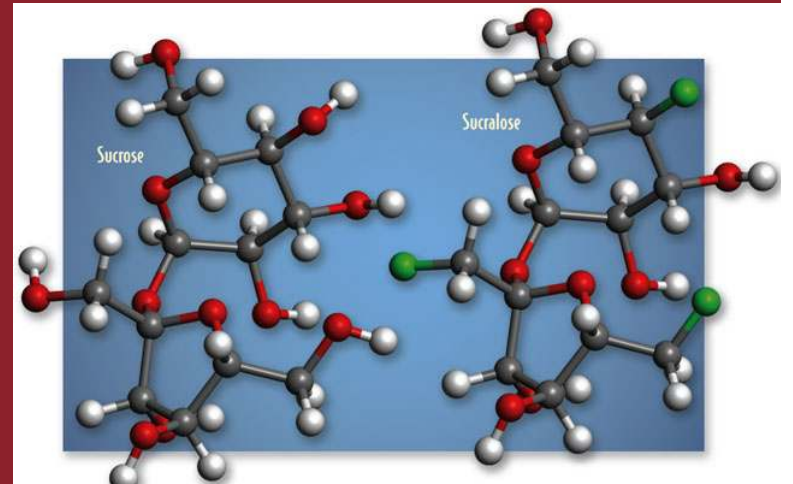


3

Macromolecules and the Origin of Life



3 Macromolecules and the Origin of Life

- 3.1 What Kinds of Molecules Characterize Living Things?
- 3.2 What Are the Chemical Structures and Functions of Proteins?
- 3.3 What Are the Chemical Structures and Functions of Carbohydrates?
- 3.4 What Are the Chemical Structures and Functions of Lipids?
- 3.5 What Are the Chemical Structures and Functions of Nucleic Acids?
- 3.6 How Did Life on Earth Begin?

3.1 What Kinds of Molecules Characterize Living Things?

Molecules in living organisms: proteins, carbohydrates, lipids, nucleic acids

Most are **polymers** of smaller molecules called **monomers**.

Macromolecules: polymers with molecular weights >1000

TABLE 3.1**The Building Blocks of Organisms**

MONOMER	COMPLEX POLYMER (MACROMOLECULE)
Amino acid	Polypeptide (protein)
Monosaccharide (sugar)	Polysaccharide (carbohydrate)
Nucleotide	Nucleic acid

3.1 What Kinds of Molecules Characterize Living Things?

Functional groups: groups of atoms with specific chemical properties and consistent behavior; it confers those properties when attached to large molecules

Figure 3.1 Some Functional Groups Important to Living Systems (Part 1)

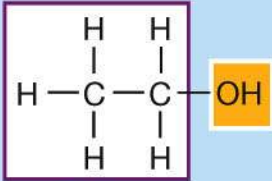
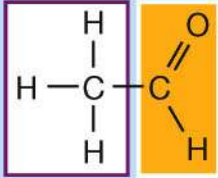

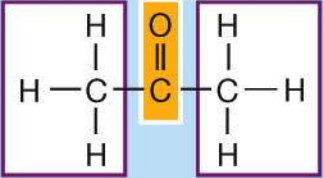
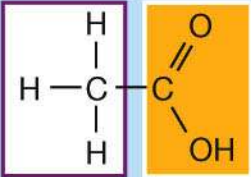
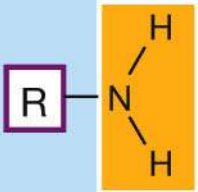
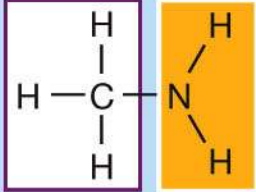
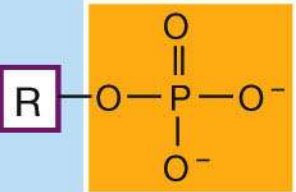
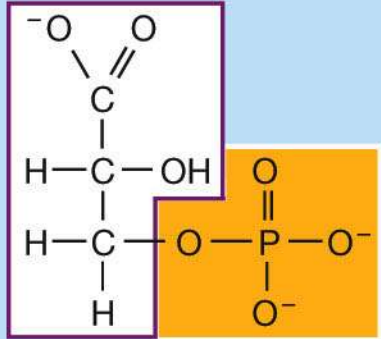
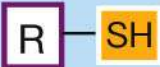
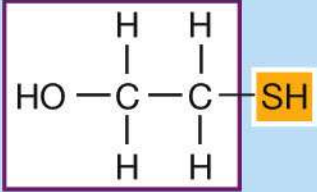
Functional group	Class of compounds	Structural formula	Example
Hydroxyl —OH or HO—	Alcohols	R—OH	 Ethanol
Aldehyde —CHO	Aldehydes	R—C(=O)H	 Acetaldehyde
Keto 	Ketones	R—C(=O)—R	 Acetone
Carboxyl —COOH	Carboxylic acids	R—C(=O)OH	 Acetic acid

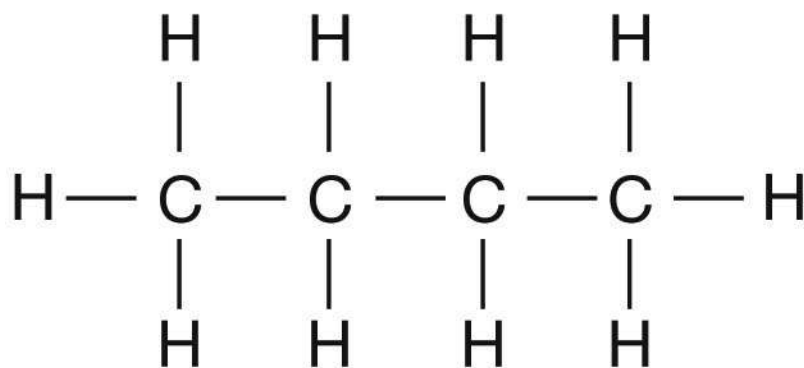
Figure 3.1 Some Functional Groups Important to Living Systems (Part 2)

Functional group	Class of compounds	Structural formula	Example
Amino —NH_2	Amines		 Methylamine
Phosphate —OPO_3^{2-}	Organic phosphates		 3-Phosphoglycerate
Sulfhydryl —SH	Thiols		 Mercaptoethanol

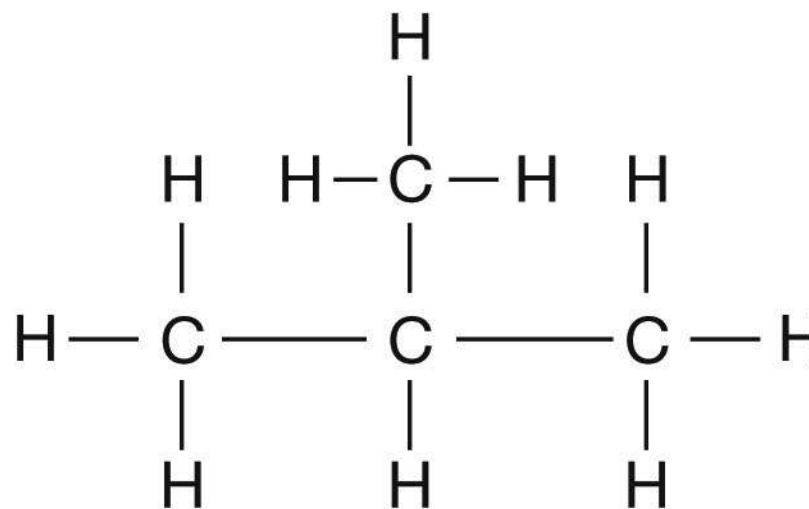
3.1 What Kinds of Molecules Characterize Living Things?

Isomers: molecules with the same chemical formula, but atoms are arranged differently

Structural isomers: differ in how their atoms are joined together

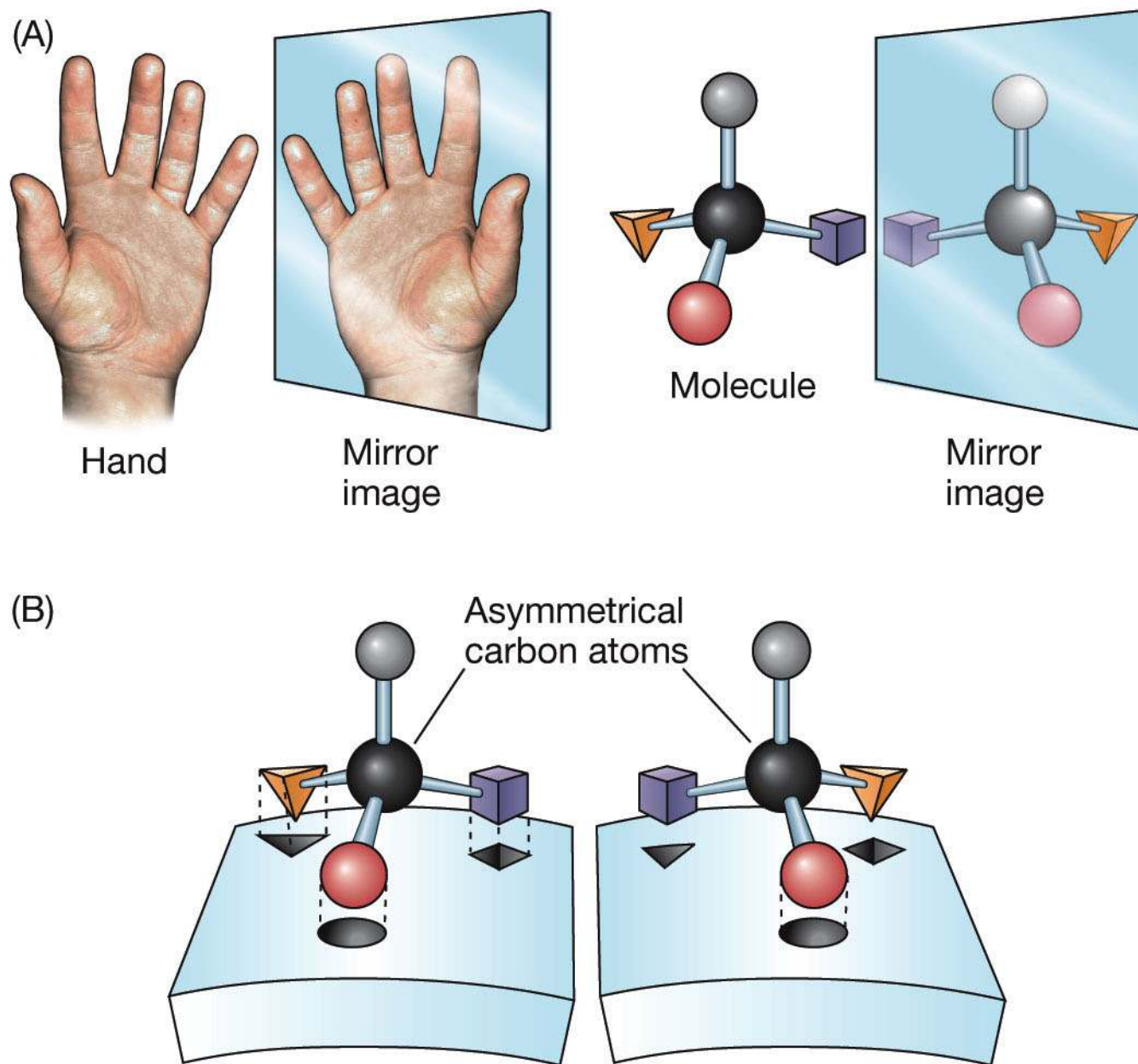


Butane



Isobutane

Figure 3.2 Optical Isomers



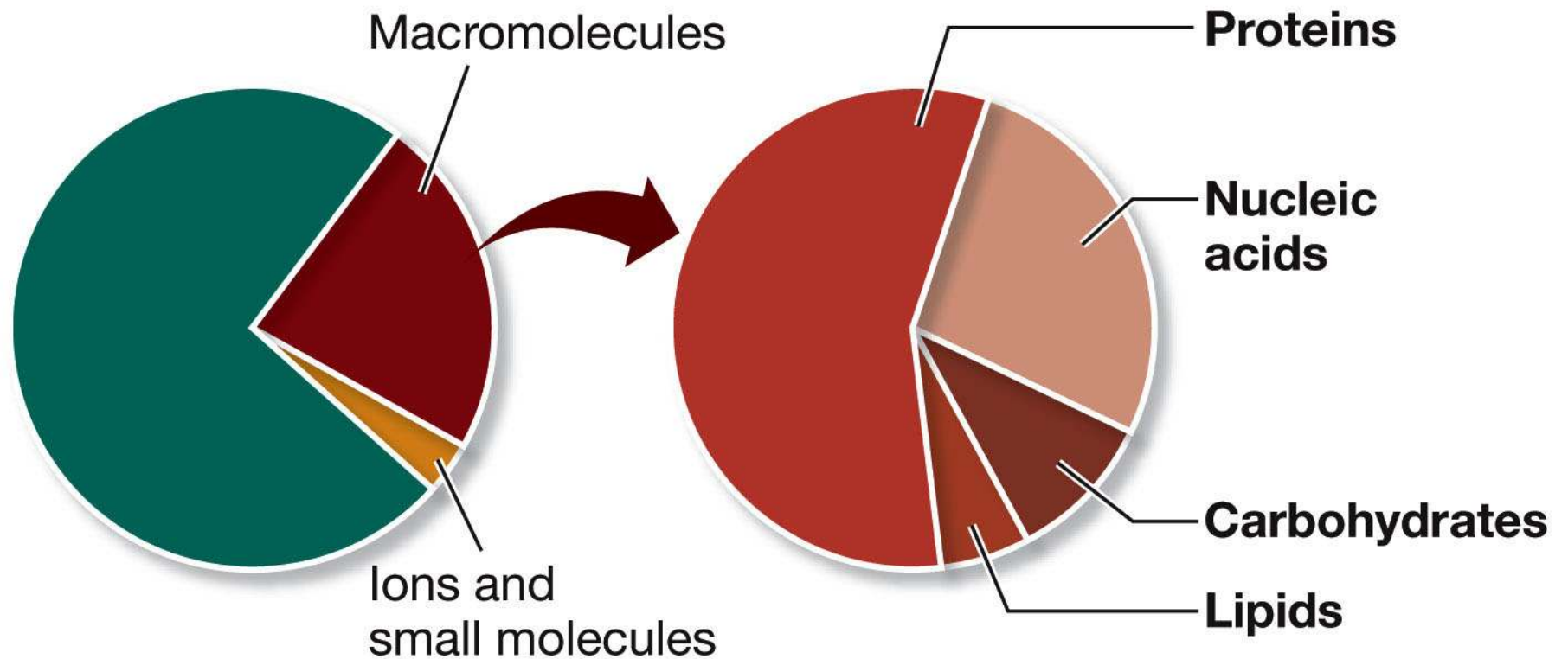
LIFE 8e, Figure 3.2

3.1 What Kinds of Molecules Characterize Living Things?

Biochemical unity—organisms can obtain required macromolecules by eating other organisms.

One macromolecule can contain many different functional groups—determines shape and function.

Figure 3.3 Substances Found in Living Tissues



3.1 What Kinds of Molecules Characterize Living Things?

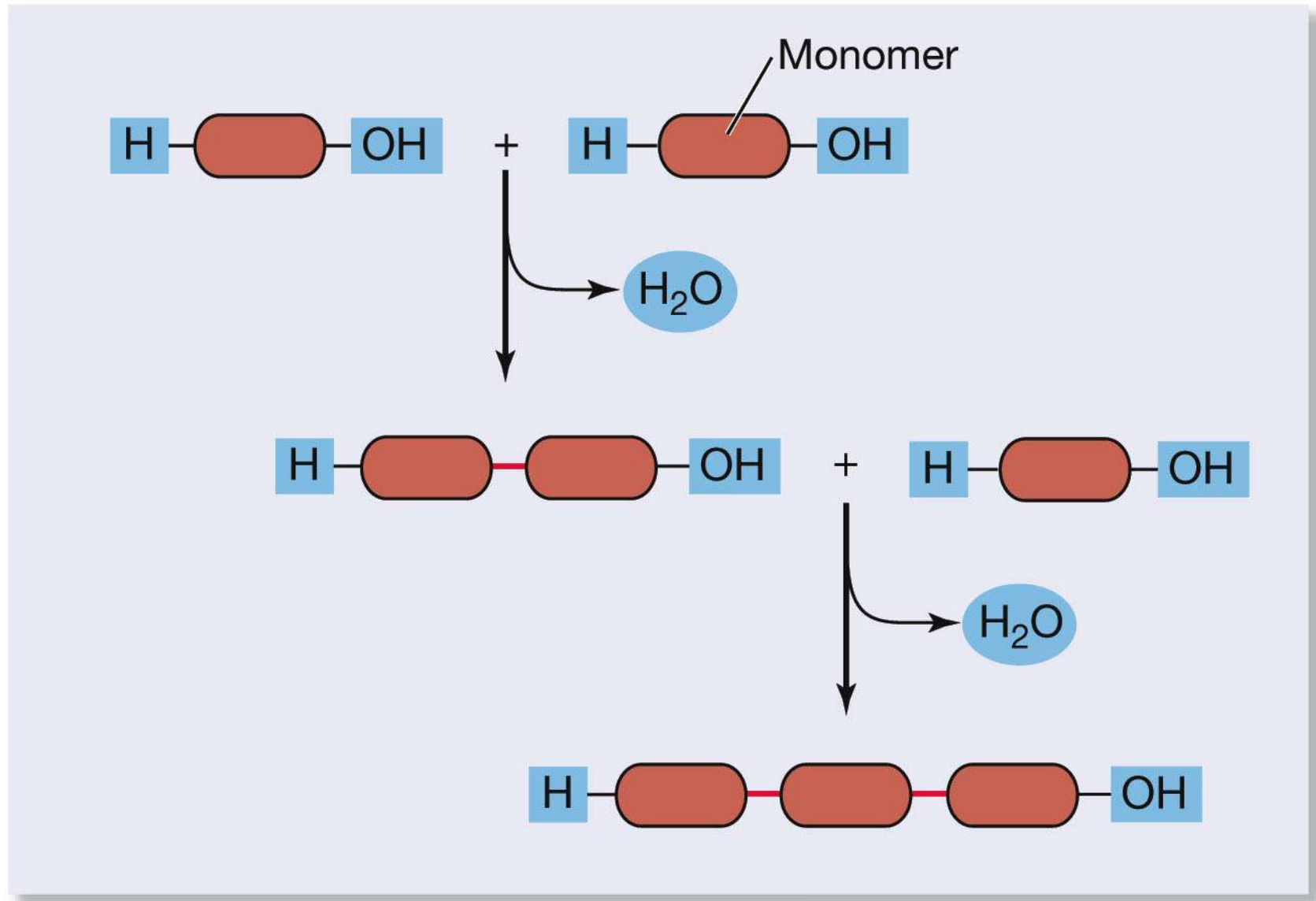
Polymers are formed in **condensation reactions**.

