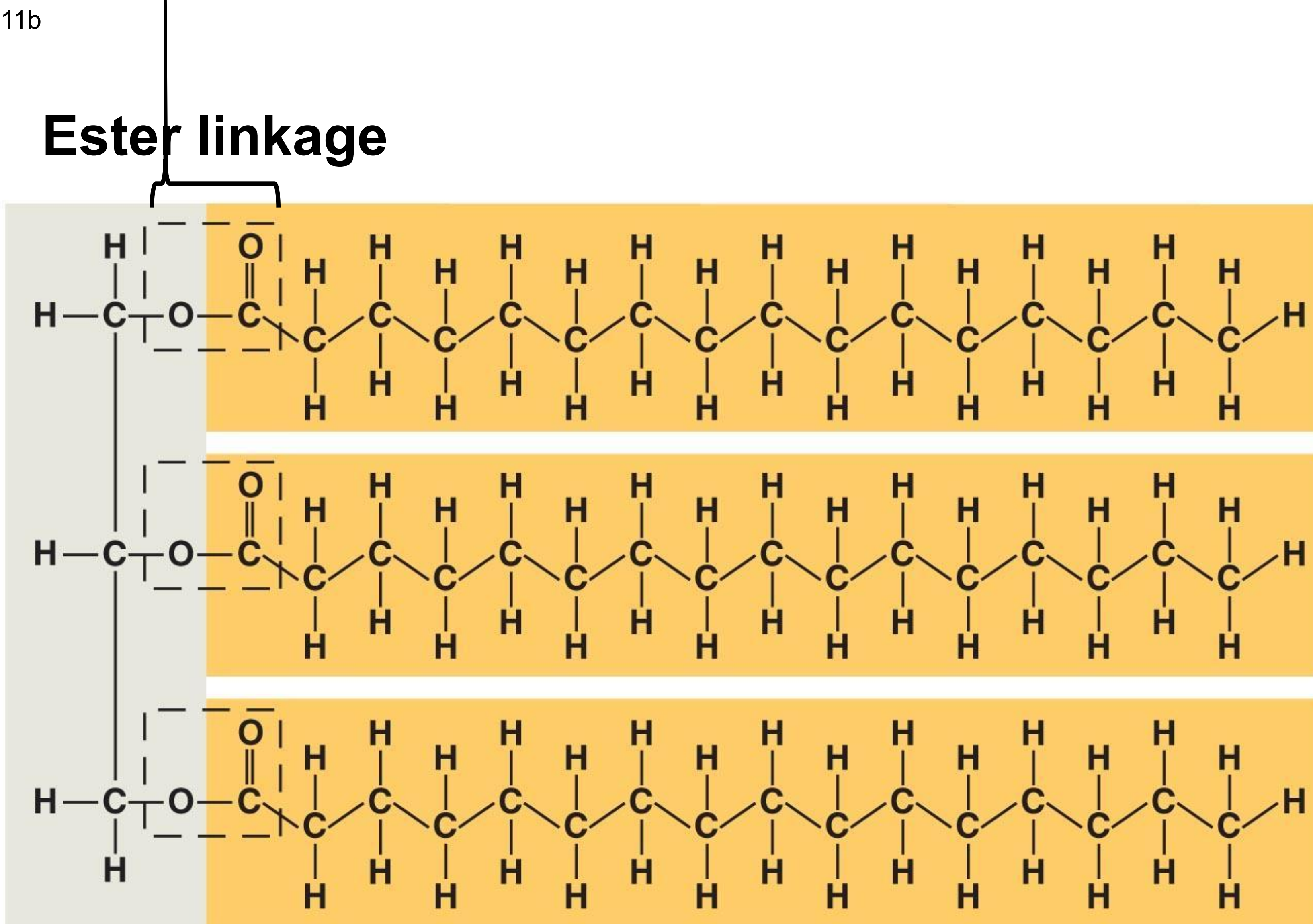
(a) Dehydration reaction in the synthesis of a fat

(b) Fat molecule (triacylglycerol)

Fig. 5-11a



(a) Dehydration reaction in the synthesis of a fat



(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 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

Fig. 5-12

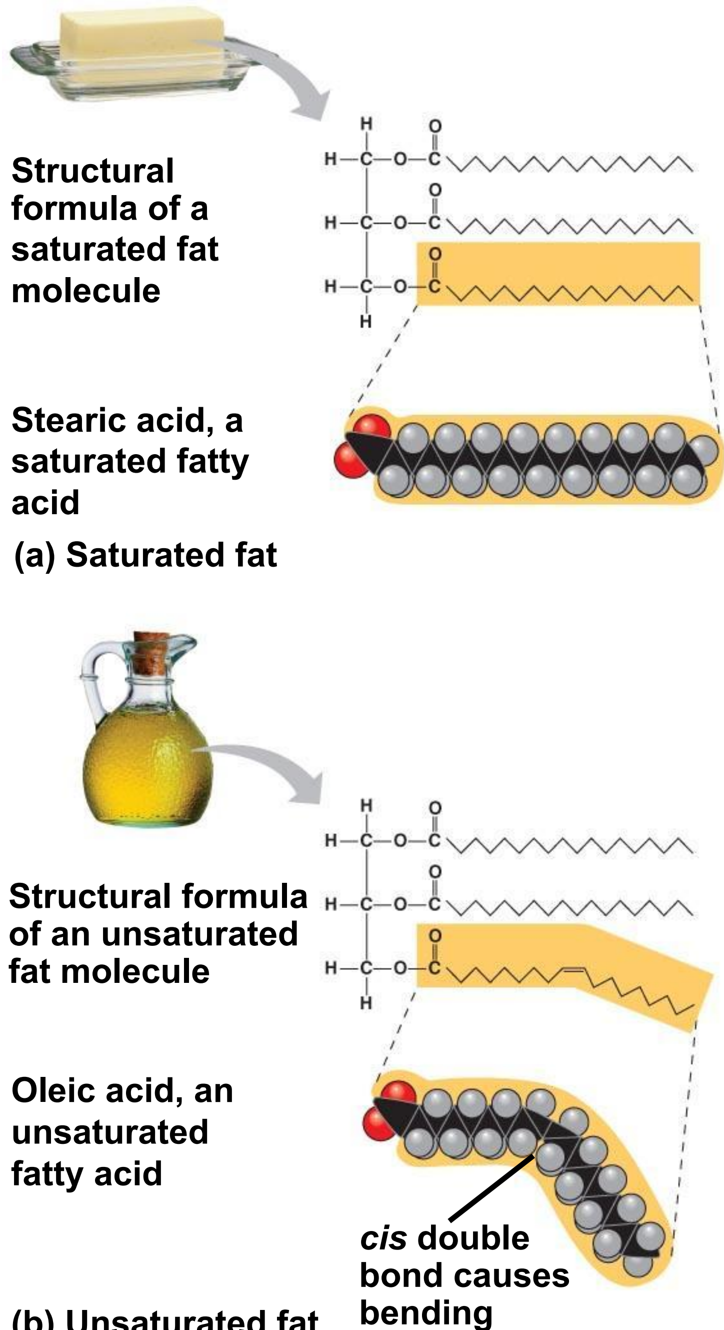
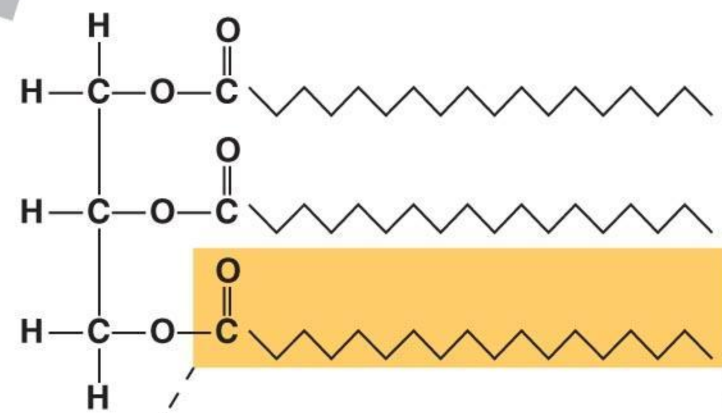
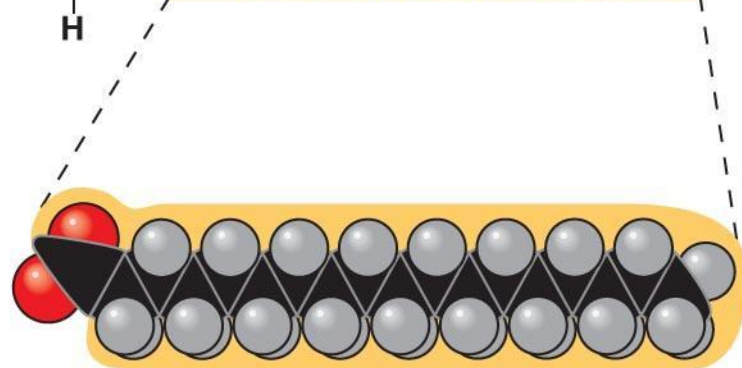

Structural formula of a saturated fat molecule
Stearic acid, a saturated fatty acid
(a) Saturated fat
Structural formula of an unsaturated fat molecule
Oleic acid, an unsaturated fatty acid
cis double bond causes bending
(b) Unsaturated fat

Fig. 5-12a

Structural formula of a saturated fat molecule

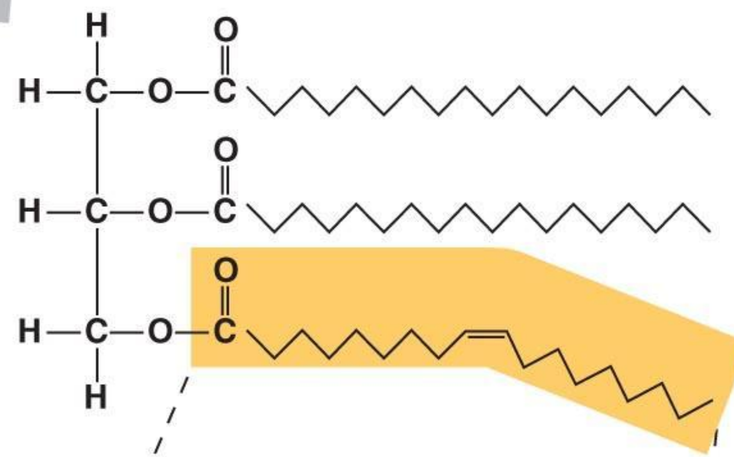


Stearic acid, a saturated fatty acid

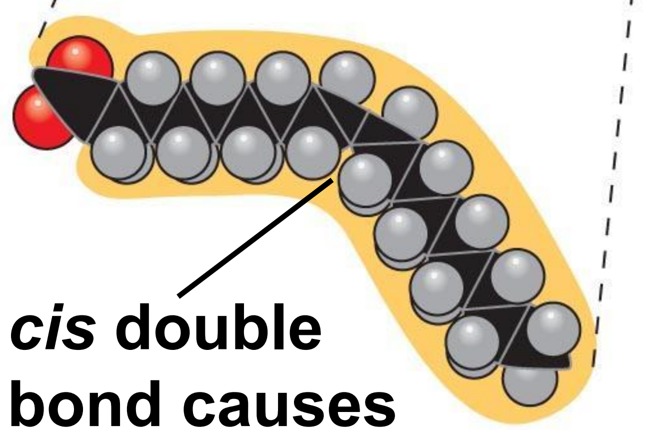


(a) Saturated fat

Fig. 5-12b



Structural formula of an unsaturated fat molecule



Oleic acid, an unsaturated fatty acid

cis **double bond causes bending**

(b) Unsaturated fat

- 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

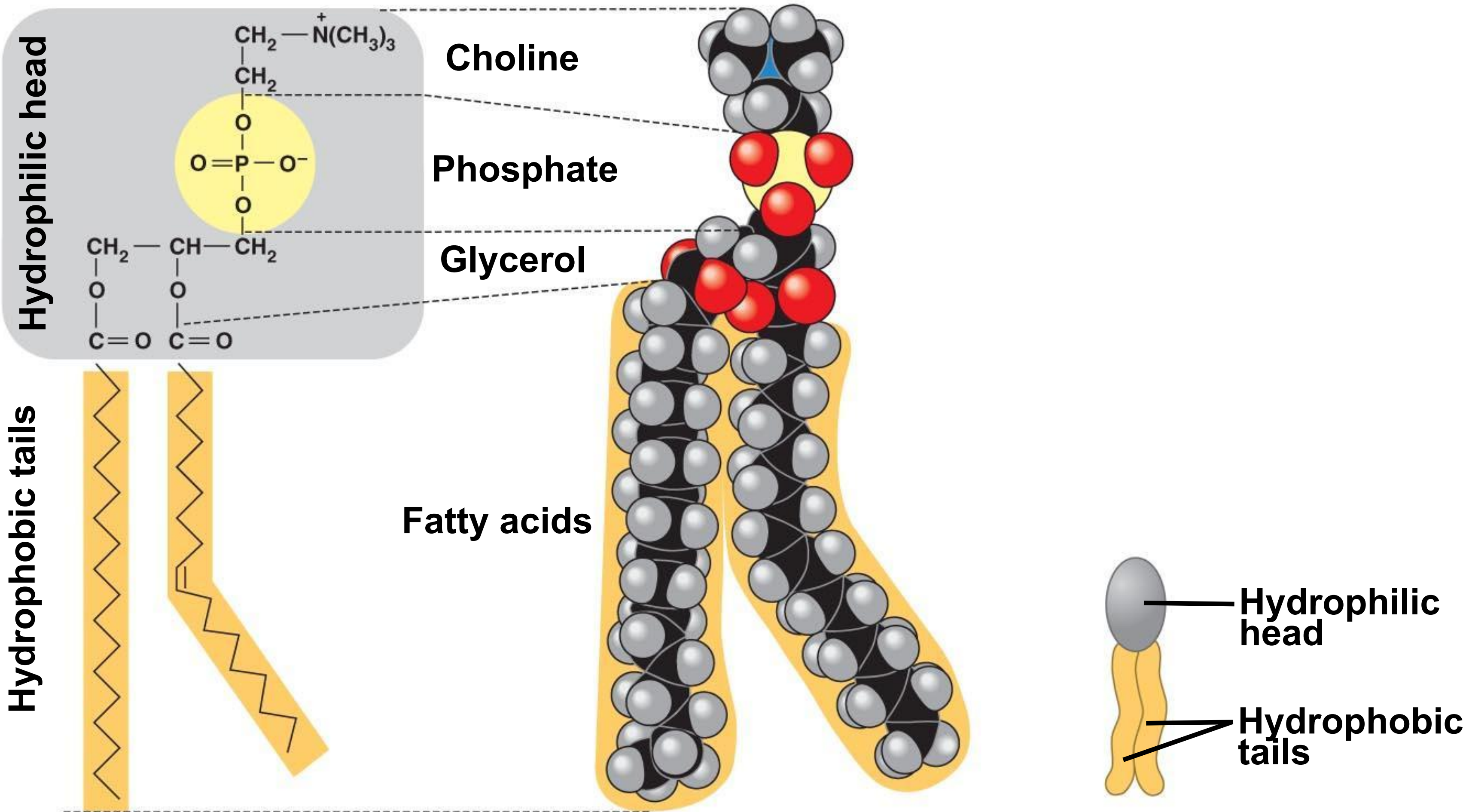
- A diet rich in saturated fats may contribute to cardiovascular disease through plaque deposits
- Hydrogenation is the process of converting unsaturated fats to saturated fats by adding hydrogen
- Hydrogenating vegetable oils also creates unsaturated fats with *trans* double bonds
- These *trans* fats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

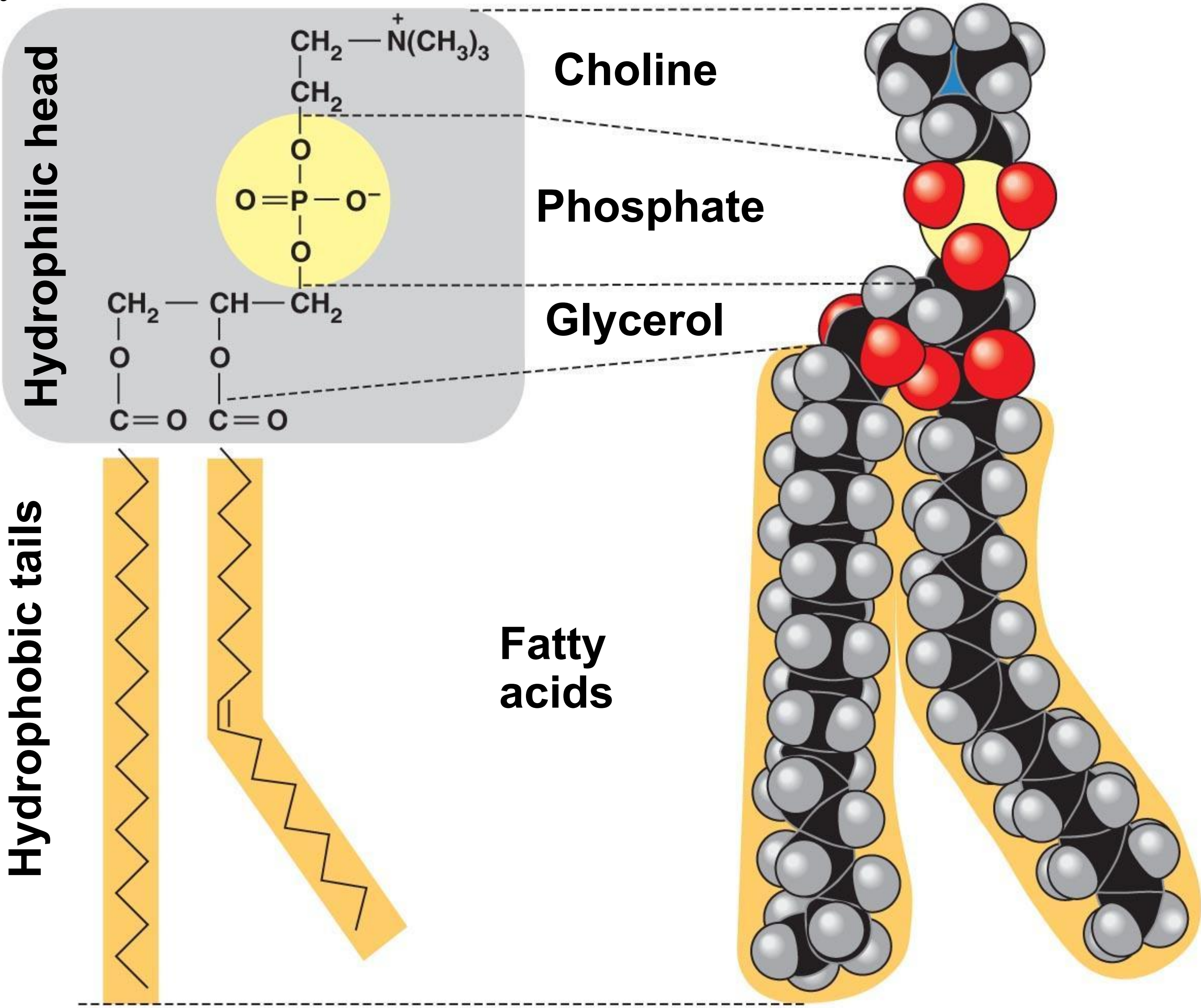
- In a **phospholipid**, two fatty acids and a phosphate group are attached to glycerol
- The two fatty acid tails are hydrophobic, but the phosphate group and its attachments form a hydrophilic head

