Chapter 5

The Structure and Function of Large Biological Molecules

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

Neil Campbell and Jane Reece

Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

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

Why do scientists study the structures of macromolecules?

Concept 5.1: Macromolecules are polymers, built from monomers

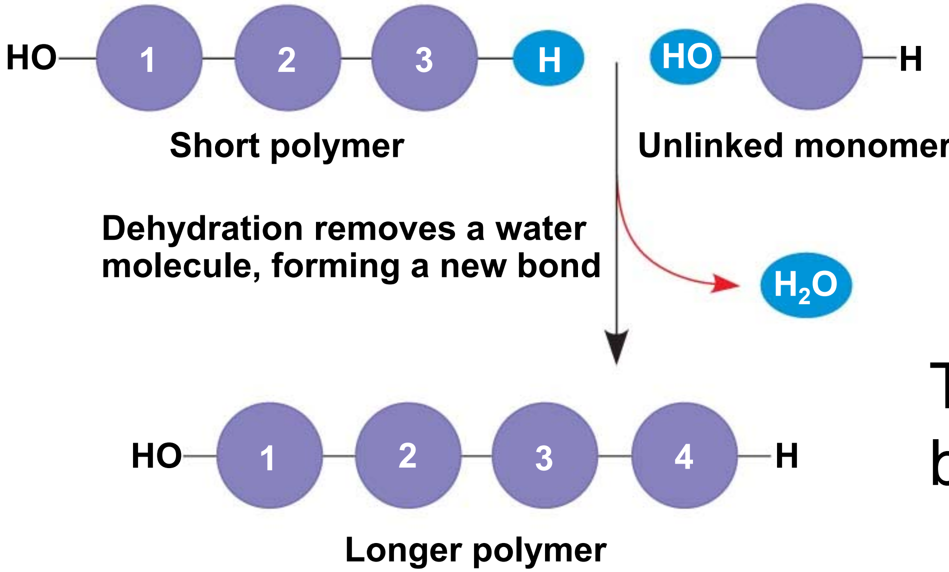
- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**
- Three of the four classes of life's organic molecules are polymers:
  – Carbohydrates
  – Proteins
  – Nucleic acids

The Synthesis and Breakdown of Polymers

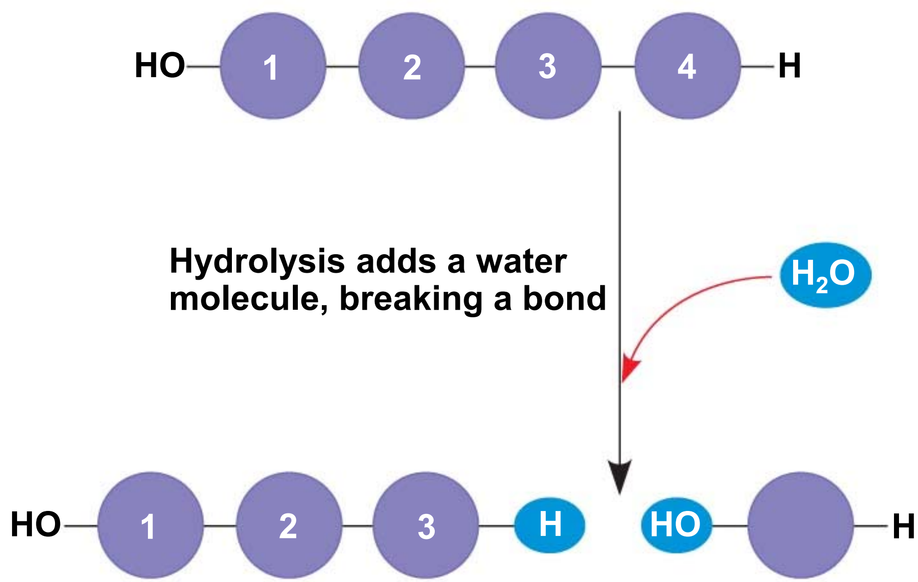
- A **condensation reaction** or more specifically a **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule
- **Enzymes** are macromolecules that speed up the dehydration process
- Polymers are disassembled to monomers by **hydrolysis**, a reaction that is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

Fig. 5-2

The synthesis and breakdown of polymers



(a) Dehydration reaction in the synthesis of a polymer



(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

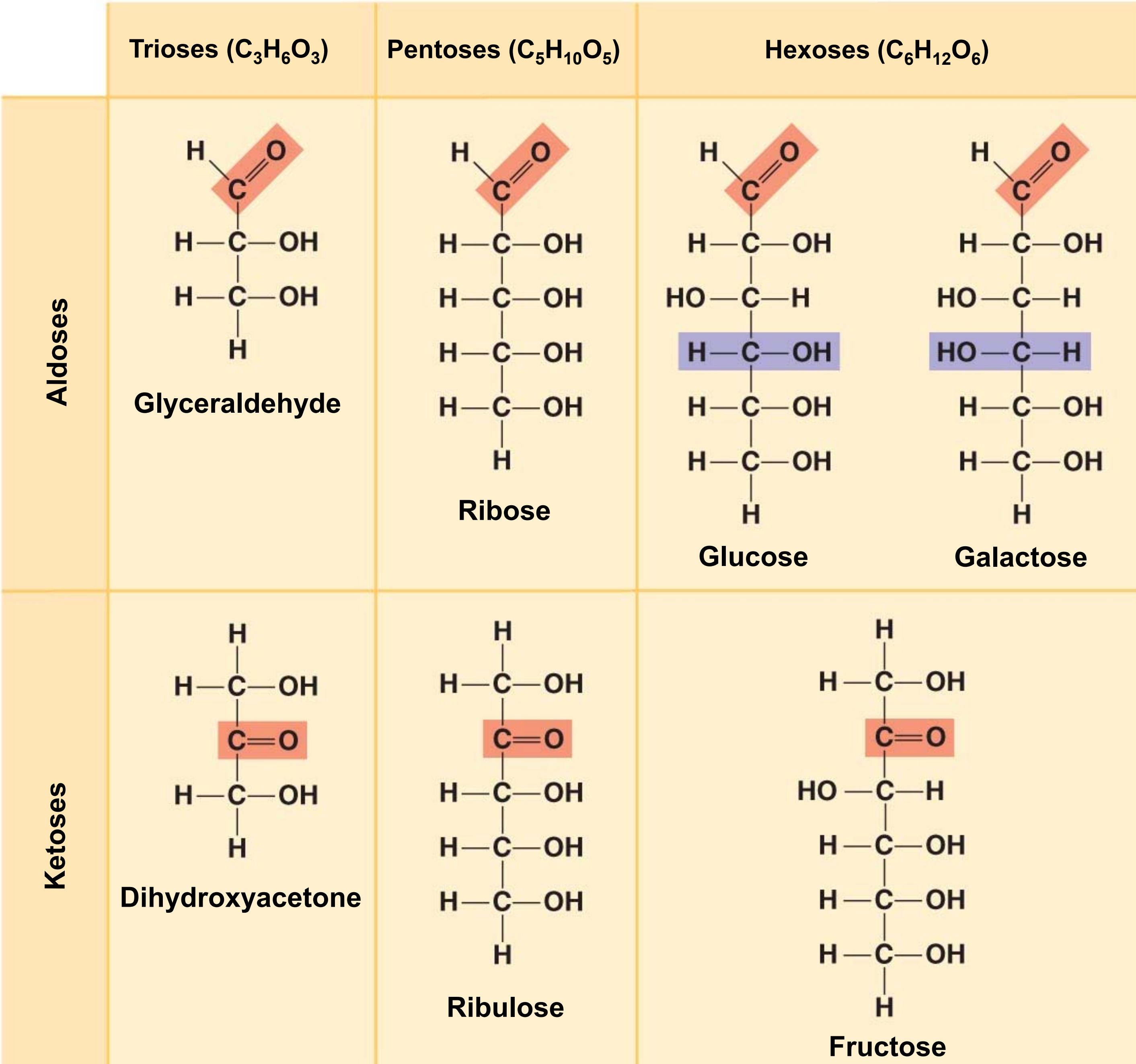
Concept 5.2: Carbohydrates serve as fuel and building material

- **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

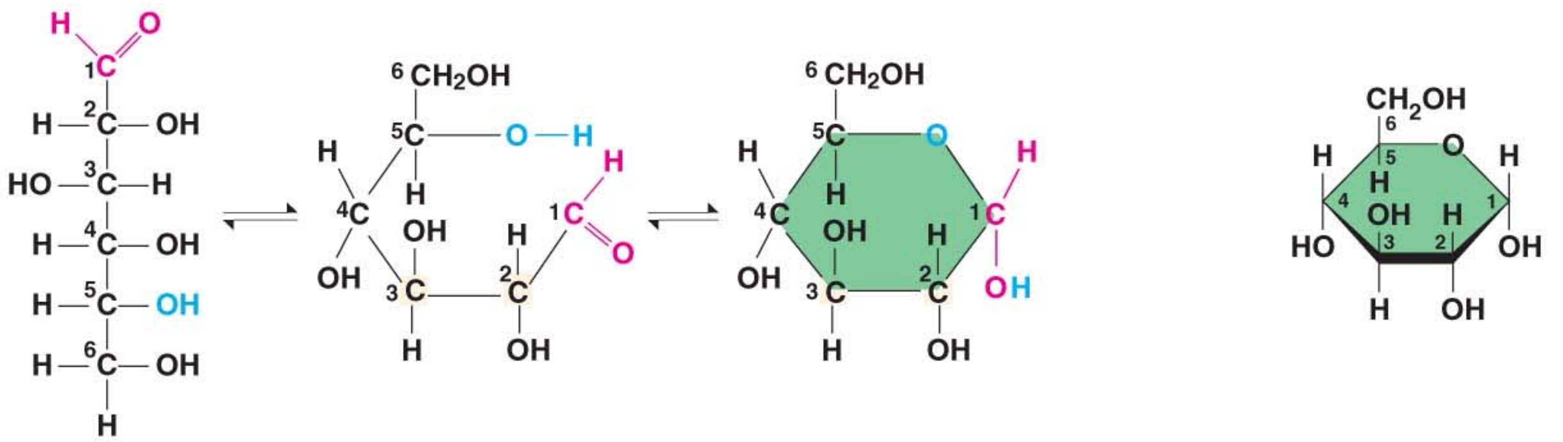
Fig. 5-3


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

Fig. 5-4

Linear and ring forms of glucose



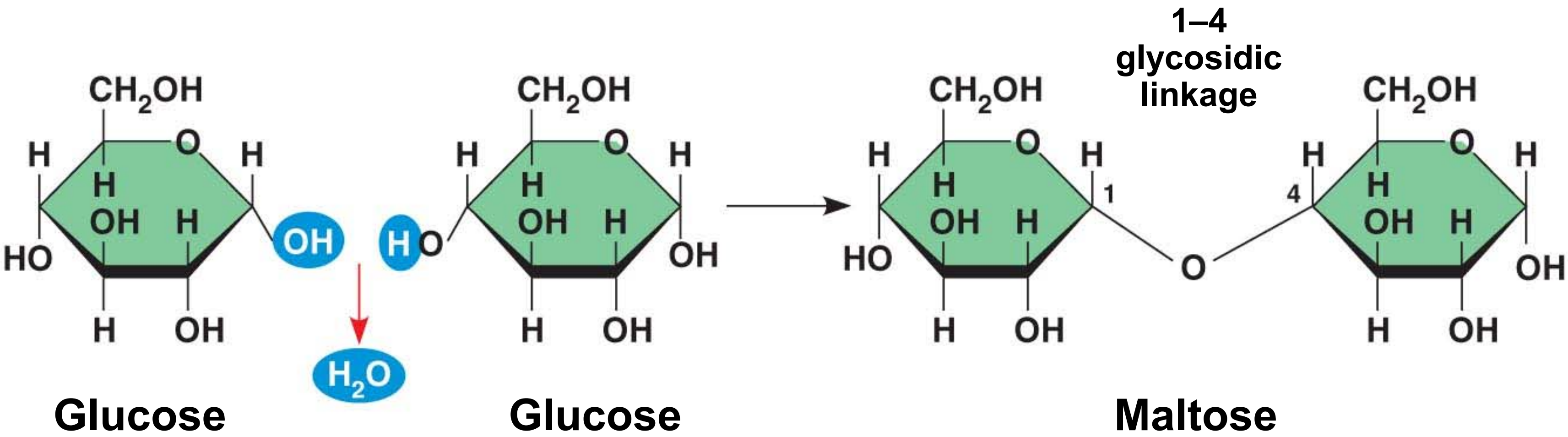
(a) Linear and ring forms

(b) Abbreviated ring structure

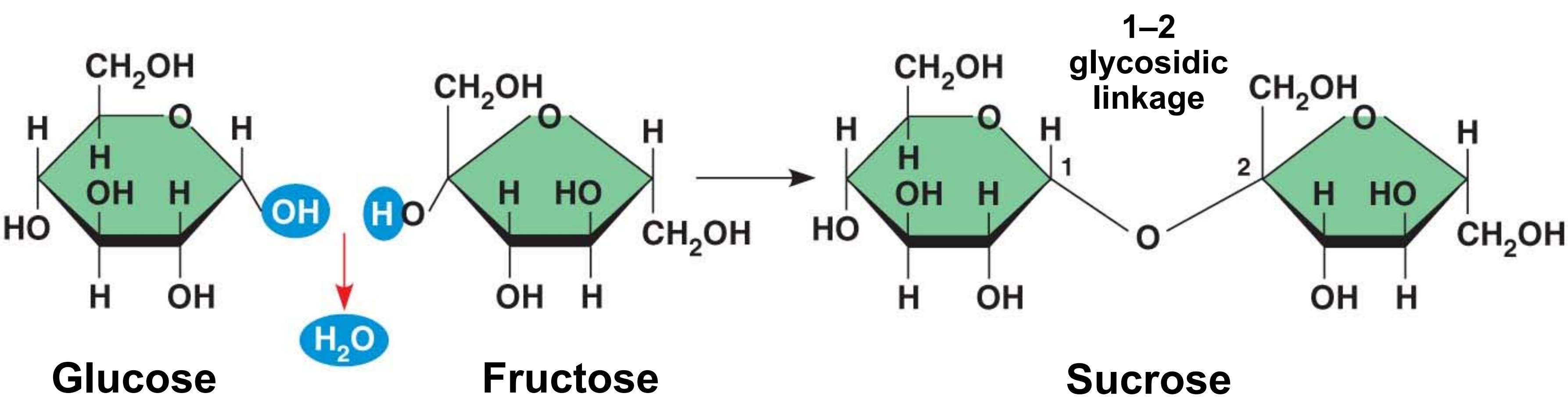
- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**

Fig. 5-5

Examples of disaccharide synthesis



(a) Dehydration reaction in the synthesis of maltose



(b) Dehydration reaction in the synthesis of sucrose

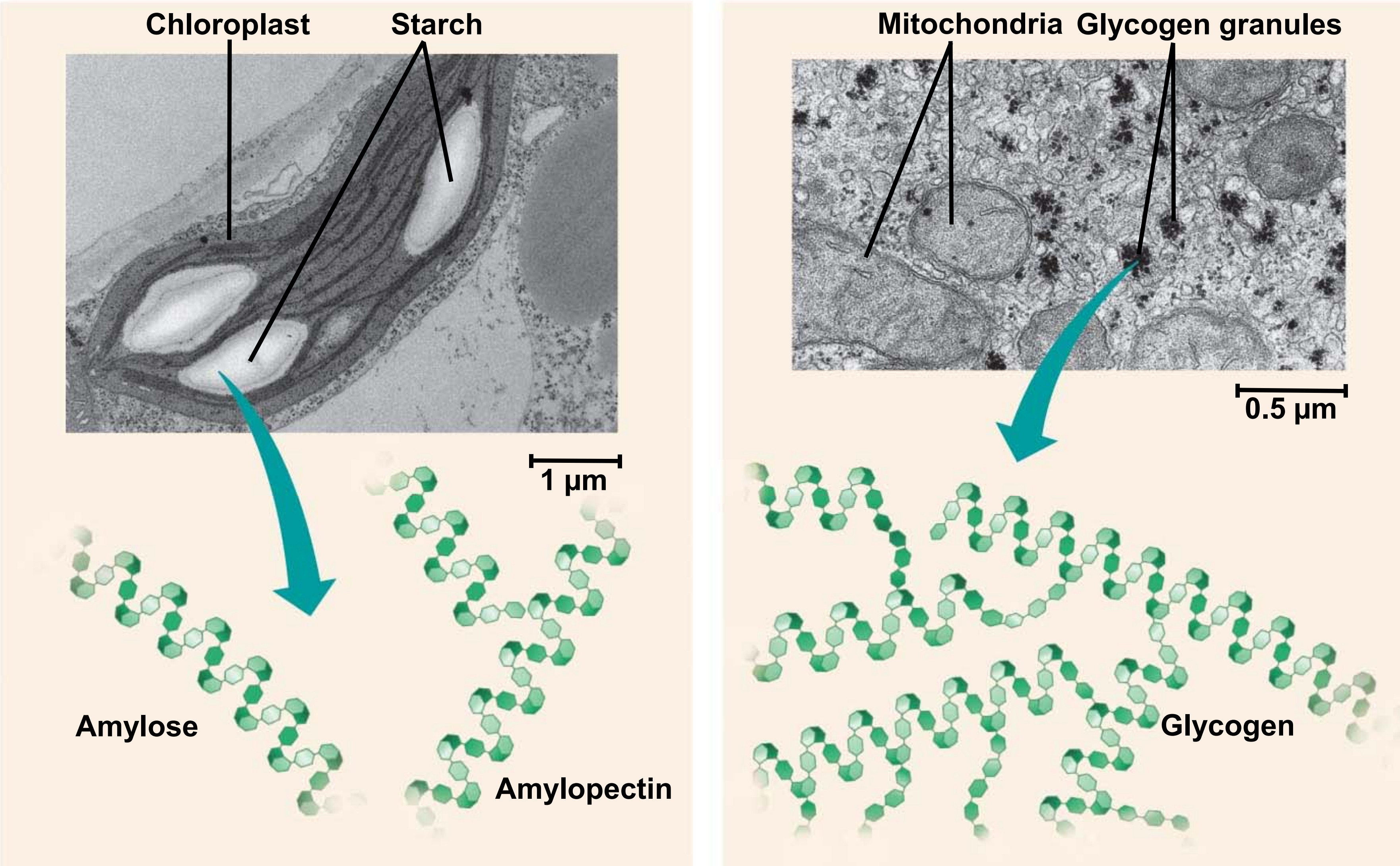
Polysaccharides

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

Storage Polysaccharides

- **Starch**, a storage polysaccharide of plants, consists entirely of 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