Monomers are joined by covalent bonds.

A water is removed—also called *dehydration reaction*.

Figure 3.4 Condensation and Hydrolysis of Polymers (A)

(A) Condensation



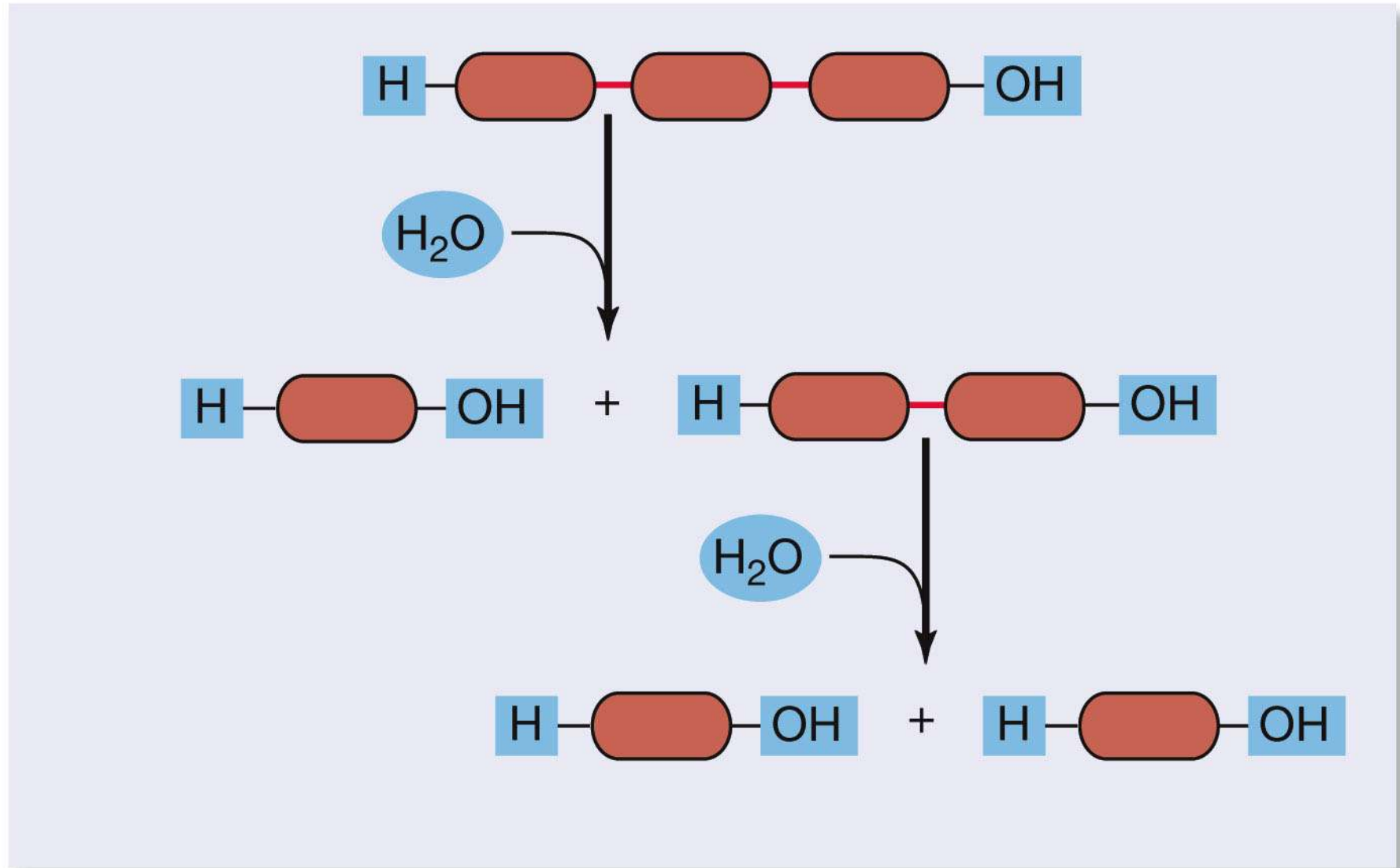
3.1 What Kinds of Molecules Characterize Living Things?

Polymers are broken down into monomers in hydrolysis reactions.

(*hydro*, “water”; *lysis*, “break”)

Figure 3.4 Condensation and Hydrolysis of Polymers (B)

(B) Hydrolysis



3.2 What Are the Chemical Structures and Functions of Proteins?

Functions of proteins:

- Structural support
- Protection
- Transport
- Catalysis
- Defense
- Regulation
- Movement

3.2 What Are the Chemical Structures and Functions of Proteins?

Proteins are made from 20 different **amino acids** (monomeric units)

Polypeptide chain: single, unbranched chain of amino acids

The chains are folded into specific three dimensional shapes.

Proteins can consist of more than one type of polypeptide chain.

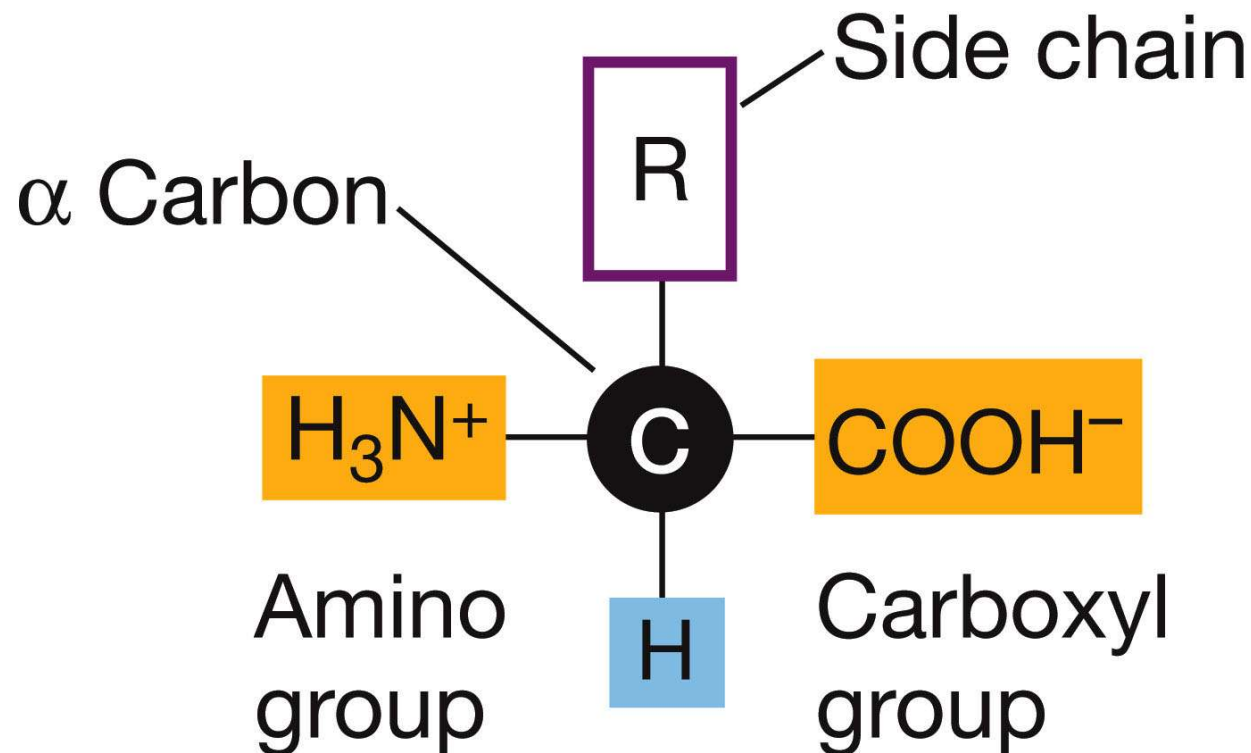
3.2 What Are the Chemical Structures and Functions of Proteins?

The *composition* of a protein: relative amounts of each amino acid present

The *sequence* of amino acids in the chain determines the protein structure and function.

3.2 What Are the Chemical Structures and Functions of Proteins?

Amino acids have carboxyl and amino groups—they function as both acid and base.



3.2 What Are the Chemical Structures and Functions of Proteins?

The α carbon atom is asymmetrical.

Amino acids exist in two isomeric forms:

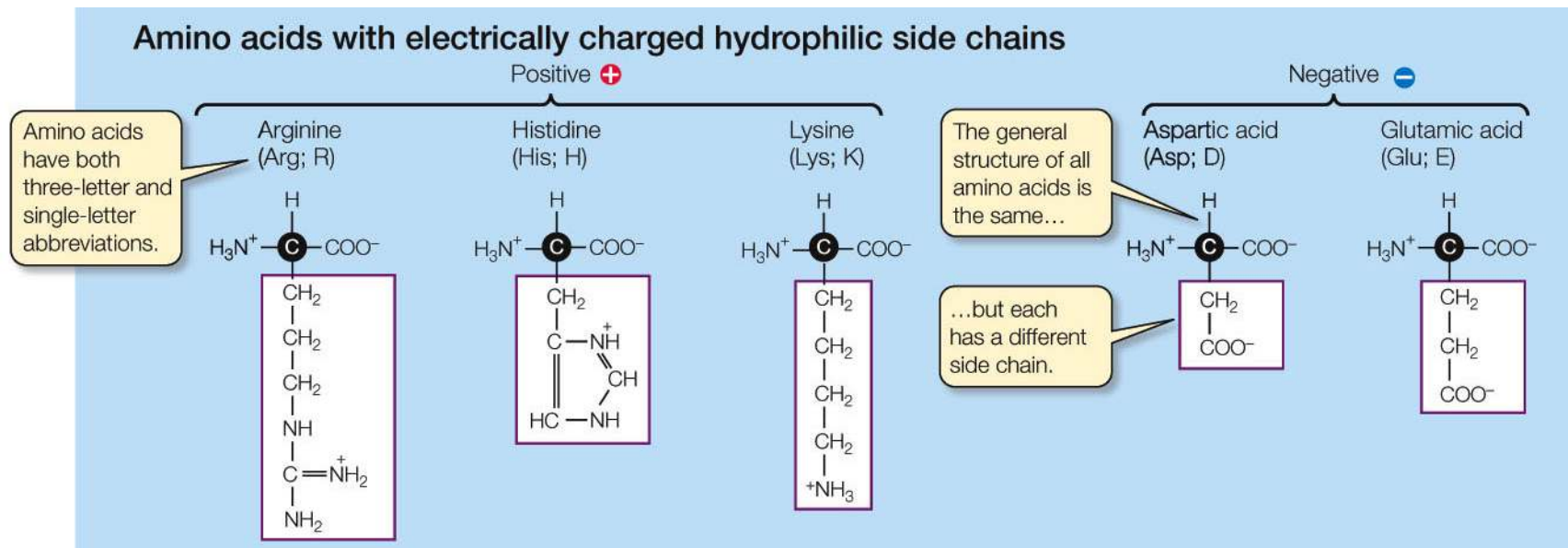
- D-amino acids (*dextro*, “right”)
- L-amino acids (*levo*, “left”)—this form is found in organisms

3.2 What Are the Chemical Structures and Functions of Proteins?

The side chains or R-groups also have functional groups.

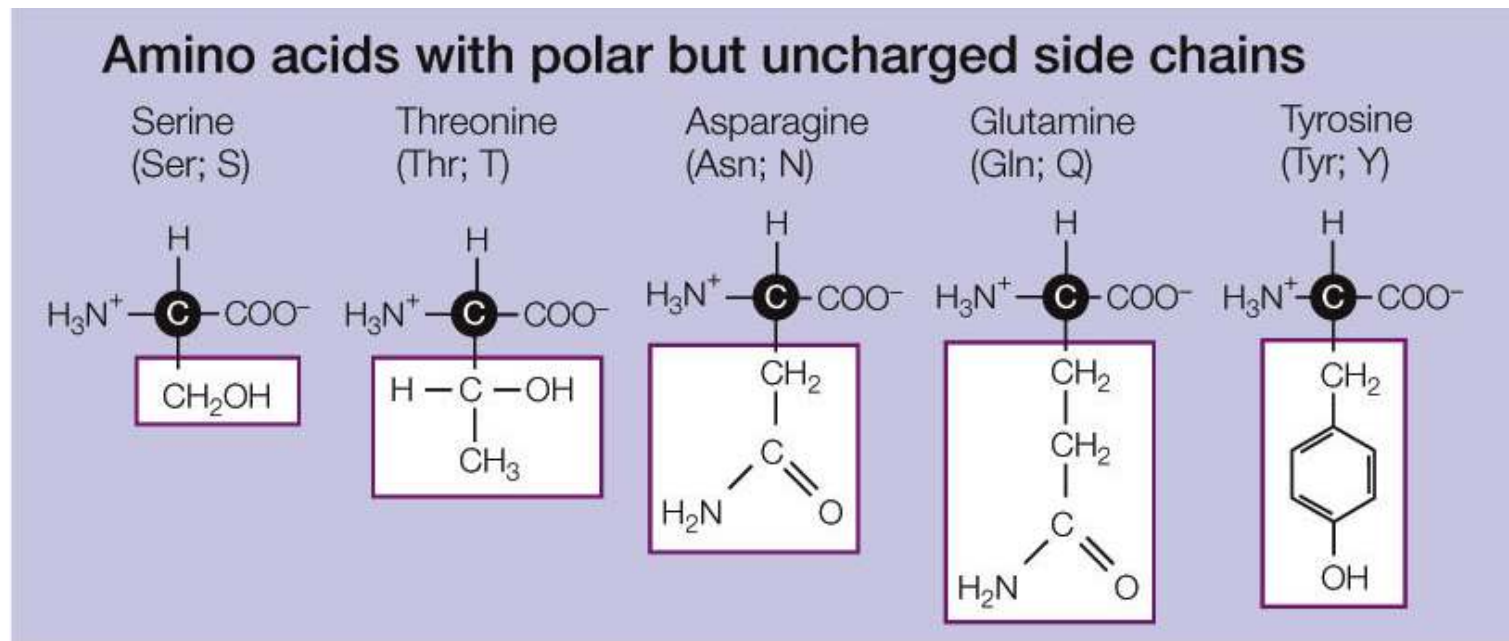
Amino acids can be grouped based on side chains.

Table 3.2 (Part 1)



These hydrophylic amino acids attract ions of opposite charges.

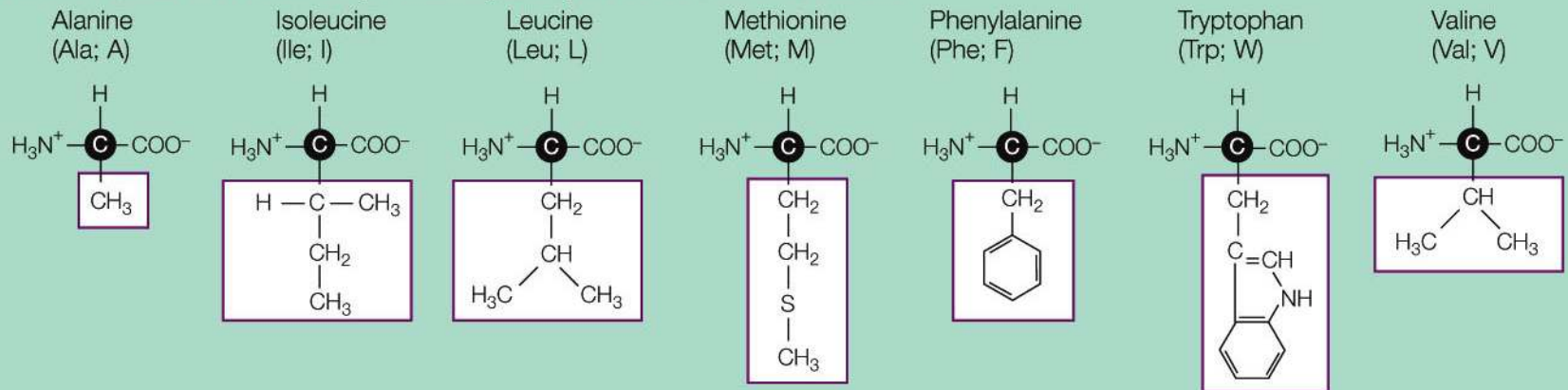
Table 3.2 (Part 2)



Hydrophylic amino acids with polar but uncharged side chains
form hydrogen bonds

Table 3.2 (Part 3)

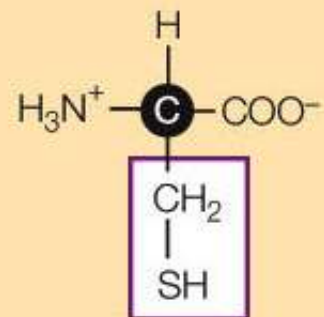
Amino acids with nonpolar hydrophobic side chains



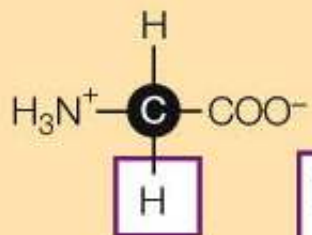
Hydrophobic amino acids

Special cases

Cysteine
(Cys; C)



Glycine
(Gly; G)



Proline
(Pro; P)