Fig. 5-13



(a) Structural formula (b) Space-filling model (c) Phospholipid symbol

Fig. 5-13ab

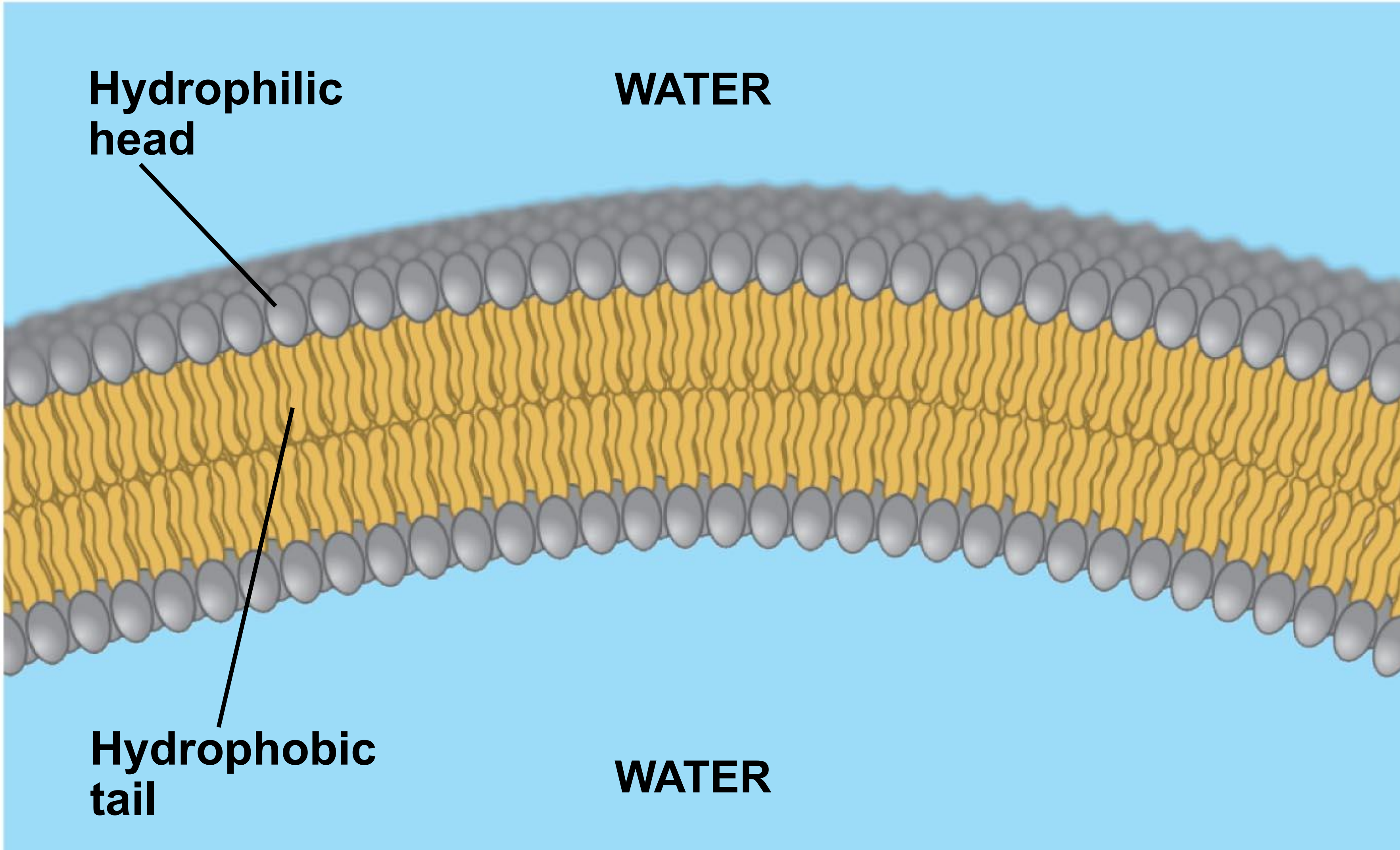


(a) Structural formula

(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

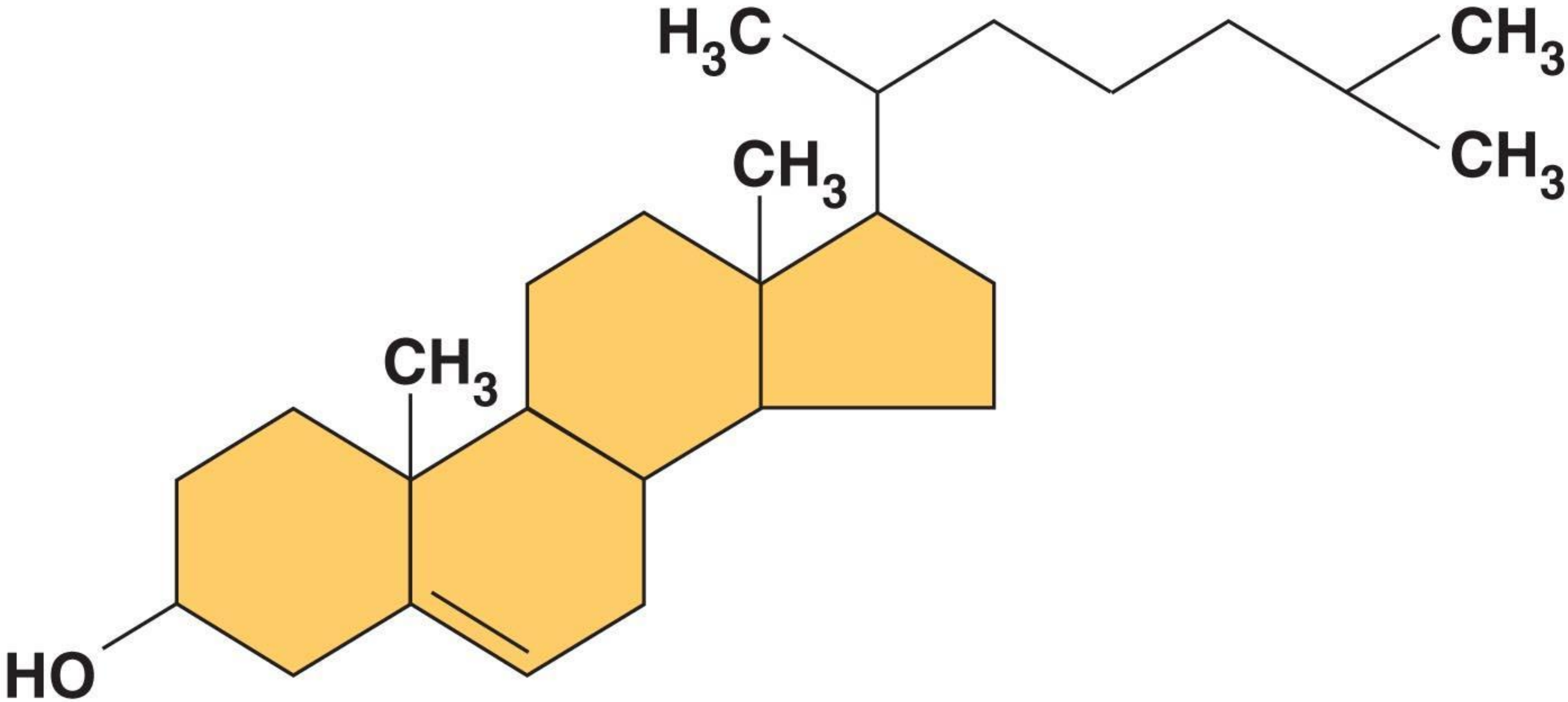
Fig. 5-14



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.

PLAY Animation: Structural Proteins

PLAY Animation: Storage Proteins

PLAY Animation: Transport Proteins

PLAY Animation: Receptor Proteins

PLAY Animation: Contractile Proteins

PLAY Animation: Defensive Proteins

PLAY Animation: Hormonal Proteins

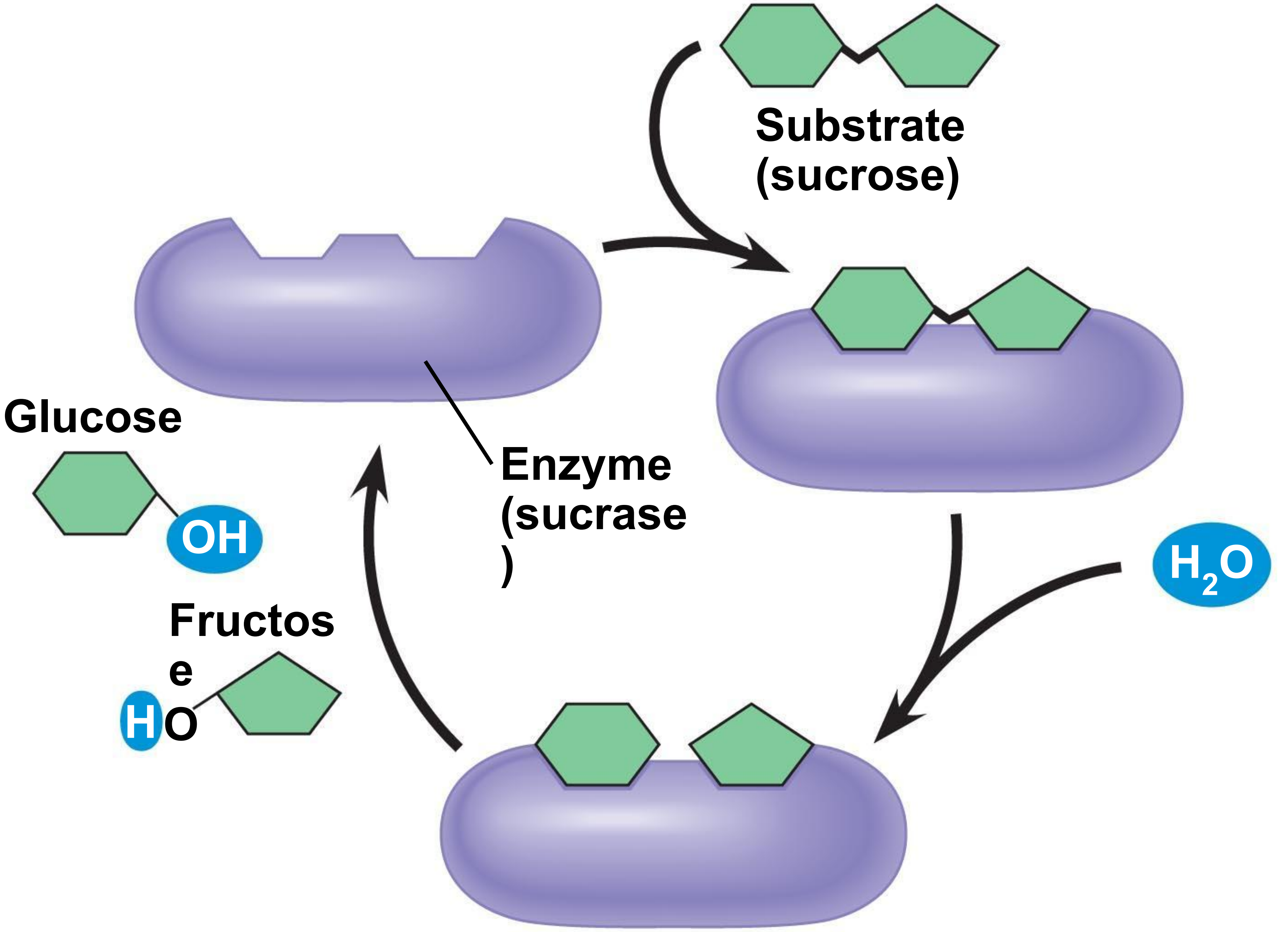
PLAY Animation: Sensory Proteins

PLAY Animation: Gene Regulatory Proteins

- **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


Substrate (sucrose)
Enzyme (sucrase
)
Glucose
OH
Fructos
e
HO
H_2O

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

Fig. 5-UN1

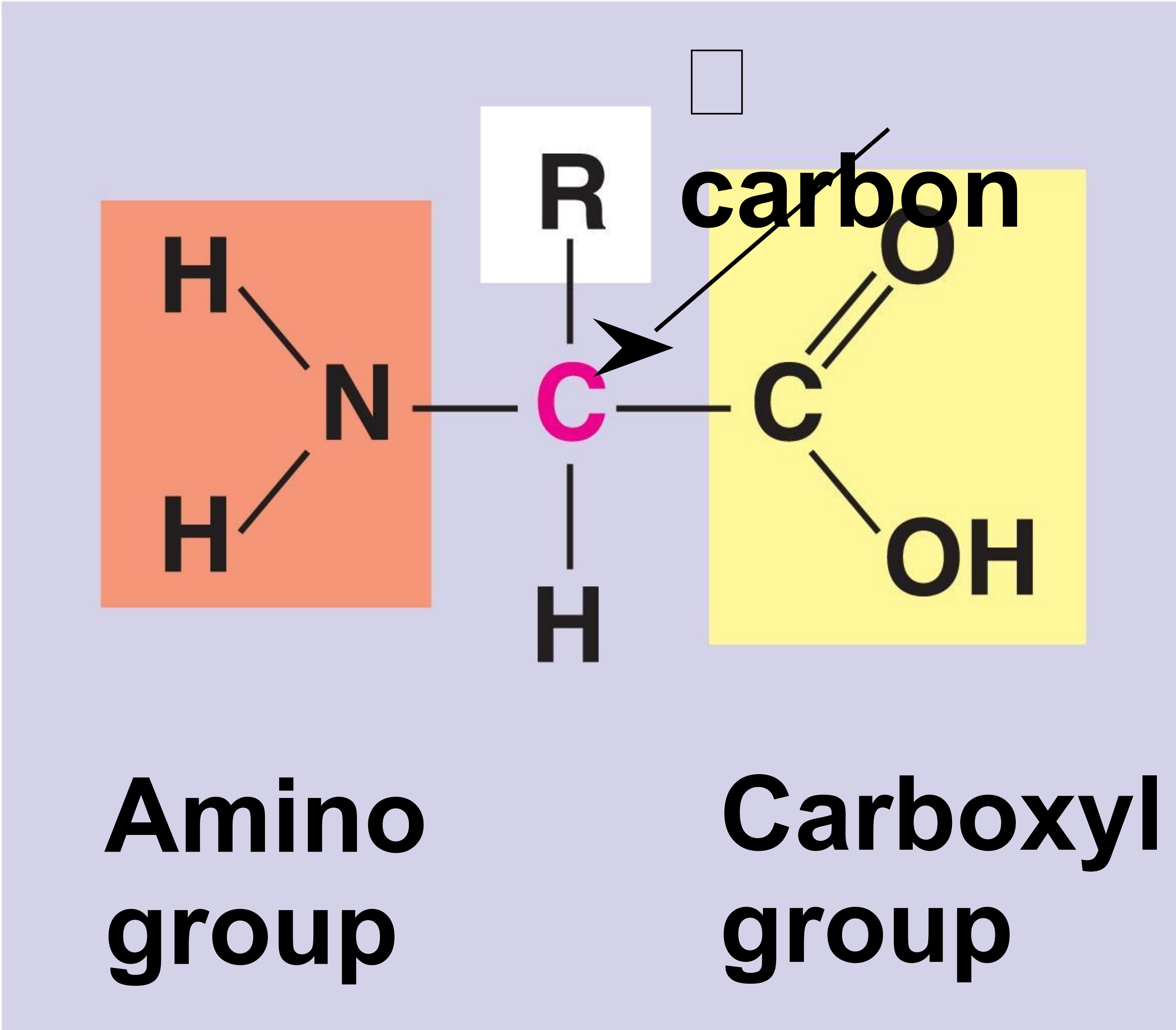


Fig. 5-17

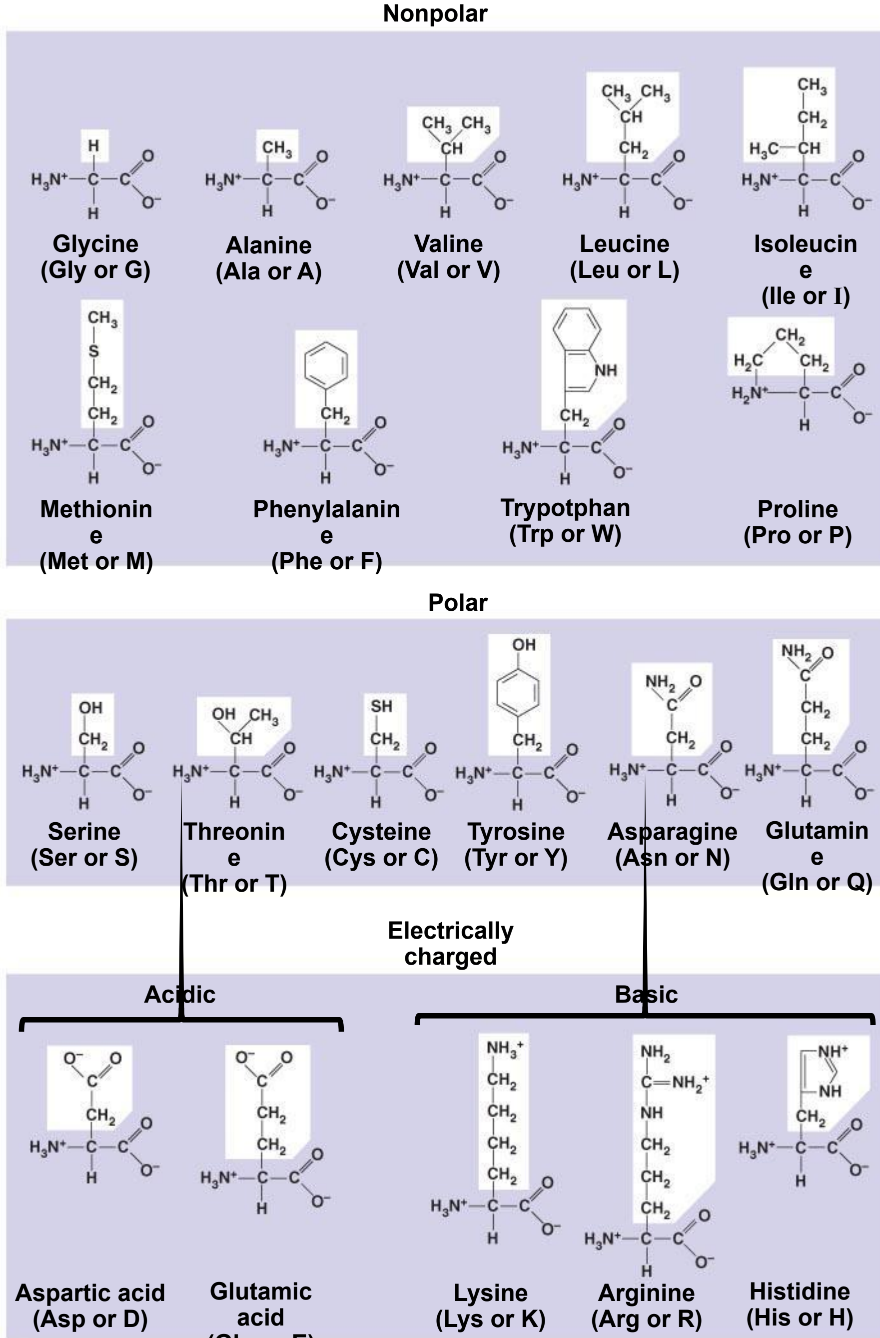

Nonpolar
Glycine
(Gly or G)
Alanine
(Ala or A)
Valine
(Val or V)
Leucine
(Leu or L)
Isoleucin
e
(Ile or I)
Methionin
e
(Met or M)
Phenylalanin
e
(Phe or F)
Trypotphan
(Trp or W)
Proline
(Pro or P)
Polar
Serine
(Ser or S)
Threonin
e
(Thr or T)
Cysteine
(Cys or C)
Tyrosine
(Tyr or Y)
Asparagine
(Asn or N)
Glutamin
e
(Gln or Q)
Electrically
charged
Acidic
Basic
Aspartic acid
(Asp or D)
Glutamic
acid
(Glu or E)
Lysine
(Lys or K)
Arginine
(Arg or R)
Histidine
(His or H)

Fig. 5-17a

Nonpolar

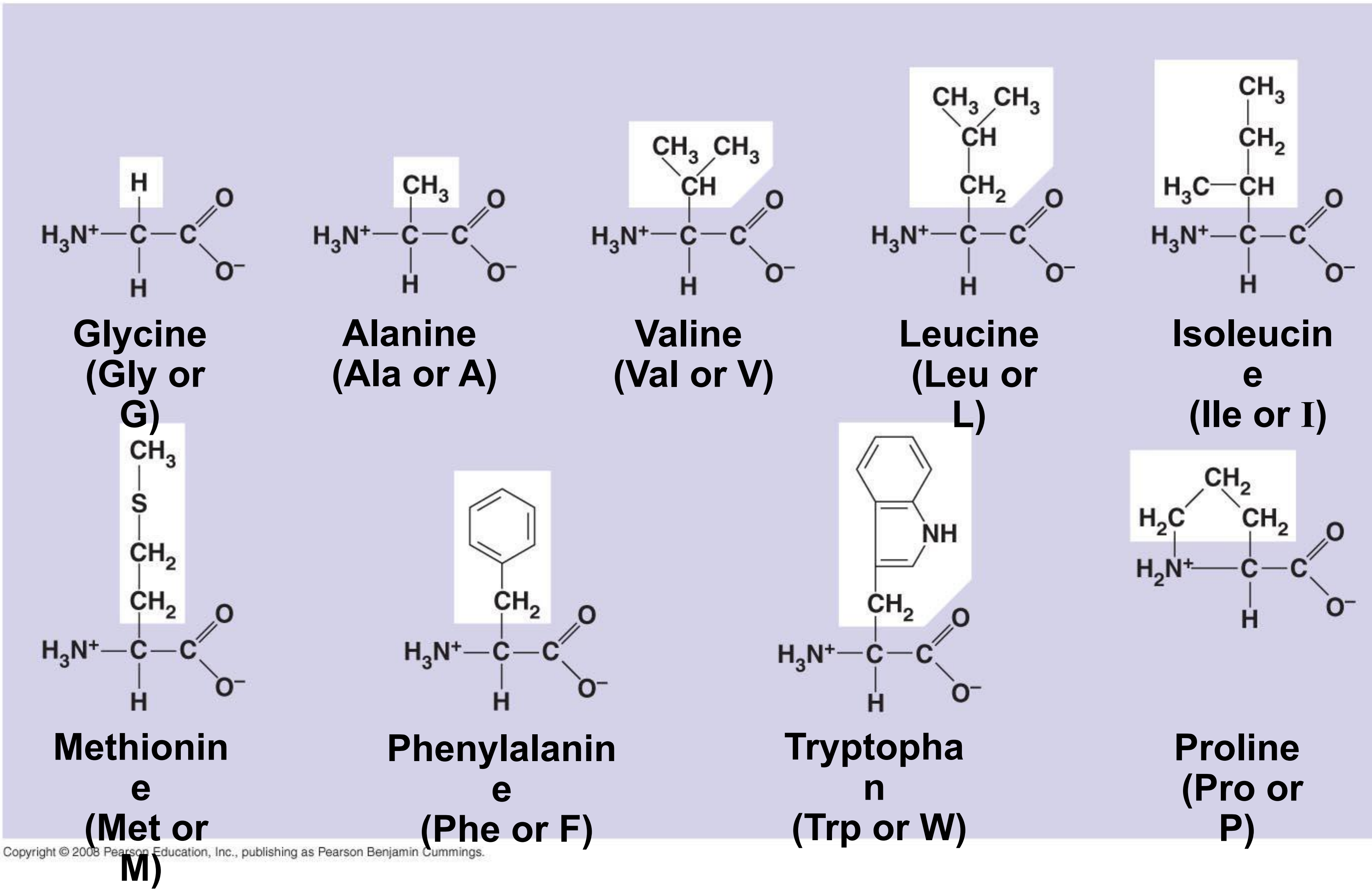
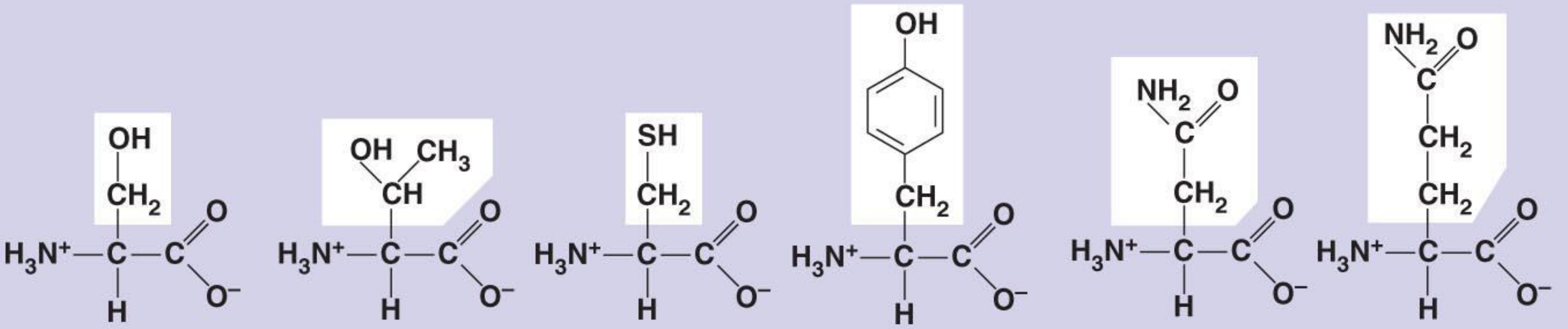


Fig. 5-17b

Polar



Serine (Ser or S)

Threonine (Thr or T)

Cysteine (Cys or C)

Tyrosine (Tyr or Y)