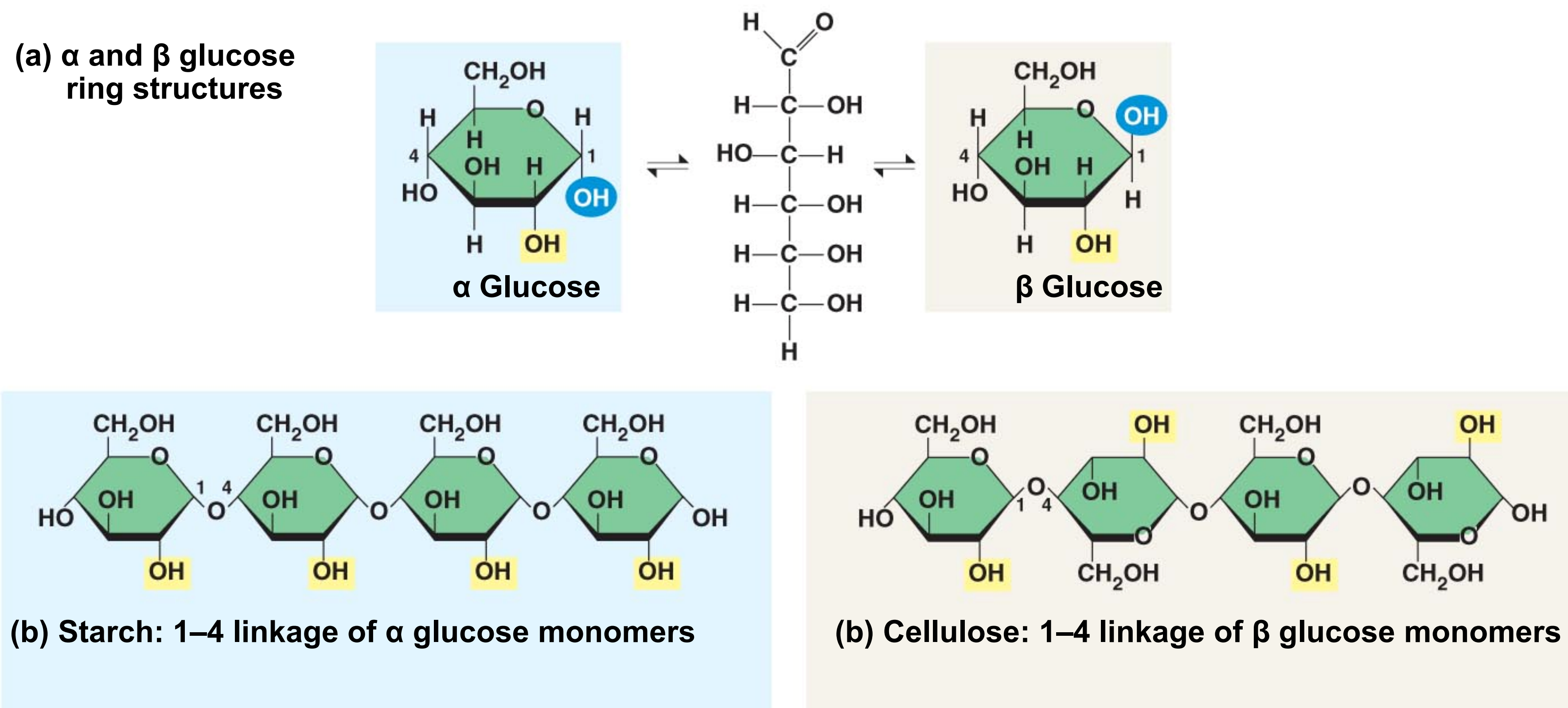
- **Glycogen** is a storage polysaccharide in animals
- Humans and other vertebrates store glycogen mainly in liver and muscle cells

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)

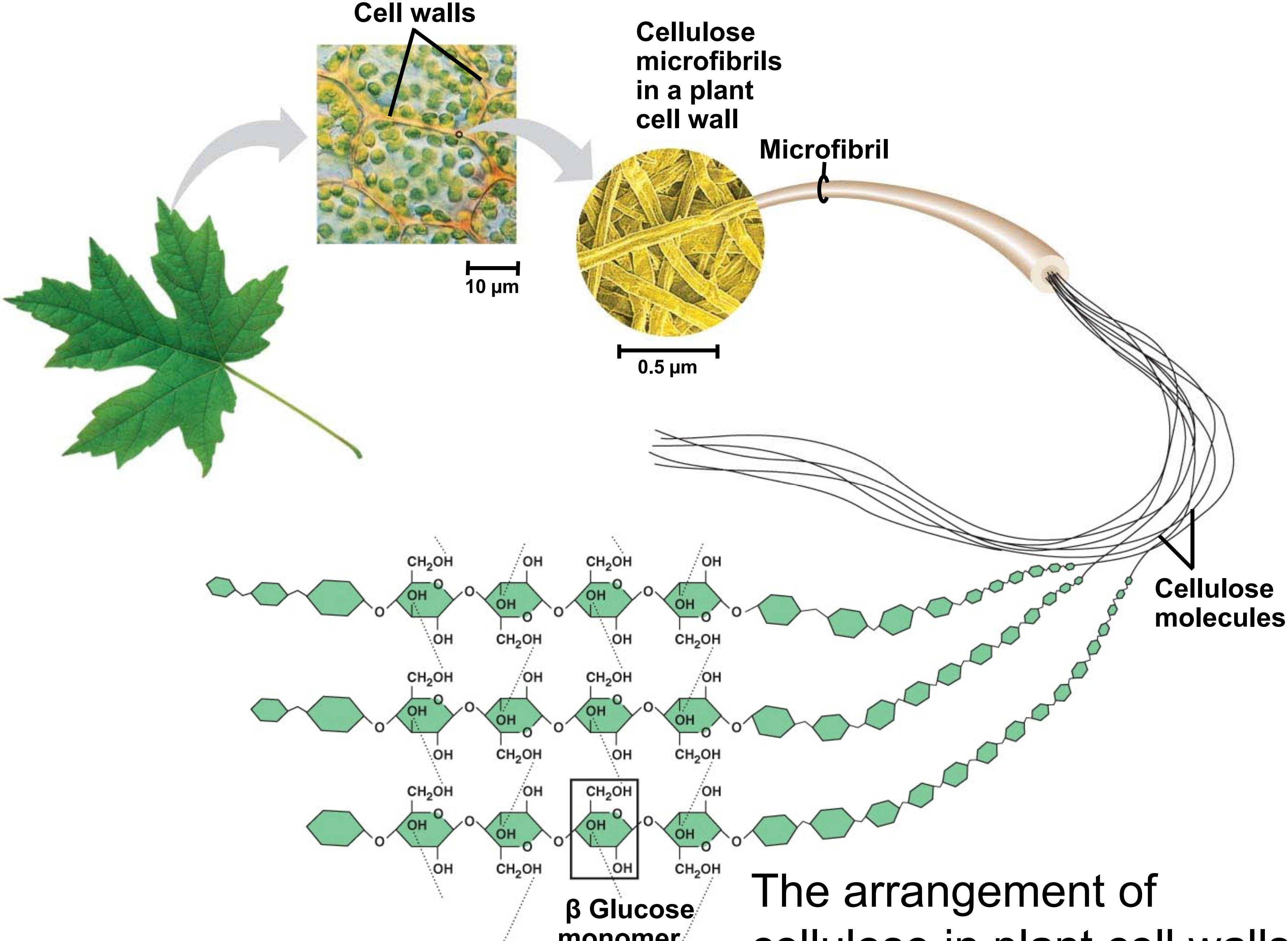
Fig. 5-7

Starch and cellulose structures



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

Fig. 5-8

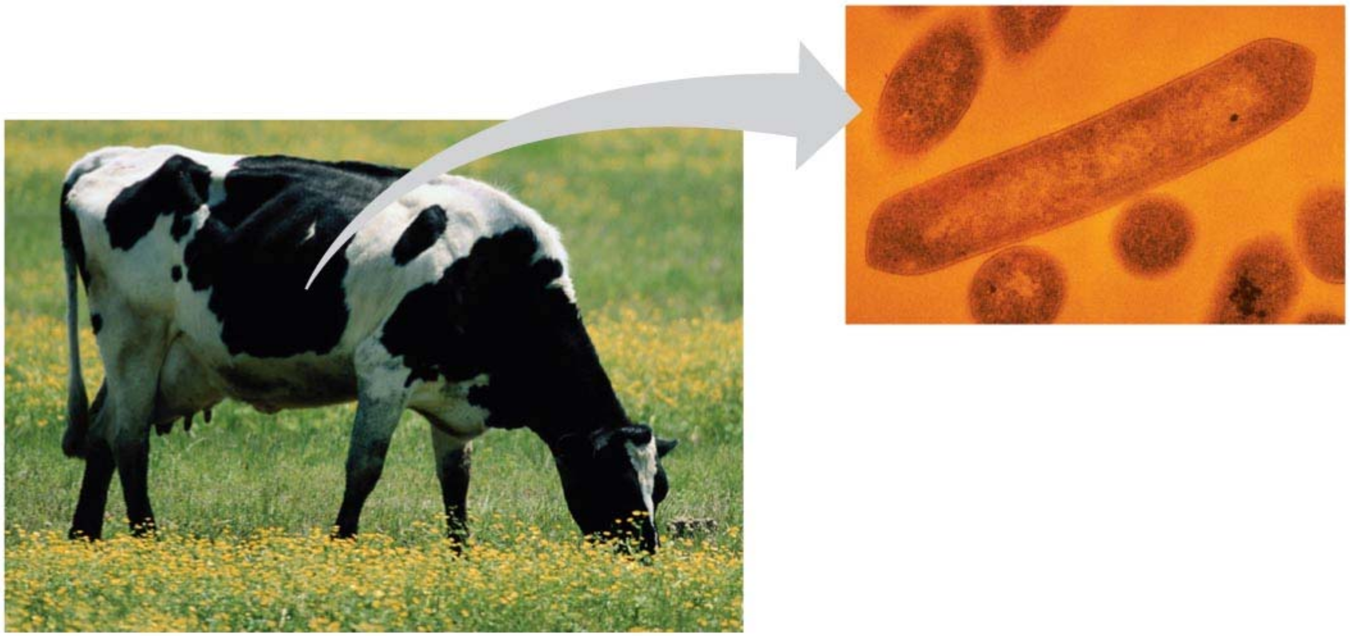


The arrangement of cellulose in plant cell walls

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

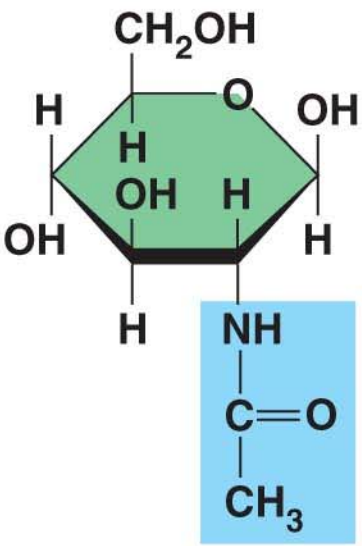
Fig. 5-9

Cellulose-digesting prokaryotes are found in grazing animals such as this cow



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

Chitin, a structural polysaccharide



(a) The structure of the chitin monomer.

(b) Chitin forms the exoskeleton of arthropods.

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

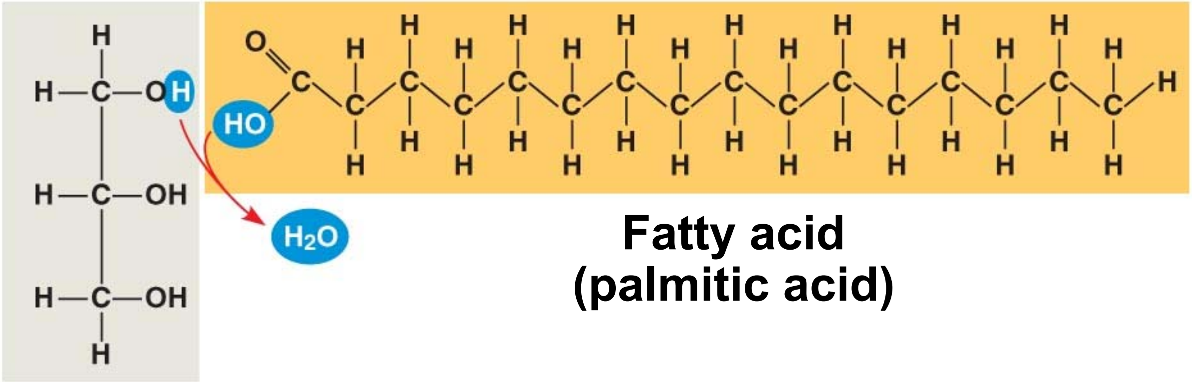
Concept 5.3: Lipids are a diverse group of hydrophobic molecules

- **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

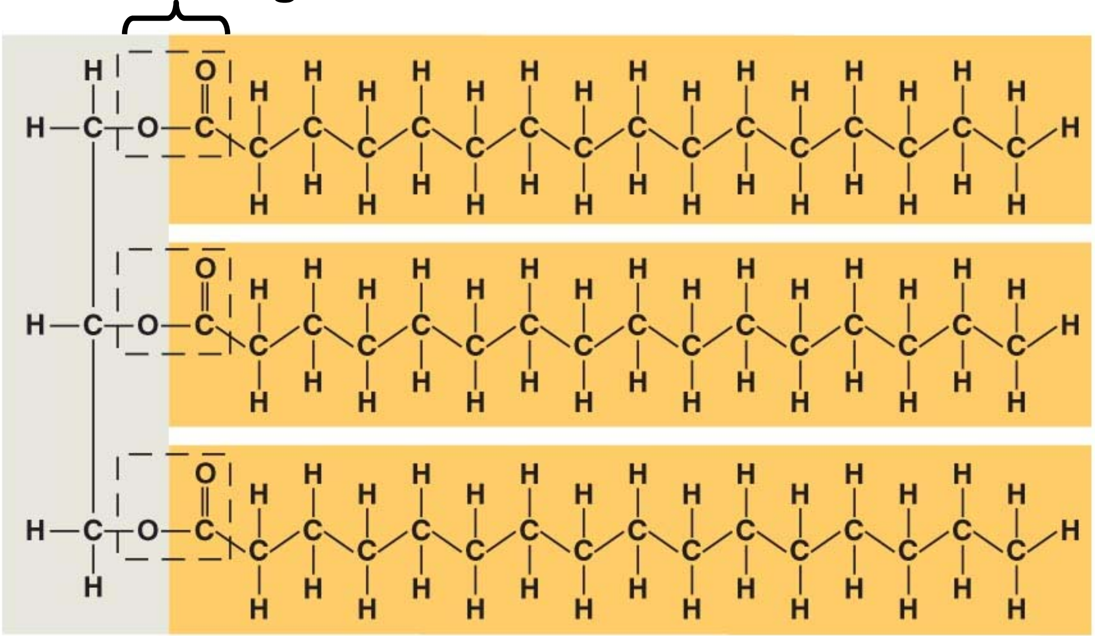
Fats

- **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



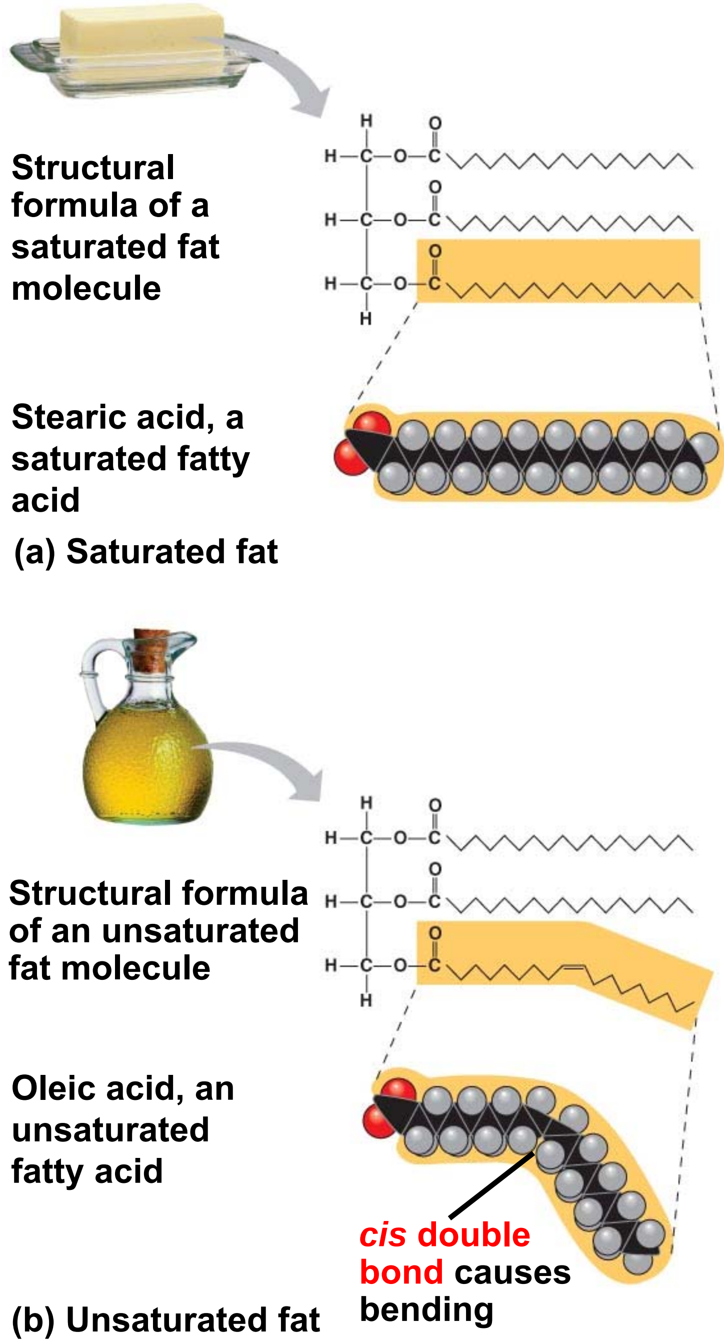
(a) Dehydration reaction in the synthesis of a fat