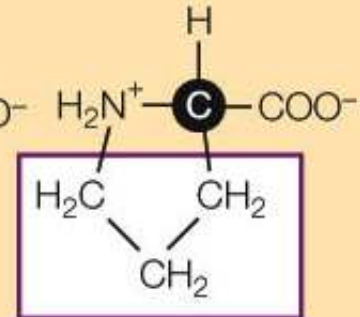
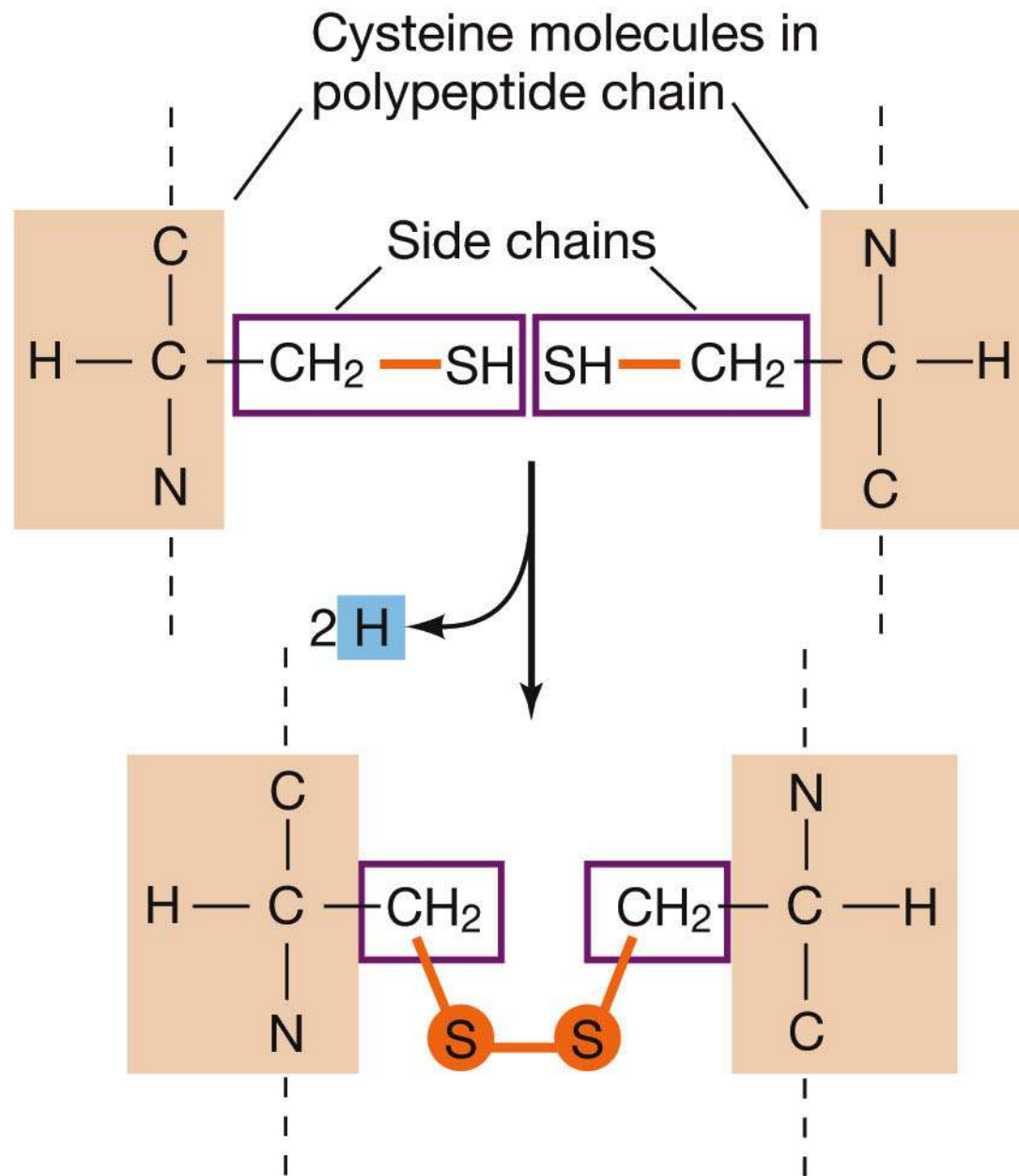


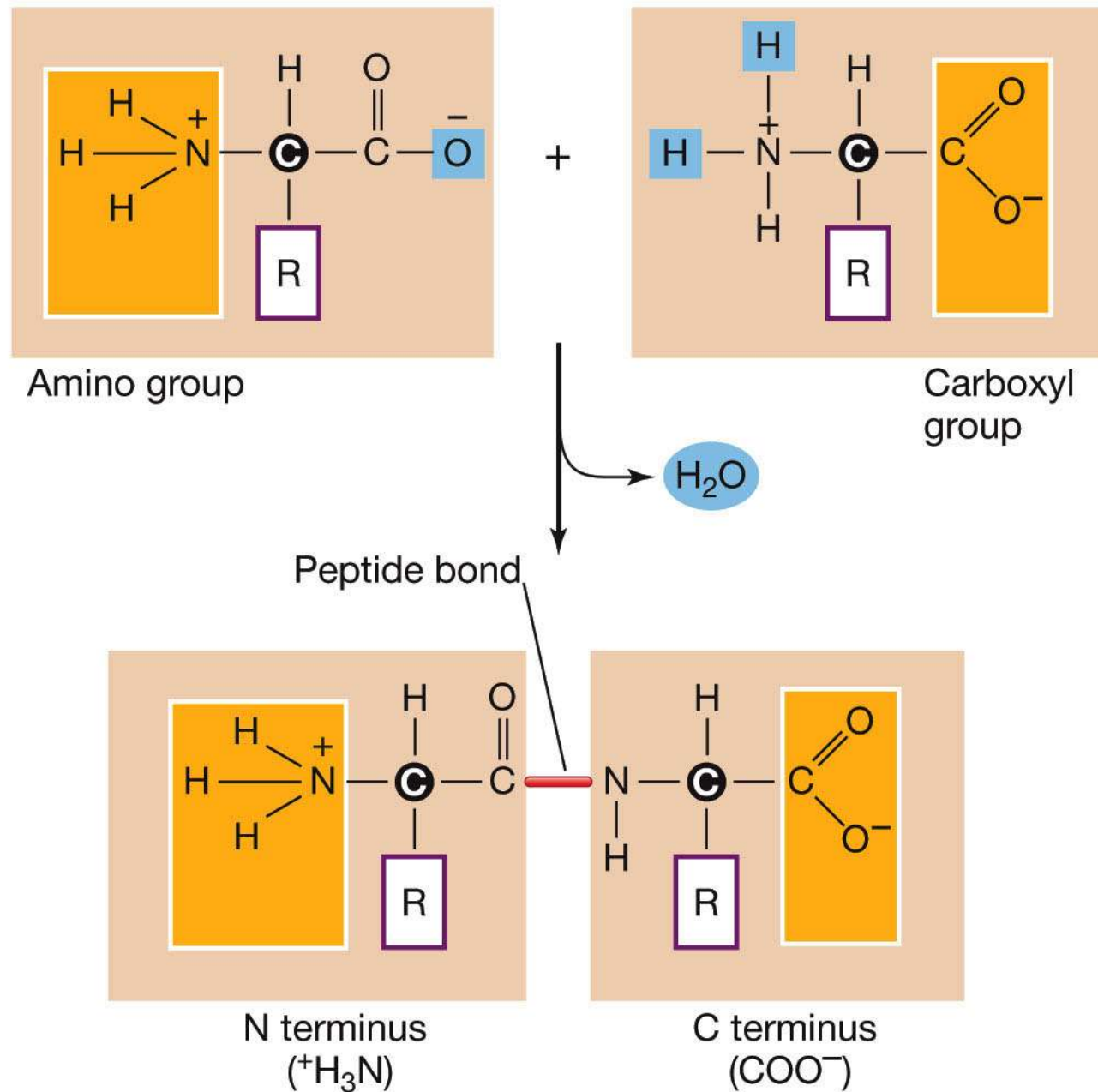
Figure 3.5 A Disulfide Bridge



3.2 What Are the Chemical Structures and Functions of Proteins?

Amino acids bond together covalently by **peptide bonds** to form the polypeptide chain.

Figure 3.6 Formation of Peptide Bonds



3.2 What Are the Chemical Structures and Functions of Proteins?

A polypeptide chain is like a sentence:

- The “capital letter” is the amino group of the first amino acid—the *N terminus*.
- The “period” is the carboxyl group of the last amino acid—the *C terminus*.

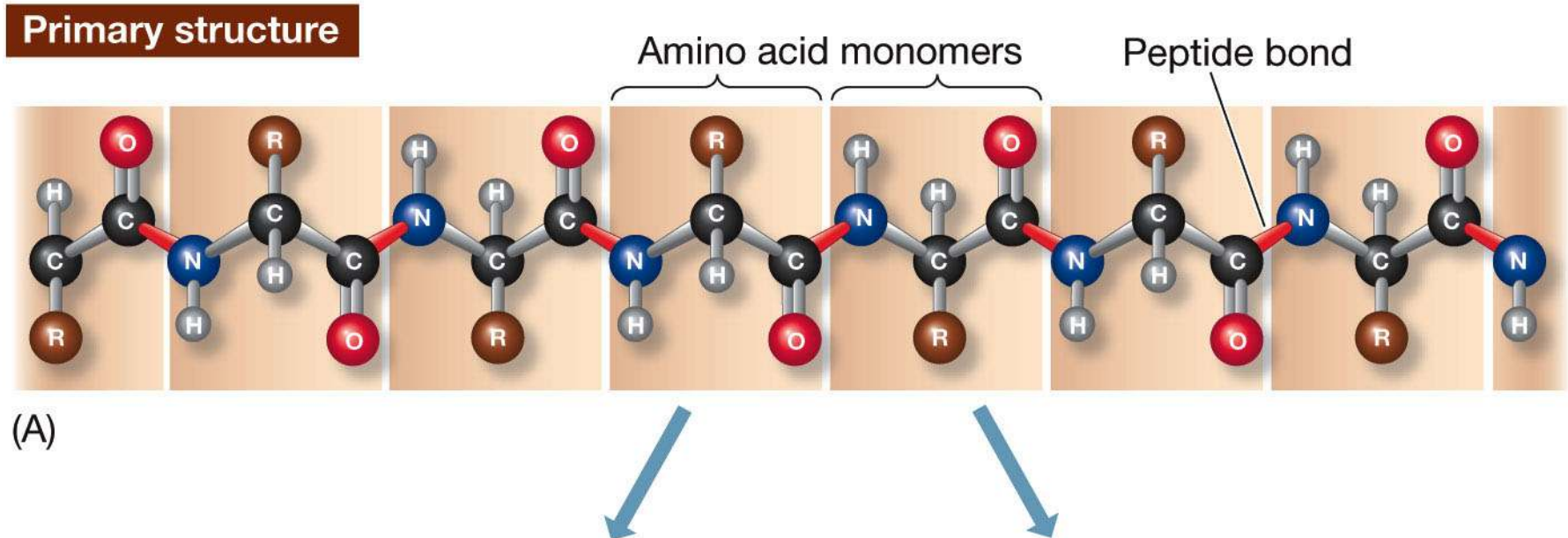
3.2 What Are the Chemical Structures and Functions of Proteins?

The **primary structure** of a protein is the sequence of amino acids.

The sequence determines secondary and tertiary structure—how the protein is folded.

The number of different proteins that can be made from 20 amino acids is enormous!

Figure 3.7 The Four Levels of Protein Structure (A)

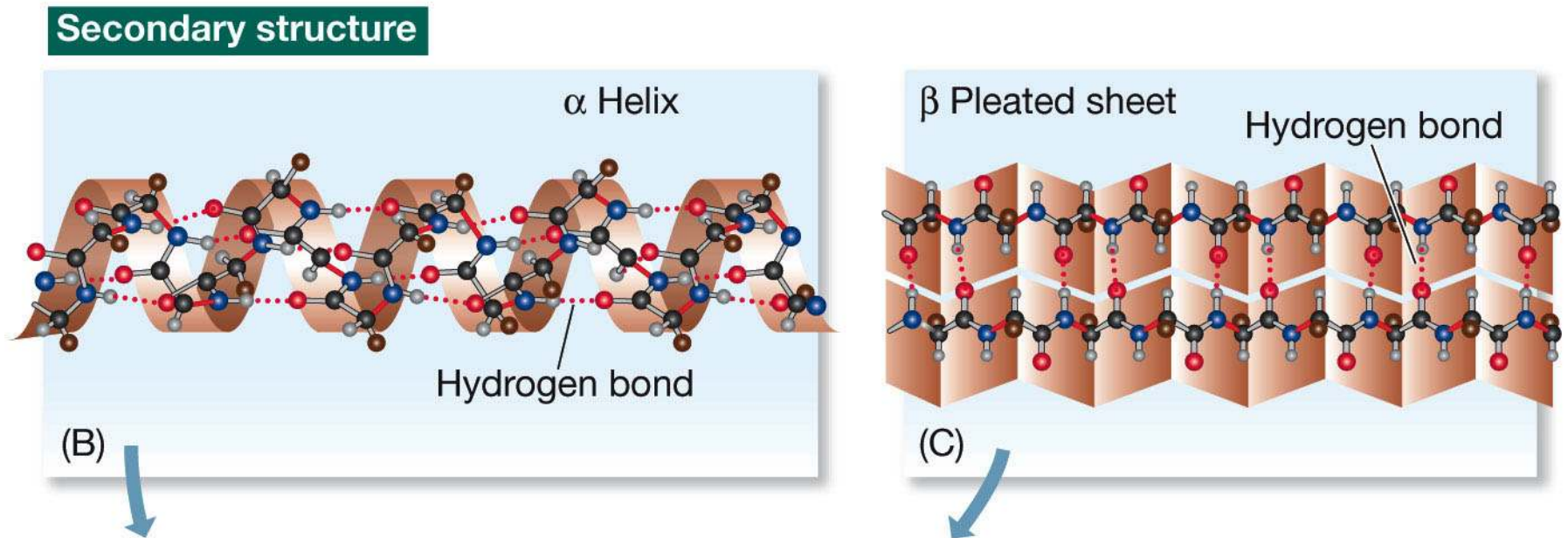


3.2 What Are the Chemical Structures and Functions of Proteins?

Secondary structure:

- **α helix**—right-handed coil resulting from hydrogen bonding; common in fibrous structural proteins
- **β pleated sheet**—two or more polypeptide chains are aligned

Figure 3.7 The Four Levels of Protein Structure (B, C)

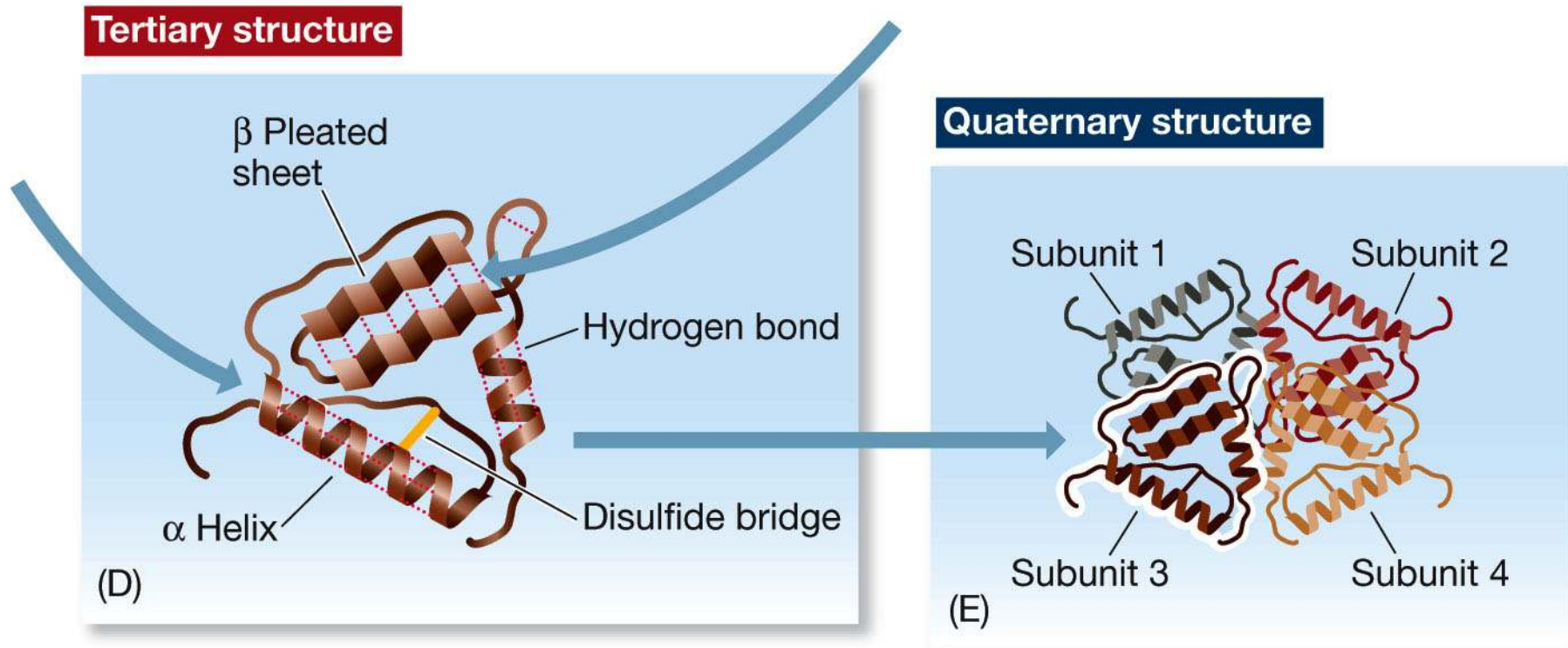


3.2 What Are the Chemical Structures and Functions of Proteins?

Tertiary structure: Bending and folding results in a macromolecule with specific three-dimensional shape.

The outer surfaces present functional groups that can interact with other molecules.

Figure 3.7 The Four Levels of Protein Structure (D, E)



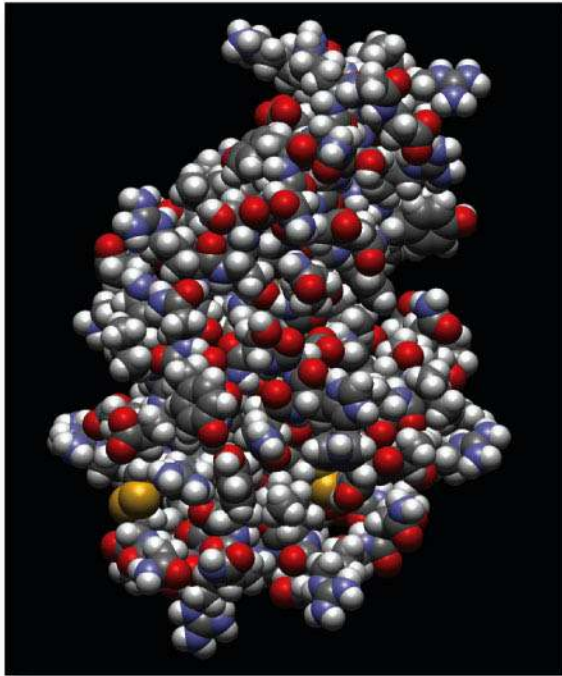
3.2 What Are the Chemical Structures and Functions of Proteins?