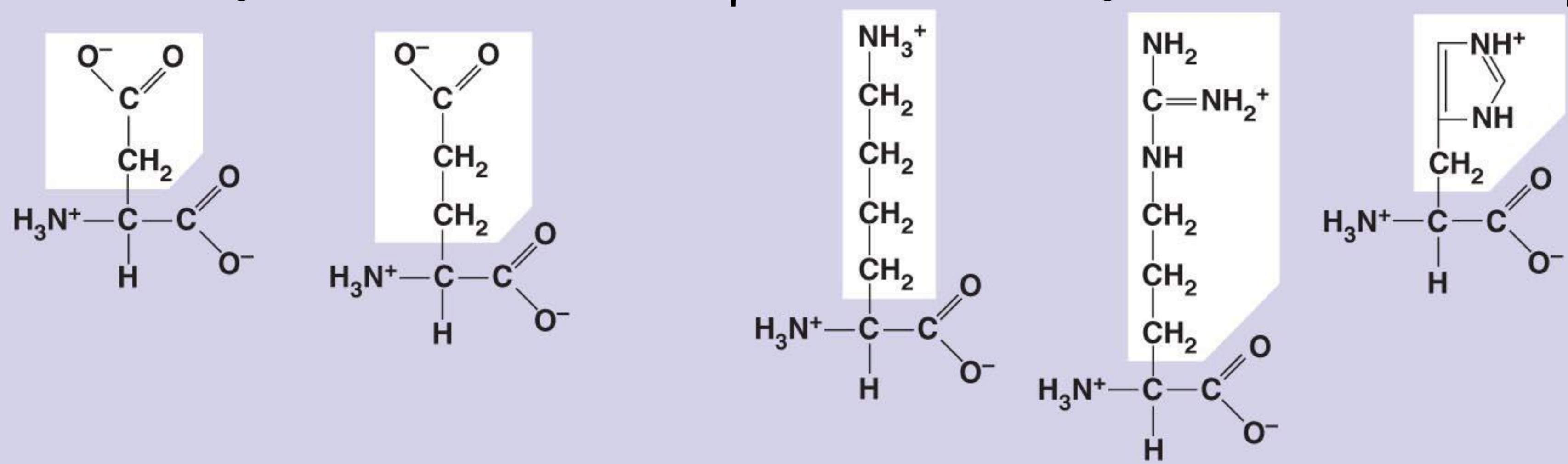
Asparagin
e
(Asn or N)

Glutamin
e
(Gln or Q)

Fig. 5-17c

Electrically charged

Acidi c | **Basi c**



Aspartic acid (Asp or D)

Glutamic acid (Glu or E)

Lysine (Lys or K)

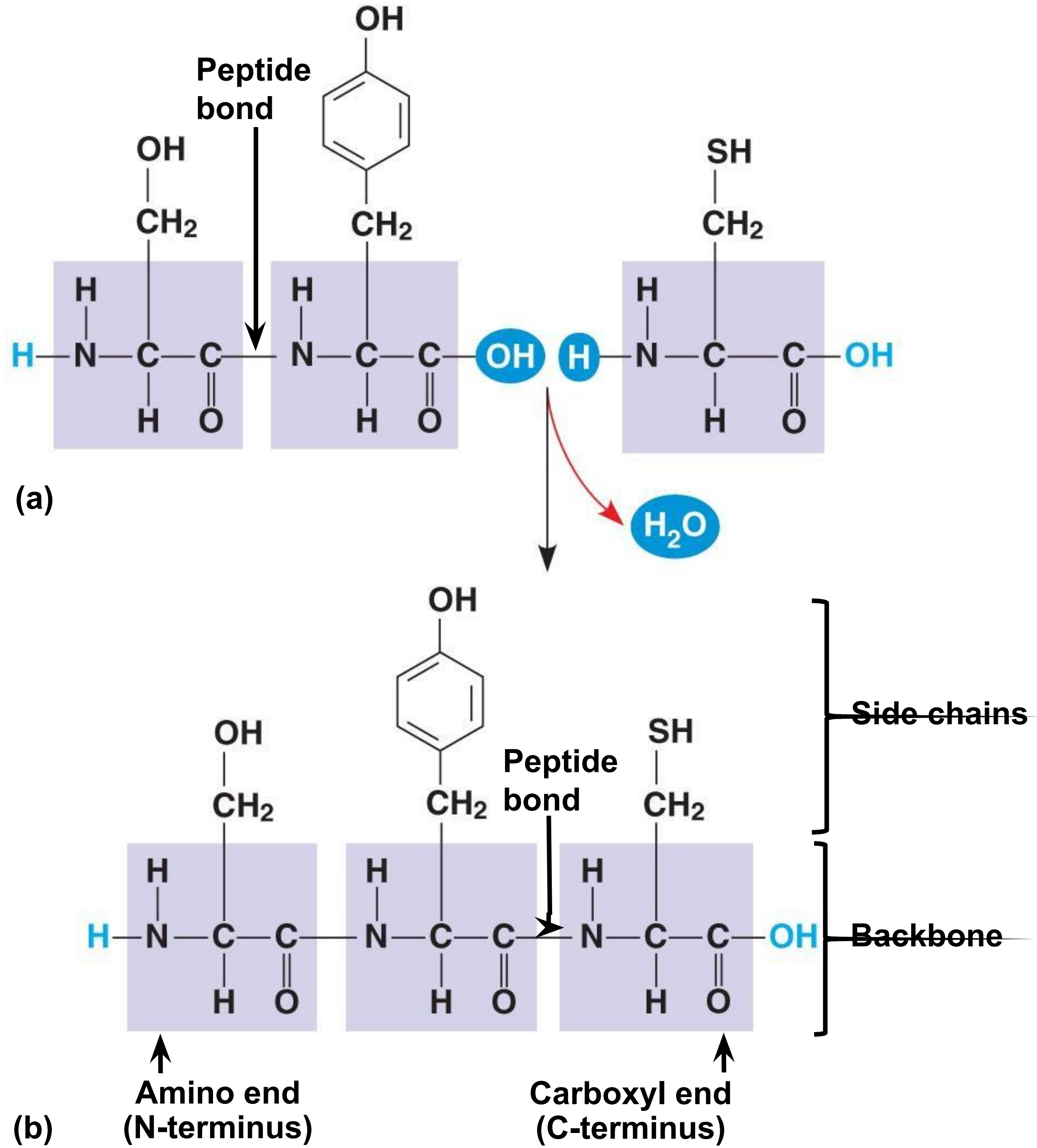
Arginine (Arg or R)

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

Fig. 5-18

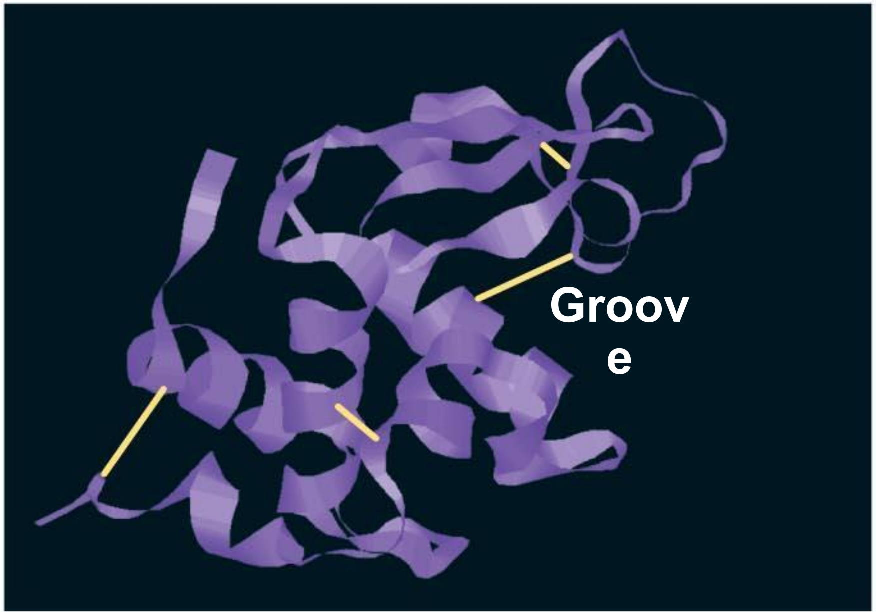


Peptide bond
OH
CH2
H
H—N—C—C
H O
N—C—C
OH H
N—C—C—OH
SH
(a)
H2O
Side chains
Backbone
Peptide bond
Amino end (N-terminus)
Carboxyl end (C-terminus)
(b)

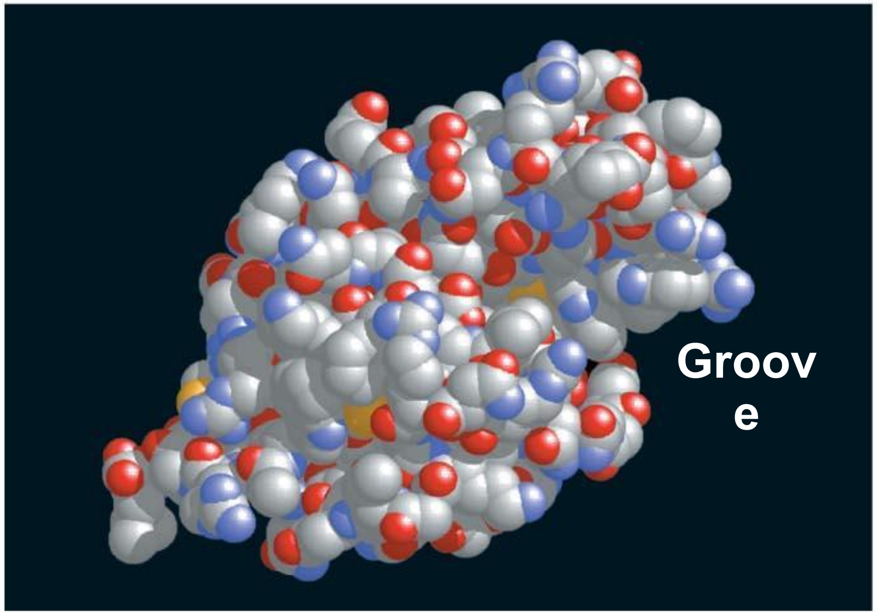
Protein Structure and Function

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

Fig. 5-19

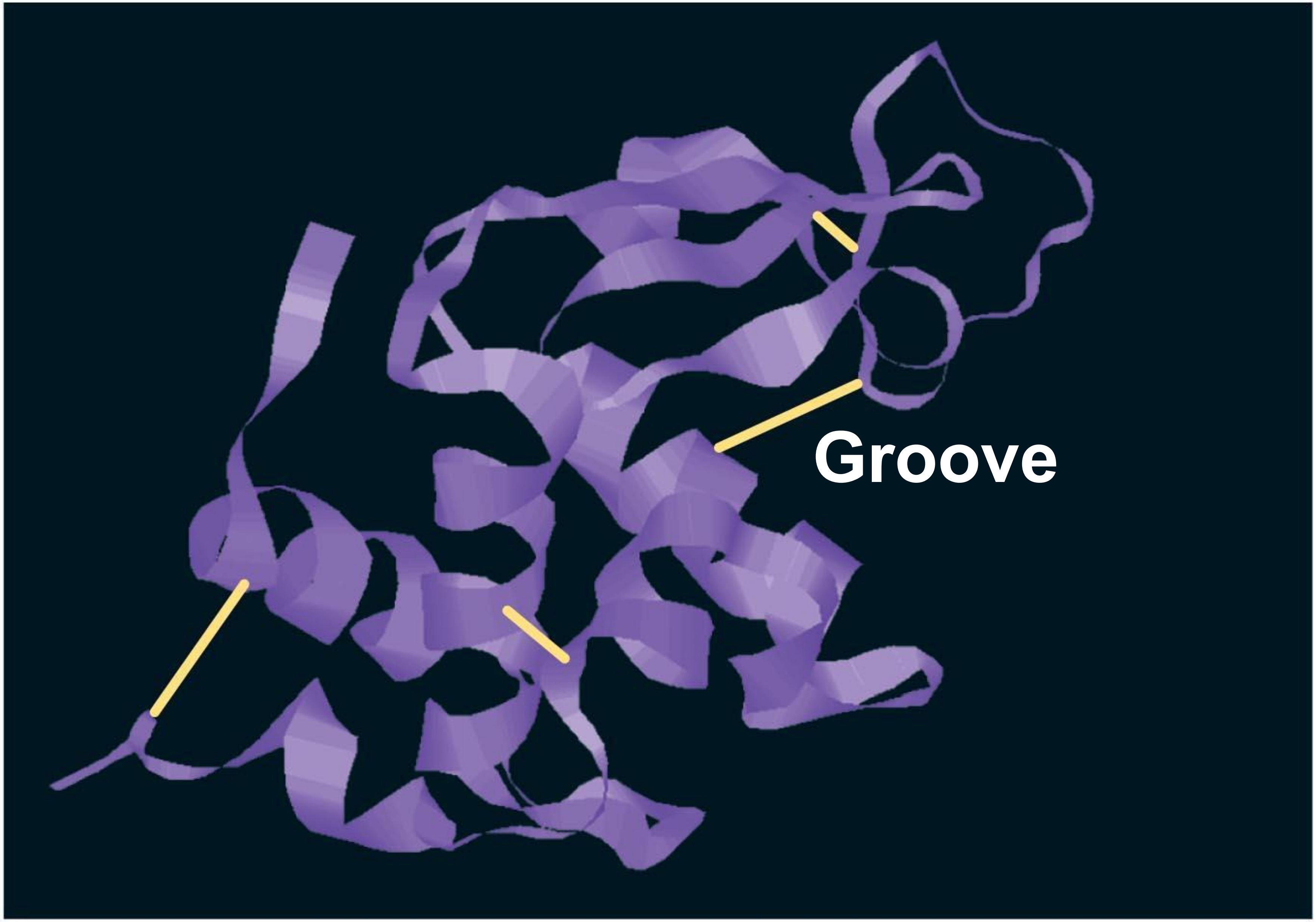


(a) A ribbon model of lysozyme



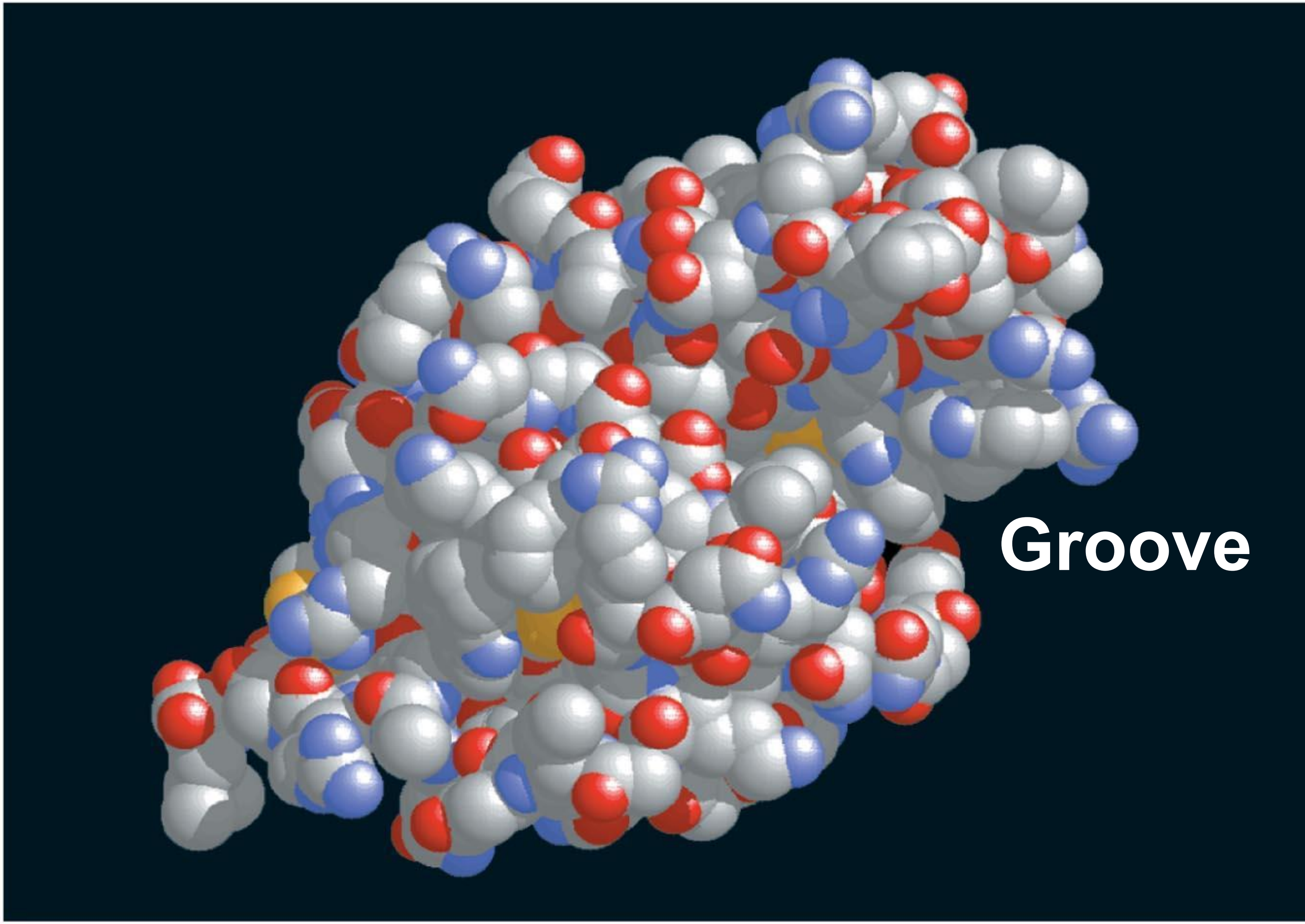
(b) A space-filling model of lysozyme

Fig. 5-19a



(a) A ribbon model of lysozyme

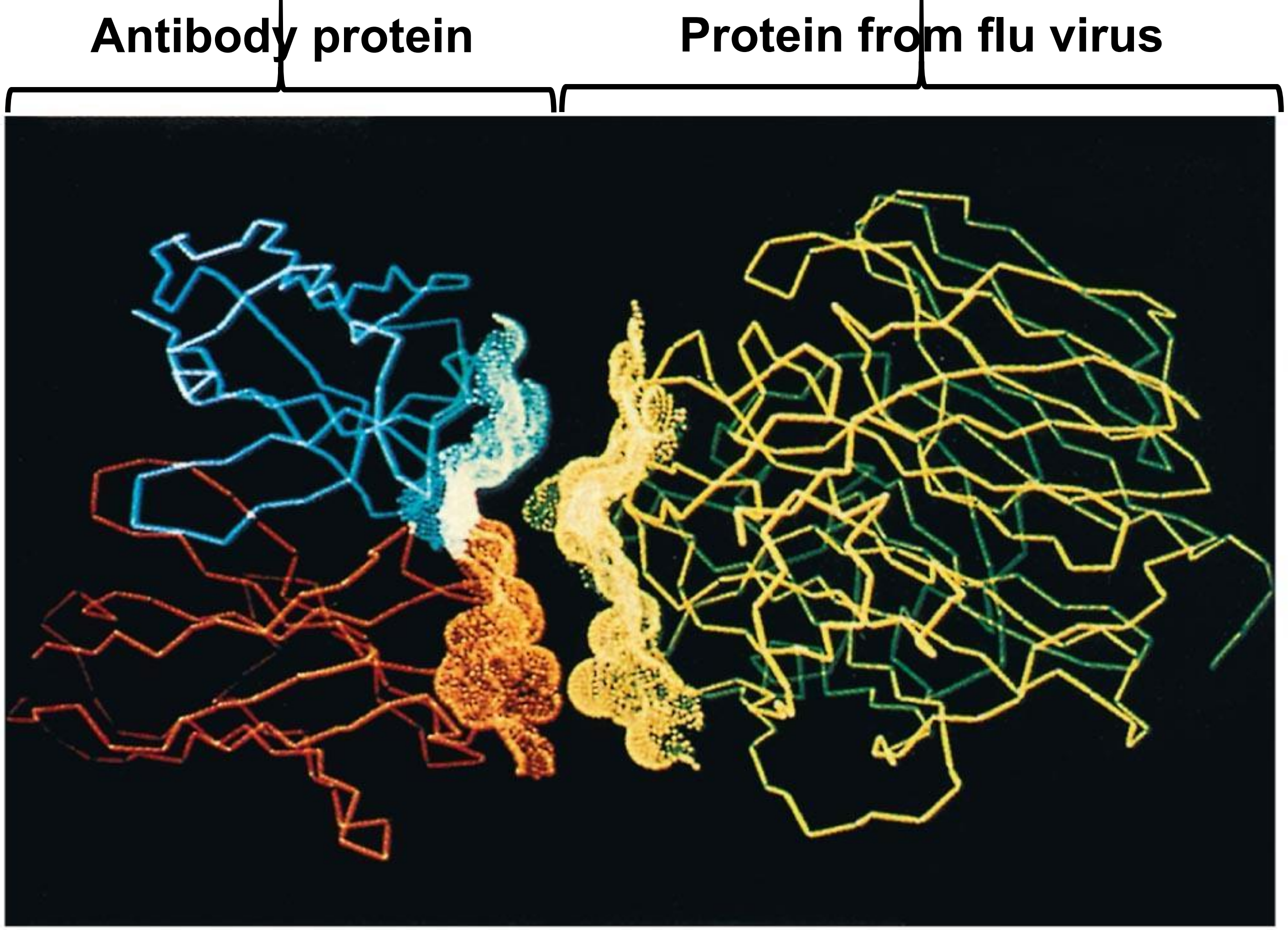
Fig. 5-19b



(b) A space-filling model of lysozyme

- The sequence 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

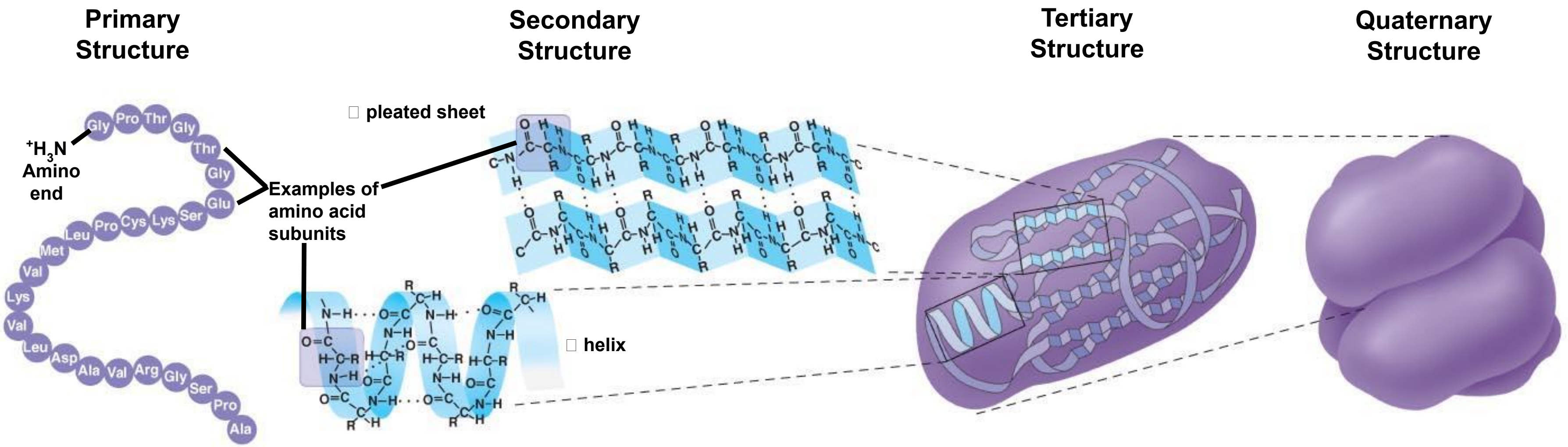
- The primary structure of a protein is its unique sequence of amino acids
- Secondary structure, found in most proteins, consists of coils and folds in the polypeptide chain
- Tertiary structure is determined by interactions among various side chains (R groups)
- Quaternary structure results when a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