(b) Fat molecule (triacylglycerol), 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

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

- 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

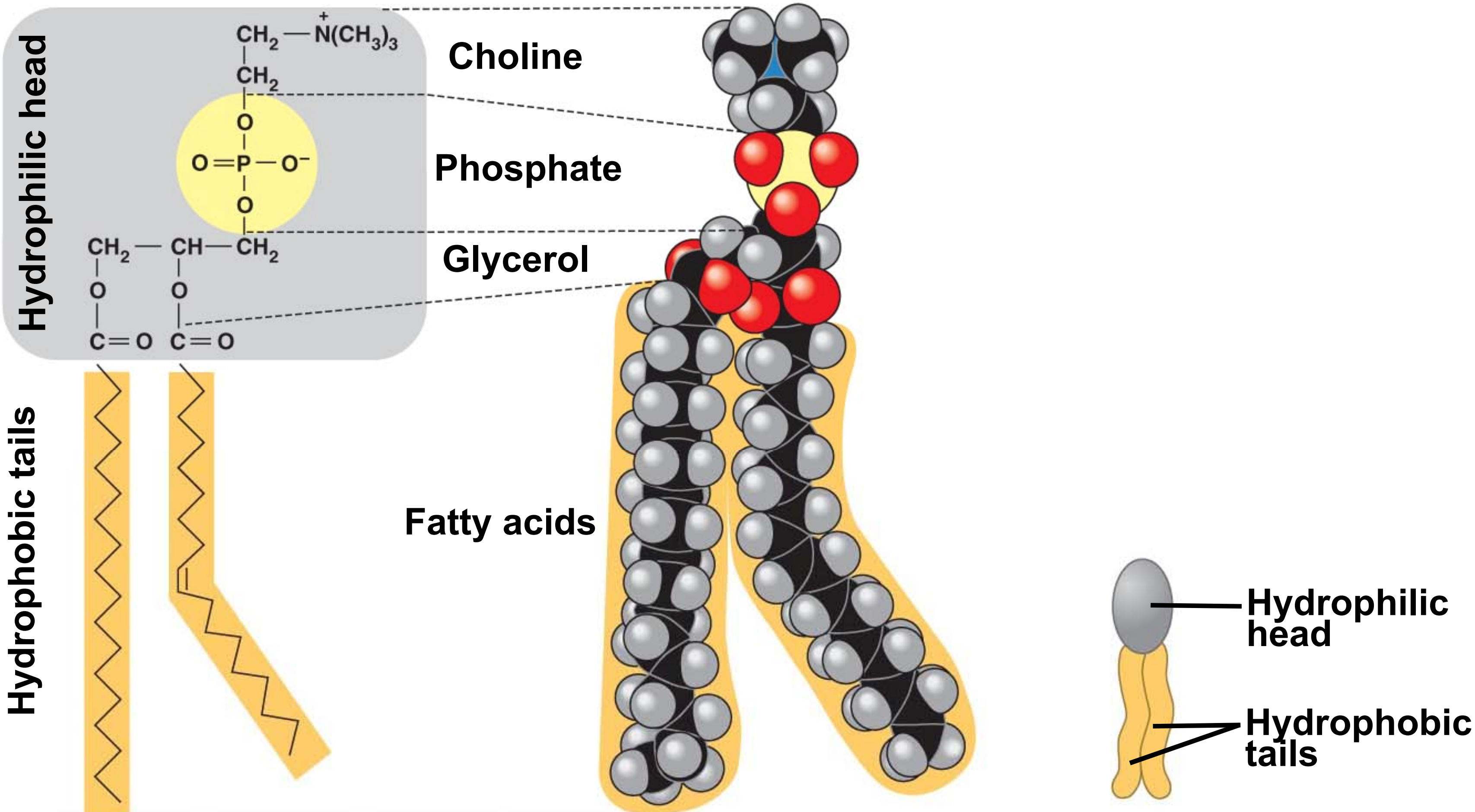
- The major function of fats is energy storage
- Humans and other mammals store their fat in adipose cells
- Adipose tissue also cushions vital organs and insulates the body

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

The structure of a phospholipid

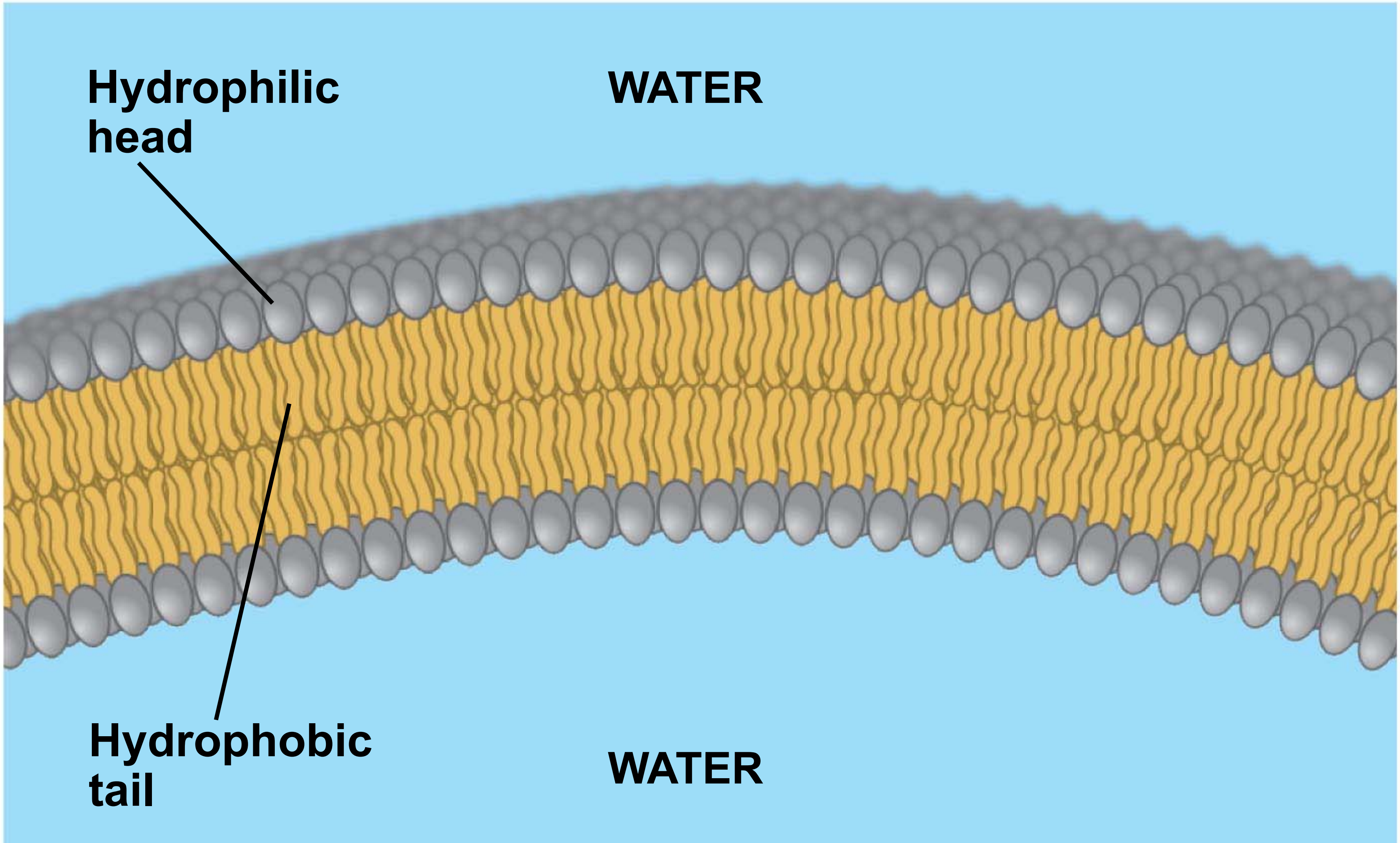


(a) Structural formula (b) Space-filling model (c) Phospholipid symbol

- 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

Bilayer structure formed by self-assembly of phospholipids in an aqueous environment

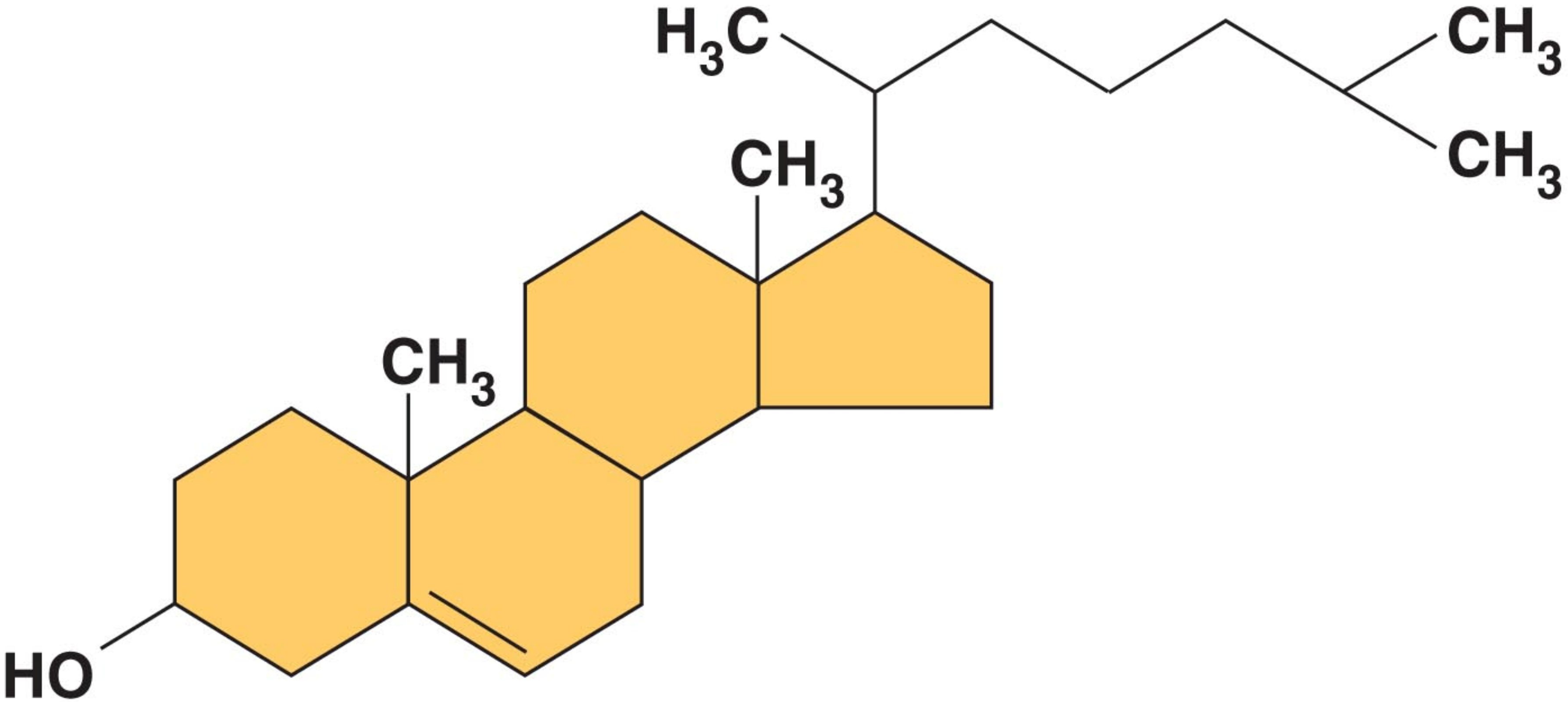


Steroids

- **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

Cholesterol, a steroid



Concept 5.4: Proteins have many structures, resulting in a wide range of functions

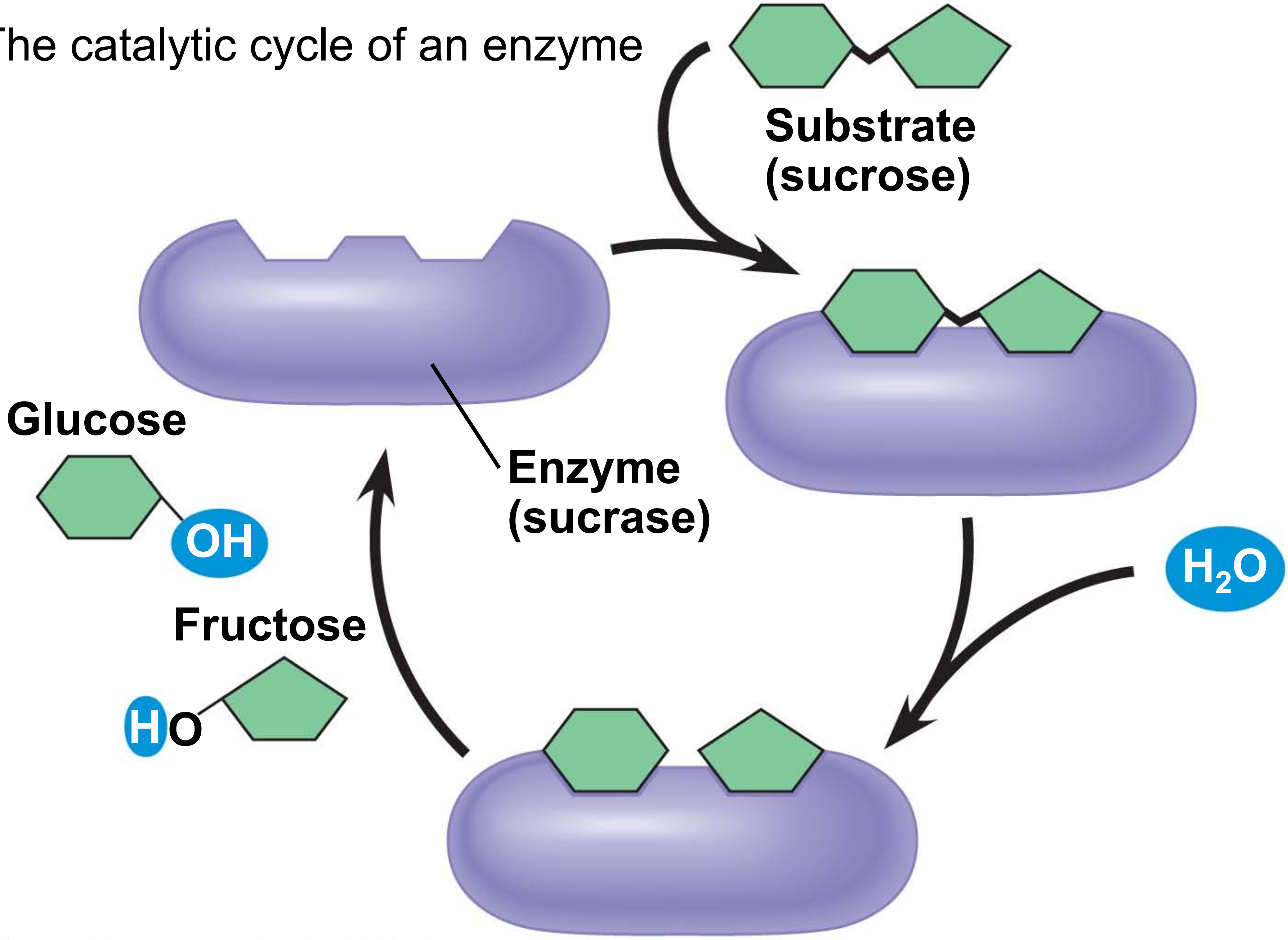
Table 5.1 An Overview of Protein Functions

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.