Tertiary structure is determined by interactions of R-groups:

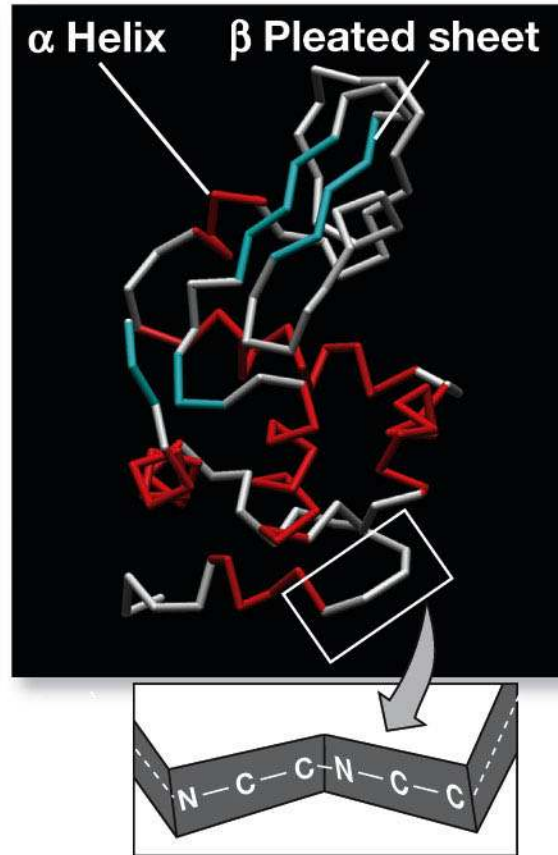
- Disulfide bonds
- Aggregation of hydrophobic side chains
- van der Waals forces
- Ionic bonds
- Hydrogen bonds

Figure 3.8 Three Representations of Lysozyme

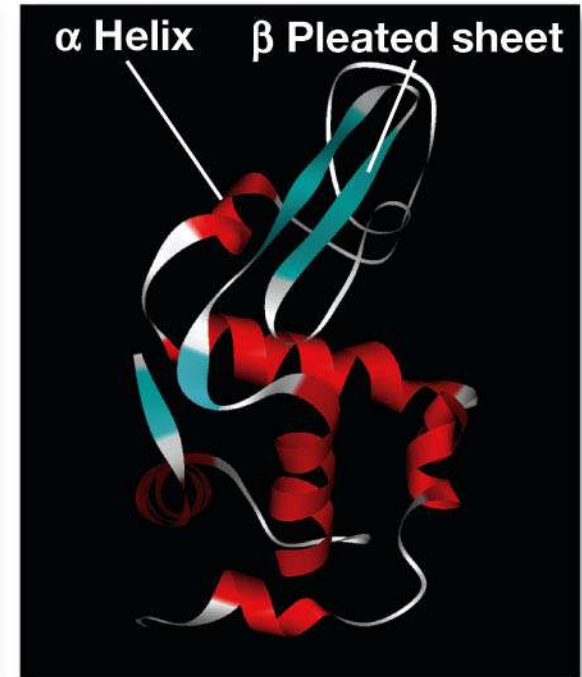
(A) Space-filling model



(B) Stick model



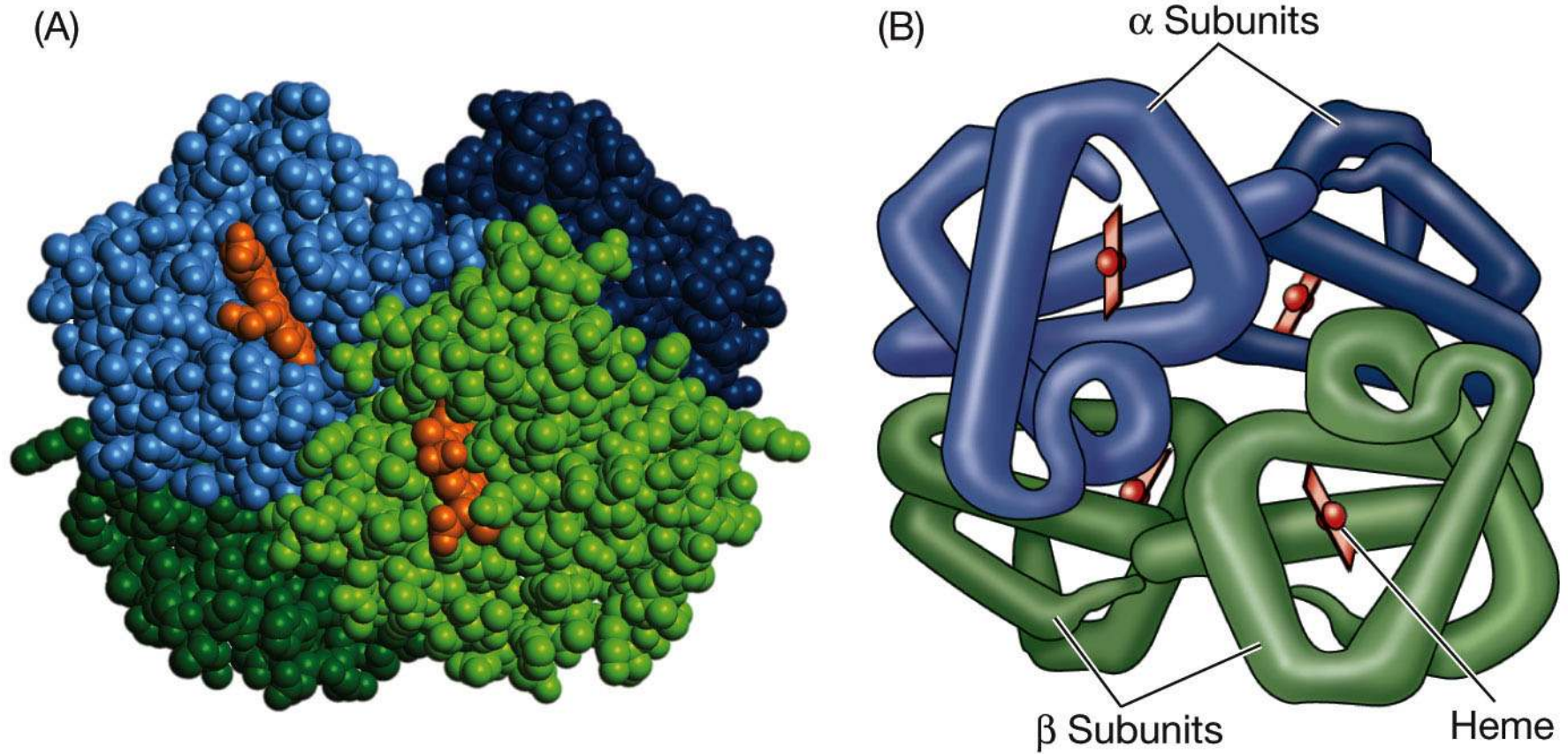
(C) Ribbon model



3.2 What Are the Chemical Structures and Functions of Proteins?

Quaternary structure results from the interaction of *subunits* by hydrophobic interactions, van der Waals forces, ionic bonds, and hydrogen bonds.

Figure 3.9 Quaternary Structure of a Protein

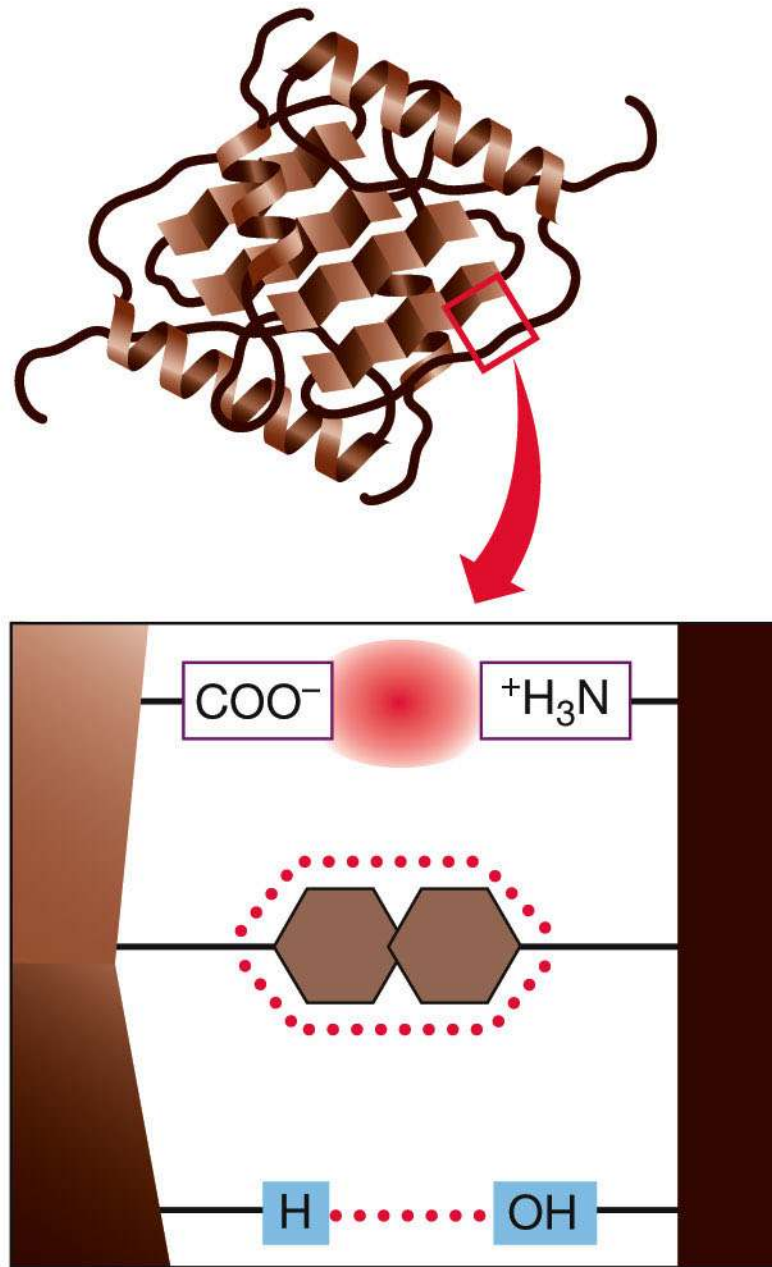


3.2 What Are the Chemical Structures and Functions of Proteins?

The specific shape and functional groups of a protein determines function and allows it to bind non-covalently with another molecule (the **ligand**).

Enzyme-substrate reactions, chemical signaling, antibody action, etc.

Figure 3.10 Noncovalent Interactions between Proteins and Other Molecules



LIFE 8e, Figure 3.10

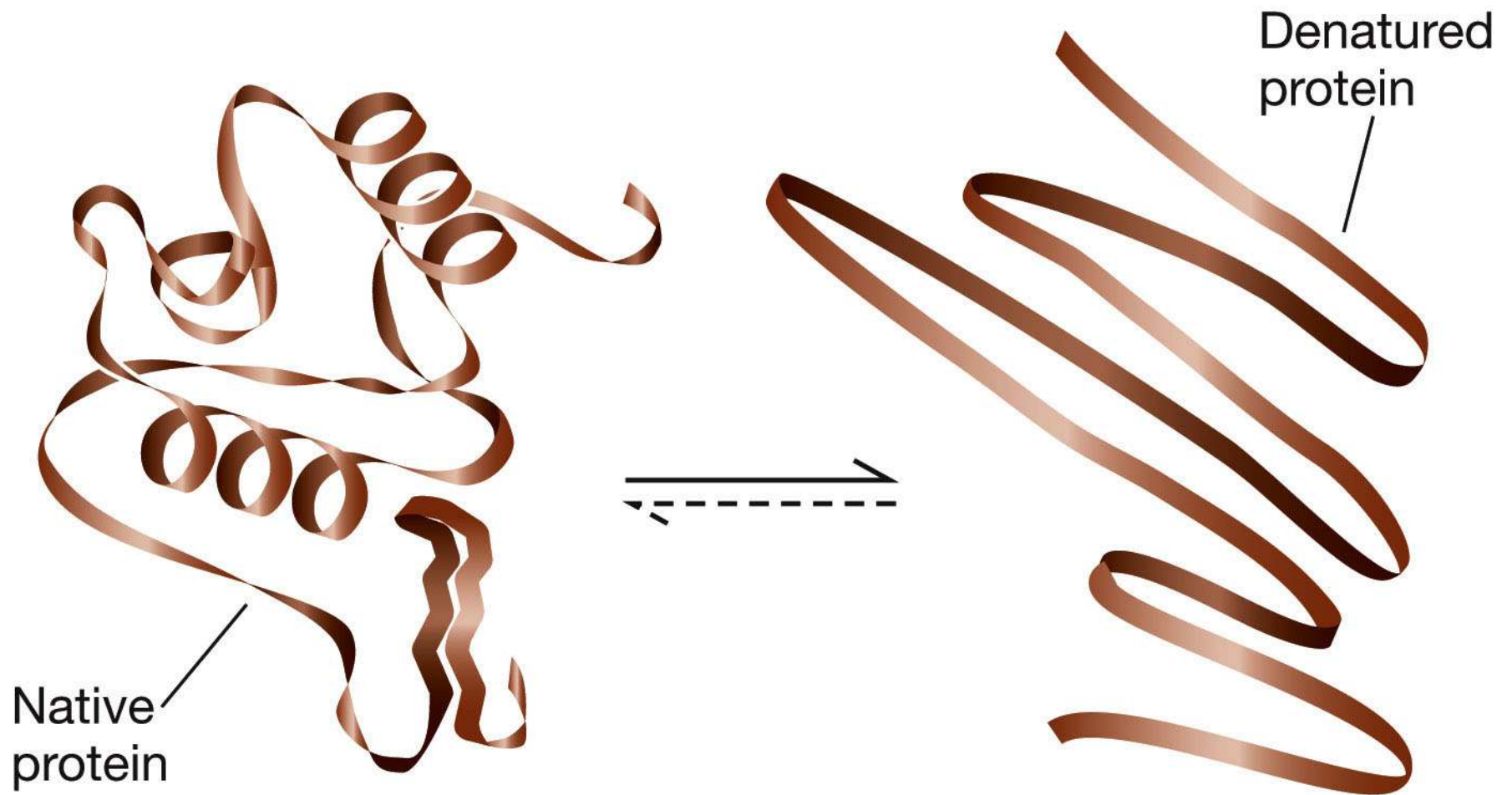
3.2 What Are the Chemical Structures and Functions of Proteins?

Conditions that affect secondary and tertiary structure:

- High temperature
- pH changes
- High concentrations of polar molecules

Denaturation: loss of 3-dimensional structure and thus function of the protein

Figure 3.11 Denaturation Is the Loss of Tertiary Protein Structure and Function

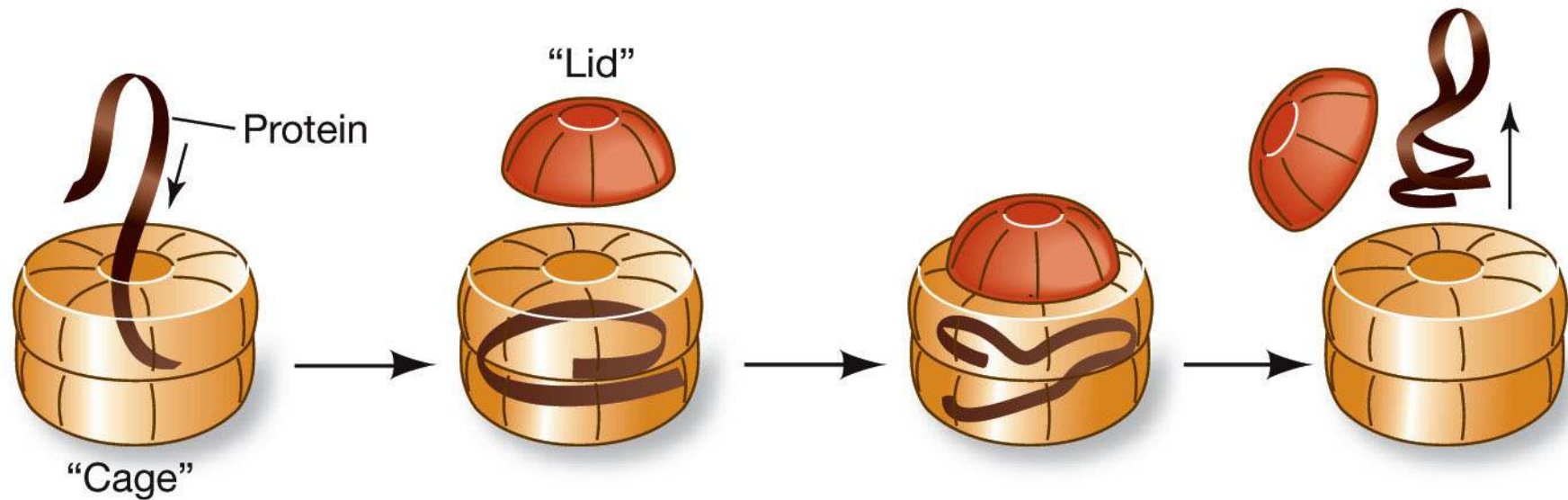


3.2 What Are the Chemical Structures and Functions of Proteins?

Proteins can sometimes bind to the wrong ligands.

Chaperonins are proteins that help prevent this.

Figure 3.12 Chaperonins Protect Proteins from Inappropriate Binding



3.3 What Are the Chemical Structures and Functions of Carbohydrates?

Carbohydrates: molecules in which carbon is flanked by hydrogen and hydroxyl groups.



Energy source

Carbon skeletons for many other molecules

3.3 What Are the Chemical Structures and Functions of Carbohydrates?

Monosaccharides: simple sugars

Disaccharides: two simple sugars linked by covalent bonds

Oligosaccharides: three to 20 monosaccharides

Polysaccharides: hundreds or thousands of monosaccharides—starch, glycogen, cellulose

3.3 What Are the Chemical Structures and Functions of Carbohydrates?

Cells use **glucose** (monosaccharide) as an energy source.

Exists as a straight chain or ring form.
Ring is more common—it is more stable.