PLAY **Animation: Protein Structure Introduction**

- **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

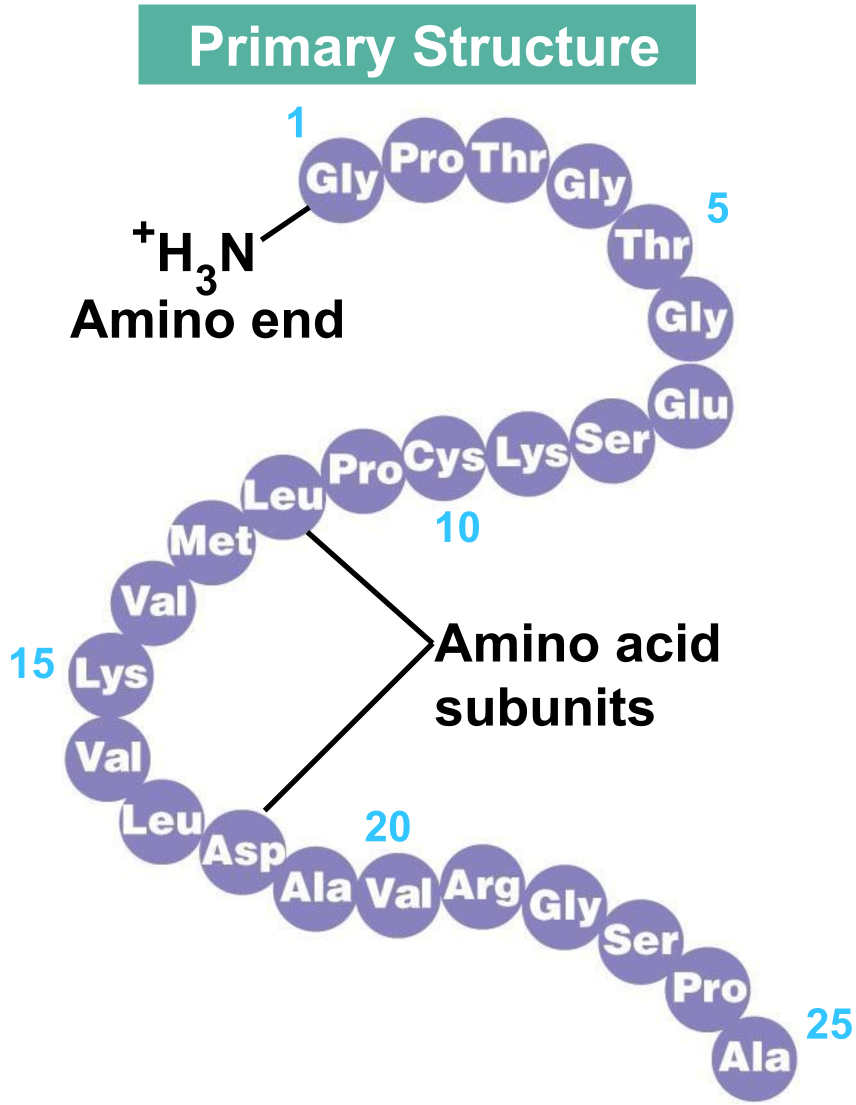
PLAY Animation: Primary Protein Structure

Fig. 5-21



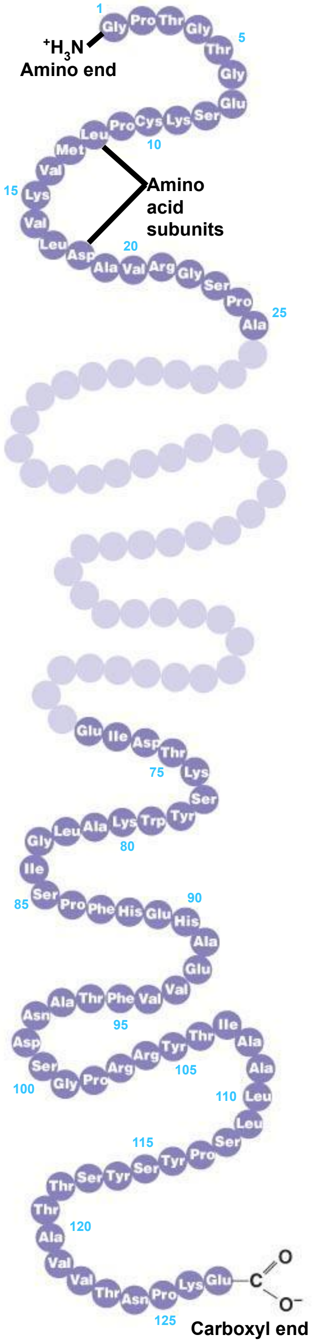
Primary Structure
Secondary Structure
Tertiary Structure
Quaternary Structure
+H3N Amino end
Gly Pro Thr Gly Thr Gly Glu Ser Lys Cys Pro Leu Met Val Lys Val Leu Asp Ala Val Arg Gly Ser Pro Ala
Examples of amino acid subunits
pleated sheet
helix

Fig. 5-21a



Primary Structure
1
Gly
Pro
Thr
Gly
5
Thr
Gly
Glu
Ser
Lys
Cys
Pro
Leu
10
Met
Val
15
Lys
Val
Leu
Asp
20
Ala
Val
Arg
Gly
Ser
Pro
25
Ala
^+H_3N
Amino end
Amino acid subunits

Fig. 5-21b



$^{+}H_3N$
Amino end
Amino acid subunits
Carboxyl end
Gly Pro Thr Gly Thr Gly Glu Ser Lys Cys Pro Leu Met Val Lys Val Leu Asp Ala Val Arg Gly Ser Pro Ala
Glu Ile Asp Thr Lys Ser Tyr Trp Lys Ala Leu Gly Ile Ser Pro Phe His Glu His Ala Glu Val Val Phe Thr Ala Asn Asp Ser Gly Pro Arg Arg Tyr Thr Ile Ala Ala Leu Leu Ser Pro Tyr Ser Tyr Ser Thr Thr Ala Val Val Thr Asn Pro Lys Glu

- 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**

PLAY Animation: Secondary Protein Structure

Fig. 5-21c

Secondary Structure

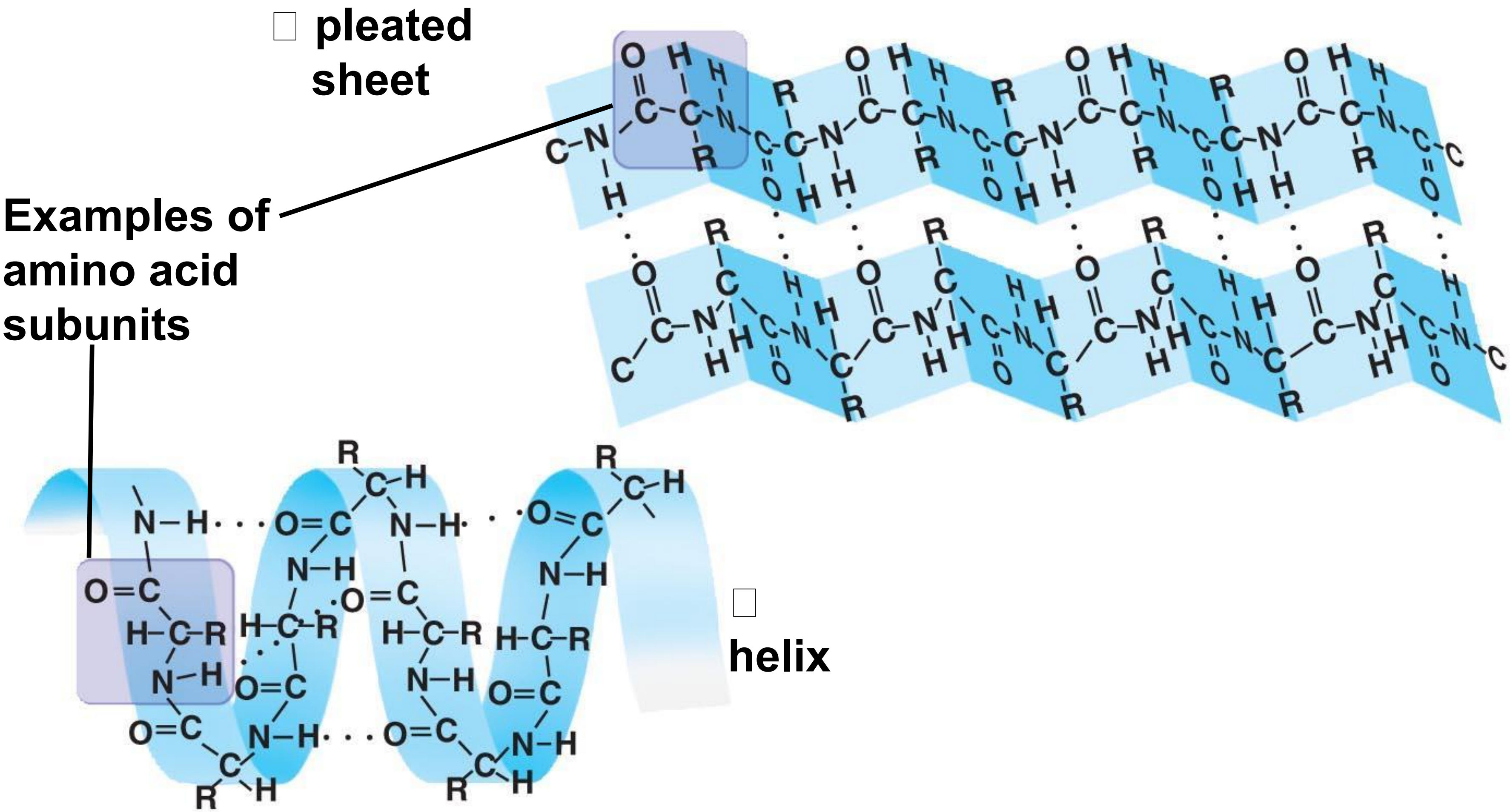


Fig. 5-21d

Abdominal glands of the spider secrete silk fibers made of a structural protein containing □ pleated sheets.

The radiating strands, made of dry silk fibers, maintain the shape of the web.

The spiral strands (capture strands) are elastic, stretching in response to wind, rain, and the touch of insects.

- **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

Fig. 5-21e

Tertiary Structure

Quaternary

tructu

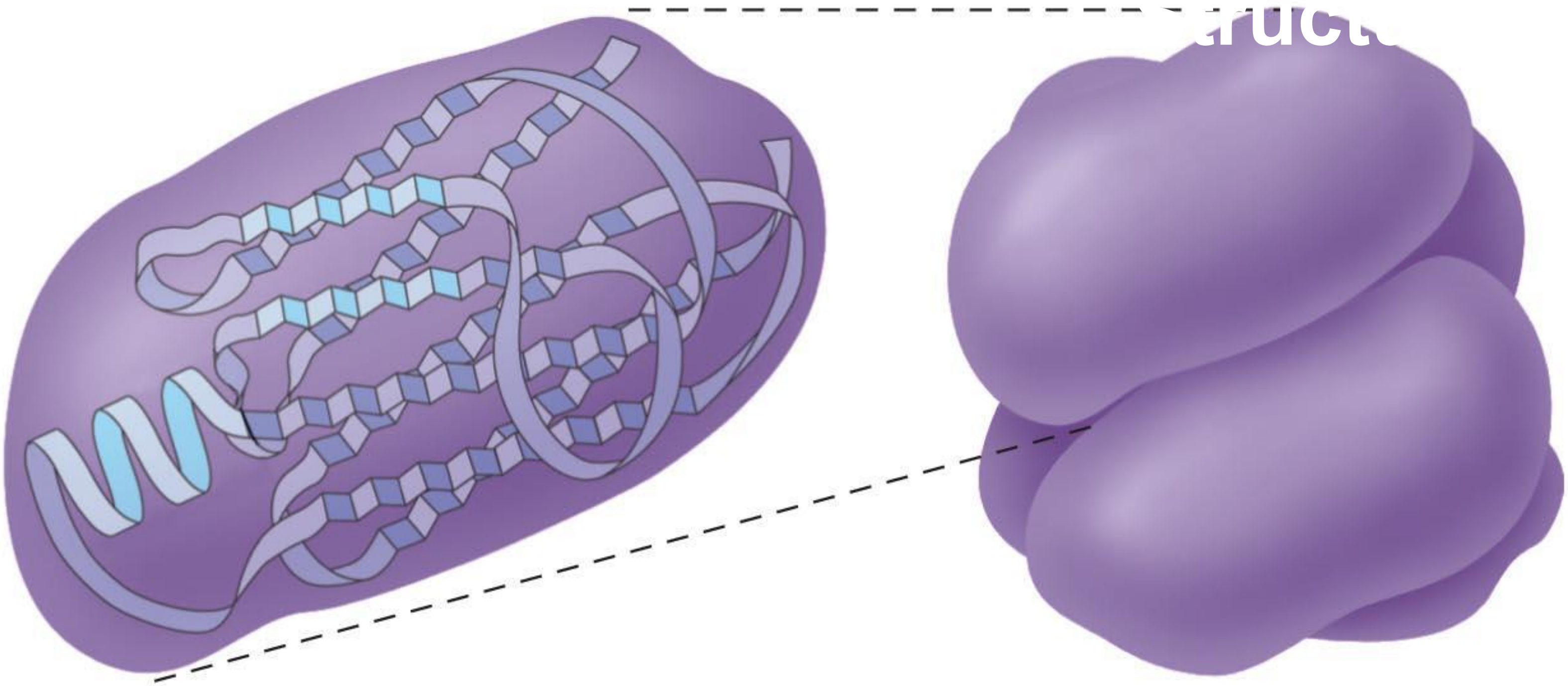


Fig. 5-21f

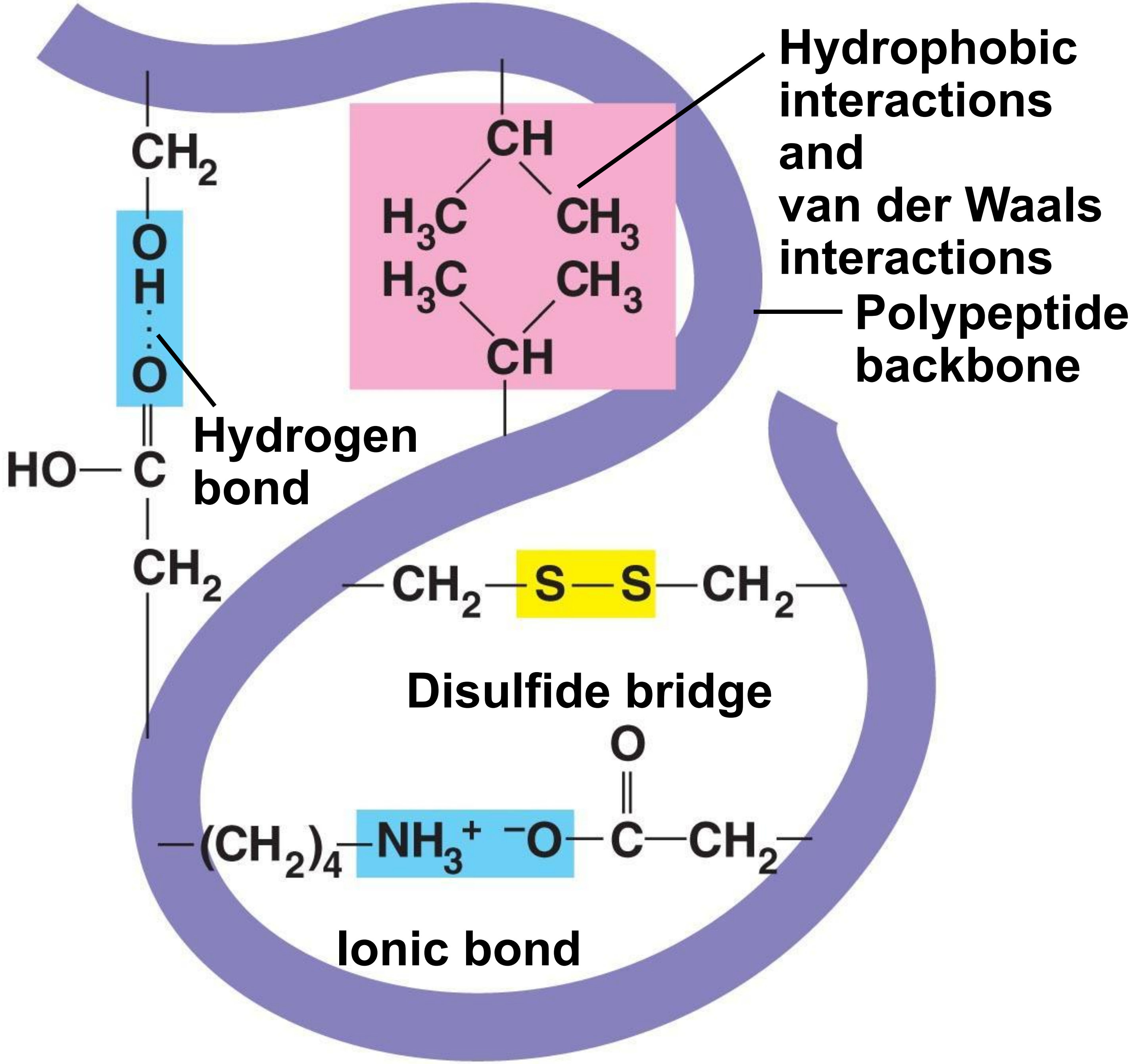
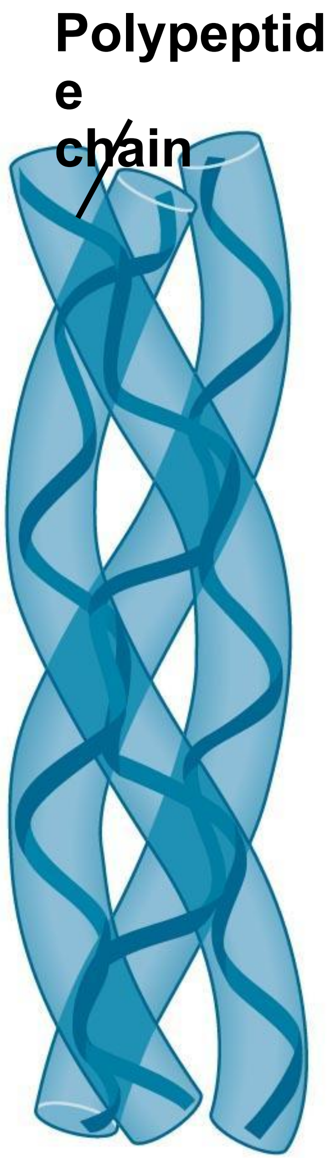
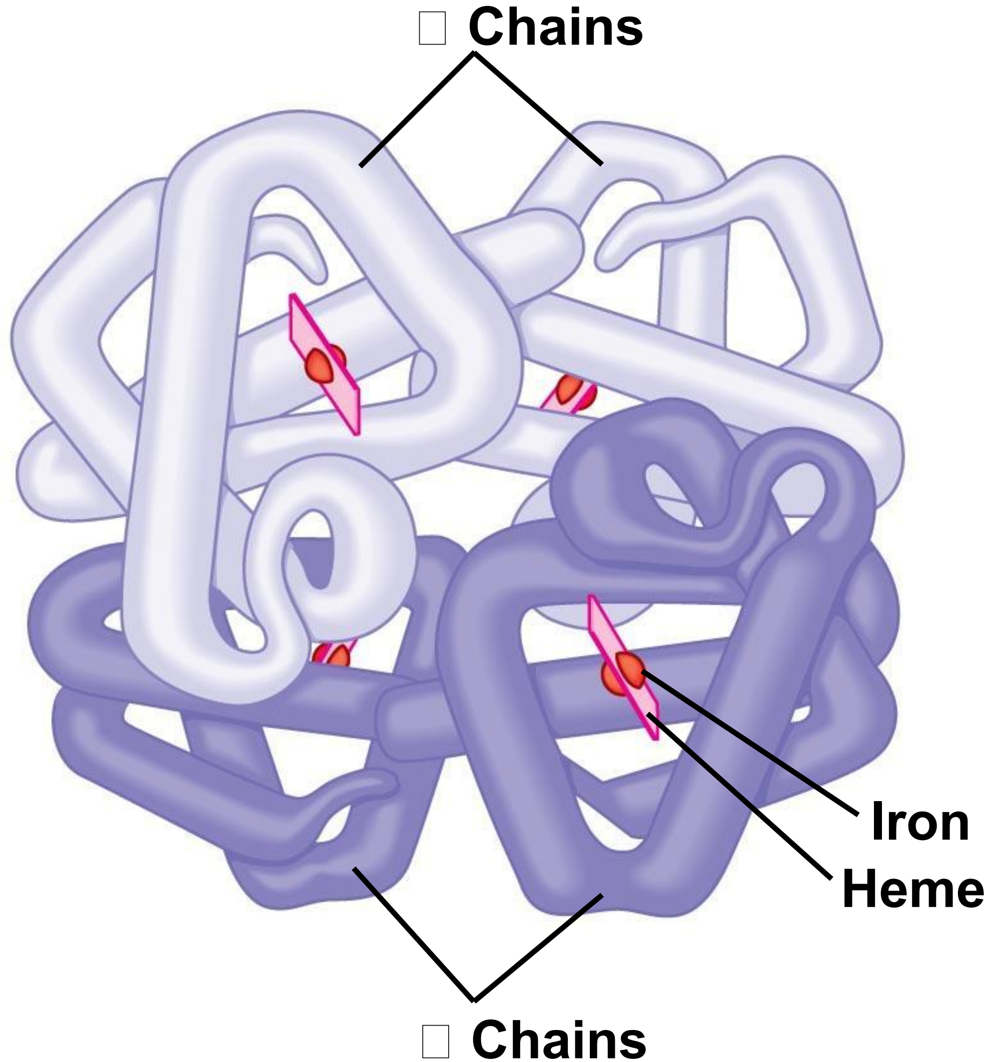

Hydrophobic interactions and van der Waals interactions
Polypeptide backbone
Hydrogen bond
Disulfide bridge
Ionic bond
CH_2
$HO-C$
CH_2
CH
H_3C
CH_3
H_3C
CH_3
CH
$-CH_2-S-S-CH_2-$
$-(CH_2)_4-NH_3^+ \; ^-O-C-CH_2-$