- **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

Fig. 5-16

The catalytic cycle of an enzyme



Polypeptides

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

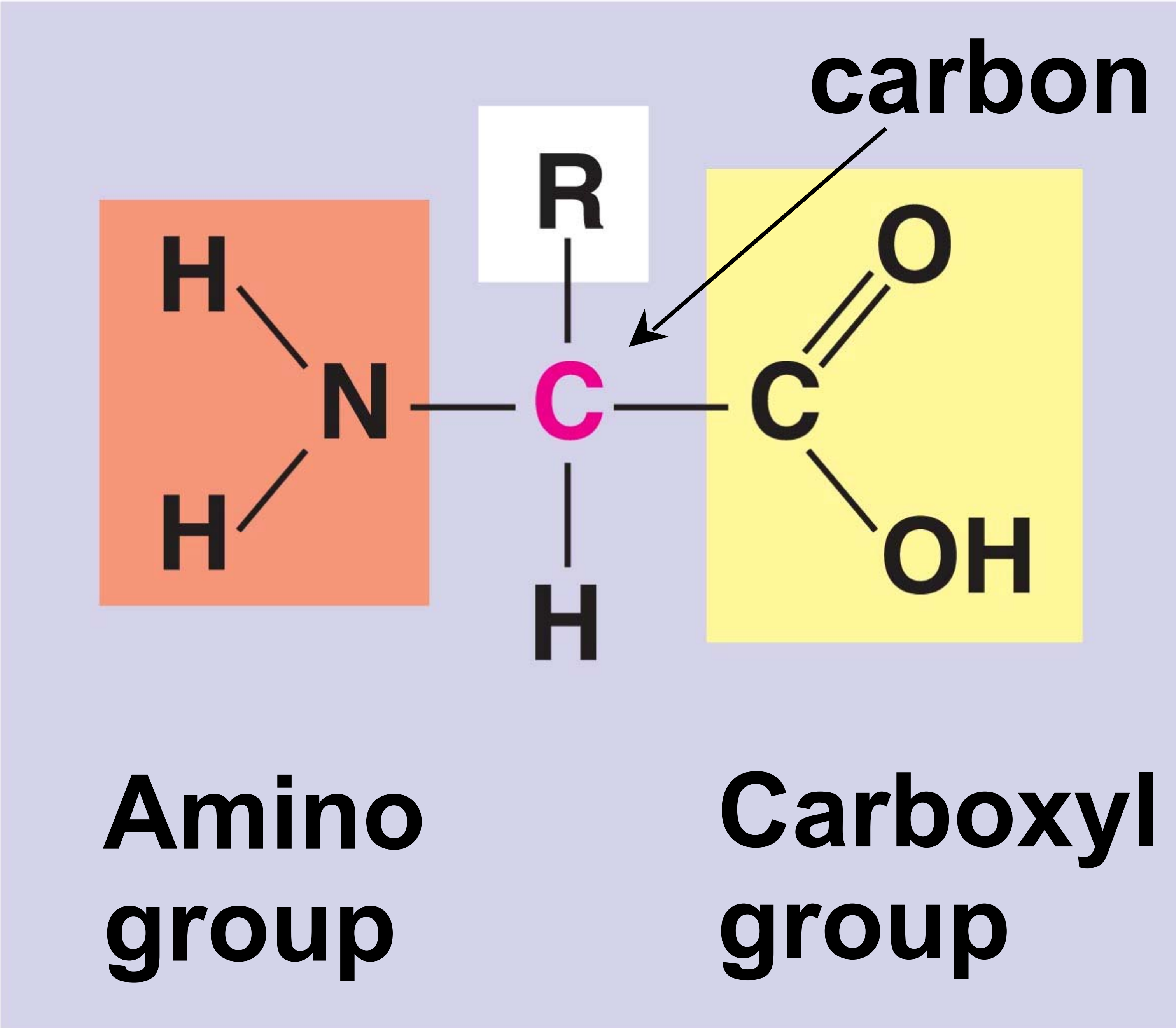


Fig. 5-17a

Nonpolar

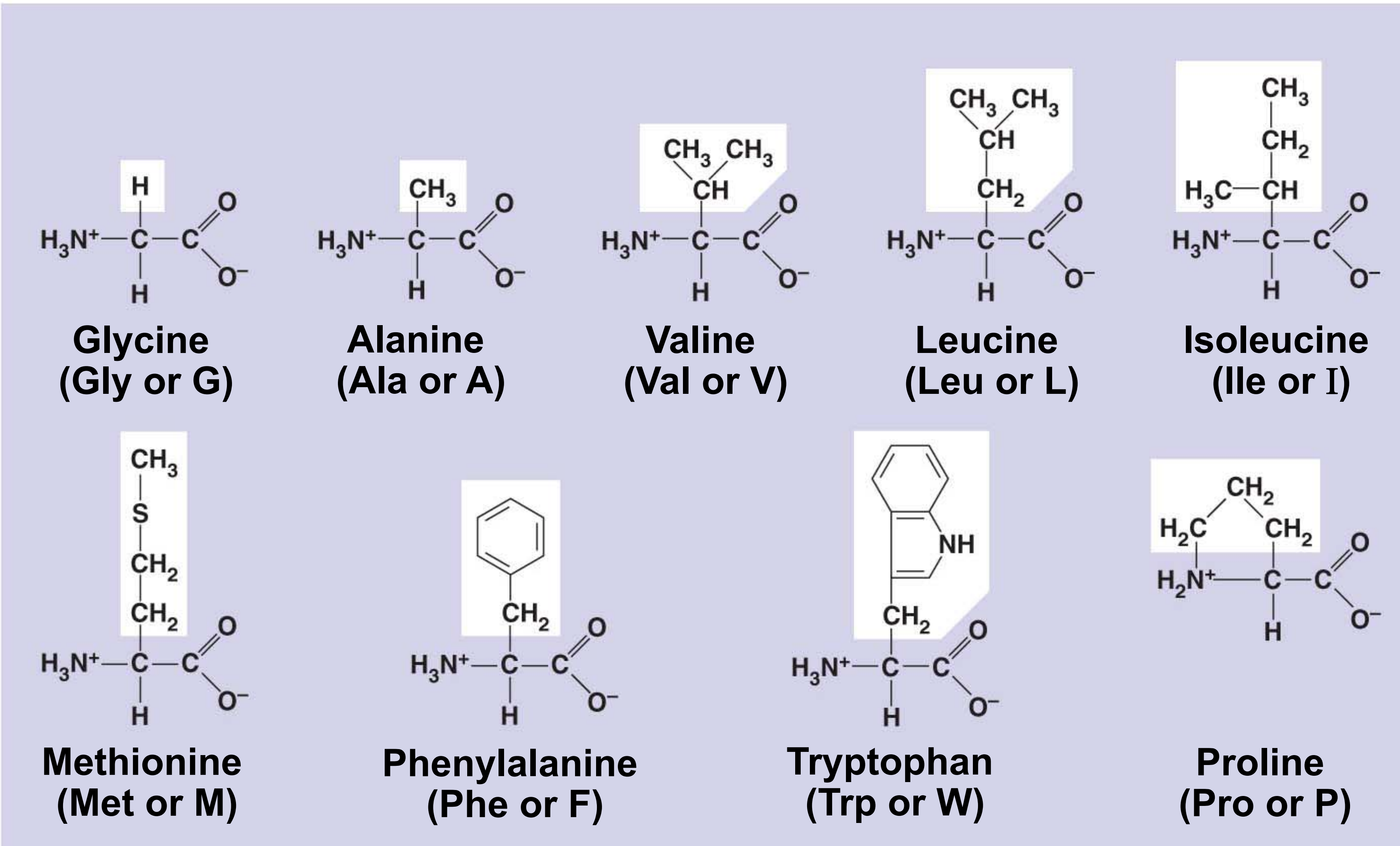


Fig. 5-17b

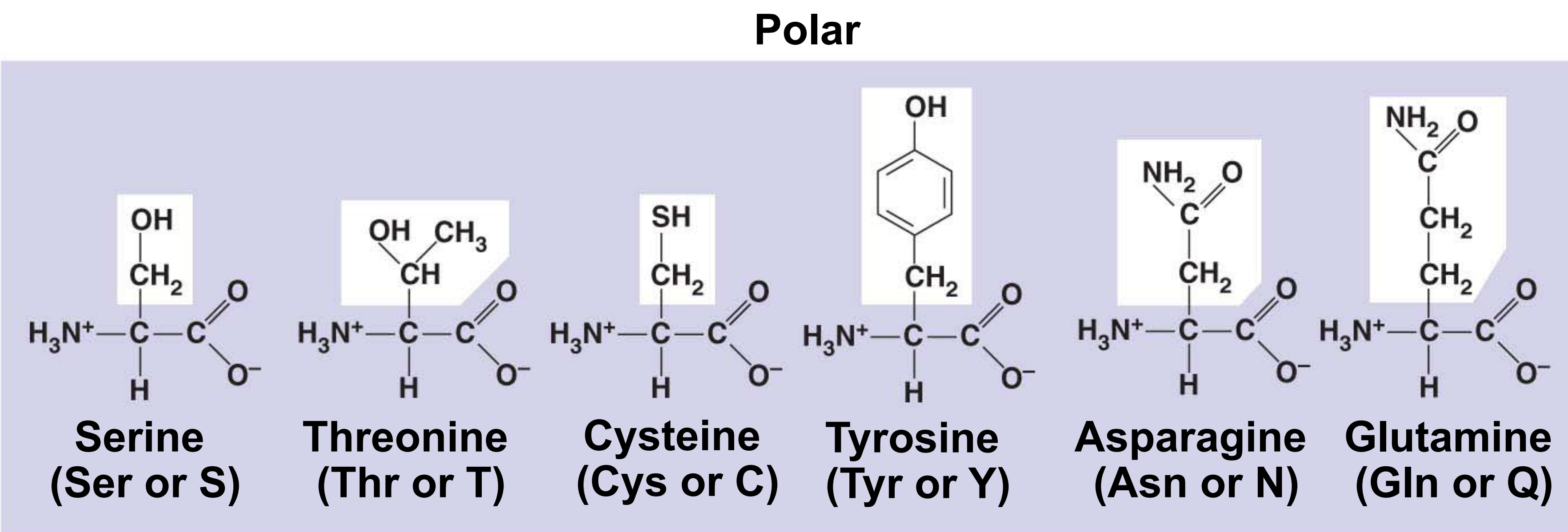
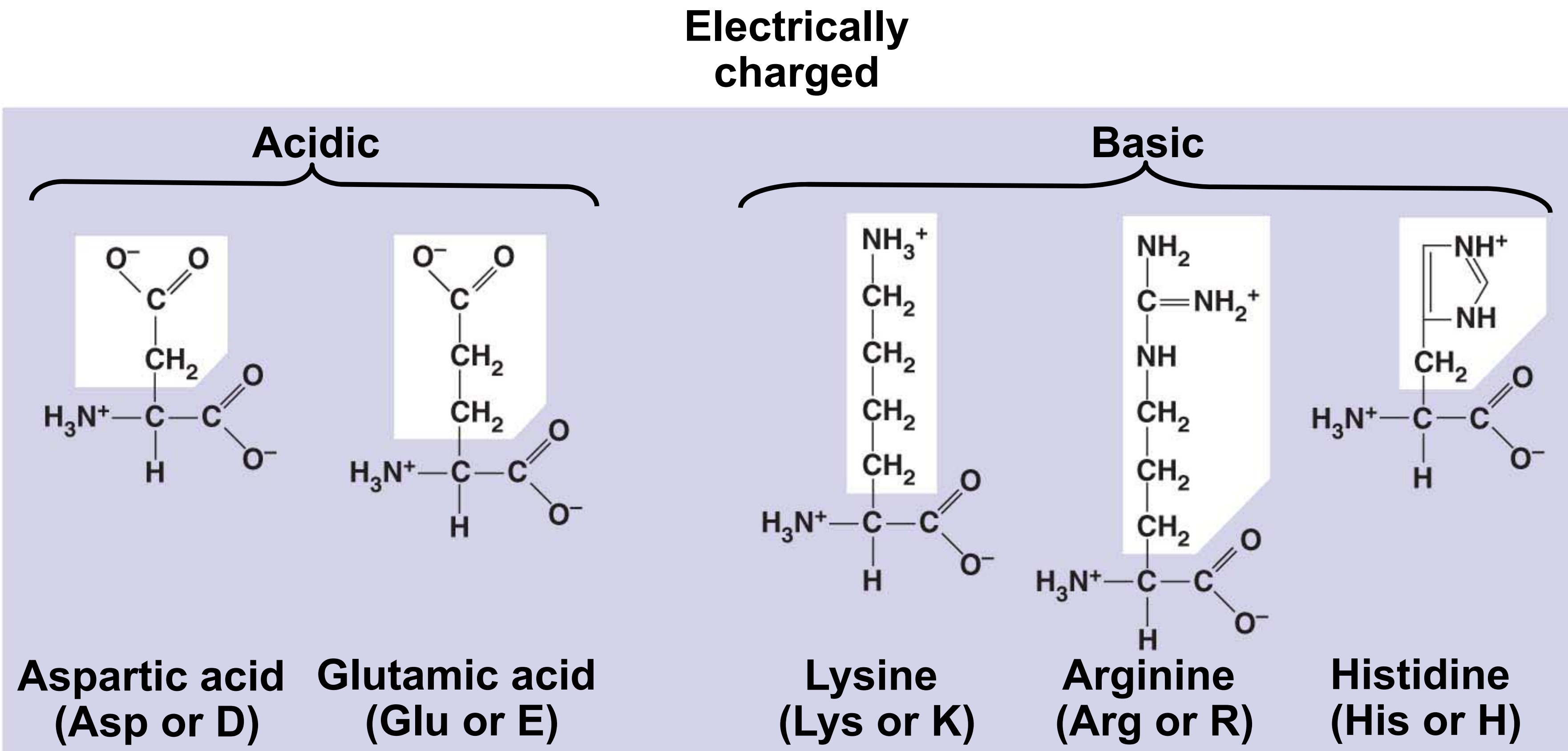

Polar
Serine
(Ser or S)
Threonine
(Thr or T)
Cysteine
(Cys or C)
Tyrosine
(Tyr or Y)
Asparagine
(Asn or N)
Glutamine
(Gln or Q)

Fig. 5-17c

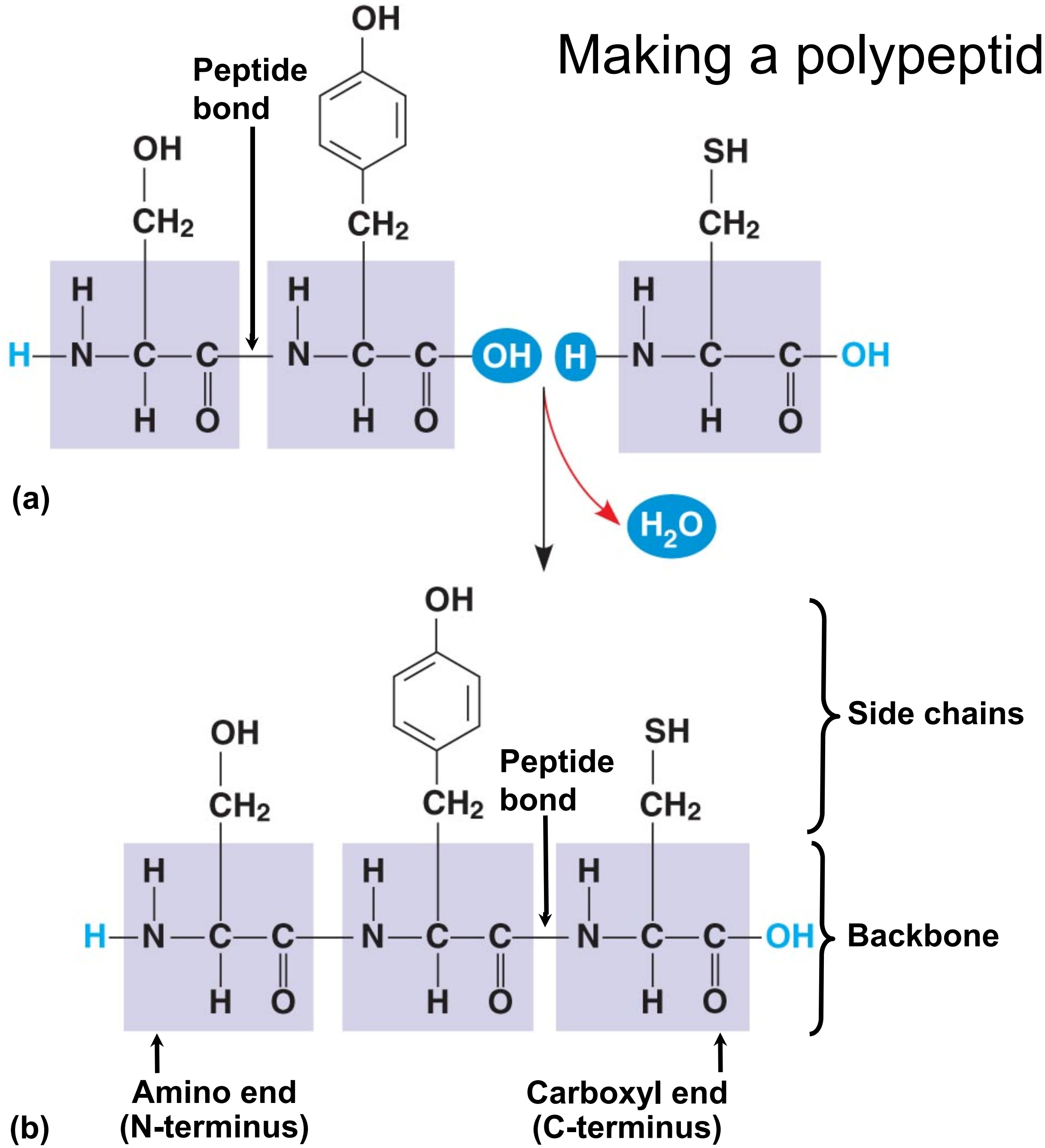

Electrically charged
Acidic
Basic
Aspartic acid (Asp or D)
Glutamic acid (Glu or E)
Lysine (Lys or K)
Arginine (Arg or R)
Histidine (His or H)