Figure 3.13 Glucose: From One Form to the Other (Part 1)

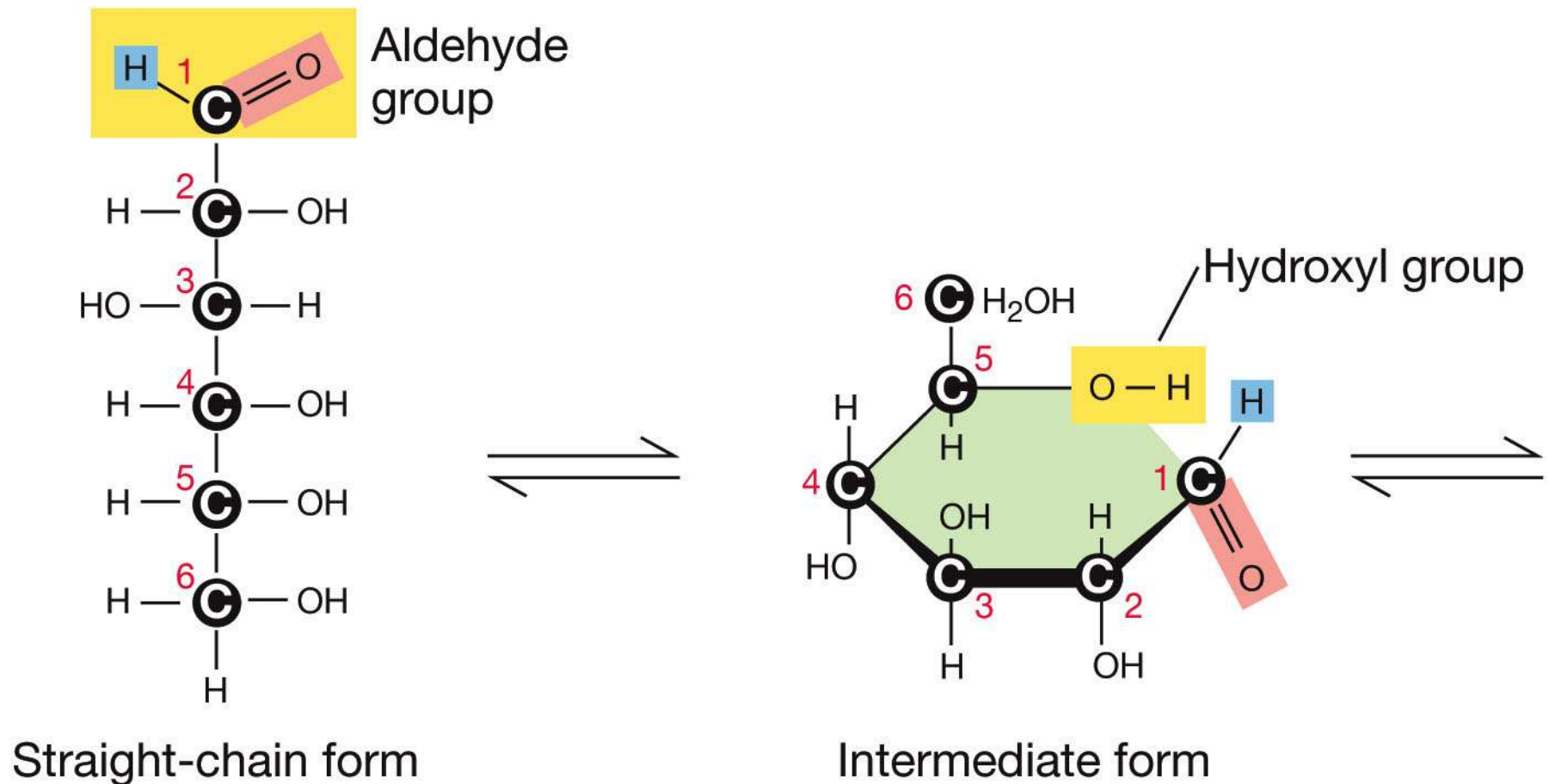
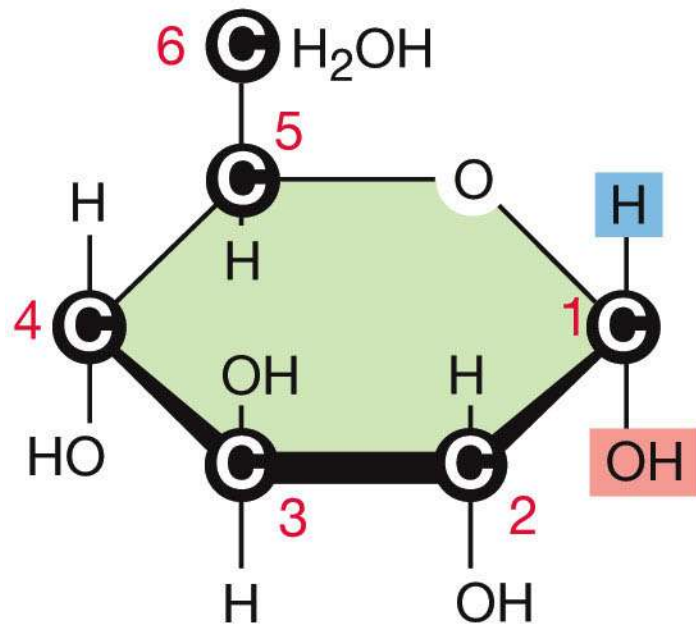
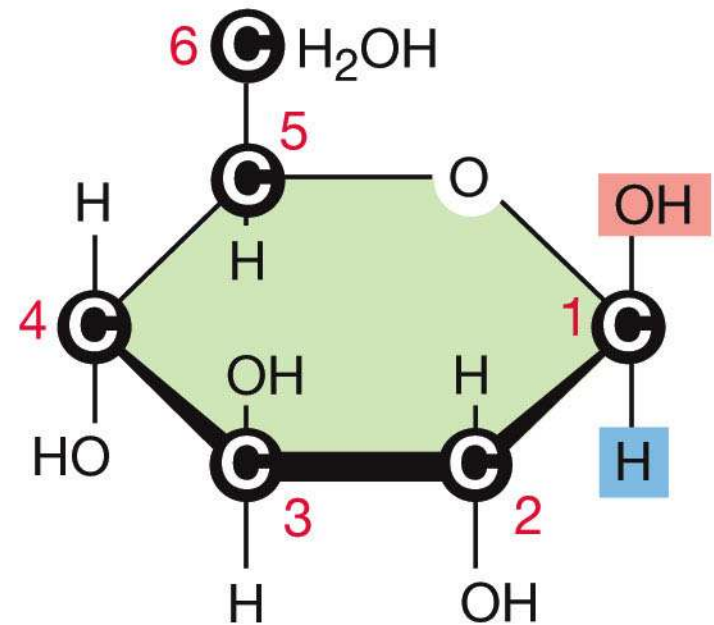


Figure 3.13 Glucose: From One Form to the Other (Part 2)



α -D-Glucose

or



β -D-Glucose

3.3 What Are the Chemical Structures and Functions of Carbohydrates?

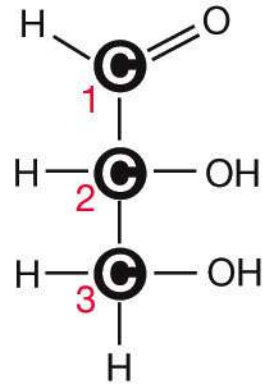
Monosaccharides have different numbers of carbons.

Hexoses: six carbons—structural isomers

Pentoses: five carbons

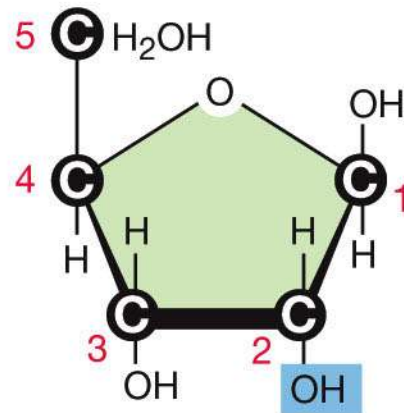
Figure 3.14 Monosaccharides Are Simple Sugars (Part 1)

Three-carbon sugar

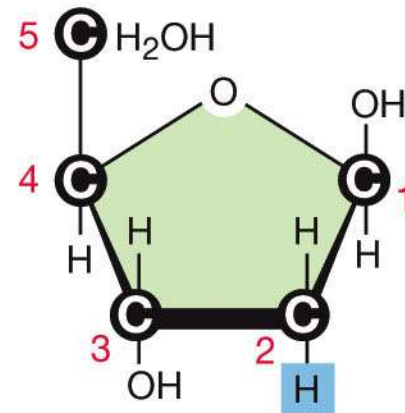


Glyceraldehyde

Five-carbon sugars



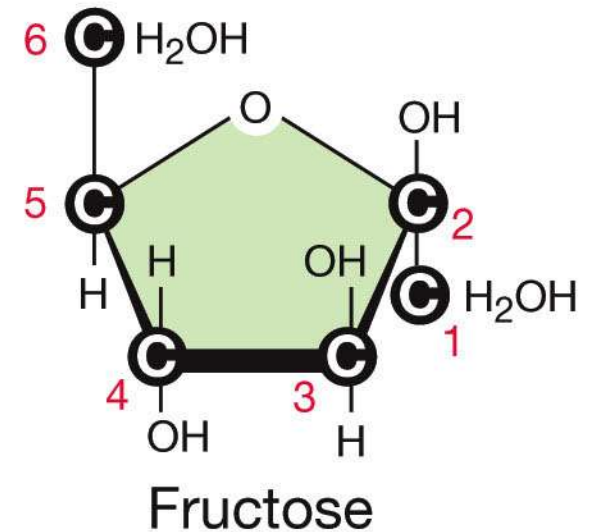
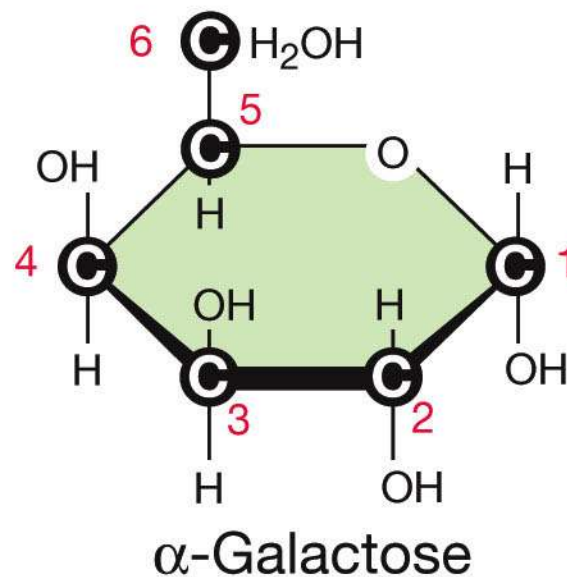
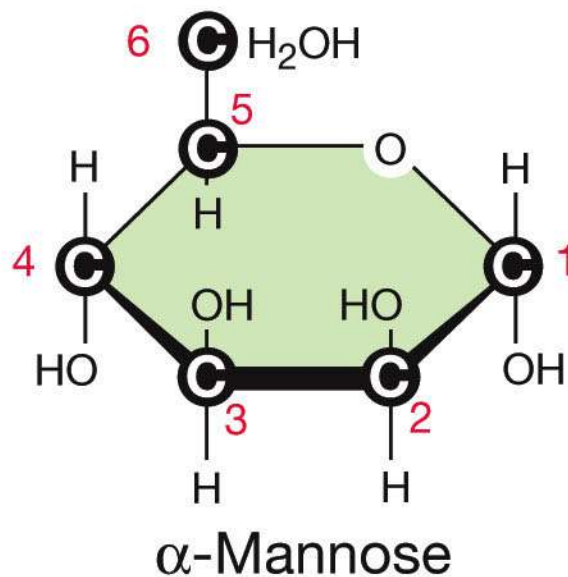
Ribose



Deoxyribose

Figure 3.14 Monosaccharides Are Simple Sugars (Part 2)

Six-carbon sugars



3.3 What Are the Chemical Structures and Functions of Carbohydrates?

Monosaccharides bind together in condensation reactions to form **glycosidic linkages**.

Glycosidic linkages can be α or β .

Figure 3.15 Disaccharides Are Formed by Glycosidic Linkages (Part 1)

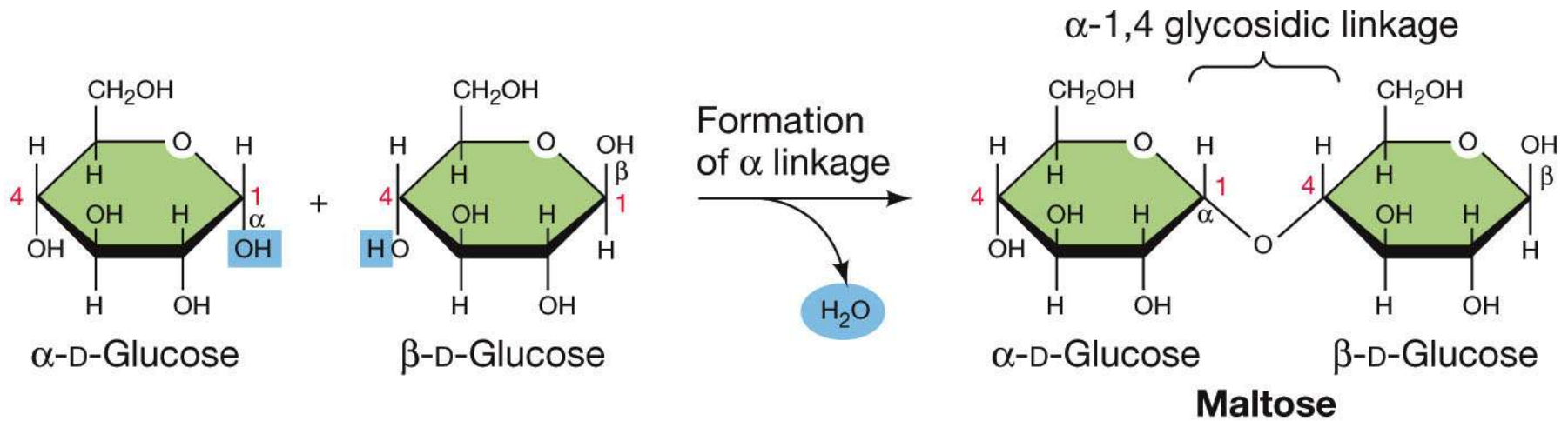


Figure 3.15 Disaccharides Are Formed by Glycosidic Linkages (Part 2)

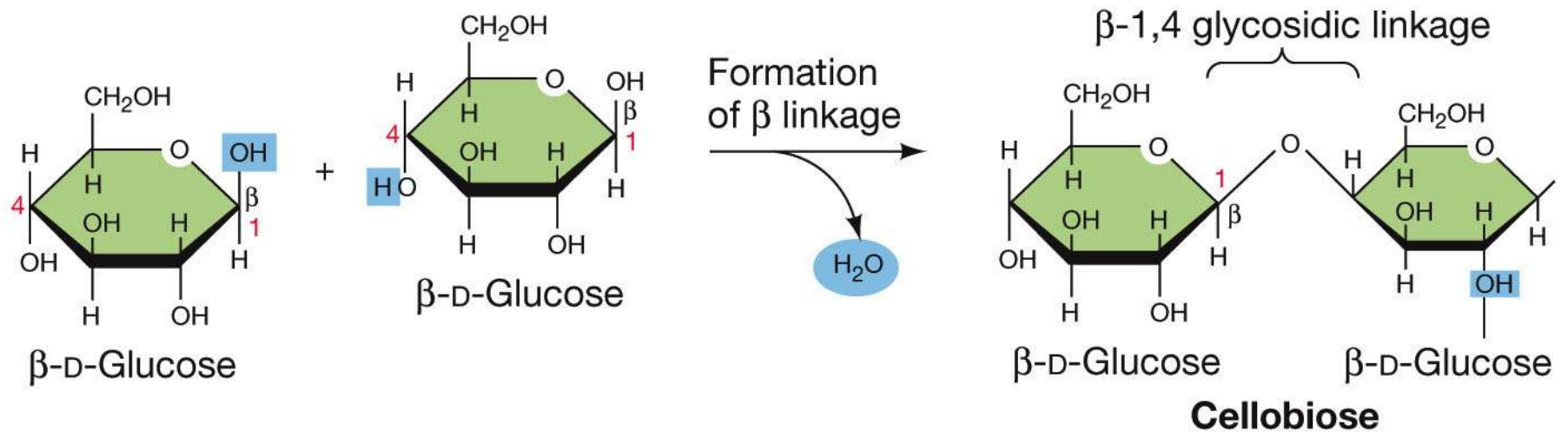
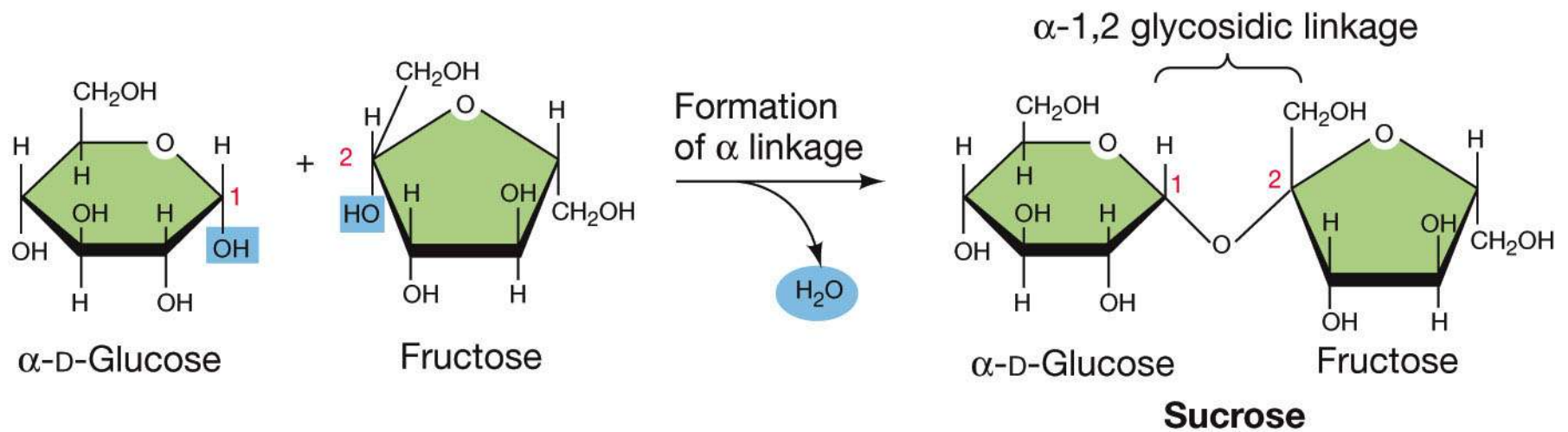


Figure 3.15 Disaccharides Are Formed by Glycosidic Linkages (Part 3)



3.3 What Are the Chemical Structures and Functions of Carbohydrates?

Oligosaccharides may include other functional groups.

Often covalently bonded to proteins and lipids on cell surfaces and act as recognition signals.

ABO blood groups

3.3 What Are the Chemical Structures and Functions of Carbohydrates?

Polysaccharides are giant polymers of monosaccharides.