Fig. 5-21g



Collagen



Hemoglobin

- **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

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

Fig. 5-22

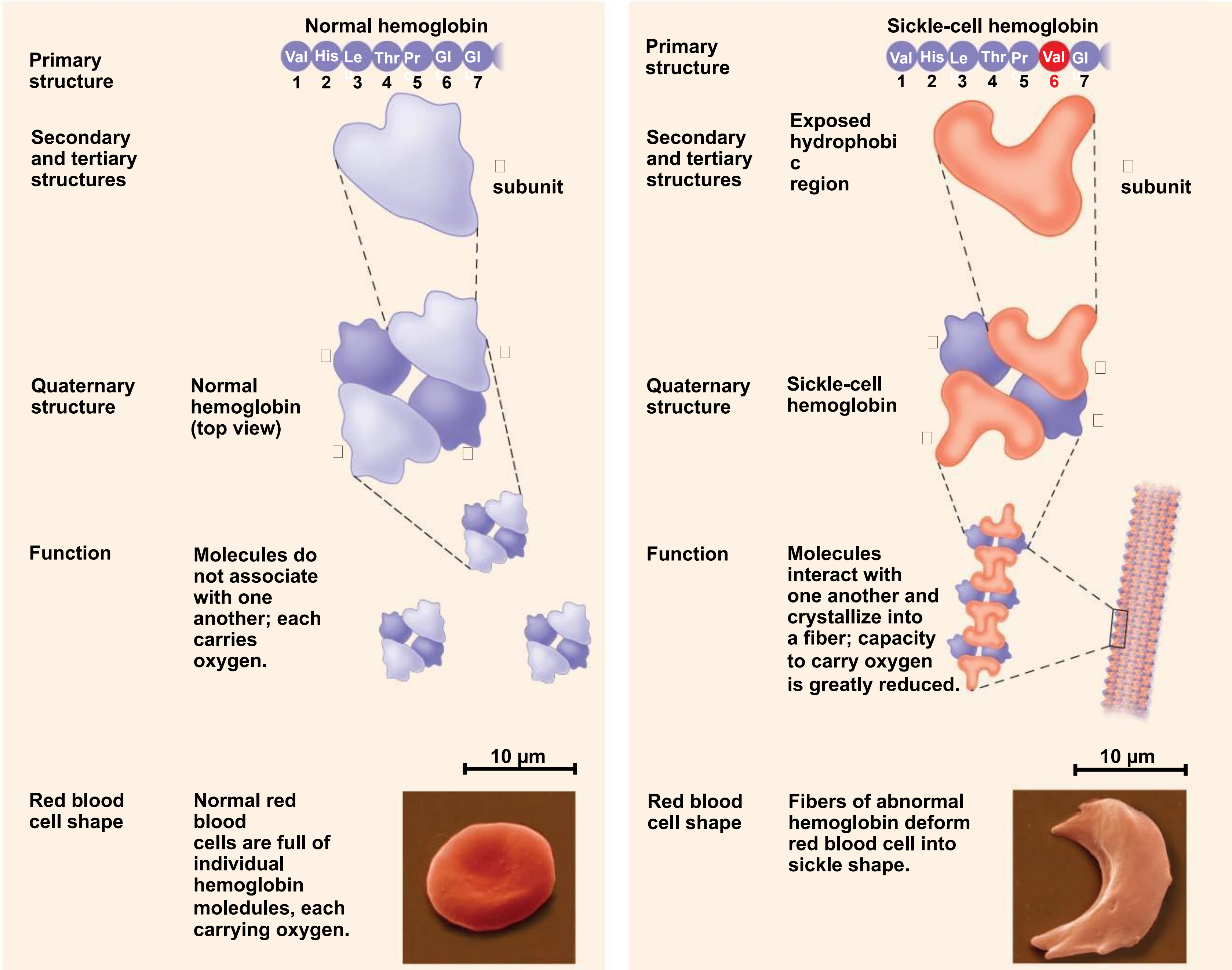
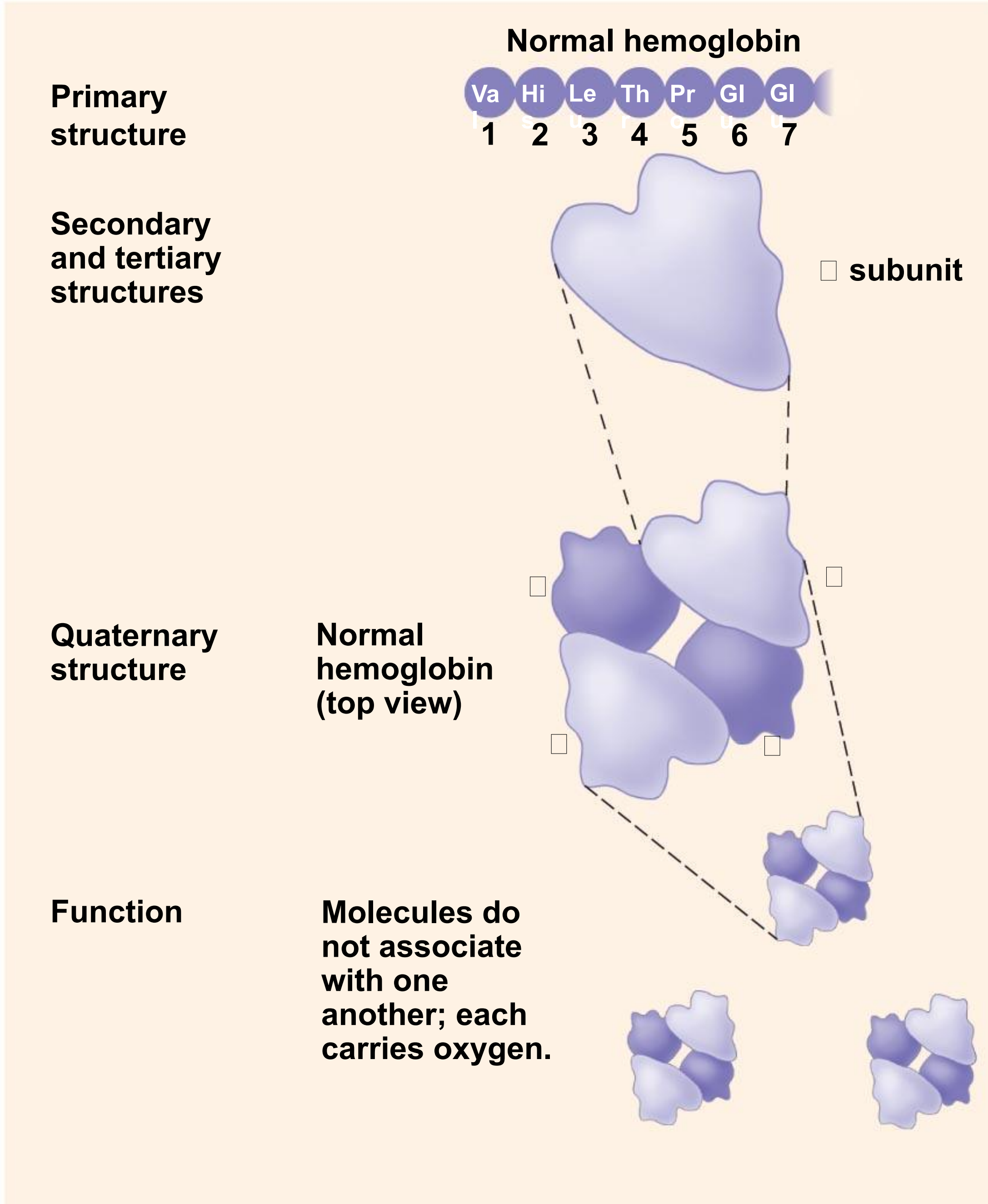

Normal hemoglobin
Primary structure
Val His Le Thr Pr Gl Gl
1 2 3 4 5 6 7
Secondary and tertiary structures
subunit
Quaternary structure
Normal hemoglobin (top view)
Function
Molecules do not associate with one another; each carries oxygen.
10 µm
Red blood cell shape
Normal red blood cells are full of individual hemoglobin moledules, each carrying oxygen.
Sickle-cell hemoglobin
Primary structure
Val His Le Thr Pr Val Gl
1 2 3 4 5 6 7
Secondary and tertiary structures
Exposed hydrophobi c region
subunit
Quaternary structure
Sickle-cell hemoglobin
Function
Molecules interact with one another and crystallize into a fiber; capacity to carry oxygen is greatly reduced.
10 µm
Red blood cell shape
Fibers of abnormal hemoglobin deform red blood cell into sickle shape.

Fig. 5-22a



Normal hemoglobin
Primary structure
Va
Hi
Le
Th
Pr
Gl
Gl
1 2 3 4 5 6 7
Secondary and tertiary structures
subunit
Quaternary structure
Normal hemoglobin (top view)
Function
Molecules do not associate with one another; each carries oxygen.

Fig. 5-22b

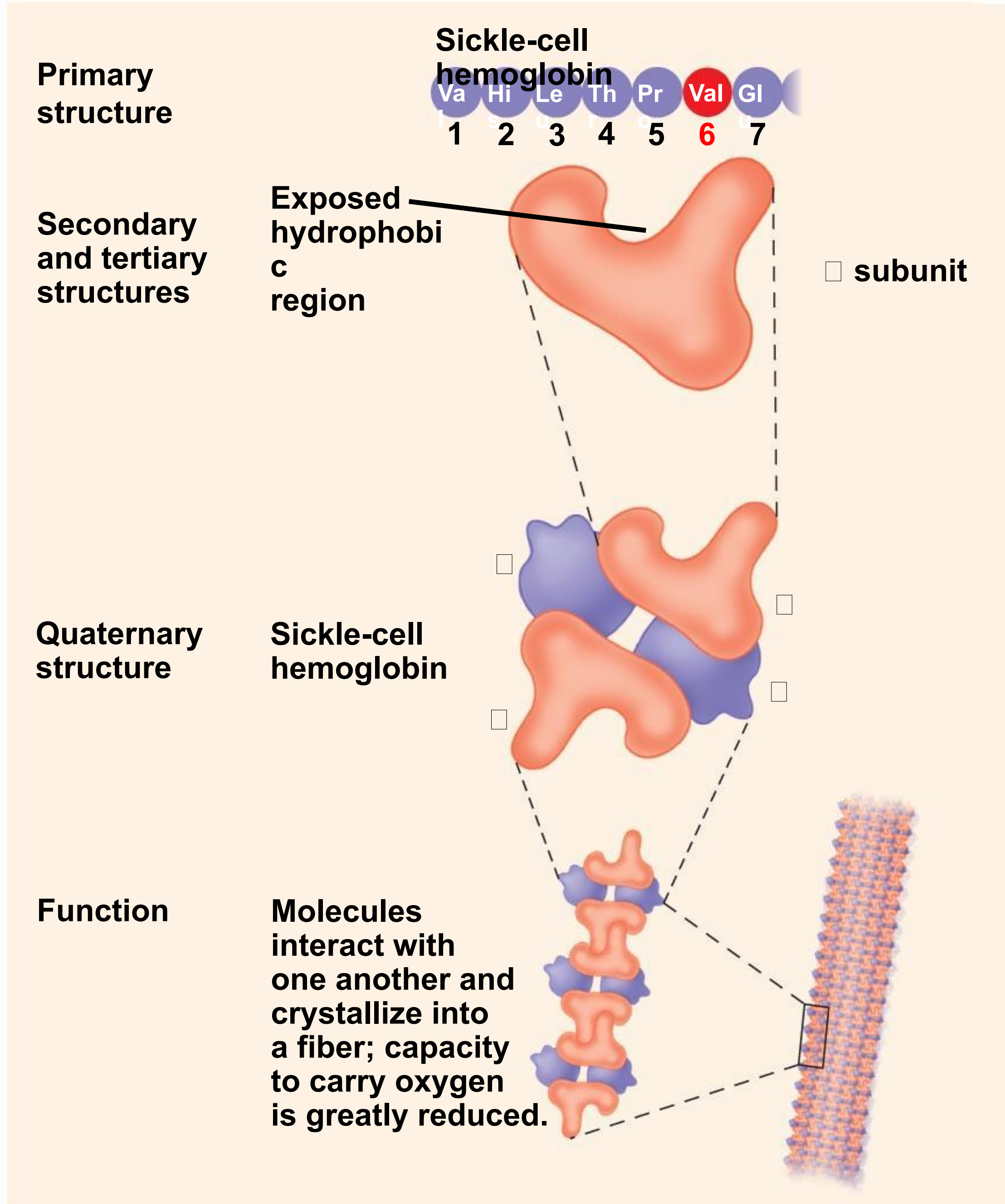
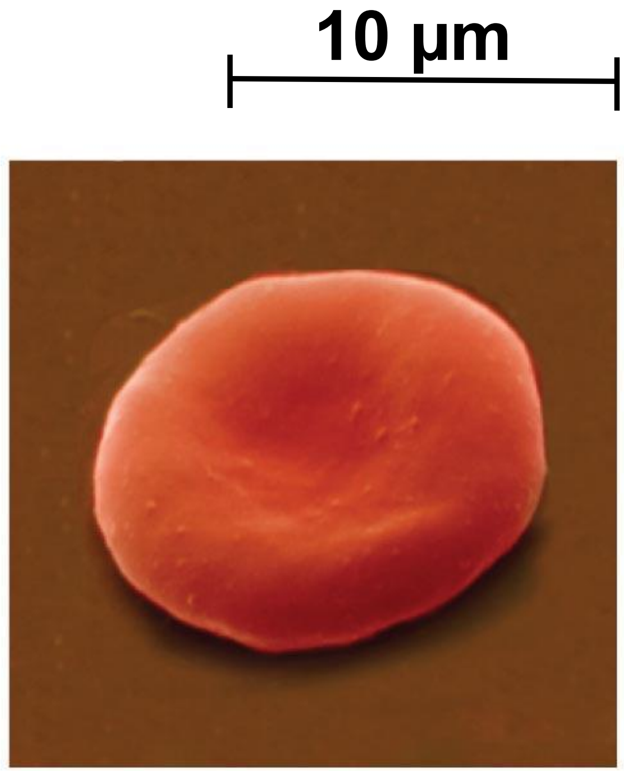
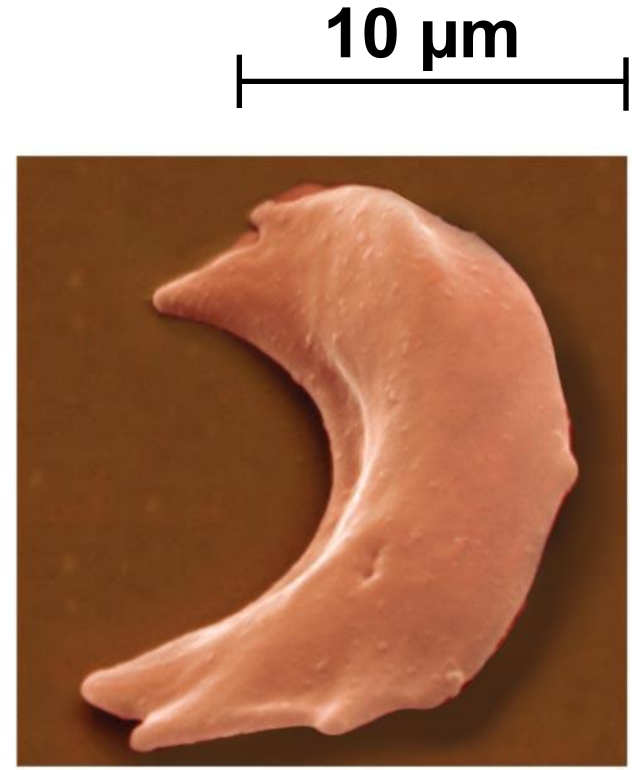

Primary structure
Sickle-cell hemoglobin
Va l
Hi s
Le u
Th r
Pr o
Val
Gl u
1 2 3 4 5 6 7
Secondary and tertiary structures
Exposed hydrophobi c region
subunit
Quaternary structure
Sickle-cell hemoglobin
Function
Molecules interact with one another and crystallize into a fiber; capacity to carry oxygen is greatly reduced.

Fig. 5-22c



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

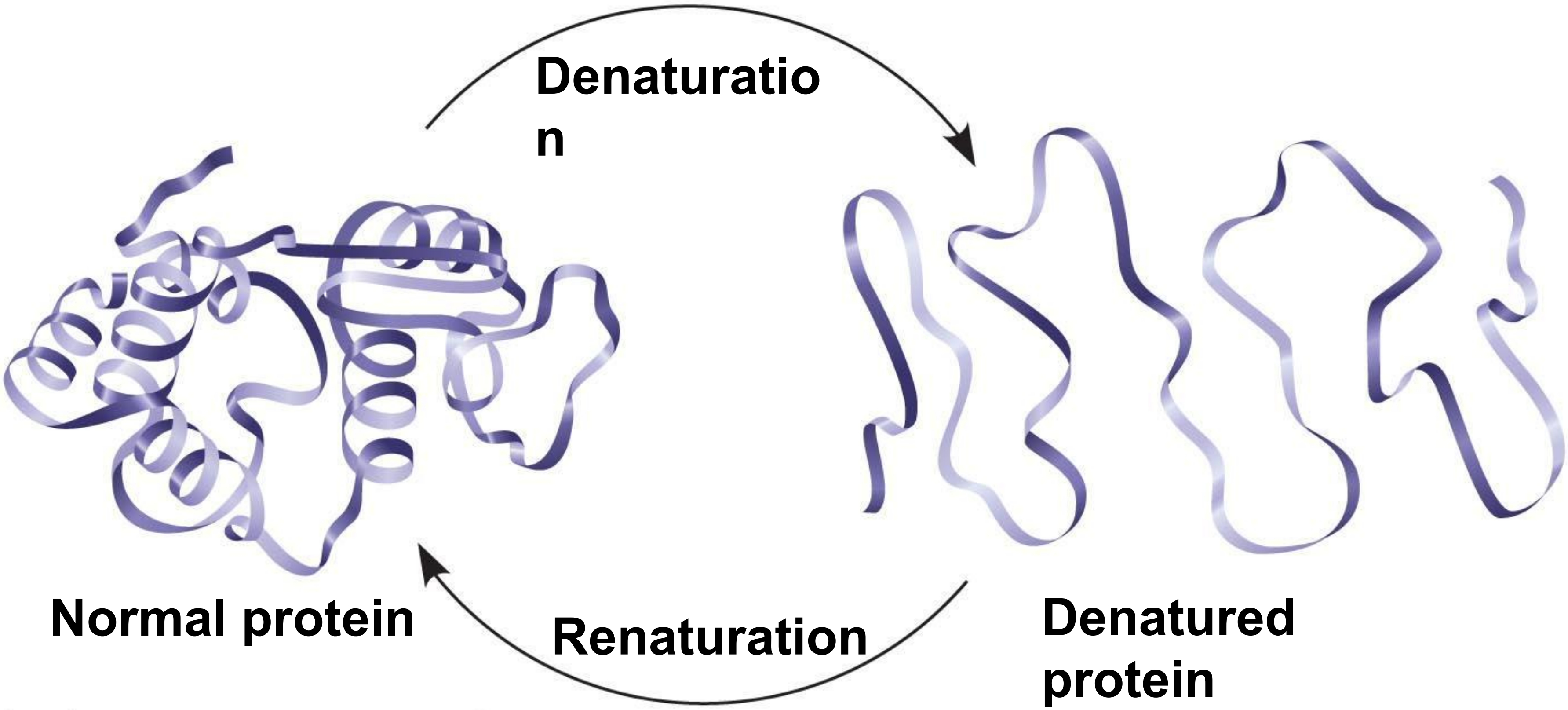


Fibers of abnormal hemoglobin deform red blood cell into sickle shape.

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

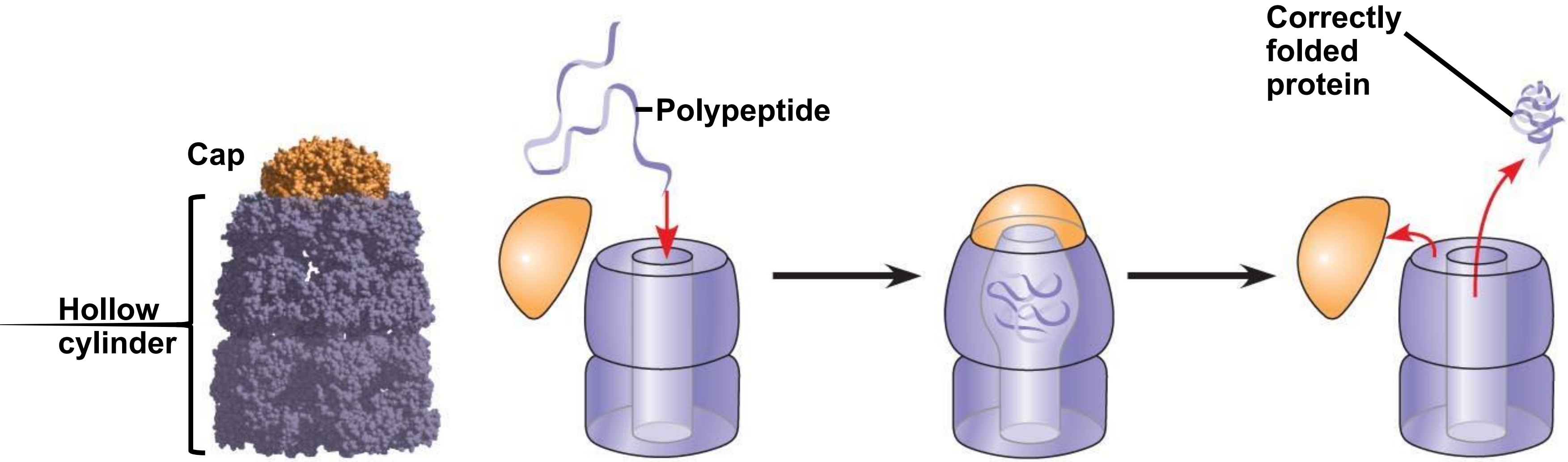
Fig. 5-23


Denaturatio
n
Normal protein
Renaturation
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 states on their way to a stable structure
- **Chaperonins** are protein molecules that assist the proper folding of other proteins

Fig. 5-24



Chaperonin (fully assembled)

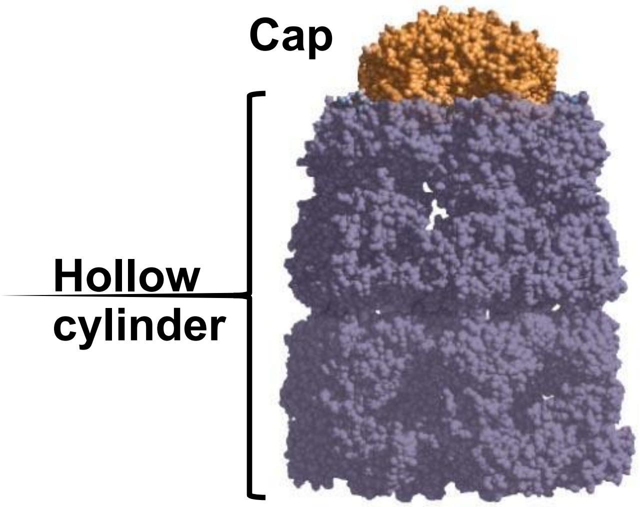
Steps of Chaperonin Action:

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.