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

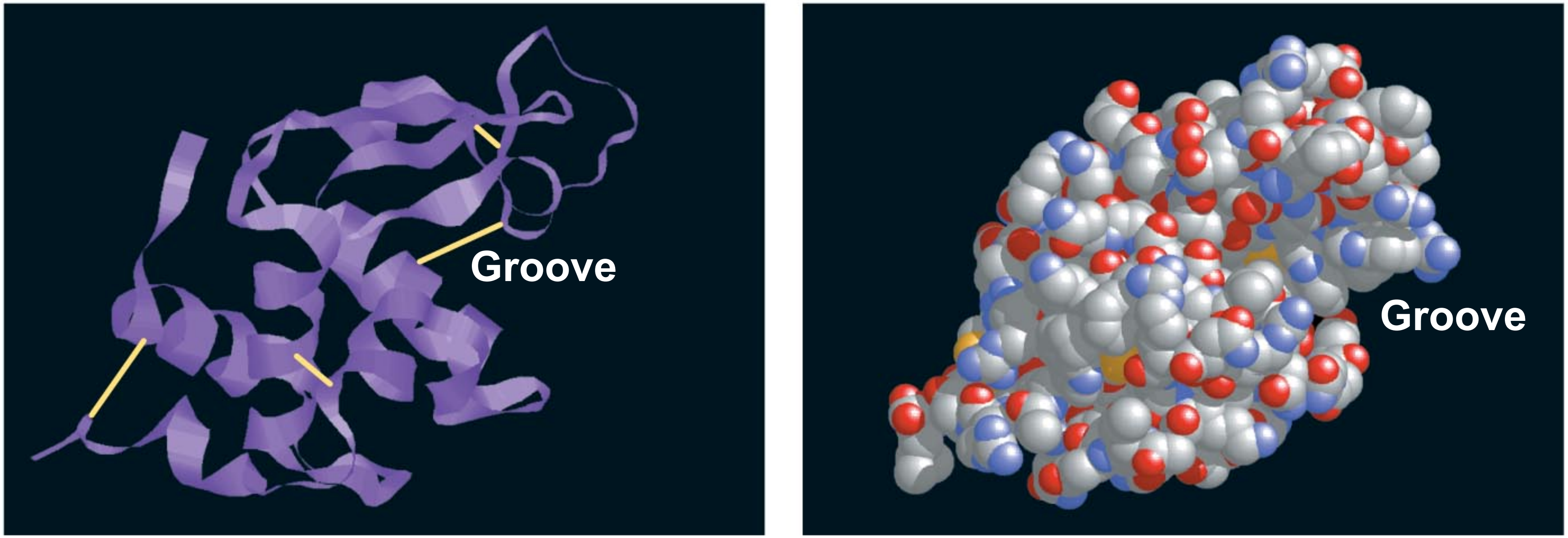
Fig. 5-18

Making a polypeptide chain



Protein Structure and Function

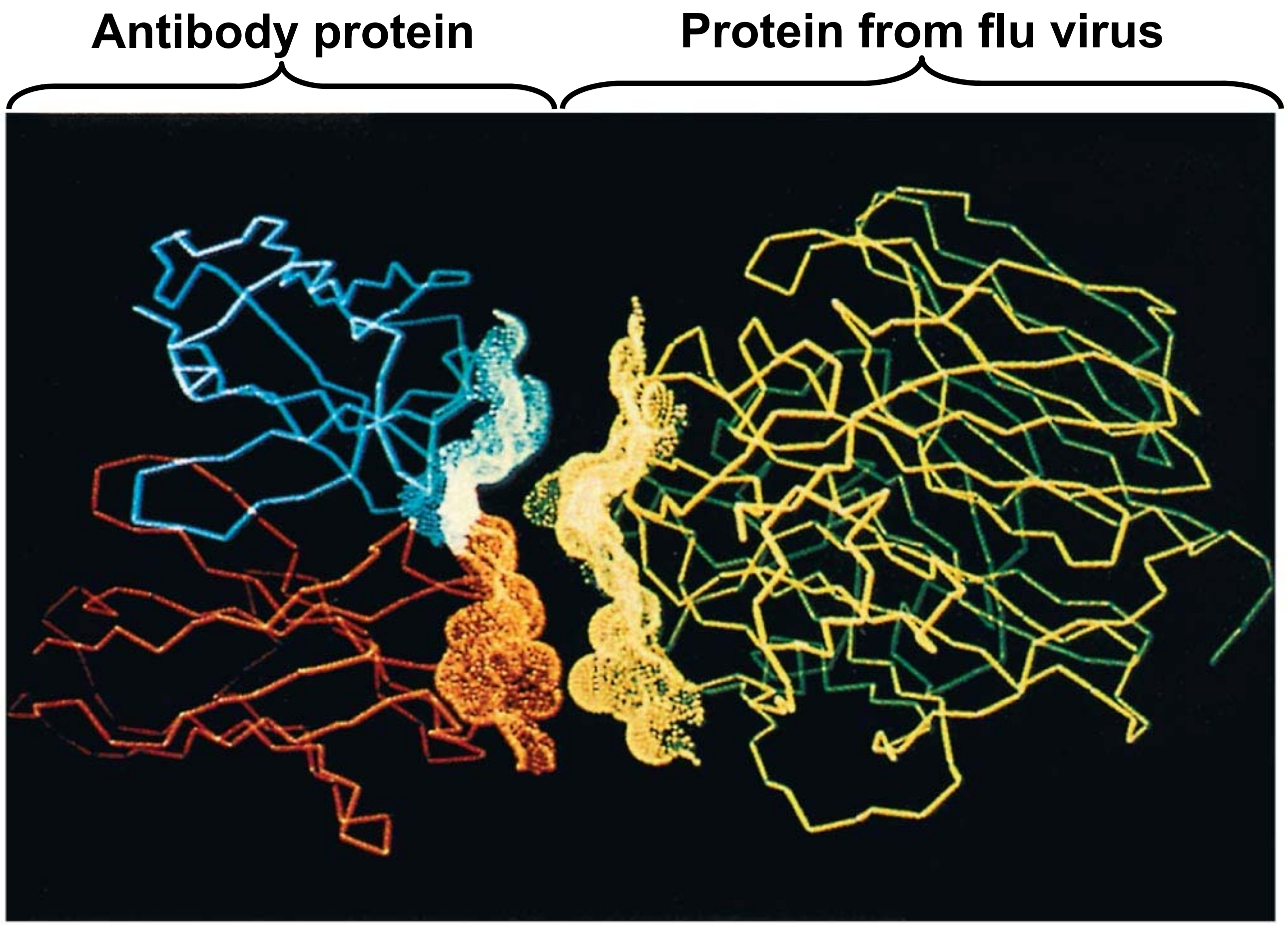
A functional protein consists of one or more polypeptides twisted, folded, and coiled into a unique shape



(a) A ribbon model of lysozyme **(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

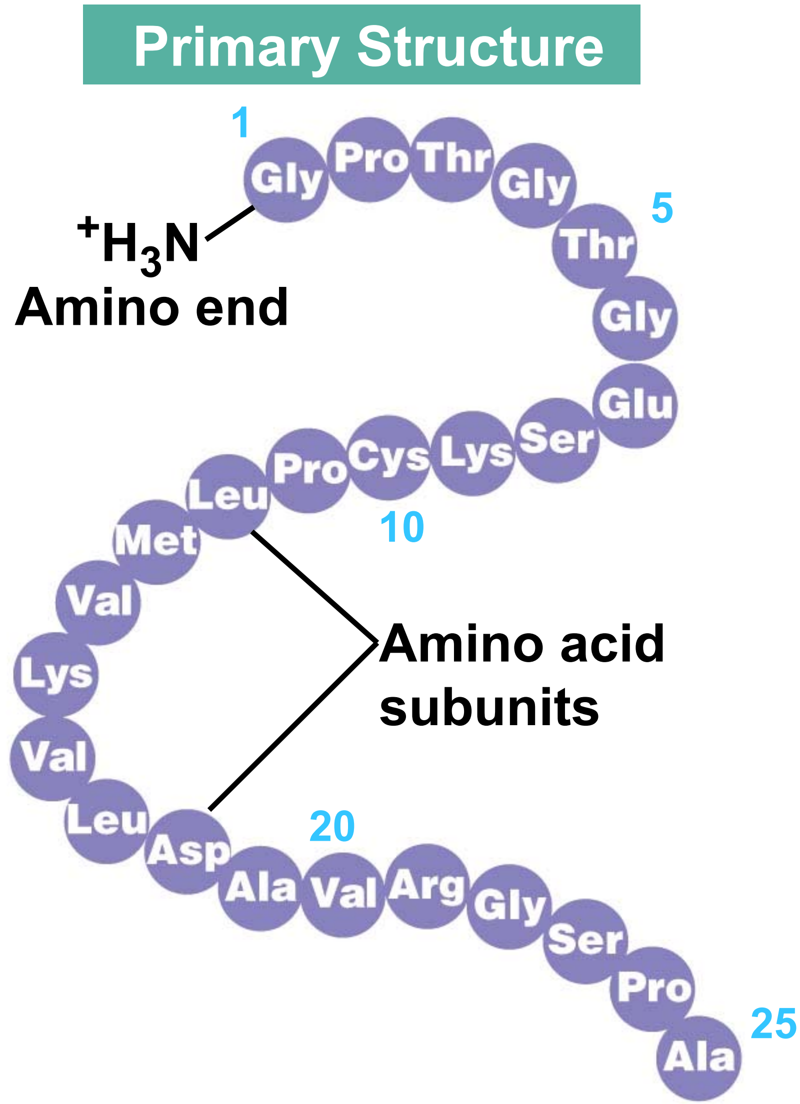
An antibody binding to a protein from a flu virus



- **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

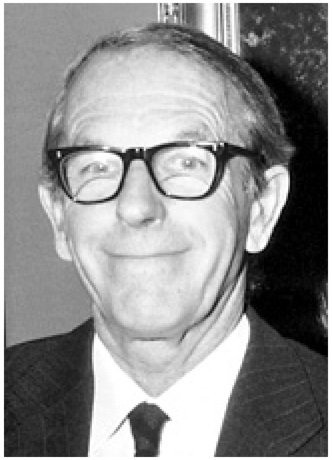
Fig. 5-21a

Transthyretin



Frederick Sanger
University of Cambridge
United Kingdom
b. 1918

The Nobel Prize in Chemistry 1958
"for his work on the structure of proteins, especially that of insulin"



The Nobel Prize in Chemistry 1980
"for their contributions concerning the determination of base sequences in nucleic acids"

- 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**

Fig. 5-21c

Secondary Structure

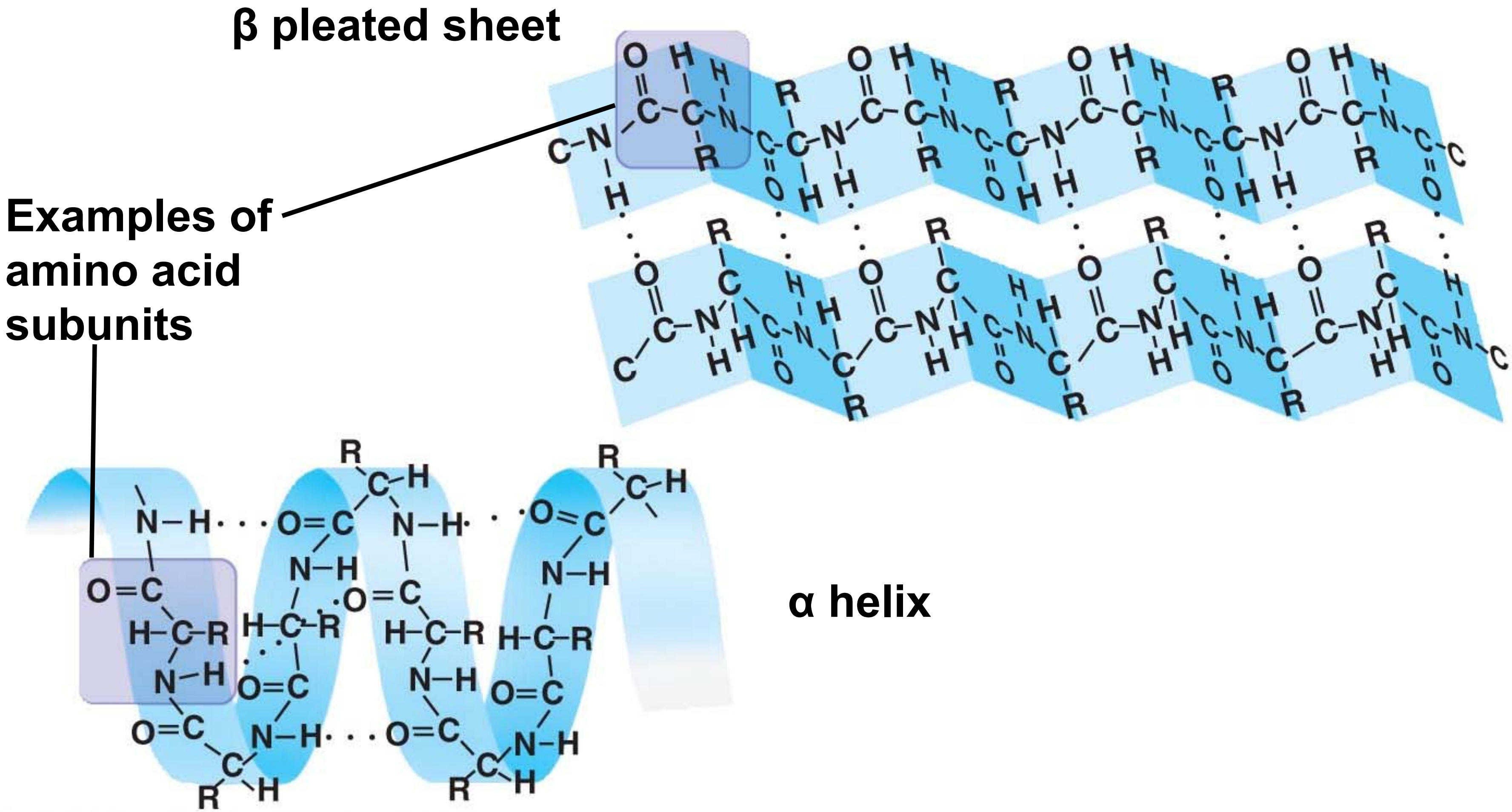


Fig. 5-21d

Abdominal glands of the spider secrete silk fibers made of a structural protein containing β 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