Starch: storage of glucose in plants

Glycogen: storage of glucose in animals

Cellulose: very stable, good for structural components

Figure 3.16 Representative Polysaccharides (A)

(A) Molecular structure

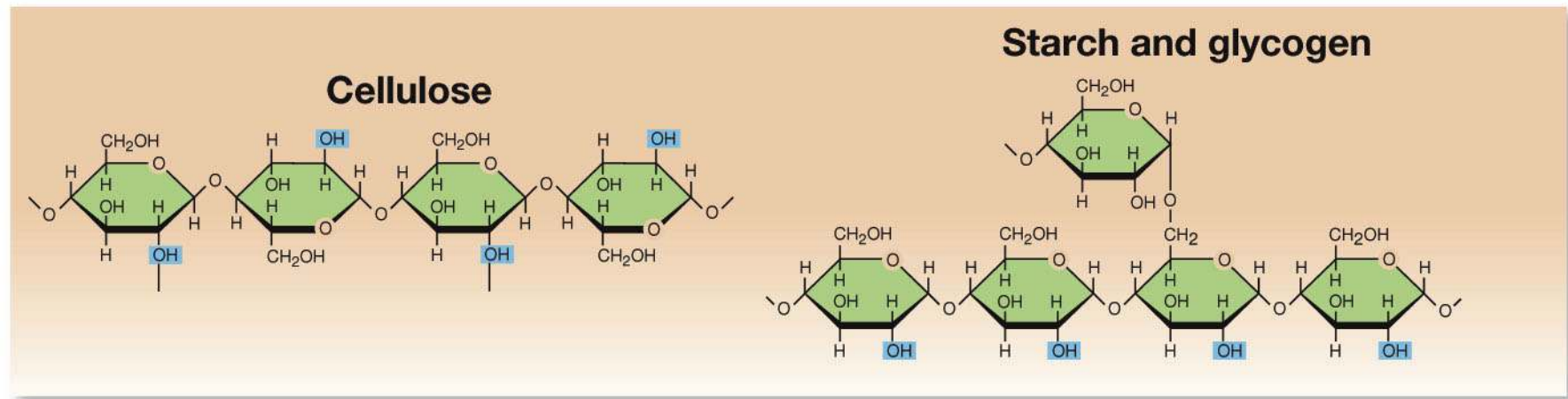


Figure 3.16 Representative Polysaccharides (B)

(B) Macromolecular structure

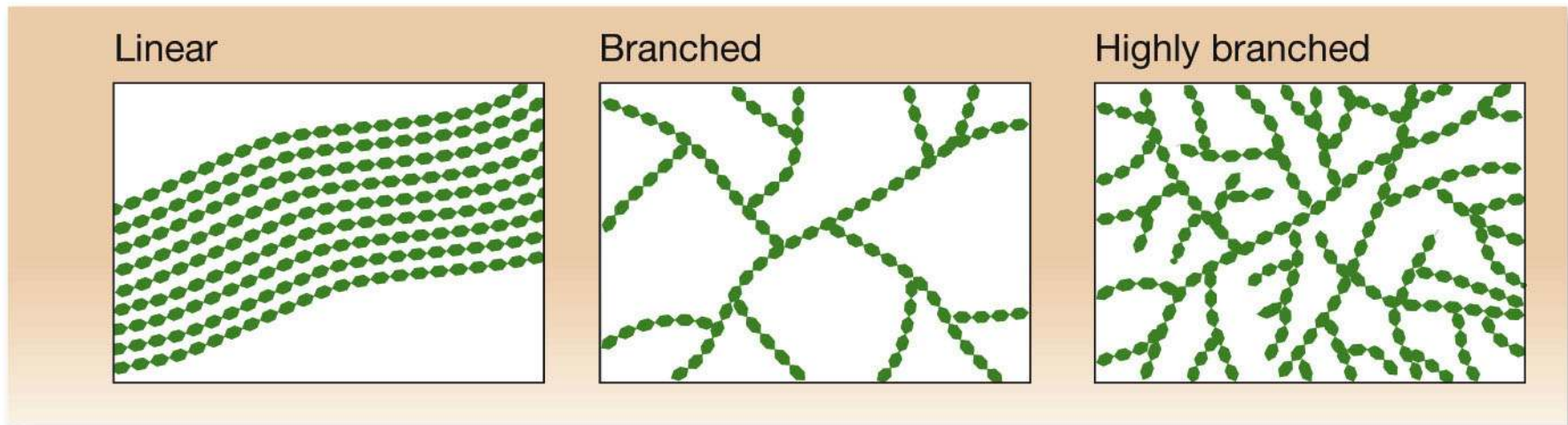
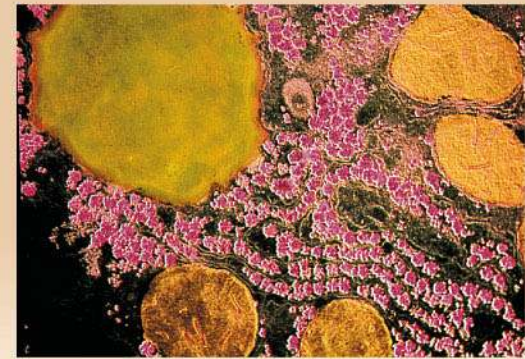
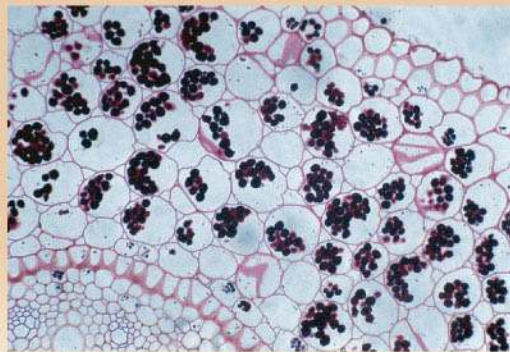


Figure 3.16 Representative Polysaccharides (C)

(C) Polysaccharides in cells



3.3 What Are the Chemical Structures and Functions of Carbohydrates?

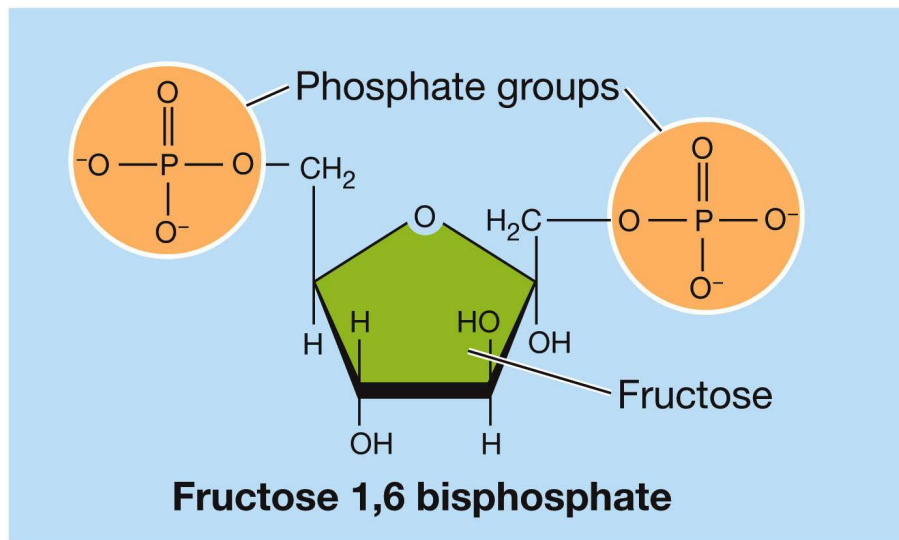
Carbohydrates can be modified by the addition of functional groups.

Sugar phosphates

Amino sugars

Figure 3.17 Chemically Modified Carbohydrates (A, B)

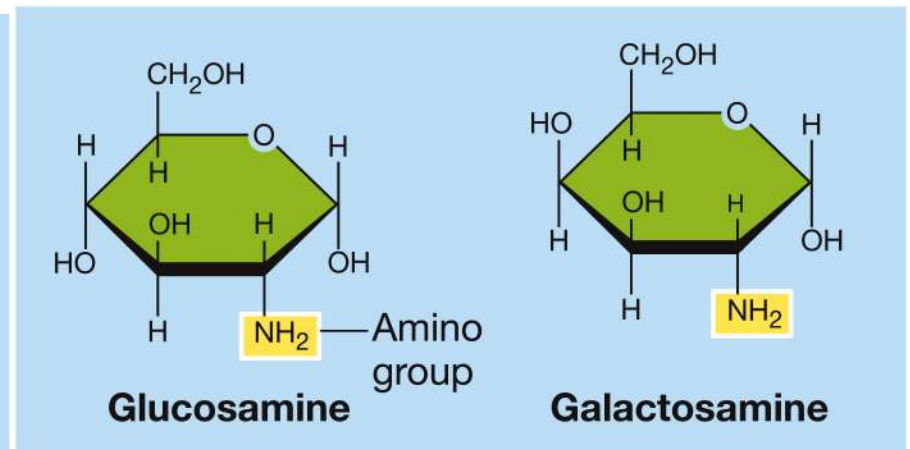
(A) Sugar phosphate



LIFE 8e, Figure 3.17 (Part 1)

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(B) Amino sugars

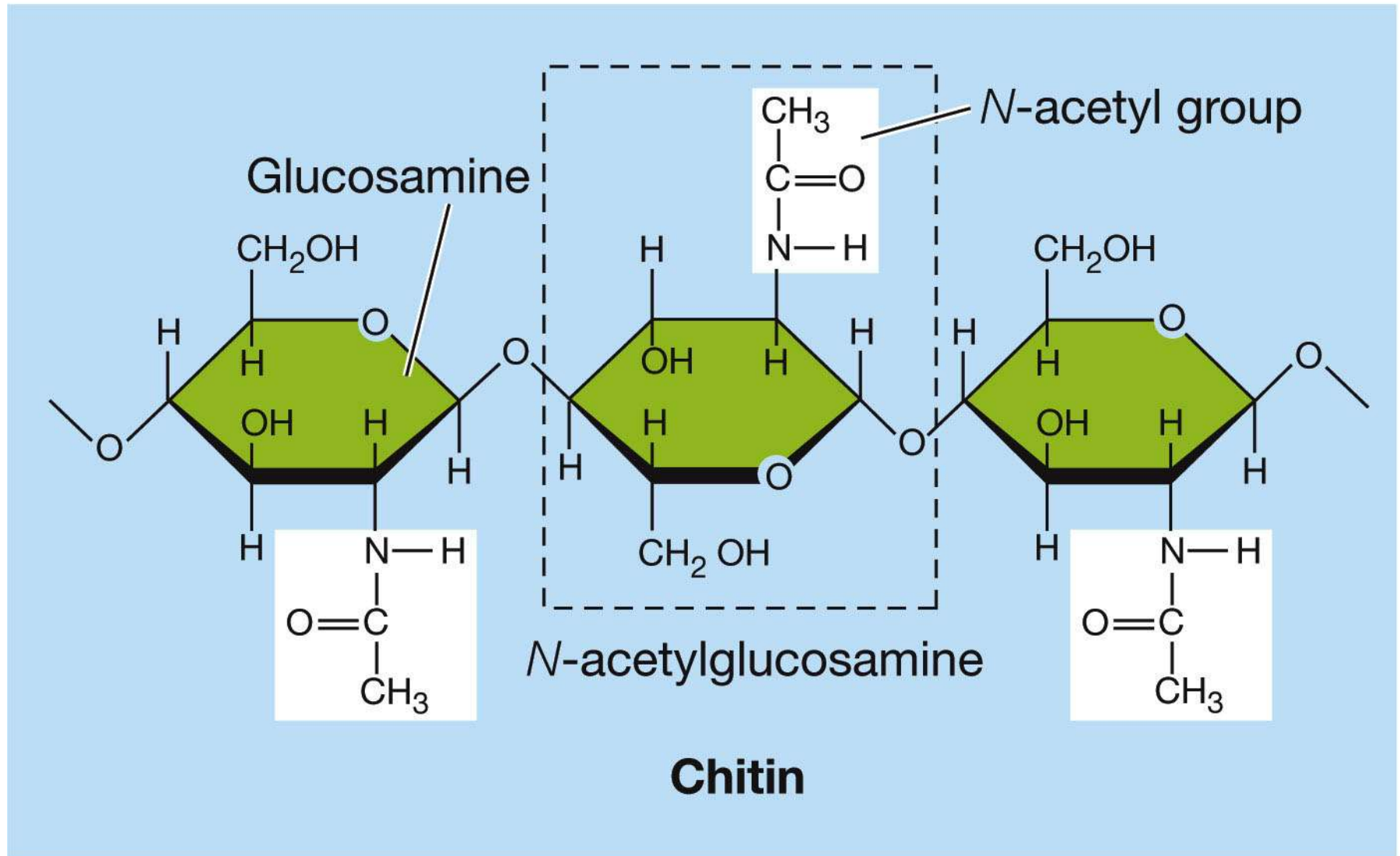


LIFE 8e, Figure 3.17 (Part 2)

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Figure 3.17 Chemically Modified Carbohydrates (C)

(C) Chitin



3.4 What Are the Chemical Structures and Functions of Lipids?

Lipids are nonpolar hydrocarbons:

- Fats and oils—energy storage
- Phospholipids—cell membranes
- Carotenoids
- Steroids
- Waxes

Fats serve as insulation in animals, lipid nerve coatings act as electrical insulation, oils and waxes repel water, prevent drying.

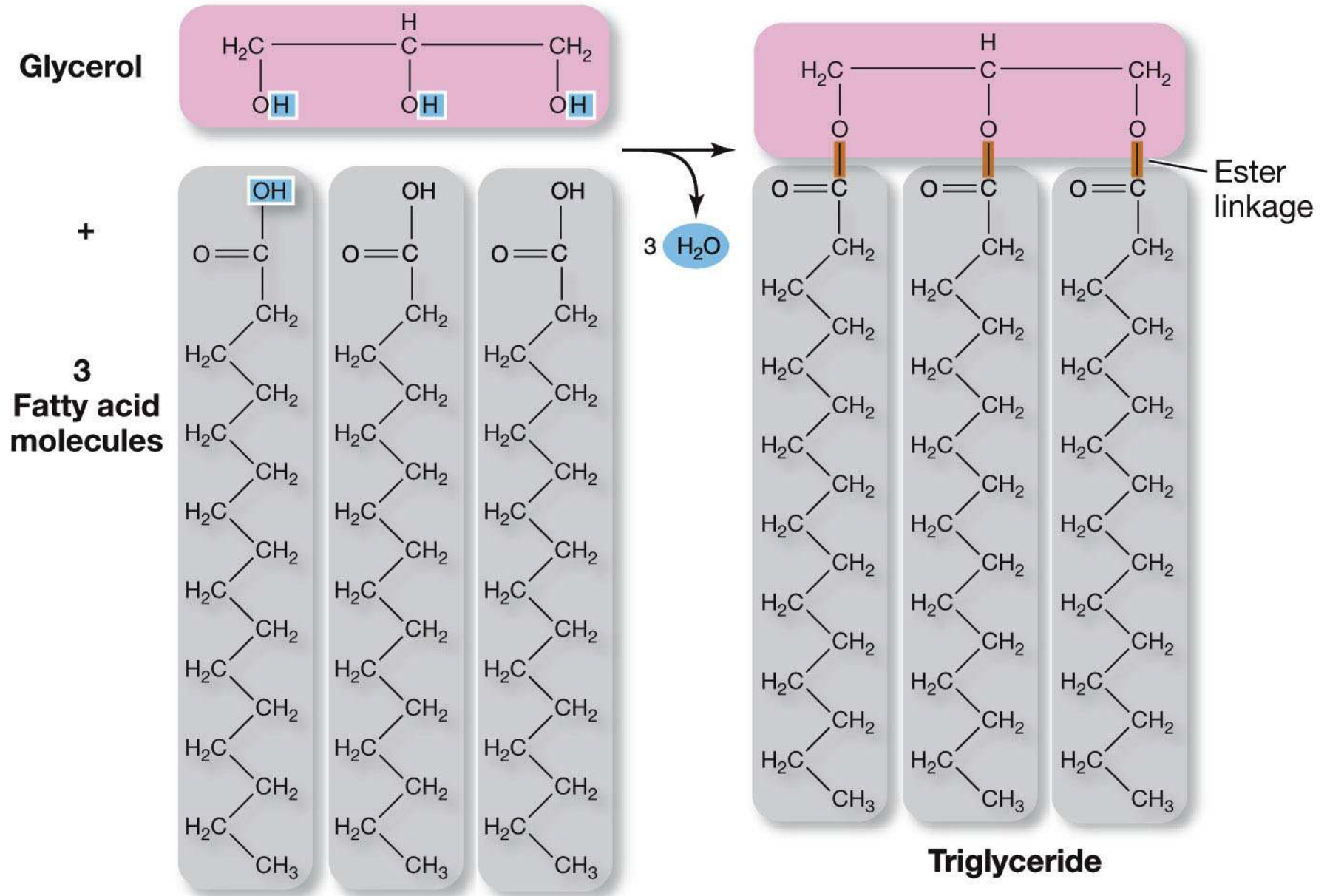
3.4 What Are the Chemical Structures and Functions of Lipids?

Fats and oils are **triglycerides**—simple lipids—made of three fatty acids and 1 glycerol.

Glycerol: 3 —OH groups—an alcohol

Fatty acid: nonpolar hydrocarbon with a polar carboxyl group—carboxyl bonds with hydroxyls of glycerol in an **ester linkage**.