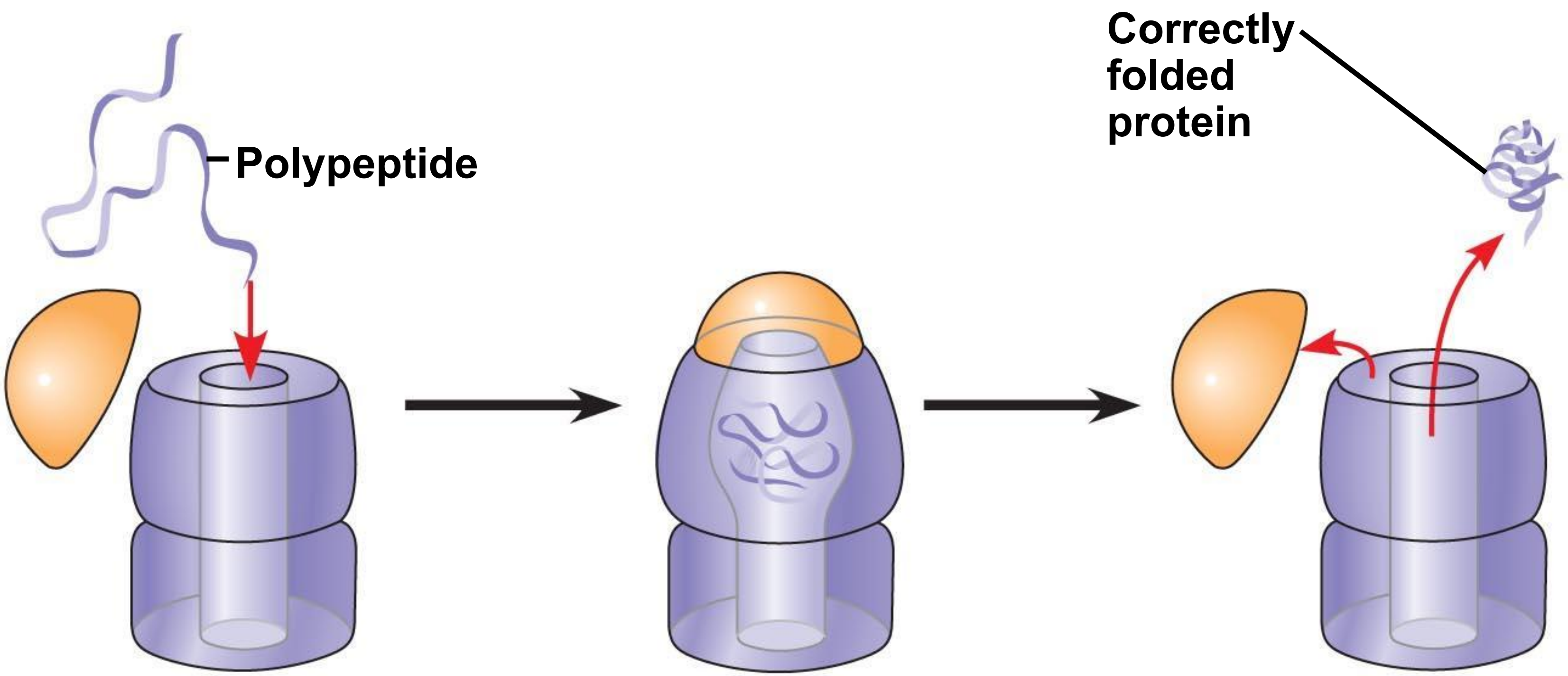
3 The cap comes off, and the properly folded protein is released.

Fig. 5-24a



Chaperonin (fully assembled)

Fig. 5-24b



Steps of Chaperonin Action:

1 An unfolded poly-peptide enters the cylinder from one end.

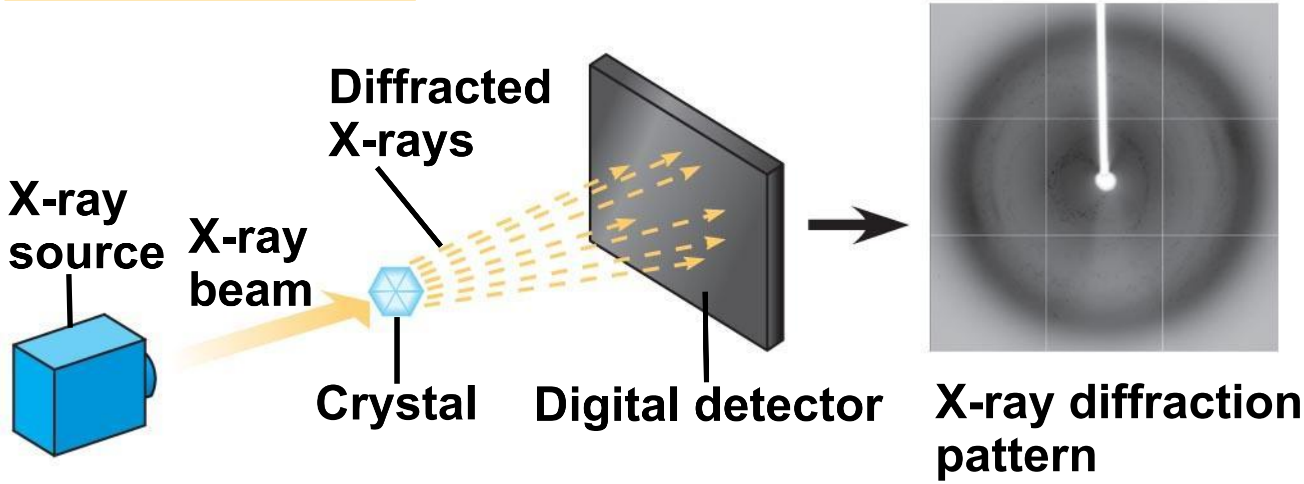
2 The cap attaches, causing the cylinder to change shape in such a way that it creates a hydrophilic environment for the folding of the polypeptide.

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

- 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

EXPERIMENT



RESULTS

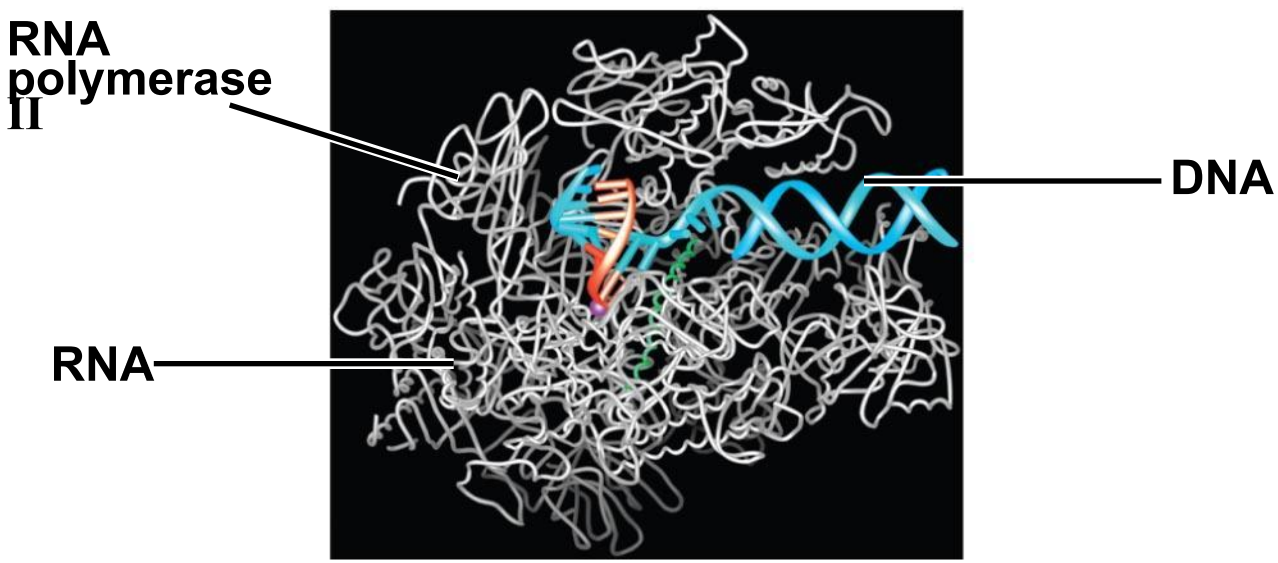


Fig. 5-25a

EXPERIMENT

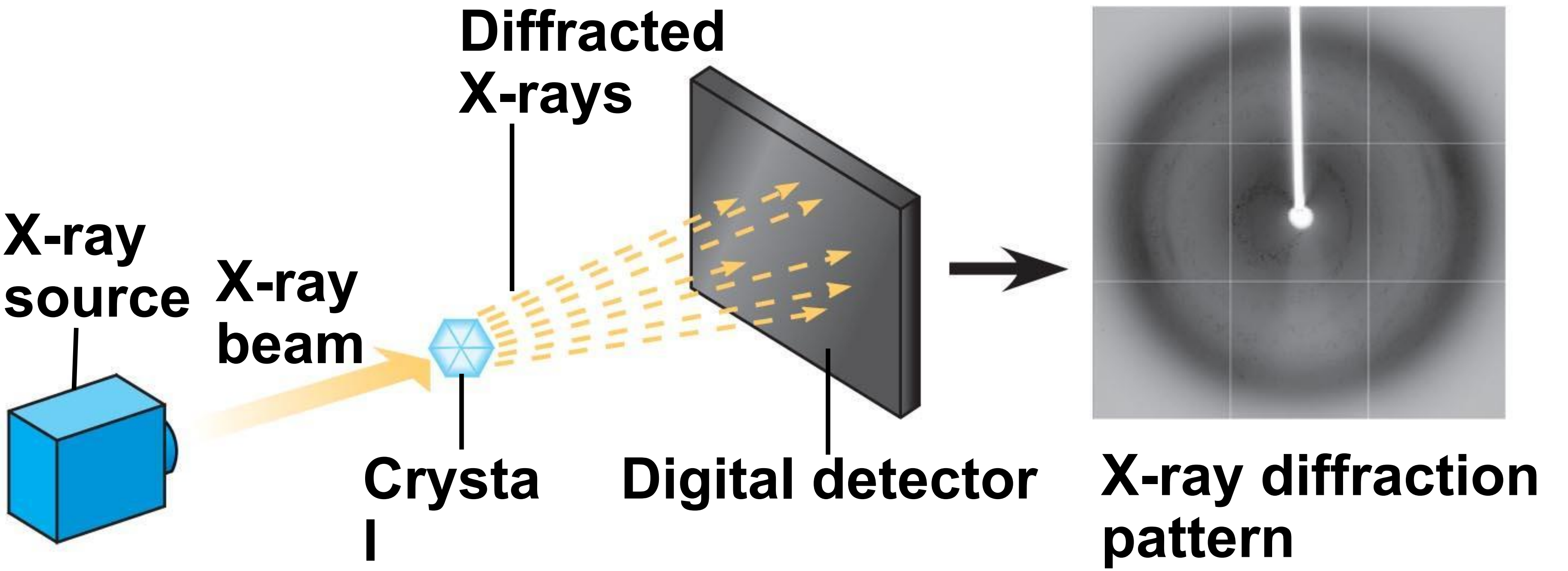
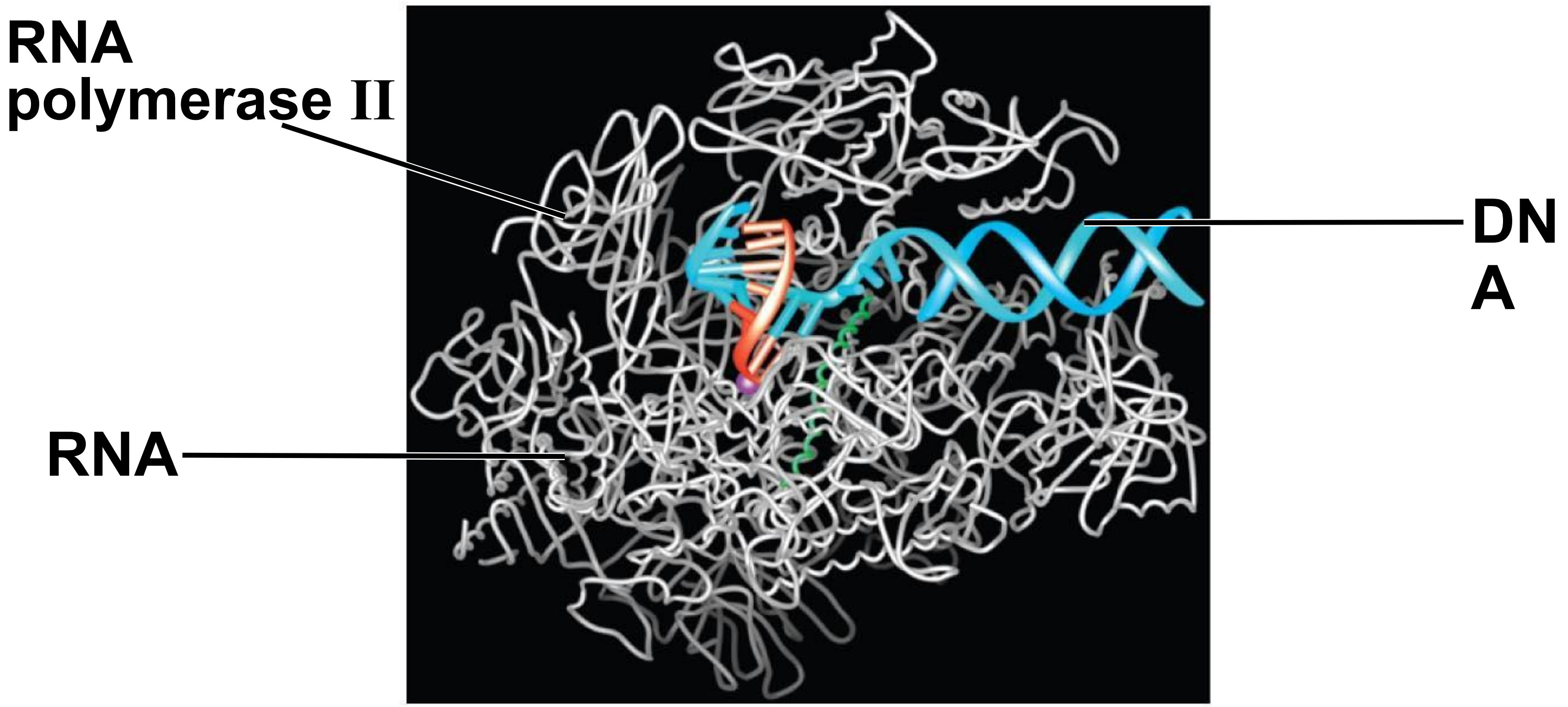


Fig. 5-25b

RESULTS



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

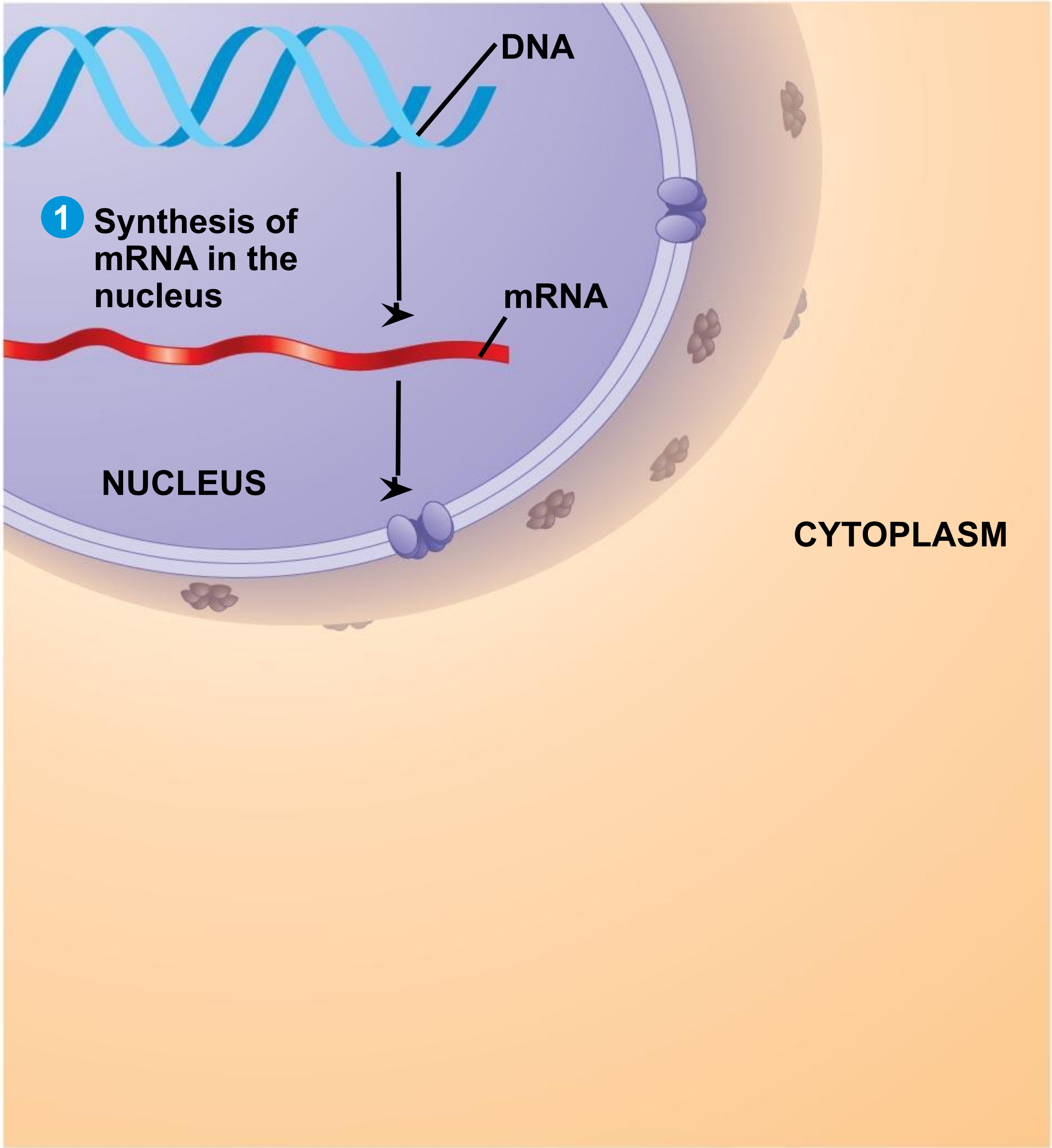

DNA
1 Synthesis of mRNA in the nucleus
mRNA
NUCLEUS
CYTOPLASM

Fig. 5-26-2

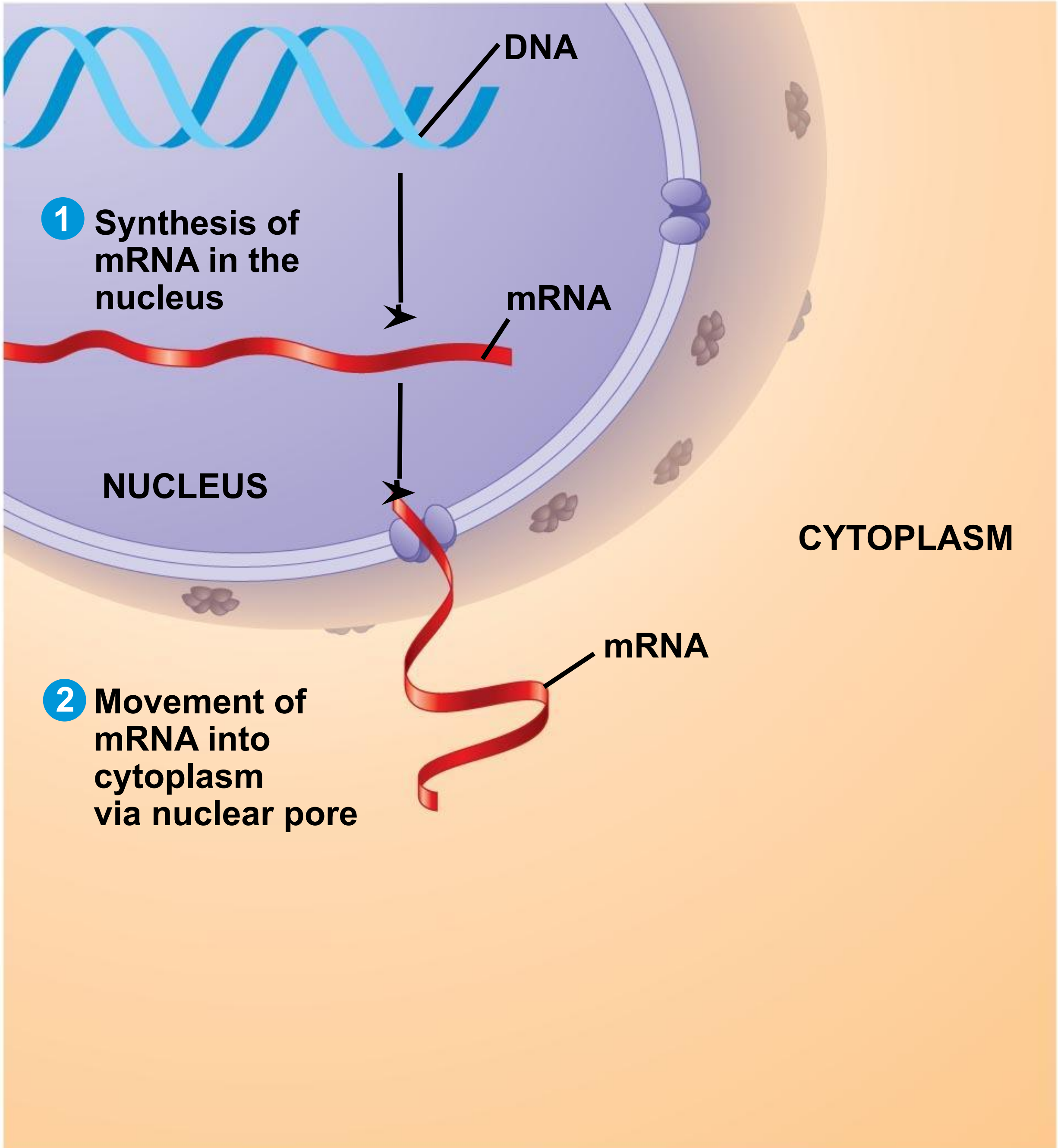
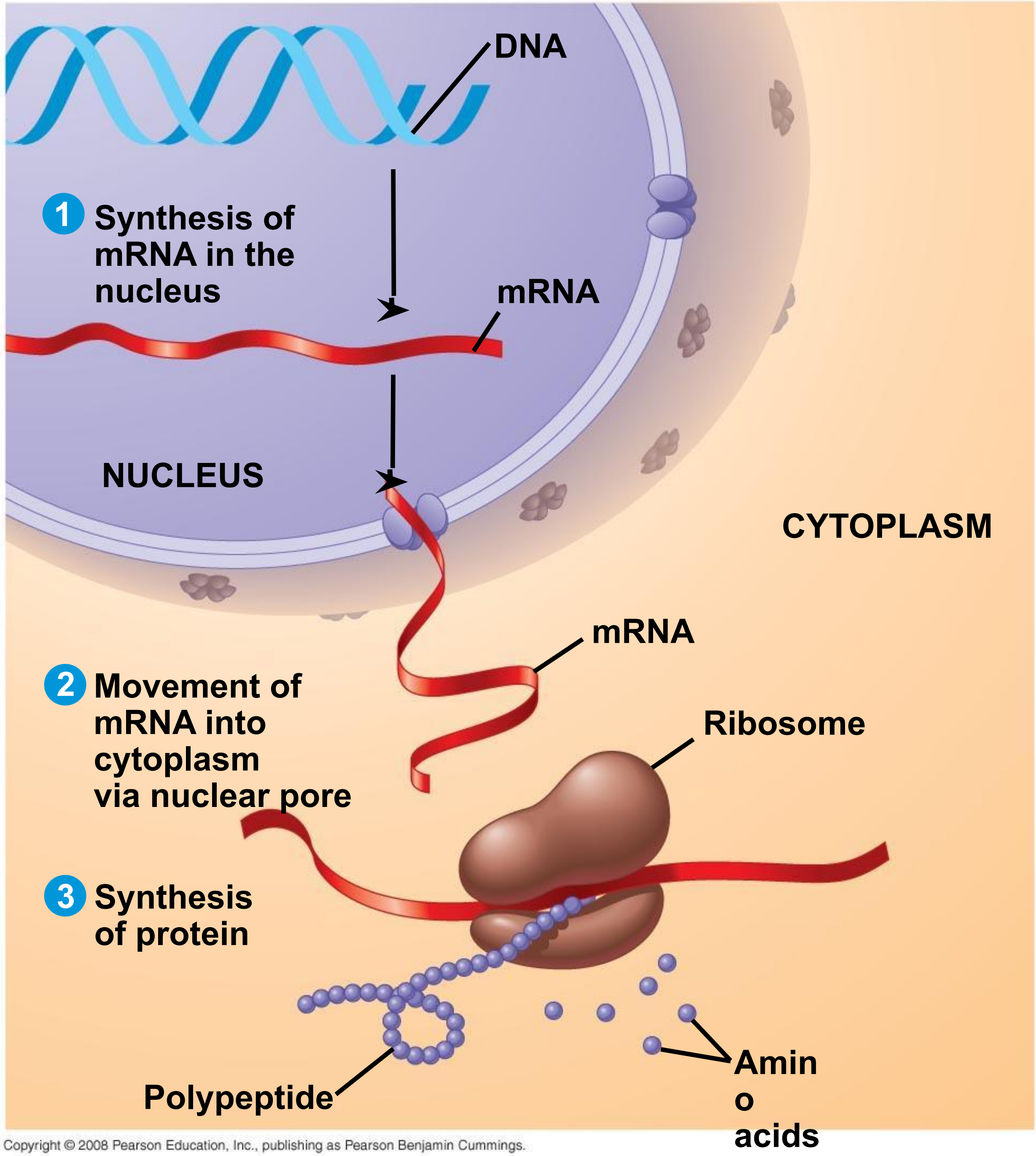