Fig. 5-21e

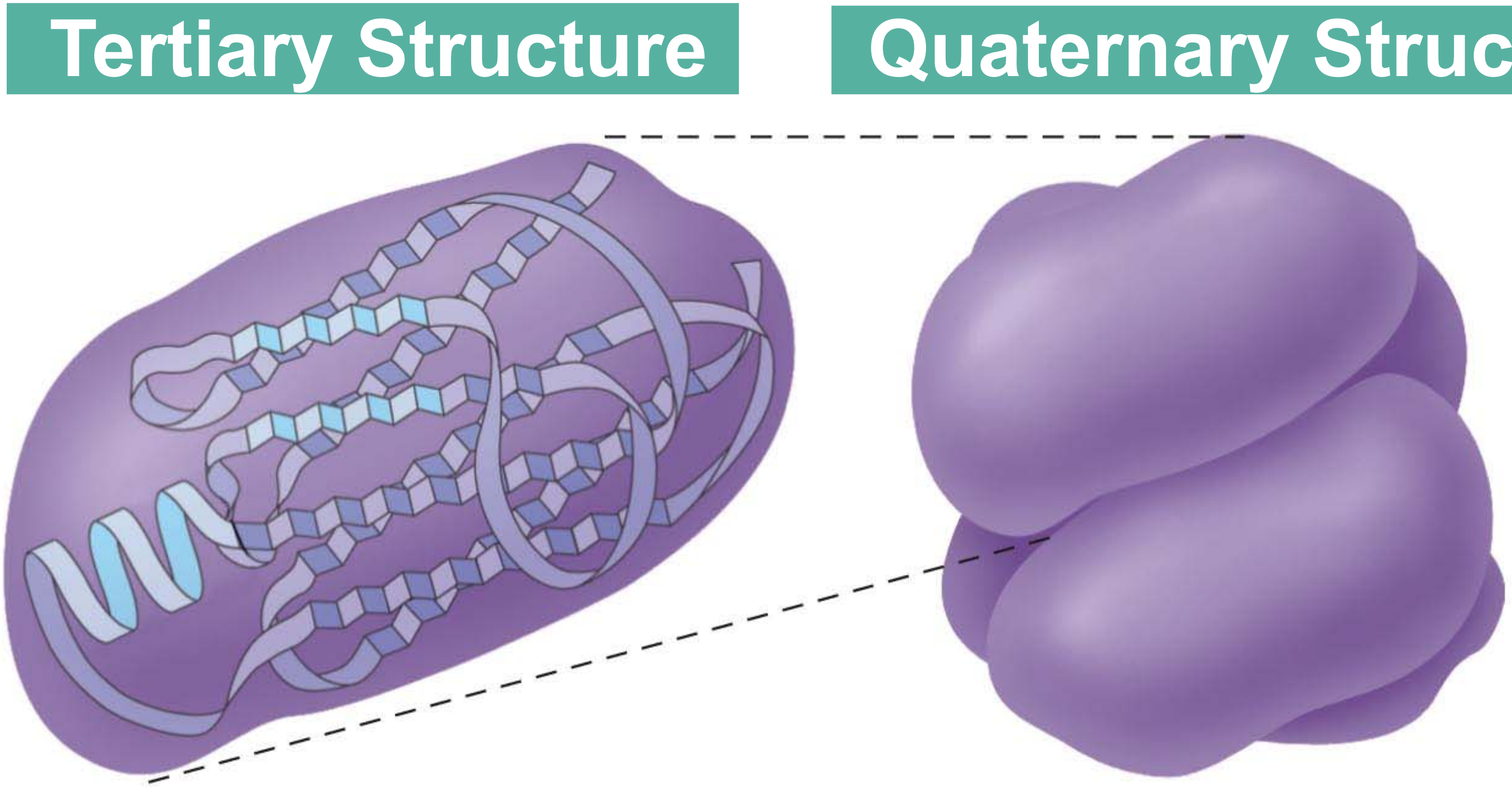
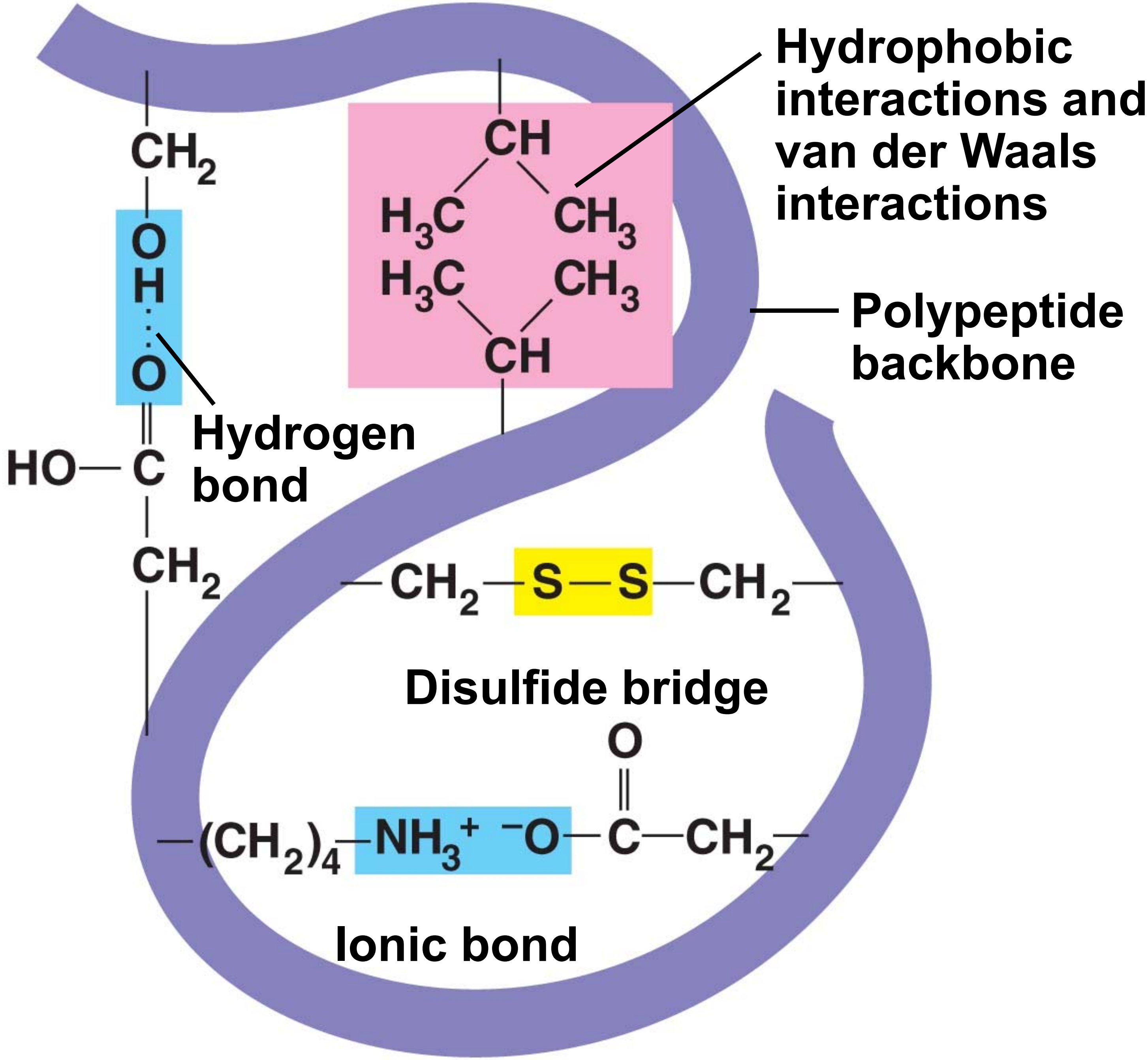


Fig. 5-21f



Hydrophobic interactions and van der Waals interactions
Polypeptide backbone
Hydrogen bond
Disulfide bridge
Ionic bond
CH
H3C
CH3
H3C
CH3
CH
CH2
O
H
O
HO
C
CH2
CH2
S
S
CH2
O
(CH2)4
NH3+
-O
C
CH2

- **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

Fig. 5-21g


Polypeptide chain
Collagen

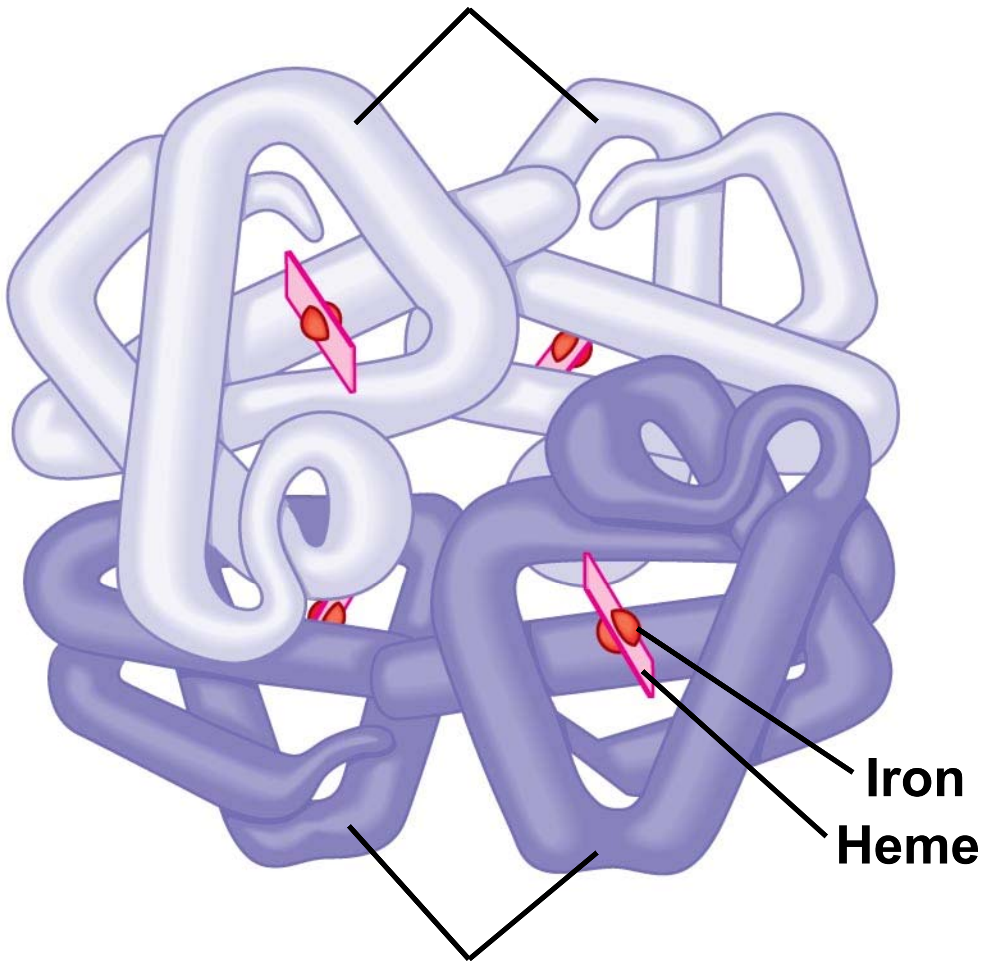
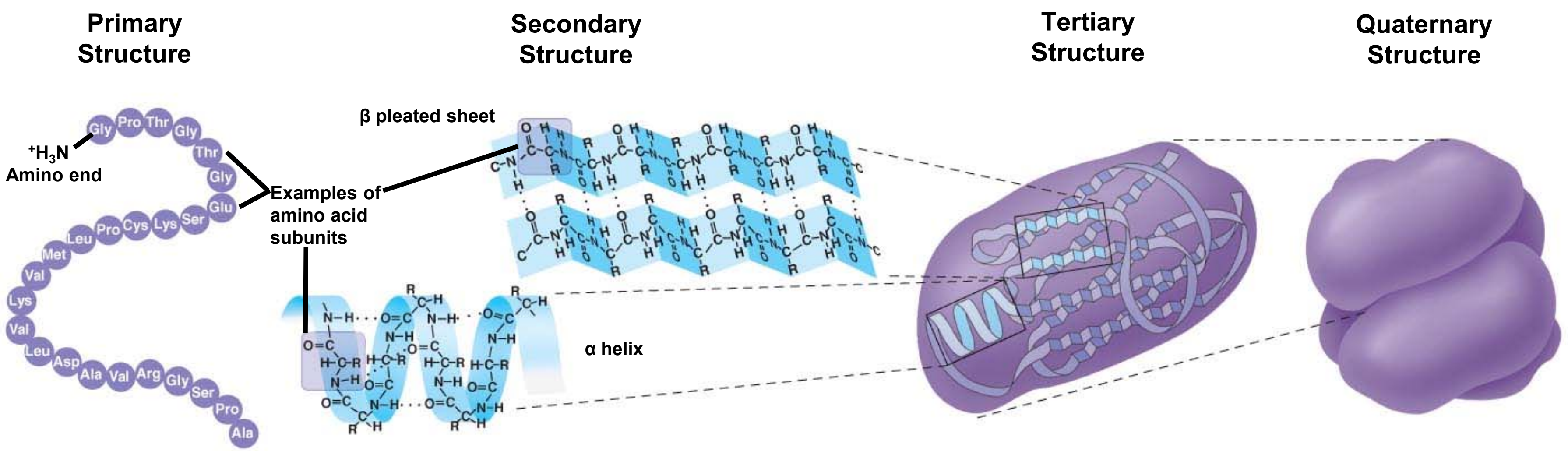

β Chains
Iron
Heme
α Chains
Hemoglobin

Fig. 5-21

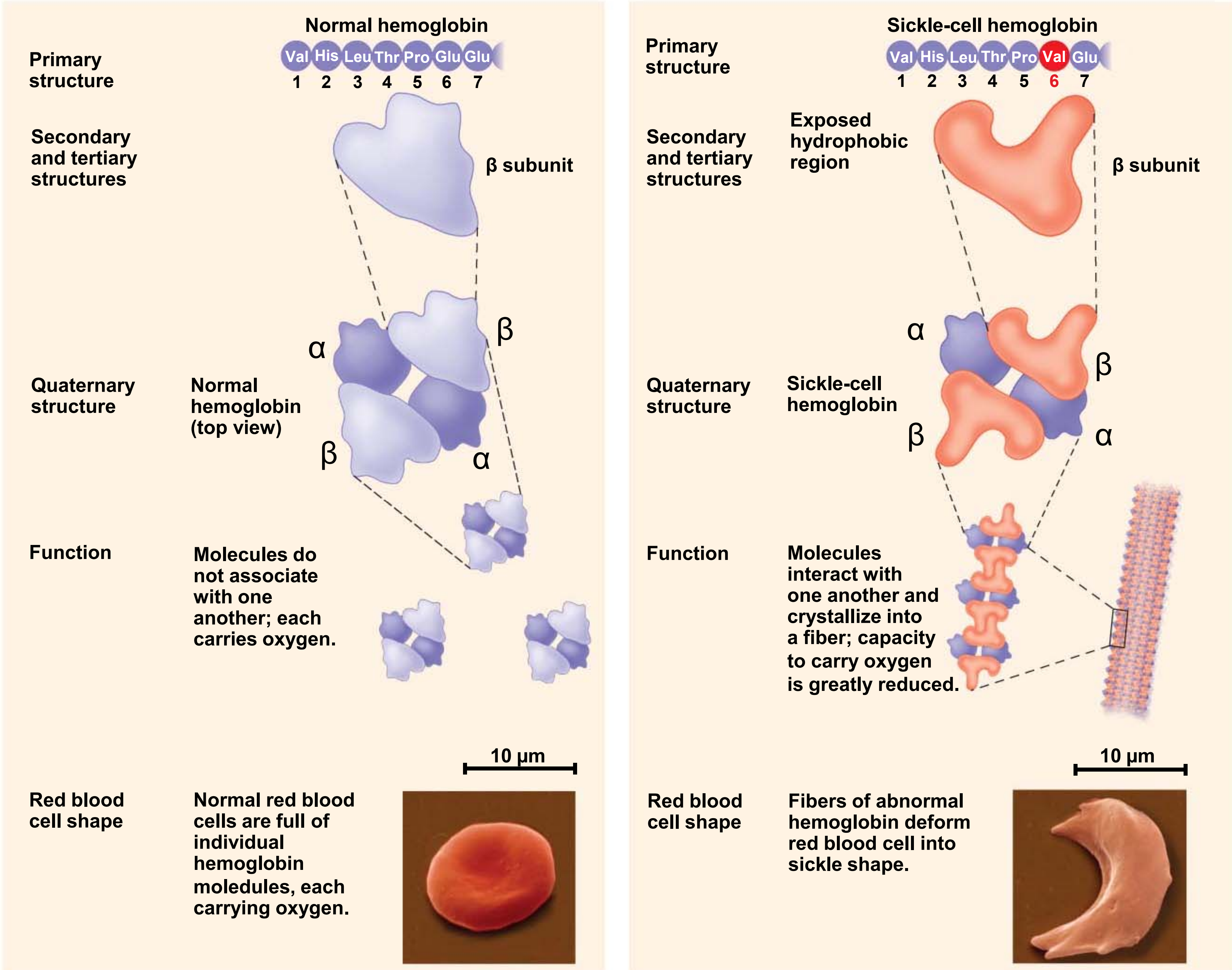
Levels of protein structure



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

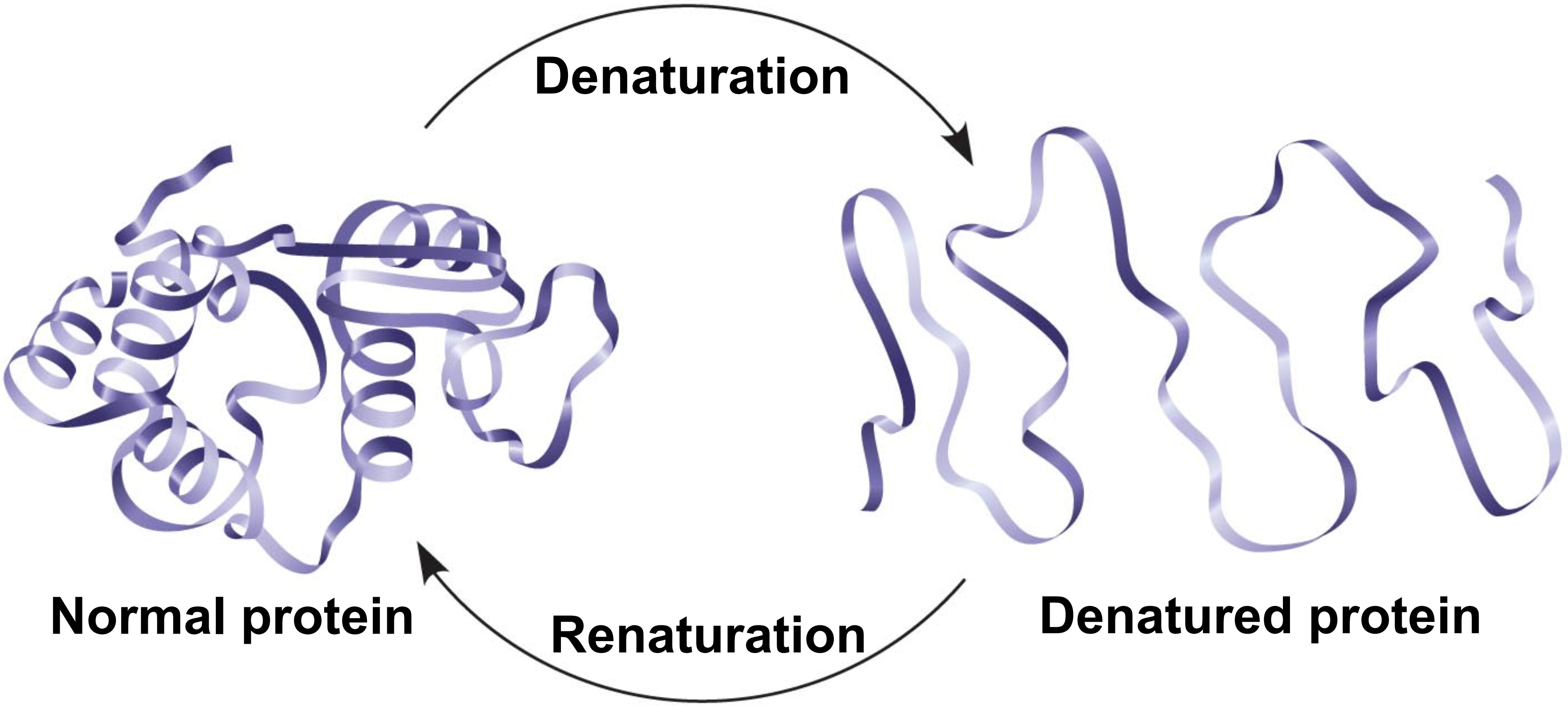

Normal hemoglobin
Primary structure
Val His Leu Thr Pro Glu Glu
1 2 3 4 5 6 7
Secondary and tertiary structures
β subunit
α
β
Quaternary structure
Normal hemoglobin (top view)
β
α
Function
Molecules do not associate with one another; each carries oxygen.
10 µm
Red blood cell shape
Normal red blood cells are full of individual hemoglobin moledules, each carrying oxygen.
Sickle-cell hemoglobin
Primary structure
Val His Leu Thr Pro Val Glu
1 2 3 4 5 6 7
Secondary and tertiary structures
Exposed hydrophobic region
β subunit
α
β
Quaternary structure
Sickle-cell hemoglobin
β
α
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.