Figure 3.18 Synthesis of a Triglyceride



3.4 What Are the Chemical Structures and Functions of Lipids?

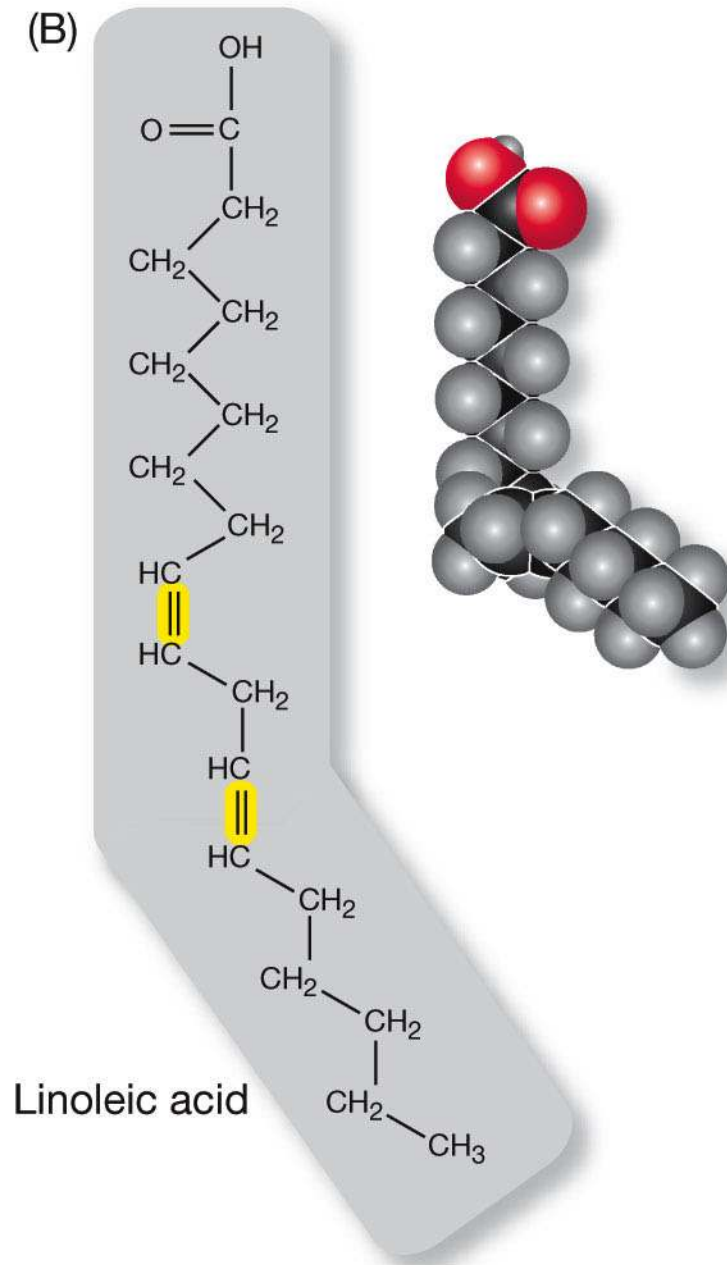
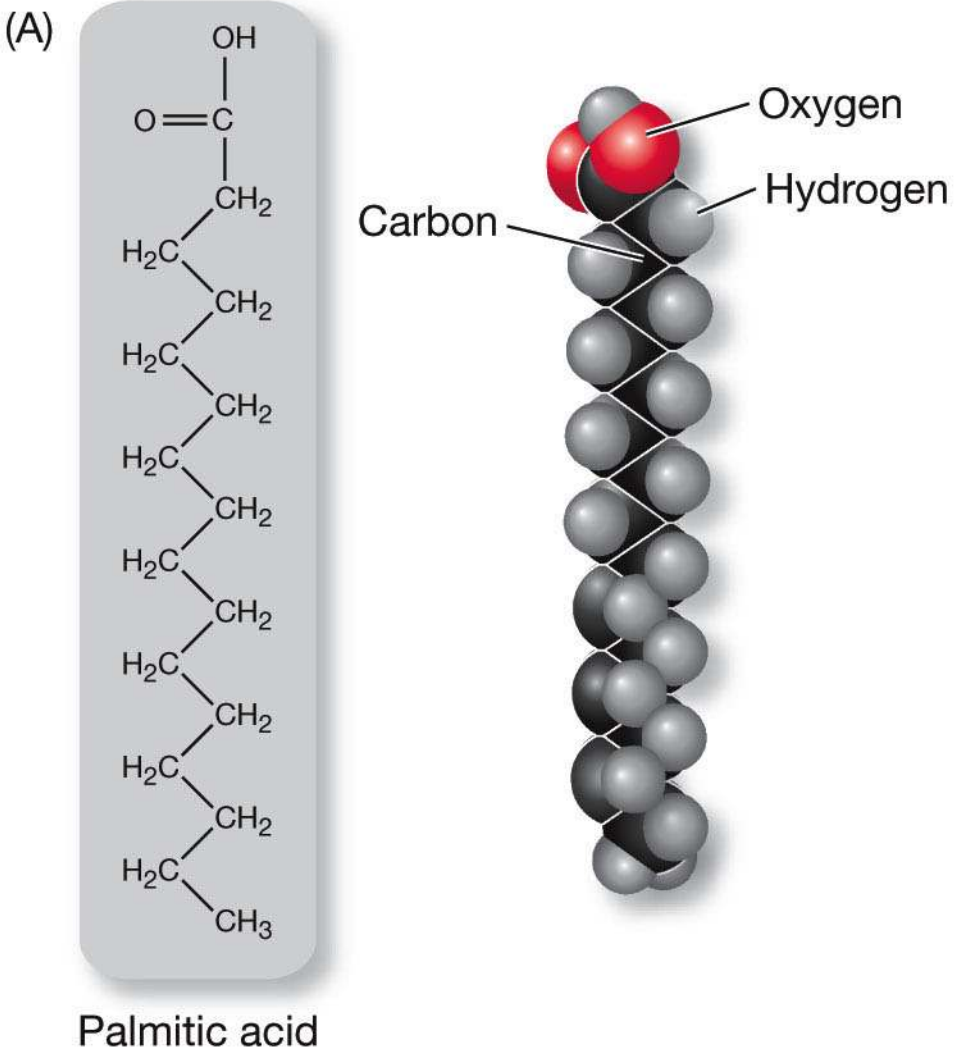
Saturated fatty acids: no double bonds between carbons—it is saturated with hydrogen atoms.

Unsaturated fatty acids: some double bonds in carbon chain.

monounsaturated: one double bond

polyunsaturated: more than one

Figure 3.19 Saturated and Unsaturated Fatty Acids



3.4 What Are the Chemical Structures and Functions of Lipids?

Animal fats tend to be saturated—packed together tightly—solid at room temperature.

Plant oils tend to be unsaturated—the “kinks” prevent packing—liquid at room temperature. Waxes.



3.4 What Are the Chemical Structures and Functions of Lipids?

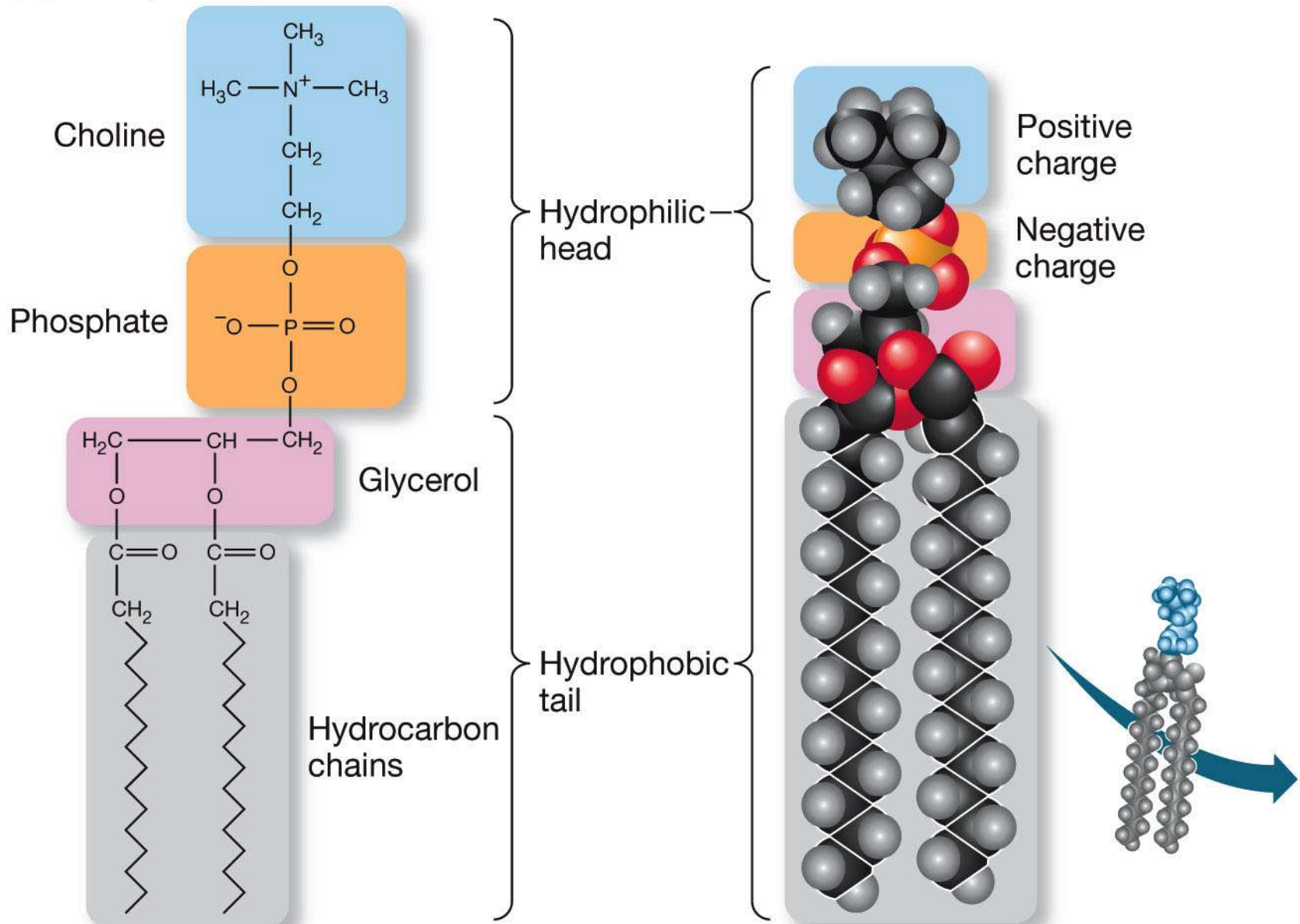
Phospholipids: fatty acids bound to glycerol, a phosphate group replaces one fatty acid.

Phosphate group is hydrophilic—the “head”

“Tails” are fatty acid chains—hydrophobic

Figure 3.20 Phospholipids (A)

(A) Phosphatidylcholine



(B) Phospholipid bilayer

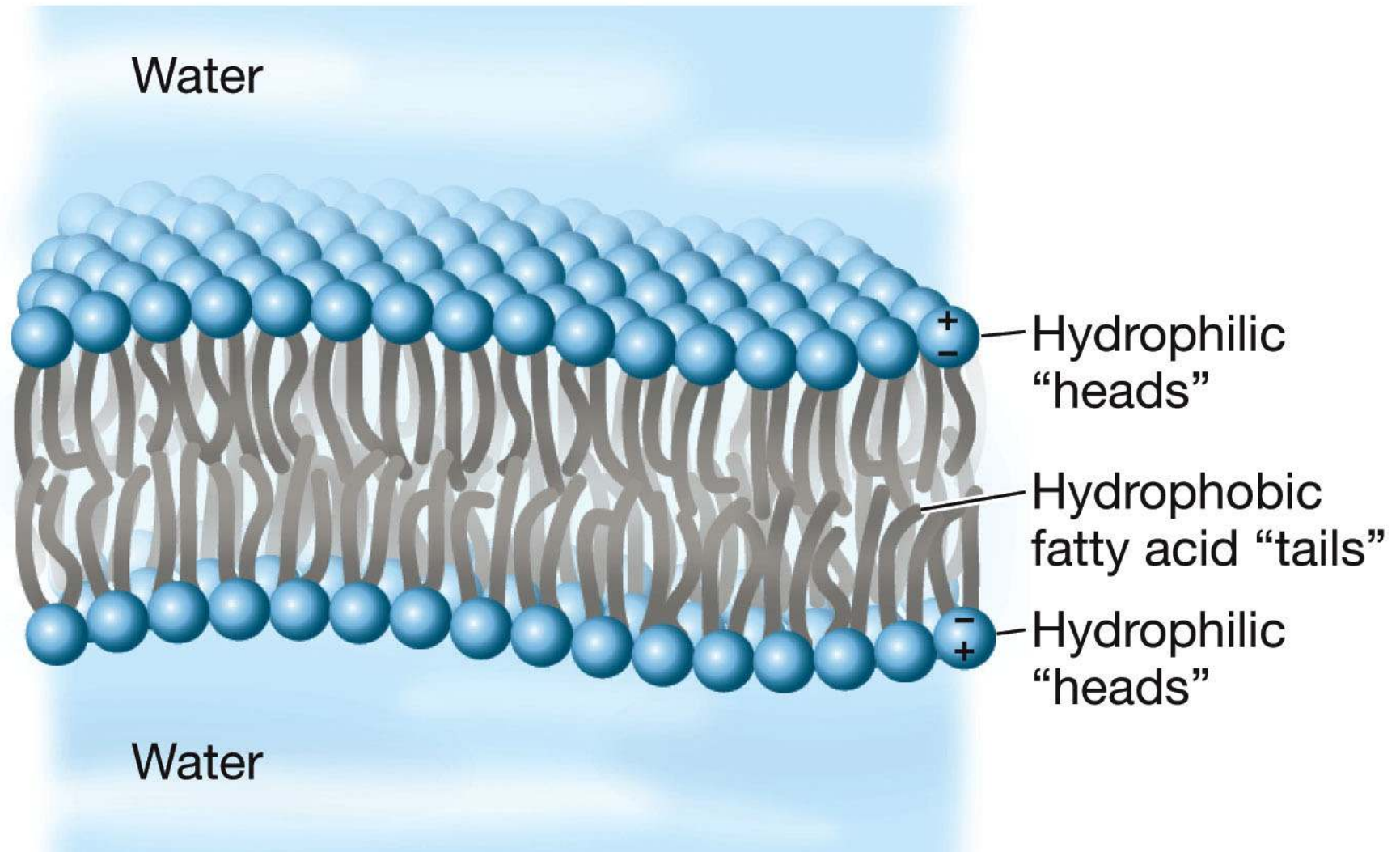


Figure 3.21 β -Carotene is the Source of Vitamin A

Carotenoids: light-absorbing pigments

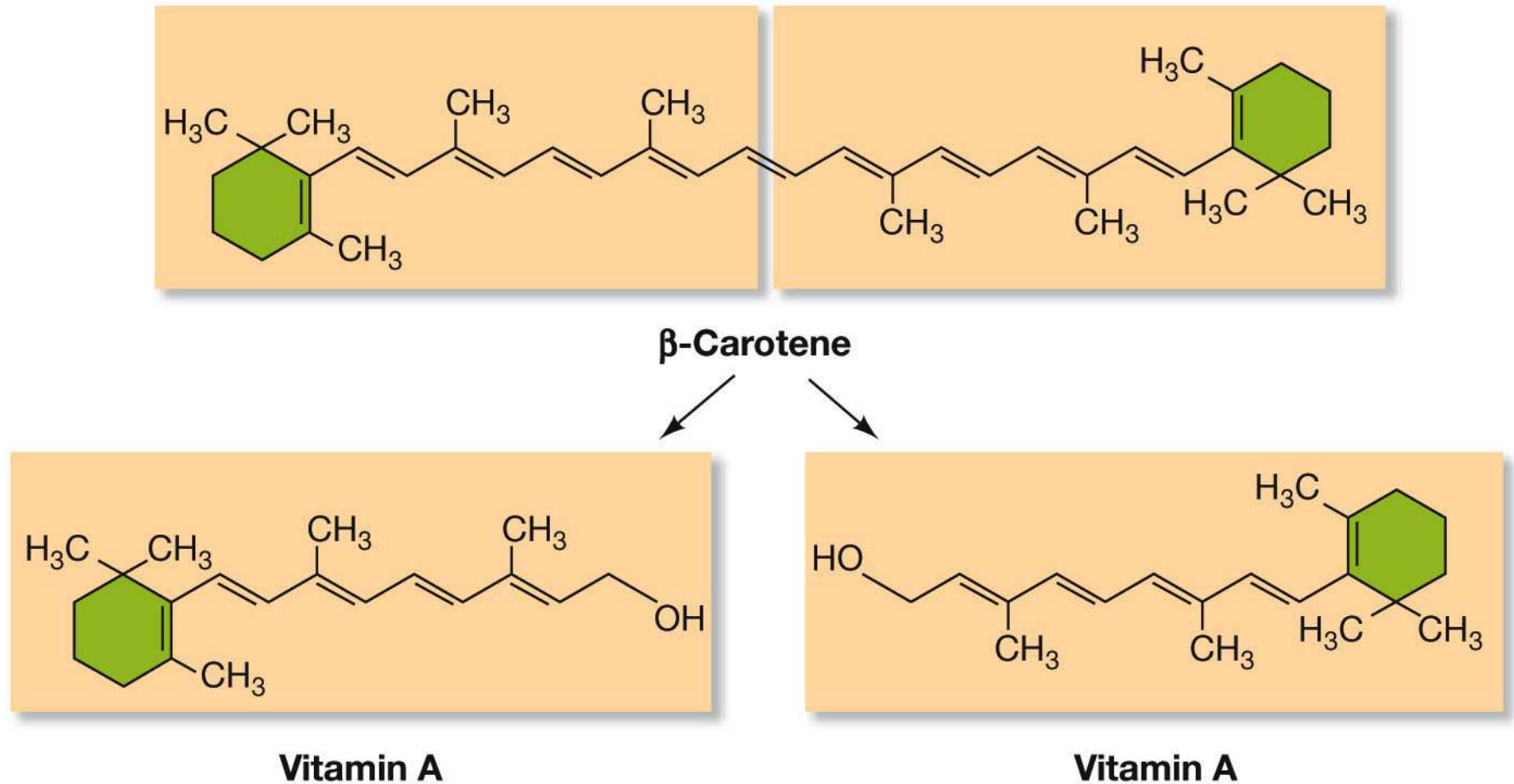
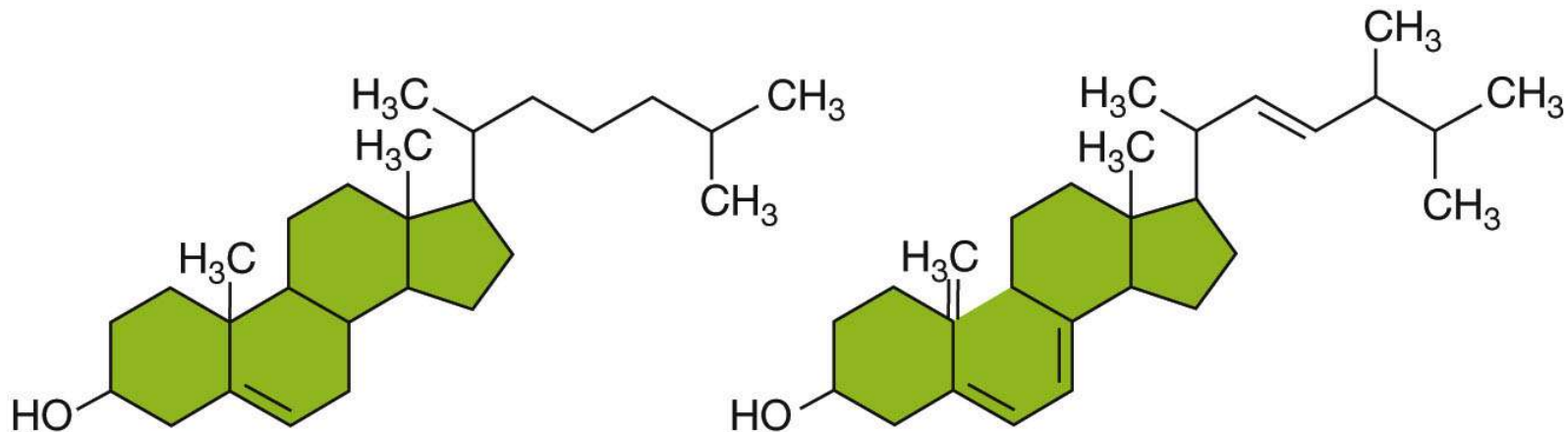