DNA
1 Synthesis of mRNA in the nucleus
mRNA
NUCLEUS
CYTOPLASM
mRNA
2 Movement of mRNA into cytoplasm via nuclear pore

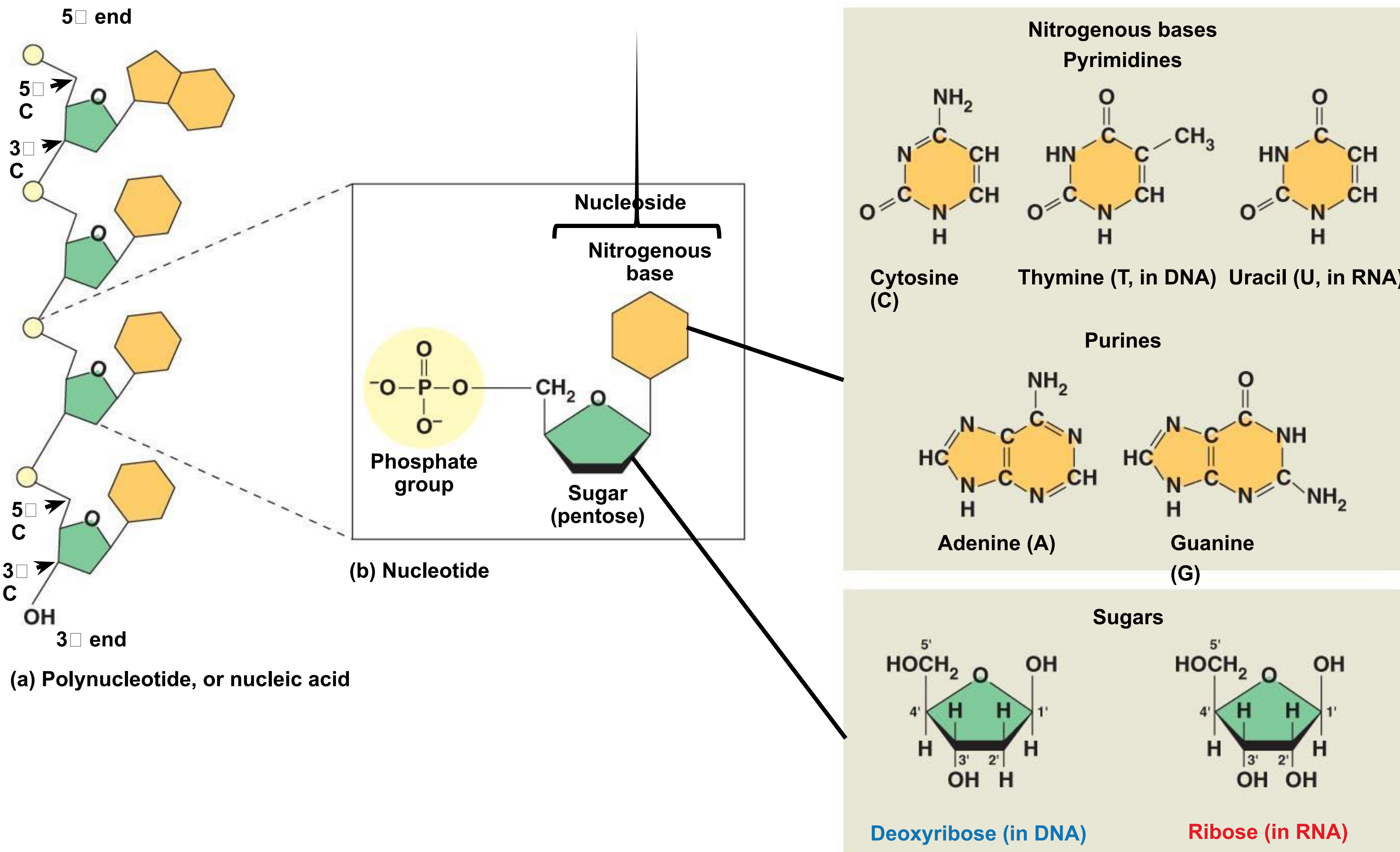
Fig. 5-26-3


DNA
1 Synthesis of mRNA in the nucleus
mRNA
NUCLEUS
CYTOPLASM
mRNA
2 Movement of mRNA into cytoplasm via nuclear pore
Ribosome
3 Synthesis of protein
Polypeptide
Amin
o
acids

The Structure of Nucleic Acids

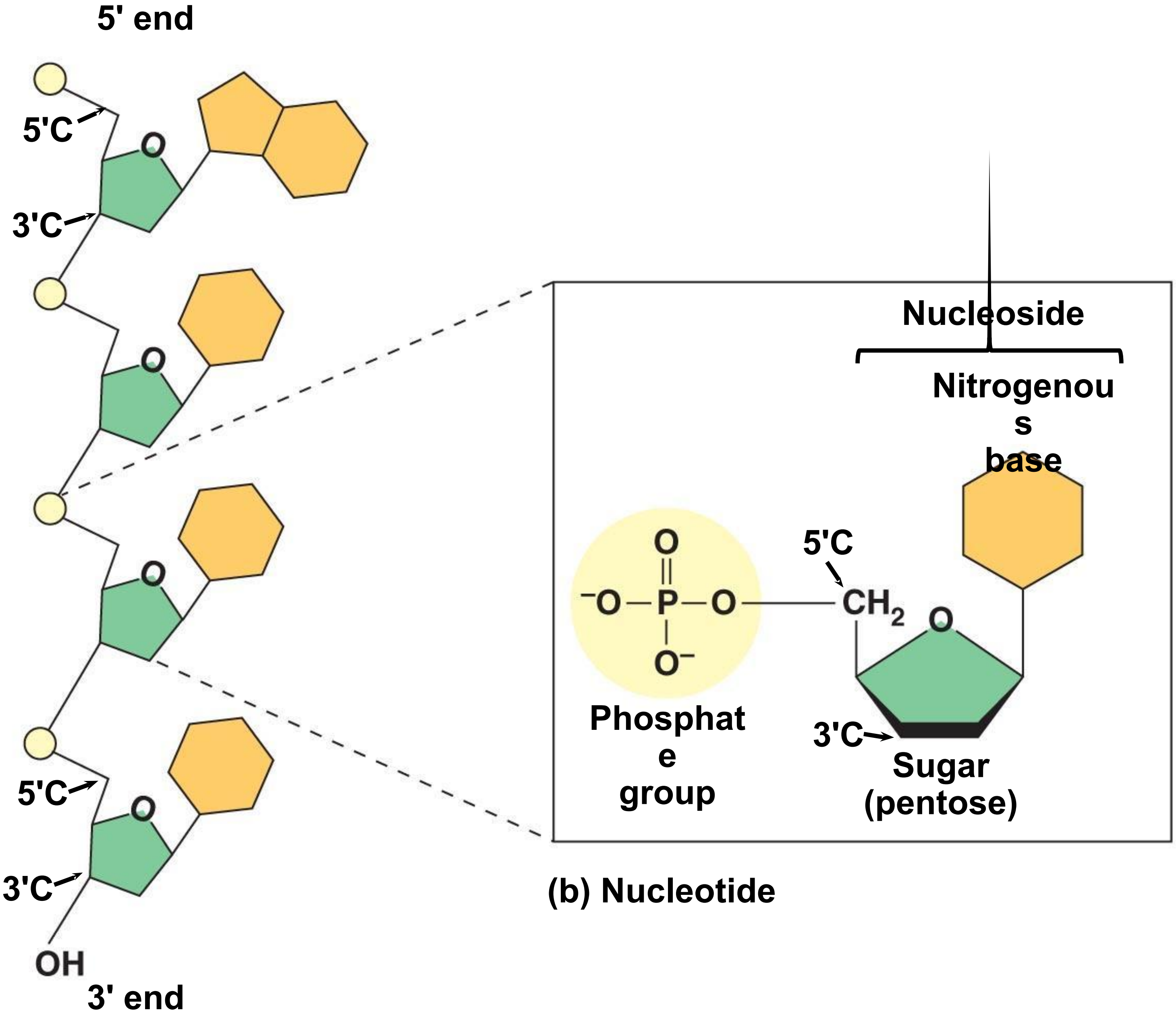
- Nucleic acids are polymers called **polynucleotides**
- Each polynucleotide is made of monomers called **nucleotides**
- Each nucleotide consists of a nitrogenous base, a pentose sugar, and a phosphate group
- The portion of a nucleotide without the phosphate group is called a *nucleoside*

Fig. 5-27



(c) Nucleoside components: sugars

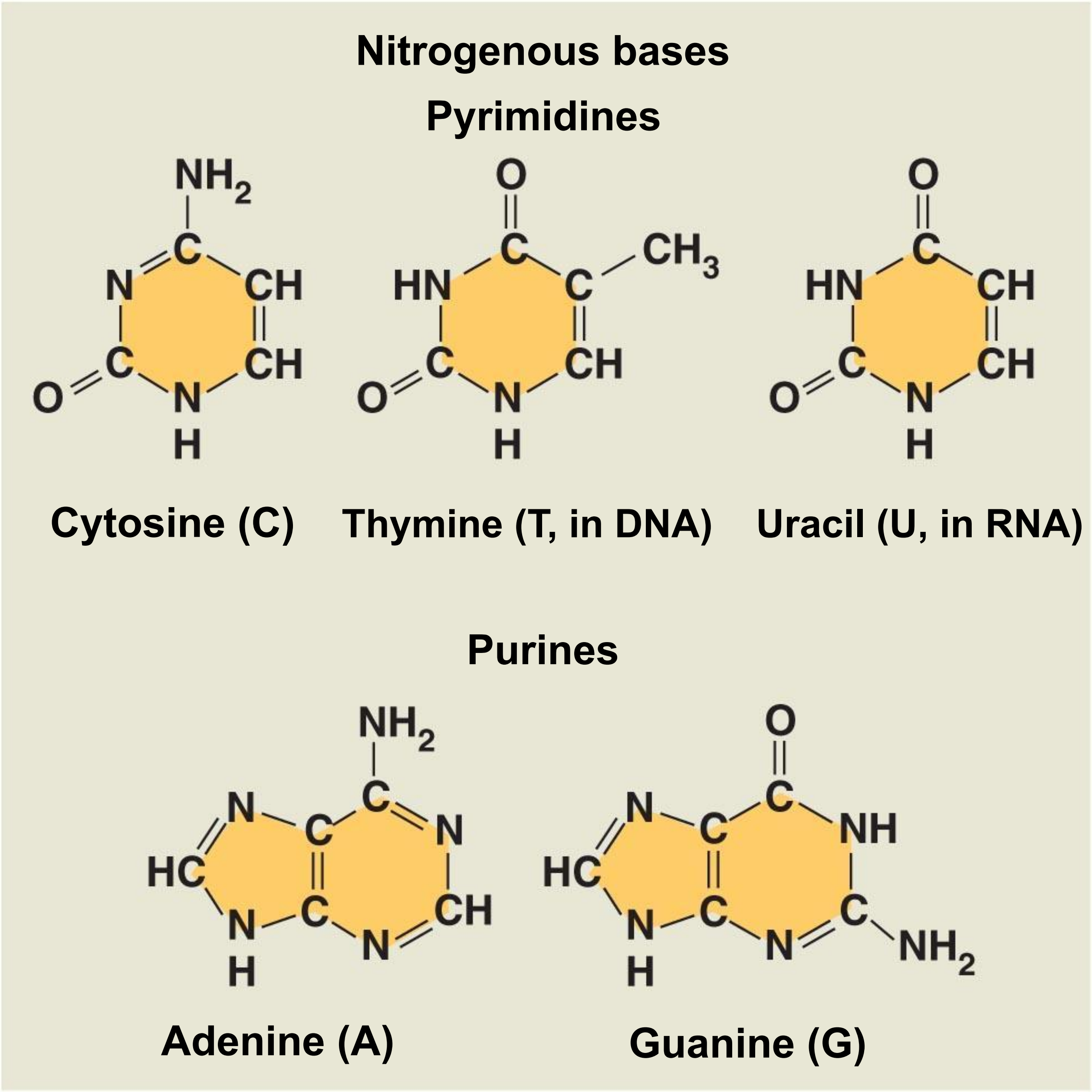
Fig. 5-27ab



(b) Nucleotide

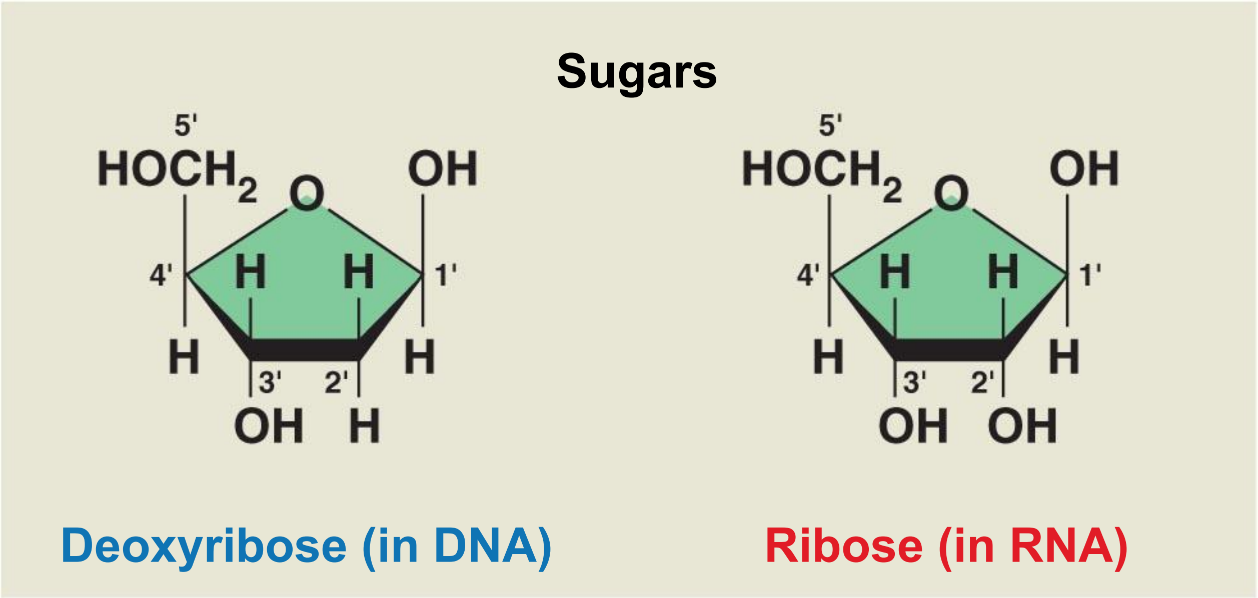
(a) Polynucleotide, or nucleic acid

Fig. 5-27c-1



(c) Nucleoside components: nitrogenous bases

Fig. 5-27c-2



(c) Nucleoside components: sugars

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

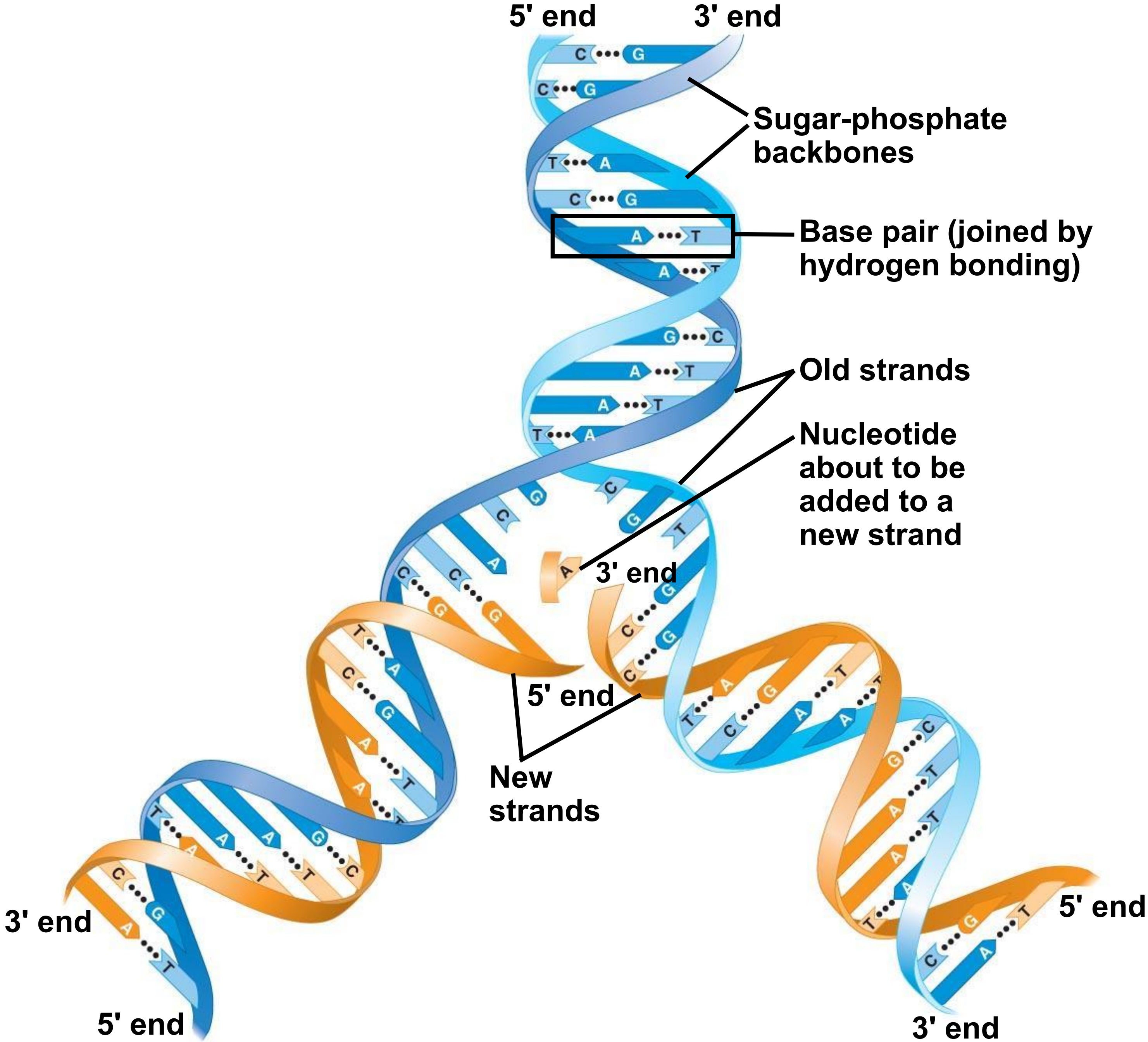
Nucleotide Polymers

- 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 $5' \rightarrow 3'$ 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)

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

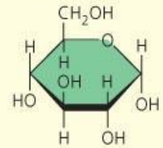
DNA and Proteins as Tape Measures of Evolution

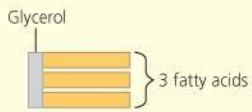
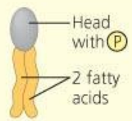
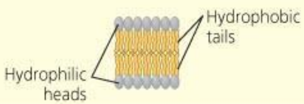
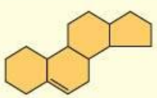
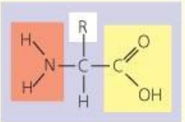
- The linear sequences of nucleotides in DNA molecules are passed from parents to offspring
- Two closely related species are more similar in DNA than are more distantly related species
- Molecular biology can be used to assess evolutionary kinship

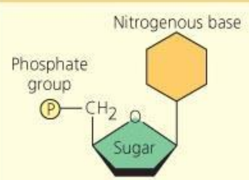
The Theme of Emergent Properties in the Chemistry of Life: *A Review*

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

Fig. 5-UN2

<table>
<tr><th>Large Biological Molecules</th><th>Components</th><th>Examples</th><th>Functions</th></tr>
<tr><td rowspan="3">Concept 5.2
Carbohydrates serve as fuel and building material</td><td rowspan="3">

Monosaccharide monomer</td><td>Monosaccharides: glucose, fructose</td><td rowspan="2">Fuel; carbon sources that can be converted to other molecules or combined into polymers</td></tr>
<tr><td>Disaccharides: lactose, sucrose</td></tr>
<tr><td>Polysaccharides:
• Cellulose (plants)
• Starch (plants)
• Glycogen (animals)
• Chitin (animals and fungi)</td><td>• Strengthens plant cell walls
• Stores glucose for energy
• Stores glucose for energy
• Strengthens exoskeletons and fungal cell walls</td></tr>
<tr><td rowspan="3">Concept 5.3
Lipids are a diverse group of hydrophobic molecules and are not macromolecules</td><td>
</td><td>Triacylglycerols (fats or oils): glycerol + 3 fatty acids</td><td>Important energy source
</td></tr>
<tr><td>
</td><td>Phospholipids: phosphate group + 2 fatty acids</td><td>Lipid bilayers of membranes

</td></tr>
<tr><td>
Steroid backbone</td><td>Steroids: four fused rings with attached chemical groups</td><td>• Component of cell membranes (cholesterol)
• Signals that travel through the body (hormones)</td></tr>
<tr><td>Concept 5.4
Proteins have many structures, resulting in a wide range of functions</td><td>