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

Denaturation and renaturation of a protein

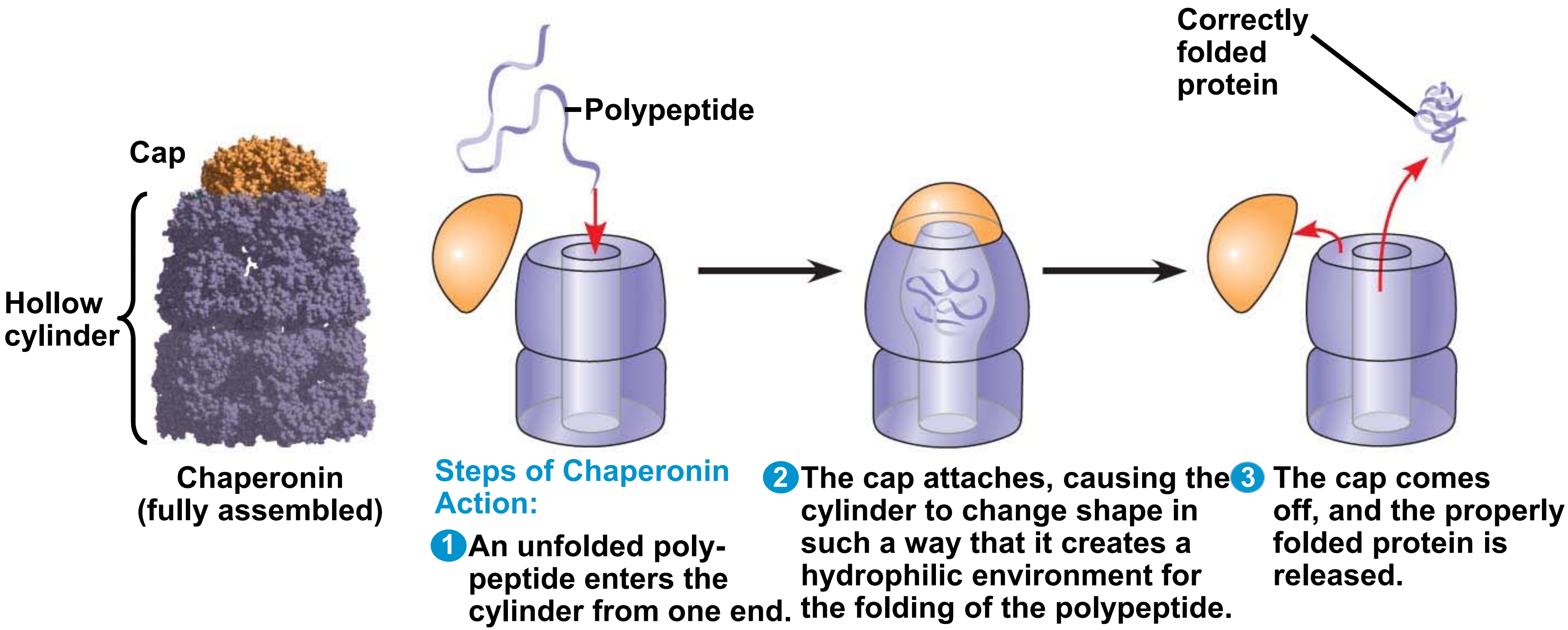


Protein Folding in the Cell

- 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

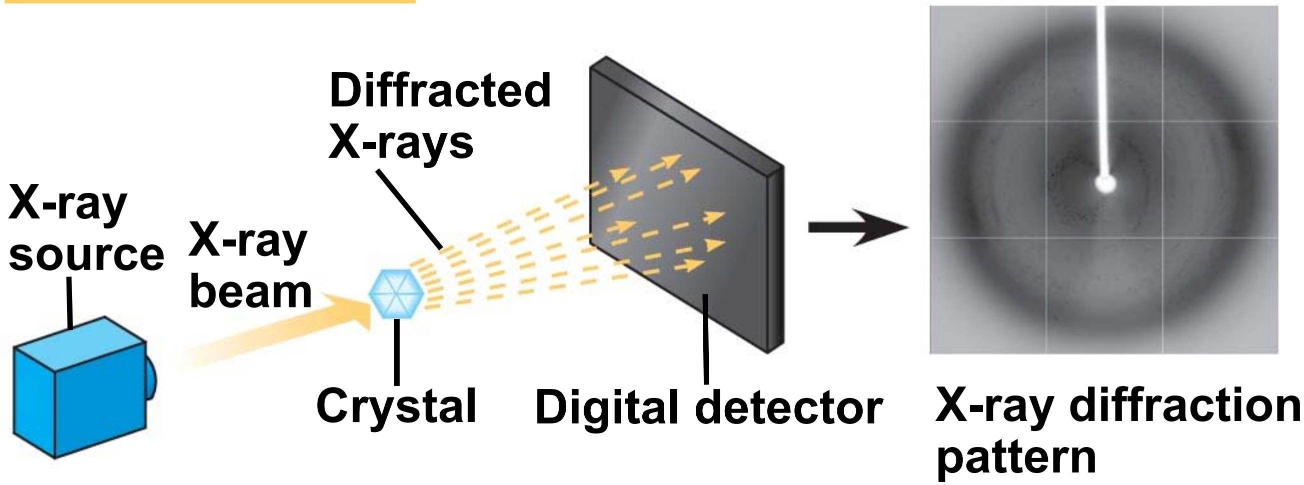
A chaperonin in action



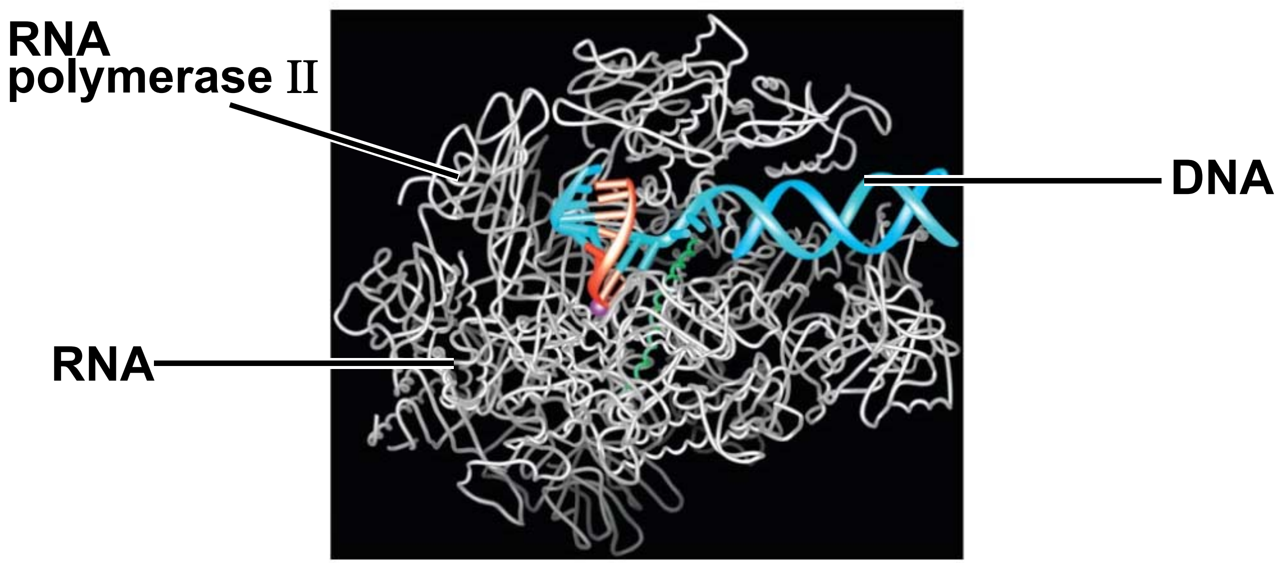
- Scientists use **X-ray crystallography** to determine a protein's structure
- Another method is nuclear magnetic resonance (NMR) spectroscopy, which does not require protein crystallization
- Bioinformatics uses computer programs to predict protein structure from amino acid sequences

Fig. 5-25

EXPERIMENT

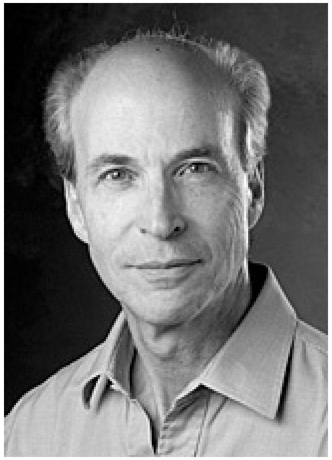


RESULTS



Arthur Kornberg & Roger Kornberg

The Nobel Prize in Physiology or Medicine 1959
"for their discovery of the mechanisms in the biological synthesis of ribonucleic acid and deoxyribonucleic acid"



The Nobel Prize in Chemistry 2006
"for his studies of the molecular basis of eukaryotic transcription"

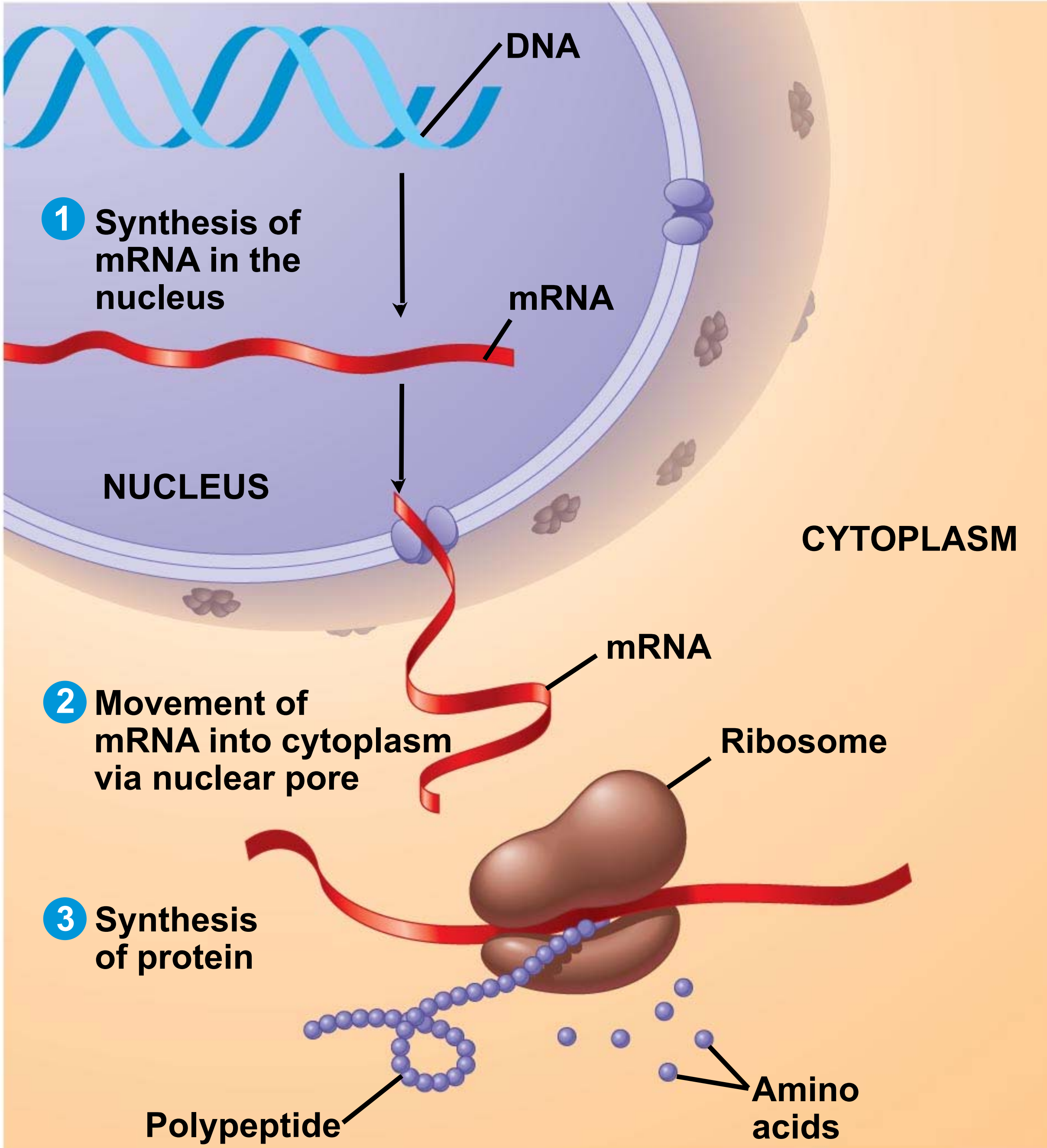
Concept 5.5: Nucleic acids store and transmit hereditary information

- 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. 5-26-3


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
Amino 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

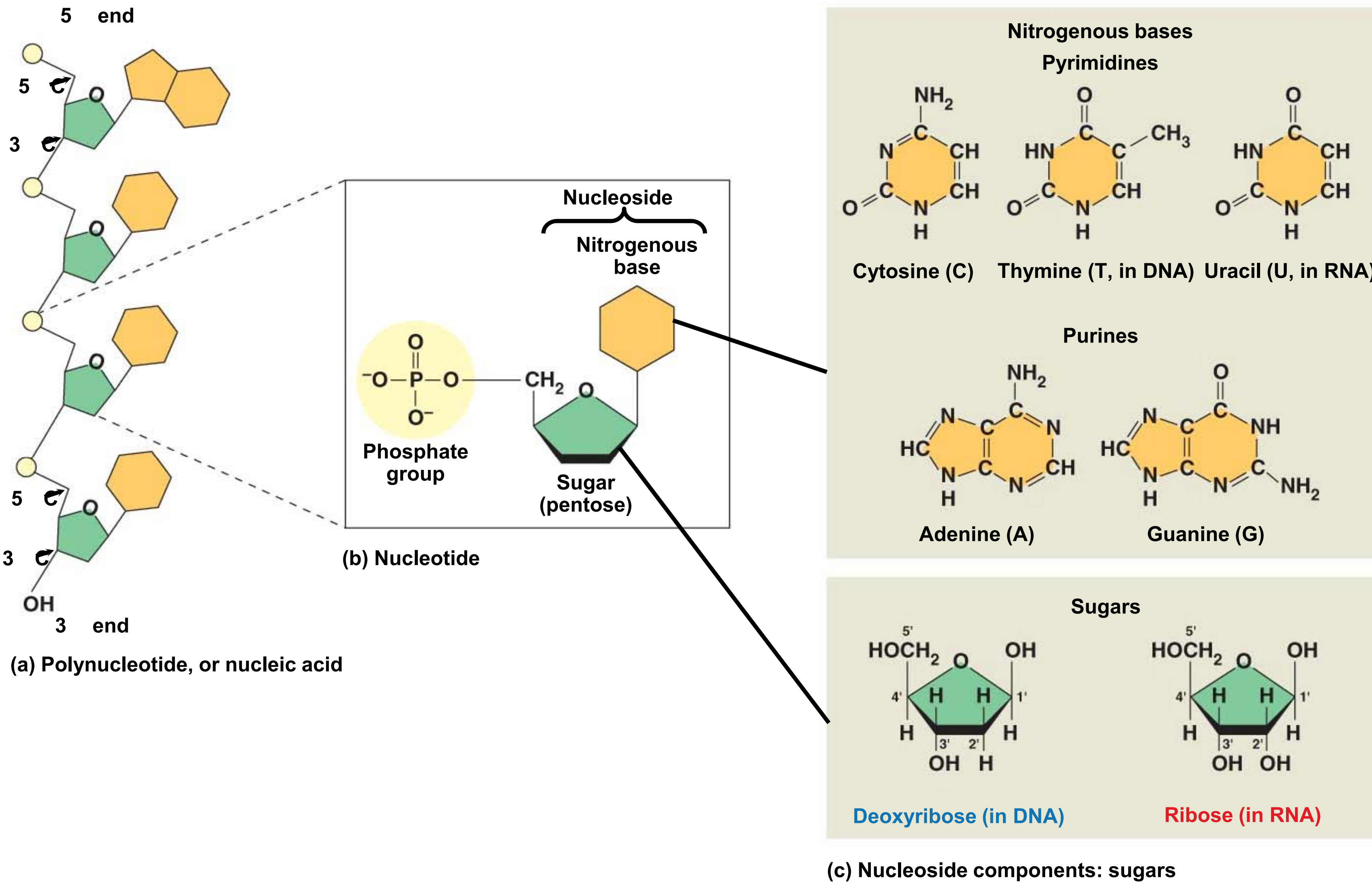
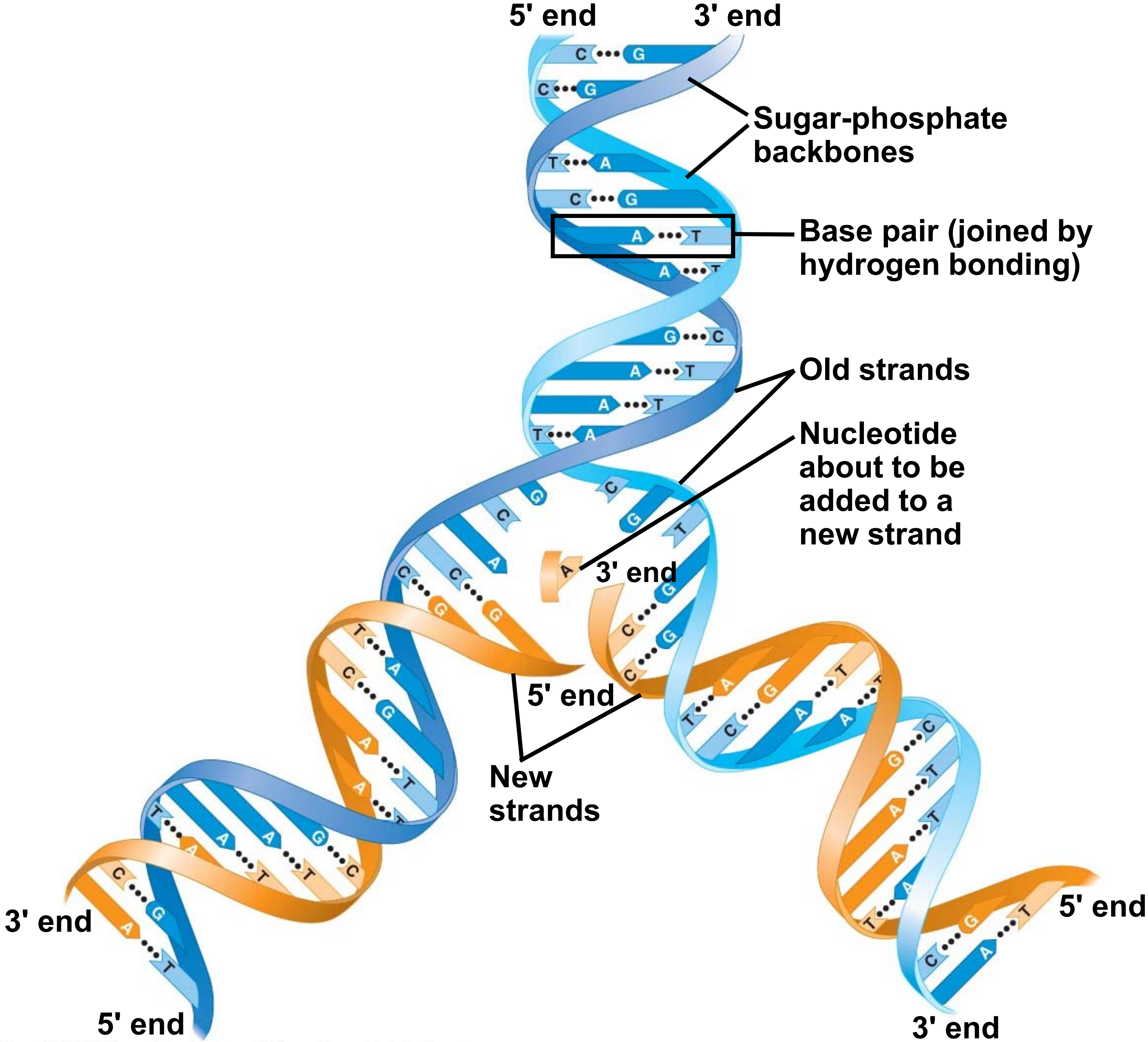

5 end
5 C
O
3 C
5 C
3 C
OH
3 end
(a) Polynucleotide, or nucleic acid
Nucleoside
Nitrogenous base
O
-O—P—O
O-
CH2
O
Phosphate group
Sugar (pentose)
(b) Nucleotide
Nitrogenous bases
Pyrimidines
NH2
N
C
CH
O
H
HN
CH3
Cytosine (C)
Thymine (T, in DNA)
Uracil (U, in RNA)
Purines
HC
NH
Adenine (A)
Guanine (G)
Sugars
5'
HOCH2
OH
4'
1'
3'
2'
Deoxyribose (in DNA)
Ribose (in RNA)
(c) Nucleoside components: sugars

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

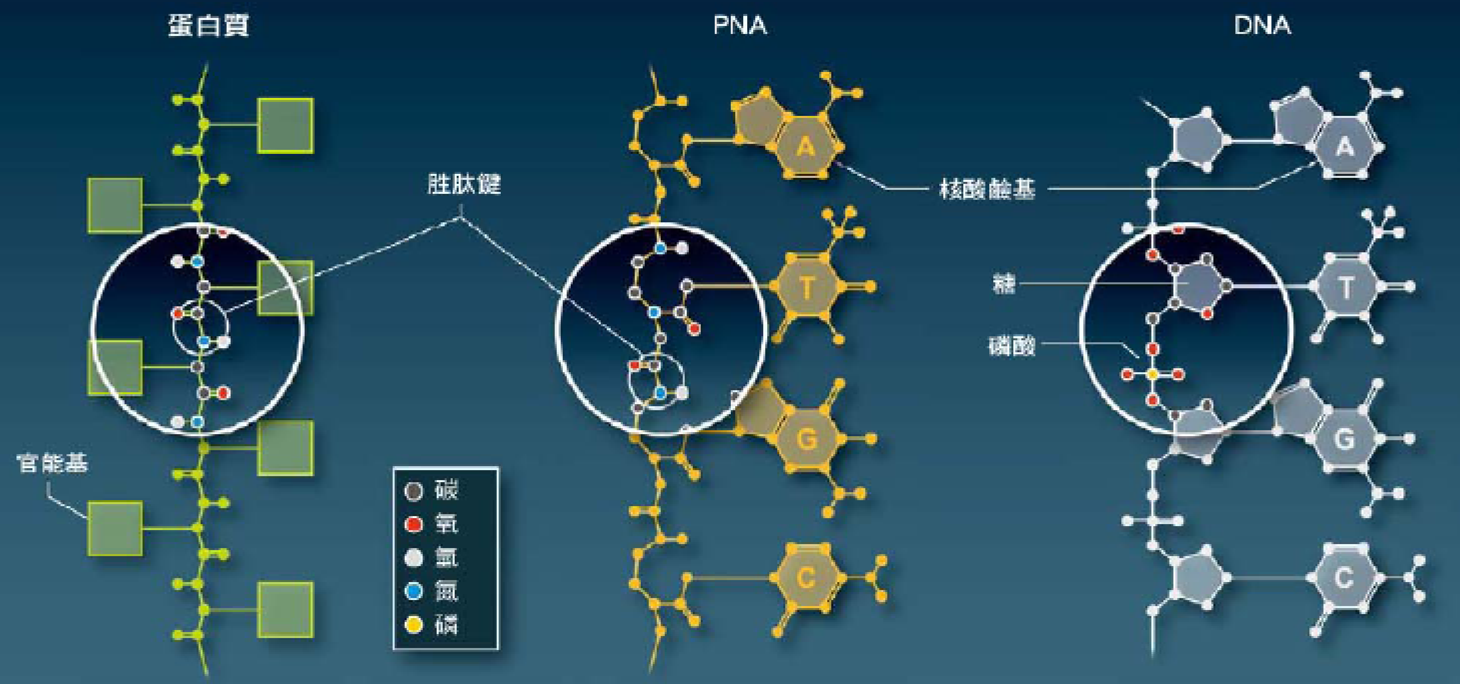
創新分子·創造生命

科學家開發出來的新分子胜肽核酸（PNA），兼具了蛋白質與DNA的特色，不但能發展成新藥物，還能用來創造完全異於自然的人工生命。

分子結構

PNA：蛋白質－DNA混成分子

胜肽核酸（PNA）兼具了蛋白質和DNA的特色。PNA的骨幹是由較為簡單的單元所構成，單元之間是以胜肽鍵連接（和蛋白質一樣）；DNA的骨幹則是由較不穩定且帶負電的糖－磷酸構成。此外，PNA的每一個單元上都帶有核酸鹼基，如同DNA鏈一般。



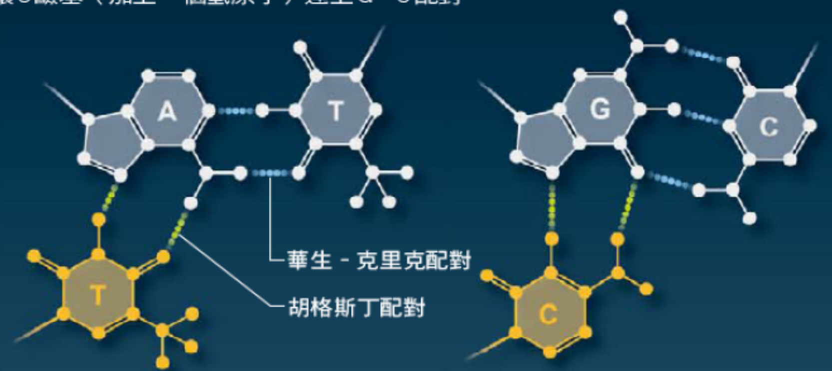
結合方式

辨識DNA

PNA可透過華生－克里克互補鹼基配對（一般雙股DNA所用的鍵結）或胡格斯丁配對來與DNA和RNA結合，而形成不同的結構，使得PNA藥物在細胞內有多樣的作用方式。

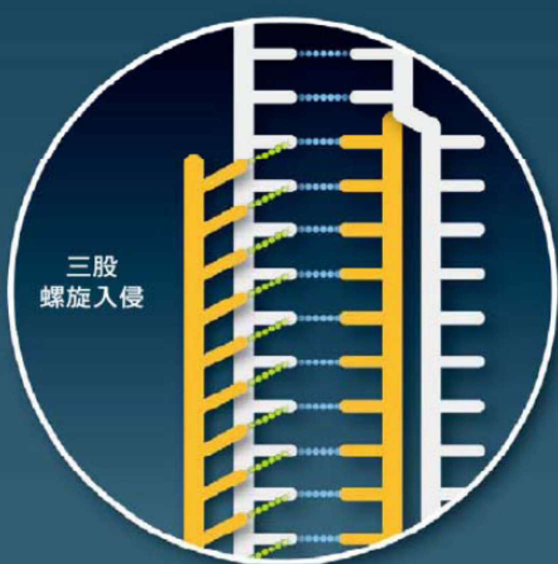
鹼基配對

華生－克里克配對（藍色鍵）連接了互補的A和T（左）與G和C（右）鹼基。胡格斯丁配對（綠色鍵）讓另一個T鹼基（左圖橘色者）連上A－T配對，或是讓C鹼基（加上一個氫原子）連上G－C配對。



PNA－DNA結構

有一種稱為三股螺旋入侵構造格外有趣，它能產生多項有用生物效應的構造。在這結構中，兩個PNA鏈（橘色）取代了雙股螺旋DNA的其中一股，而與另一股DNA形成三螺旋結構。下圖顯示了其他可能形成的構造，包括了基本的三股螺旋（亦描繪於45頁）。



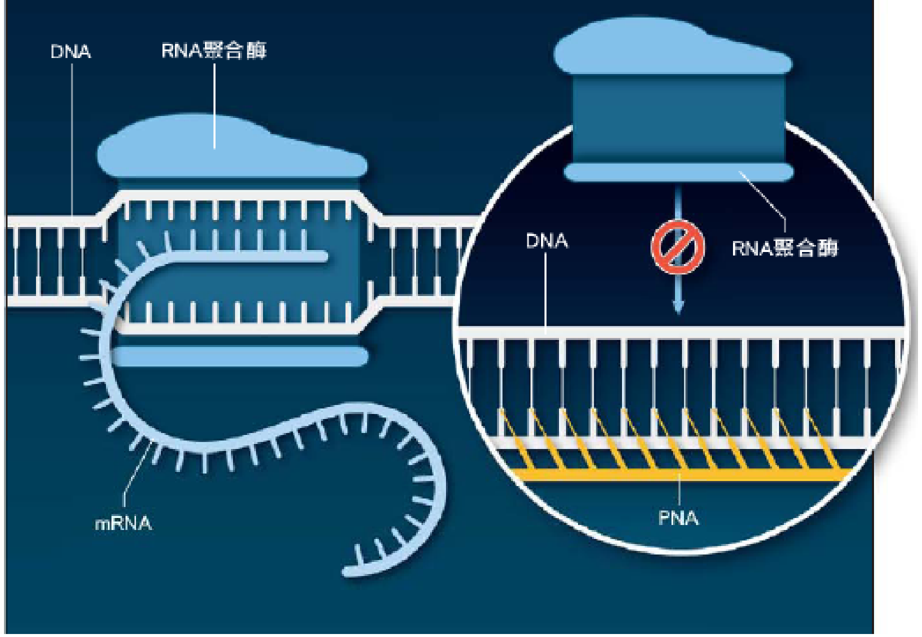
醫學效應

以PNA調控基因

PNA能和雙股DNA結合，也能和RNA結合，因此可多管齊下影響特定基因製造蛋白質的過程。

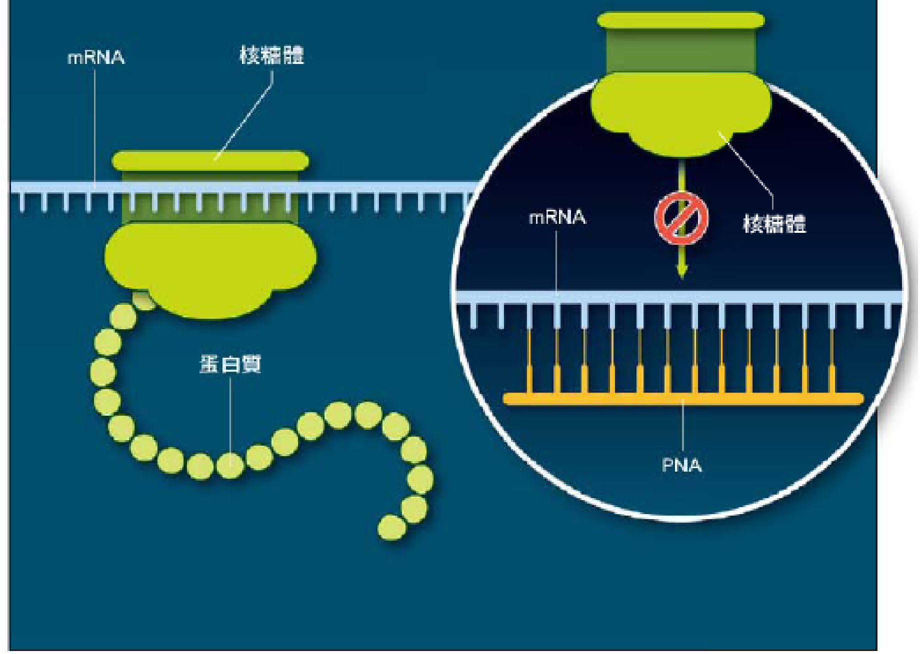
控制轉錄

在轉錄階段，RNA聚合酶會將DNA攜帶的密碼資訊轉錄成RNA分子。PNA可以和基因結合而妨礙轉錄過程（圖內插圖）；PNA也可能入侵DNA形成三股螺旋結構，而讓一段負責起始轉錄的酵素有機會辨識裸露出來的單股DNA，從而促進轉錄過程（圖中未顯示）。



阻斷轉譯

在蛋白質製造的第二階段，核糖體會將mRNA的序列轉譯成胺基酸序列，形成蛋白質。PNA可與mRNA結合而干擾轉譯過程。



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