Amino acid monomer (20 types)</td><td>• Enzymes
• Structural proteins
• Storage proteins
• Transport proteins
• Hormones
• Receptor proteins
• Motor proteins
• Defensive proteins</td><td>• 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</td></tr>
<tr><td rowspan="2">Concept 5.5
Nucleic acids store and transmit hereditary information</td><td rowspan="2">

Nucleotide monomer</td><td>DNA: 
• Sugar = deoxyribose
• Nitrogenous bases = C, G, A, T
• Usually double-stranded</td><td>Stores all hereditary information</td></tr>
<tr><td>RNA: 
• Sugar = ribose
• Nitrogenous bases = C, G, A, U
• Usually single-stranded</td><td>Carries protein-coding instructions from DNA to protein-synthesizing machinery</td></tr>
</table>

Fig. 5-UN2a

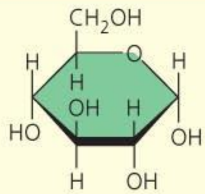
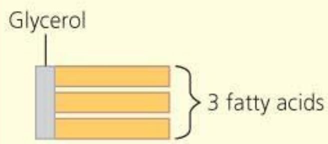
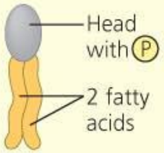
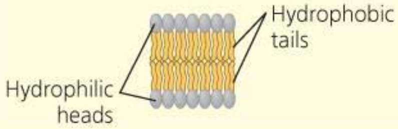
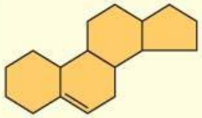
Large Biological Molecules	Components	Examples	Functions
Concept 5.2 **Carbohydrates** serve as fuel and building material	 Monosaccharide monomer	Monosaccharides: glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Disaccharides: lactose, sucrose	
		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 and are not macromolecules		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) • Signals that travel through the body (hormones)

Fig. 5-UN2b

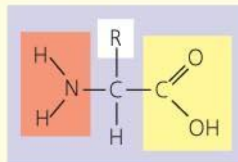
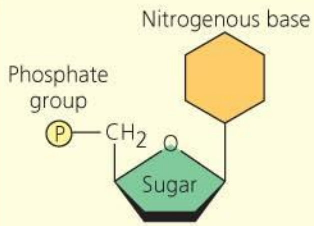
Large Biological Molecules	Components	Examples	Functions
Concept 5.4 **Proteins** have many structures, resulting in a wide range of functions	 Amino acid monomer (20 types)	• Enzymes • Structural proteins • Storage proteins • Transport proteins • Hormones • Receptor proteins • Motor proteins • Defensive 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 and transmit hereditary information	 Nucleotide monomer	DNA:  • Sugar = deoxyribose • Nitrogenous bases = C, G, A, T • Usually double-stranded	Stores all hereditary information
		RNA:  • Sugar = ribose • Nitrogenous bases = C, G, A, U • Usually single-stranded	Carries protein-coding instructions from DNA to protein-synthesizing machinery

Fig. 5-UN3

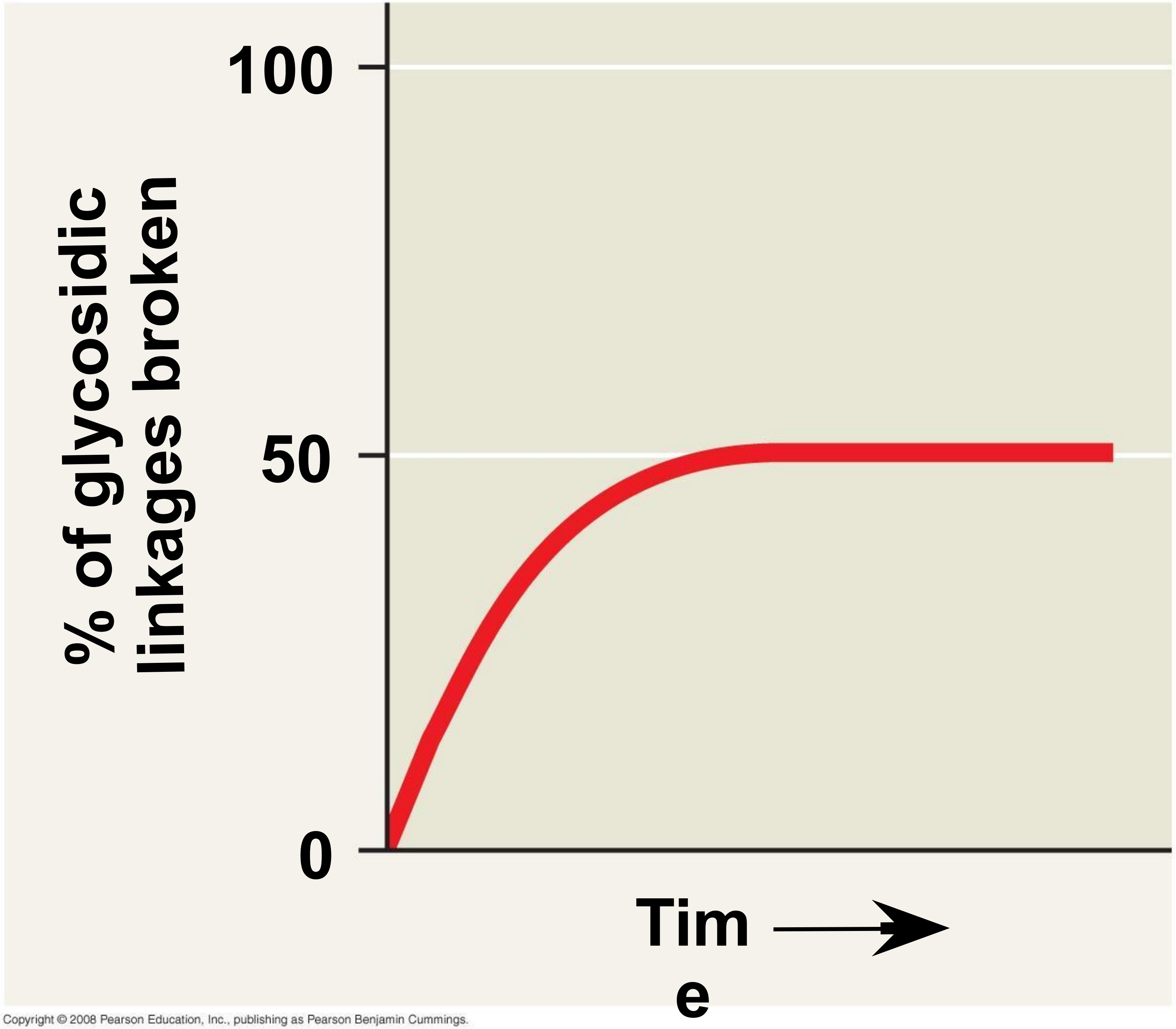


Fig. 5-UN4

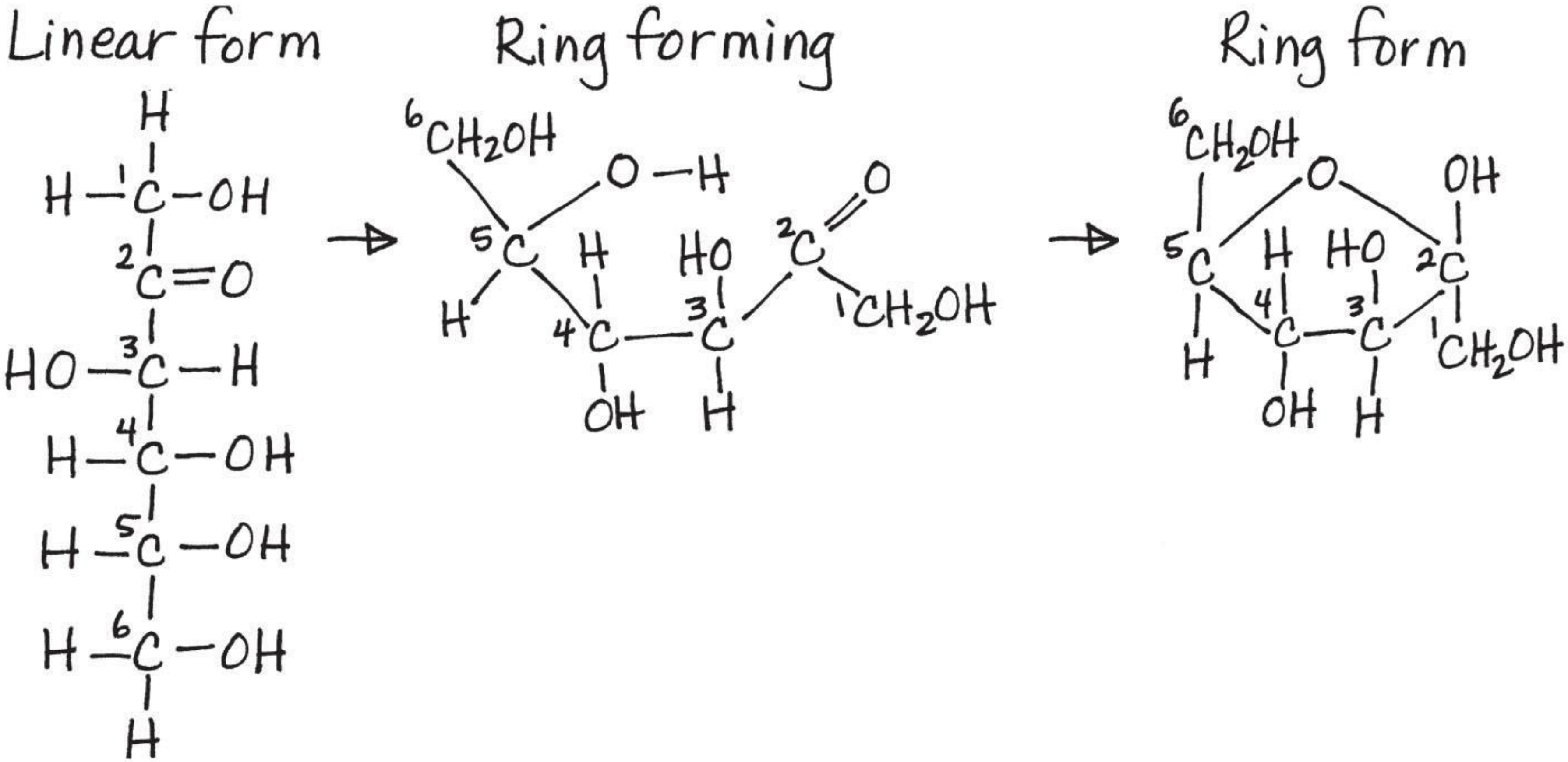


Fig. 5-UN5

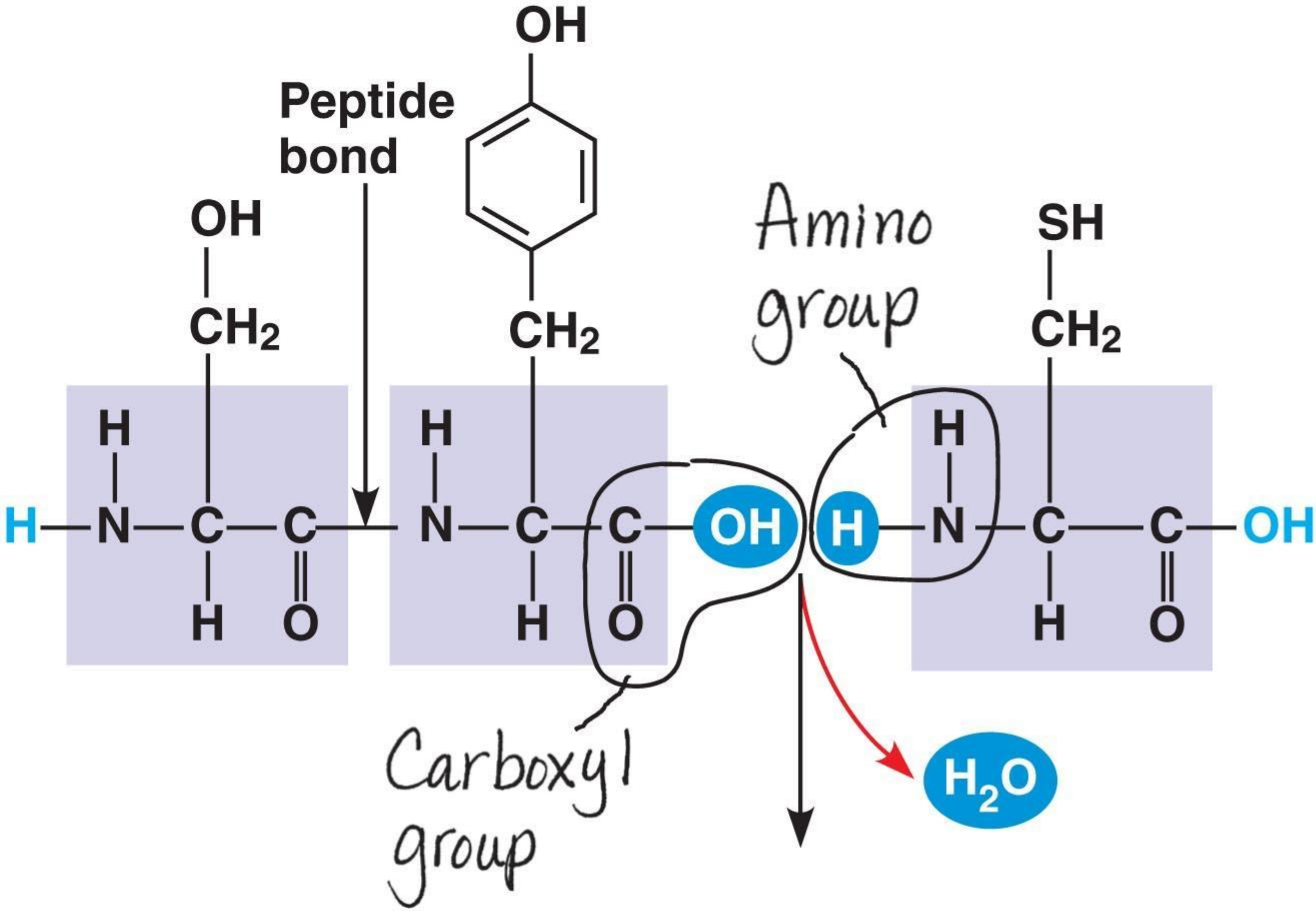

OH
Peptide bond
OH
CH2
CH2
Amino group
SH
CH2
H
H
H
H—N—C—C
N—C—C—
OH
H
—N—C—C—OH
H O
H O
H O
Carboxyl group
H2O

Fig. 5-UN6

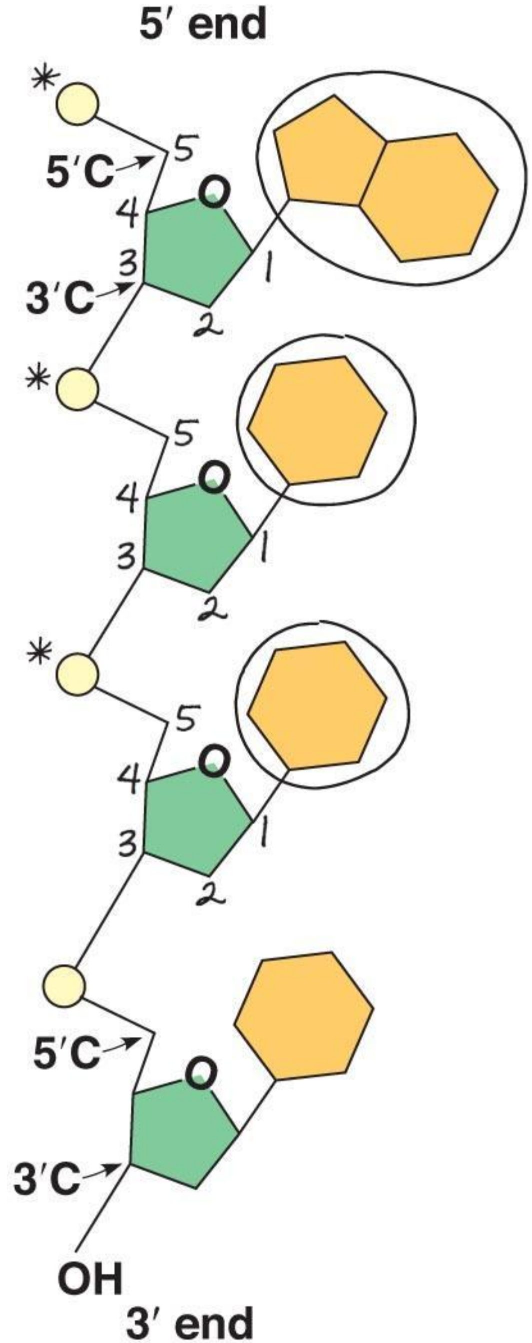


Fig. 5-UN7

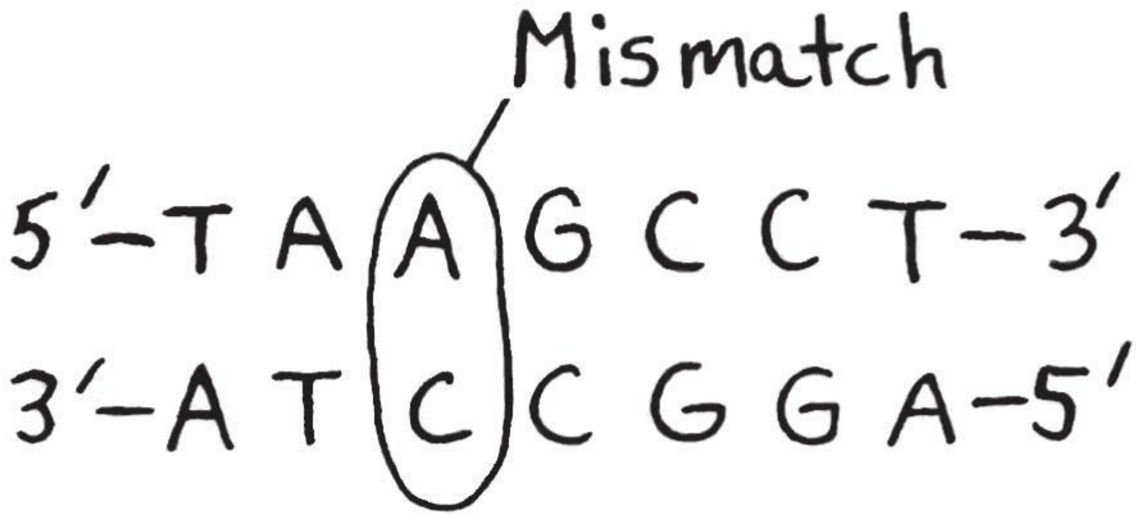


Fig. 5-UN8

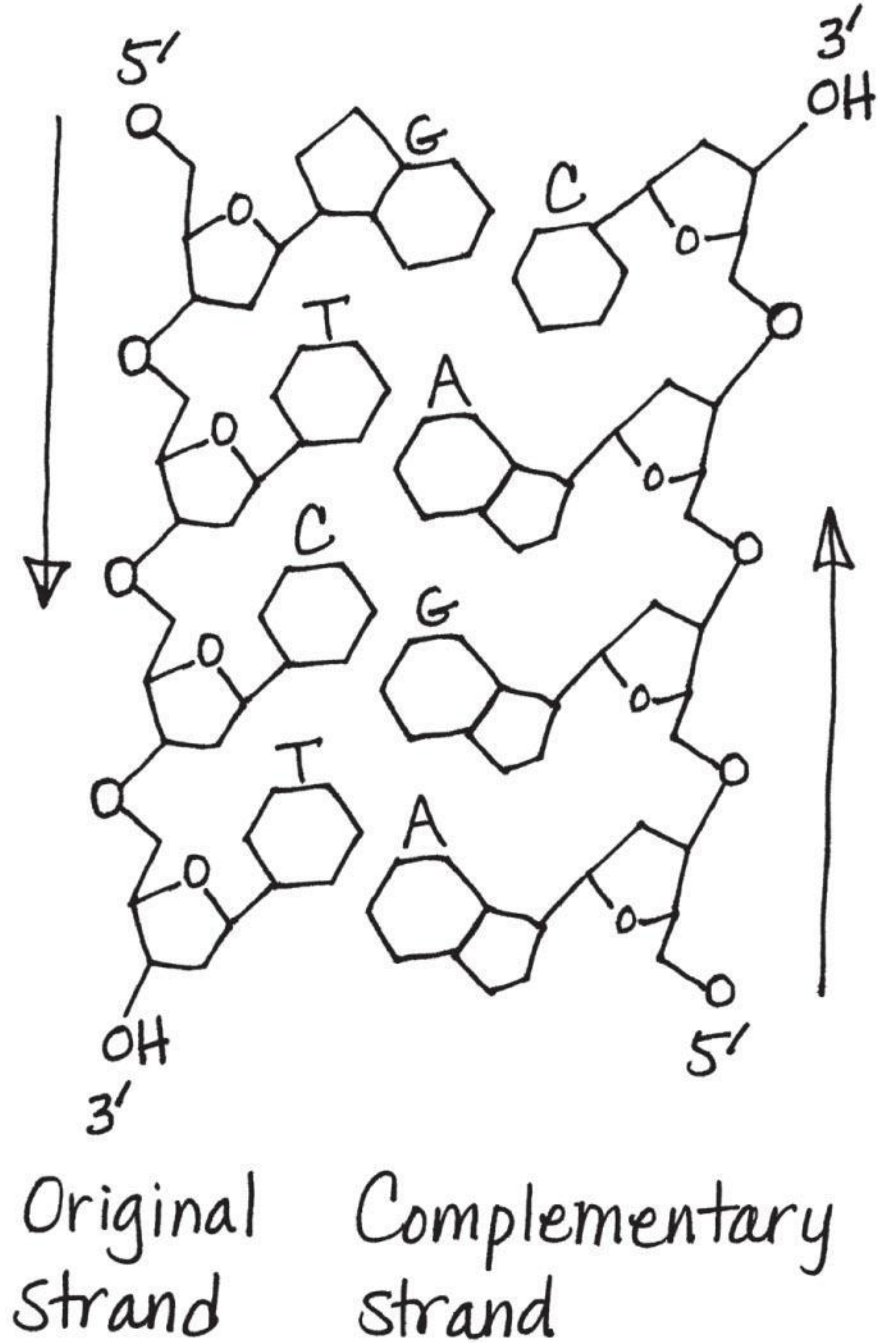
5′–T A A G C C T–3′

3′–A T T C G G A–5′

Fig. 5-UN9

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

Fig. 5-UN10



You should now be able to:

1. List and describe the four major classes of molecules
2. Describe the formation of a glycosidic linkage and distinguish between monosaccharides, disaccharides, and polysaccharides
3. Distinguish between saturated and unsaturated fats and between *cis* and *trans* fat molecules
4. Describe the four levels of protein structure

You should now be able to:

5. Distinguish between the following pairs: pyrimidine and purine, nucleotide and nucleoside, ribose and deoxyribose, the 5′ end and 3′ end of a nucleotide