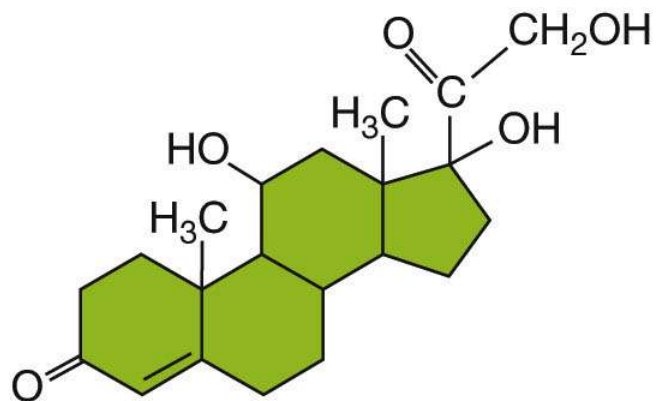
Figure 3.22 All Steroids Have the Same Ring Structure

Steroids: multiple rings share carbons

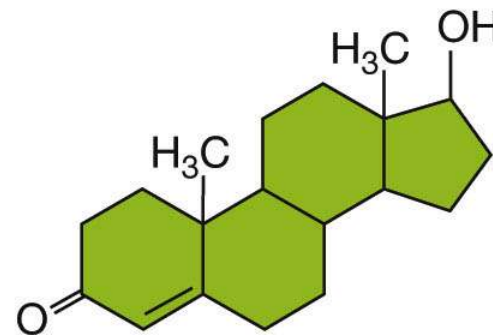


Cholesterol

Vitamin D₂



Cortisol

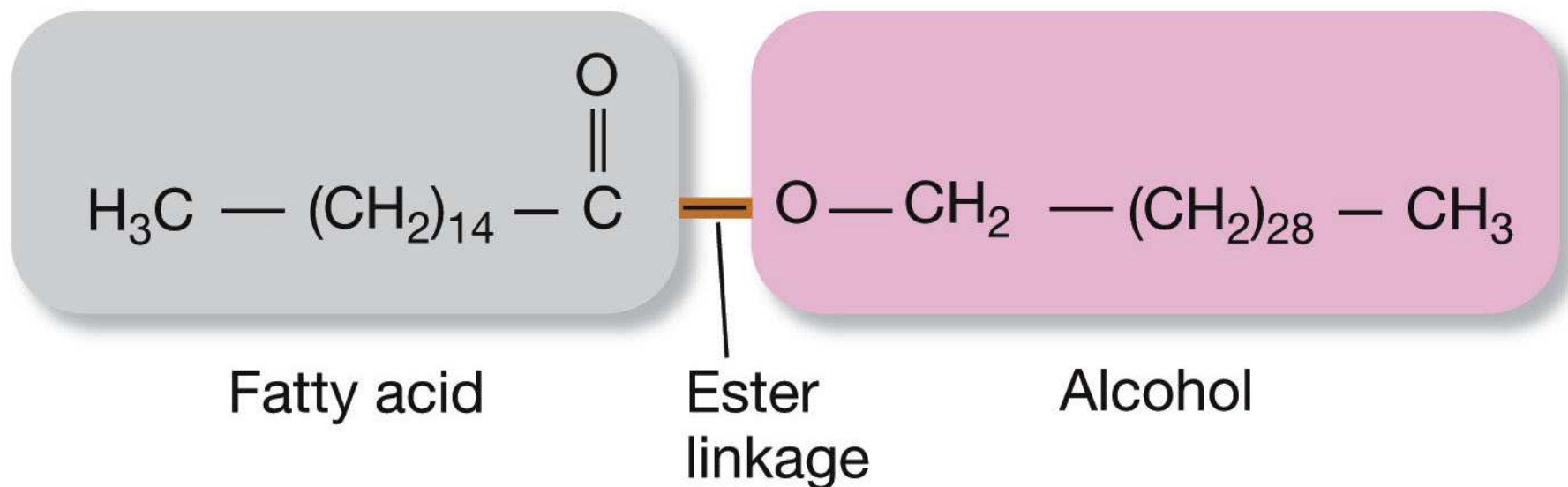


Testosterone

3.4 What Are the Chemical Structures and Functions of Lipids?

Vitamins—small molecules not synthesized by the body—must acquire in diet.

Waxes—highly nonpolar



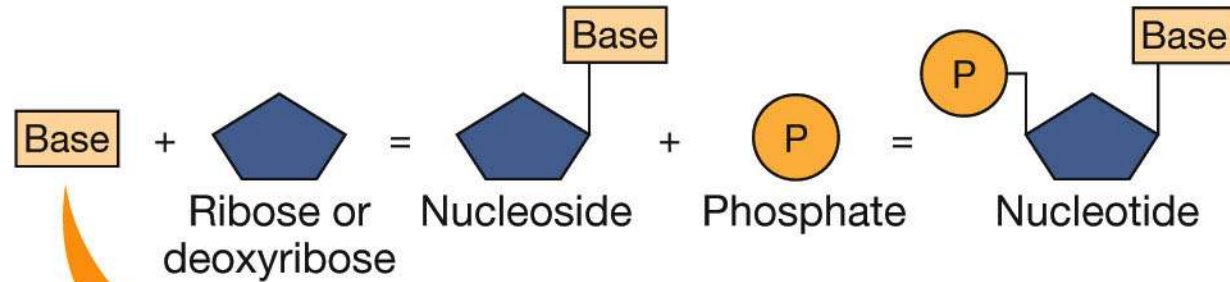
3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

Nucleic acids: DNA—(deoxyribonucleic acid) and RNA—(ribonucleic acid)

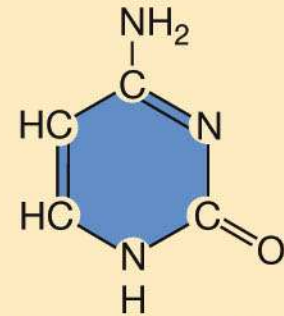
Polymers—the monomeric units are **nucleotides**.

Nucleotides consist of a pentose sugar, a phosphate group, and a nitrogen-containing **base**.

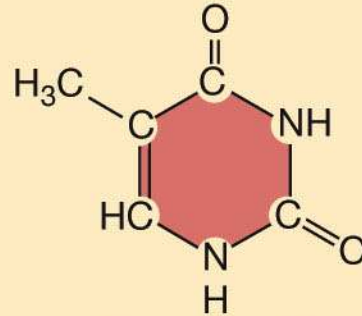
Figure 3.23 Nucleotides Have Three Components



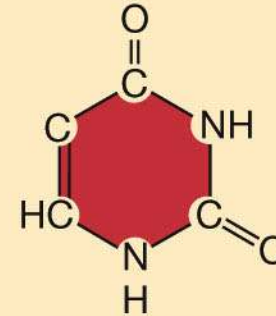
Pyrimidines



Cytosine (C)

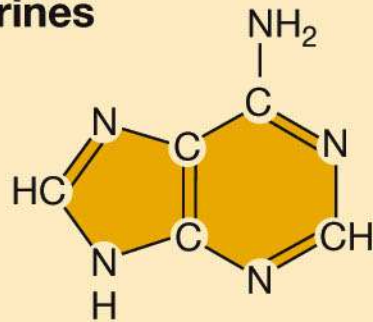


Thymine (T)

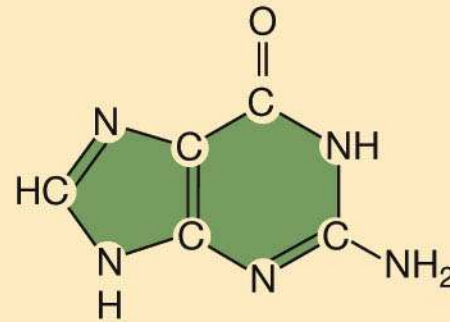


Uracil (U)

Purines



Adenine (A)

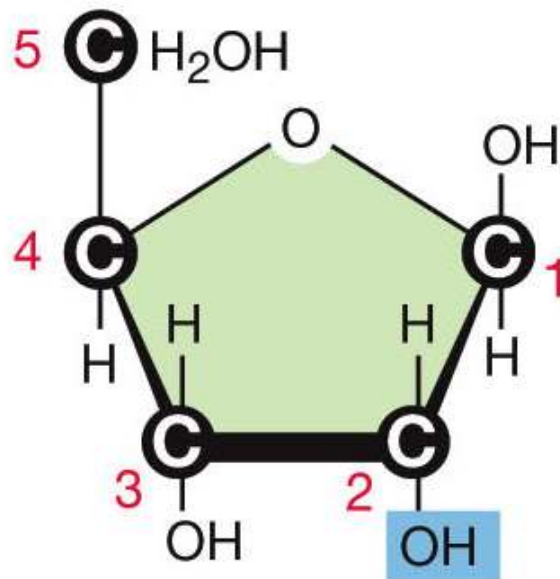


Guanine (G)

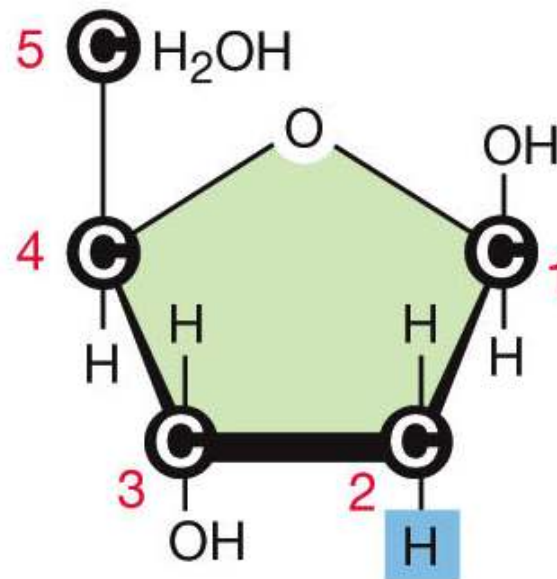
3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

DNA—deoxyribose

RNA—ribose



Ribose



Deoxyribose

3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

The “backbone” of DNA and RNA consists of the sugars and phosphate groups, bonded by phosphodiester linkages.

The phosphate groups link carbon 3' in one sugar to carbon 5' in another sugar.

The two strands of DNA run in opposite directions.

Figure 3.24 Distinguishing Characteristics of DNA and RNA (Part 1)

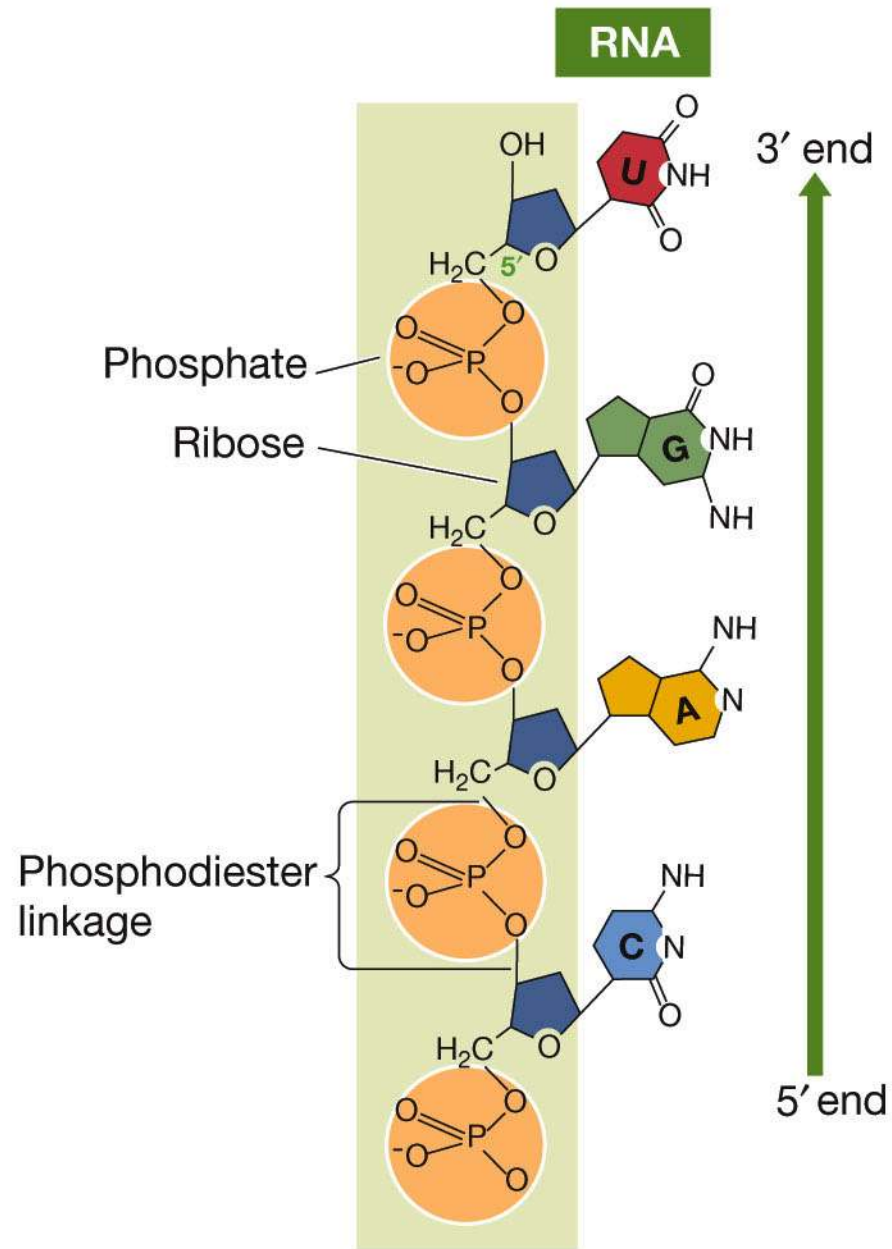
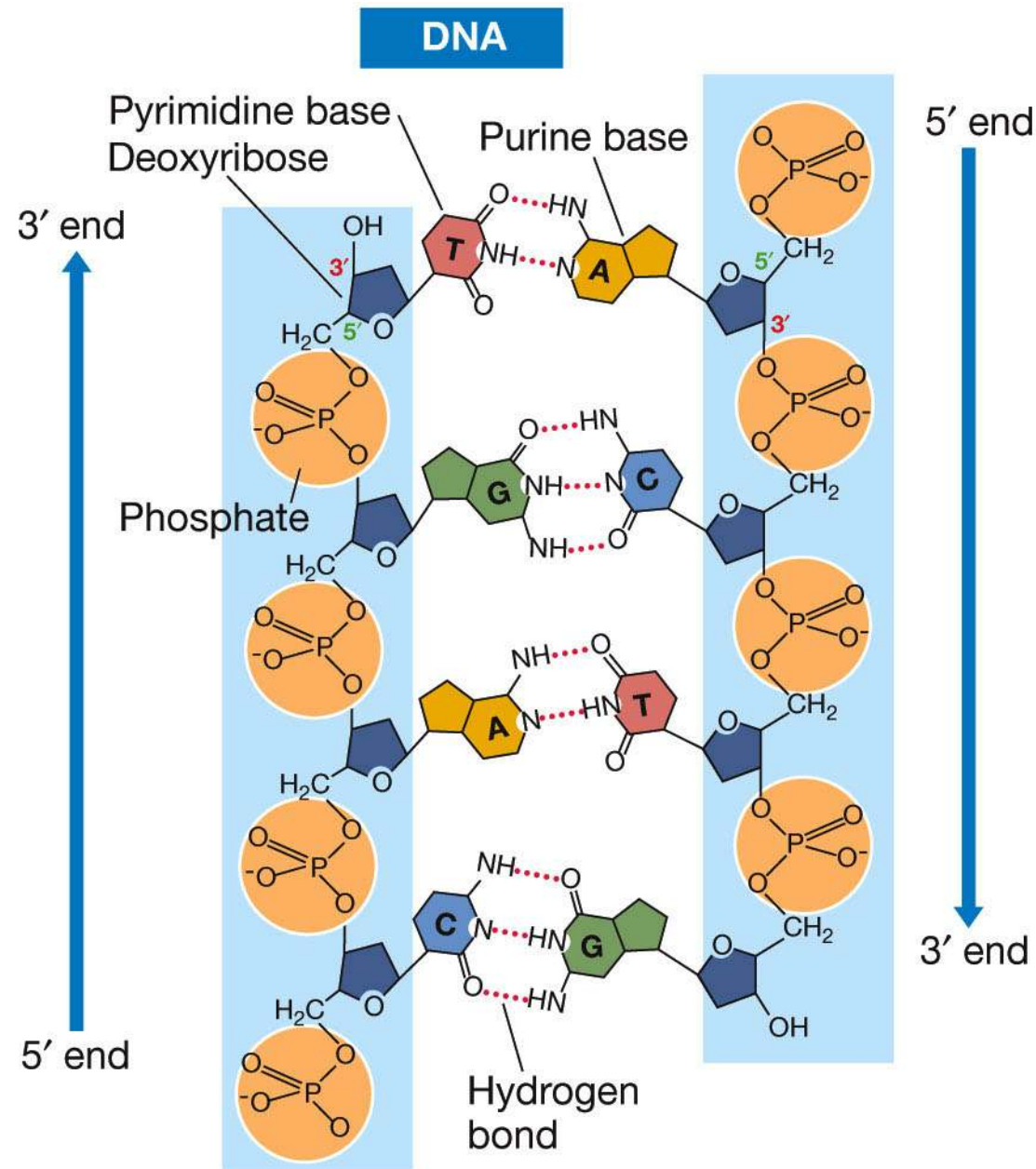


Figure 3.24 Distinguishing Characteristics of DNA and RNA (Part 2)



3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

DNA bases: adenine (A), cytosine (C), guanine (G), and thymine (T)

Complementary base pairing:

A—T

C—G

Purines pair with pyrimidines by hydrogen bonding.

3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

Instead of thymine, RNA uses the base uracil (U).

RNA is single-stranded, but complementary base pairing occurs in the structure of some types of RNA.

Figure 3.25 Hydrogen Bonding in RNA

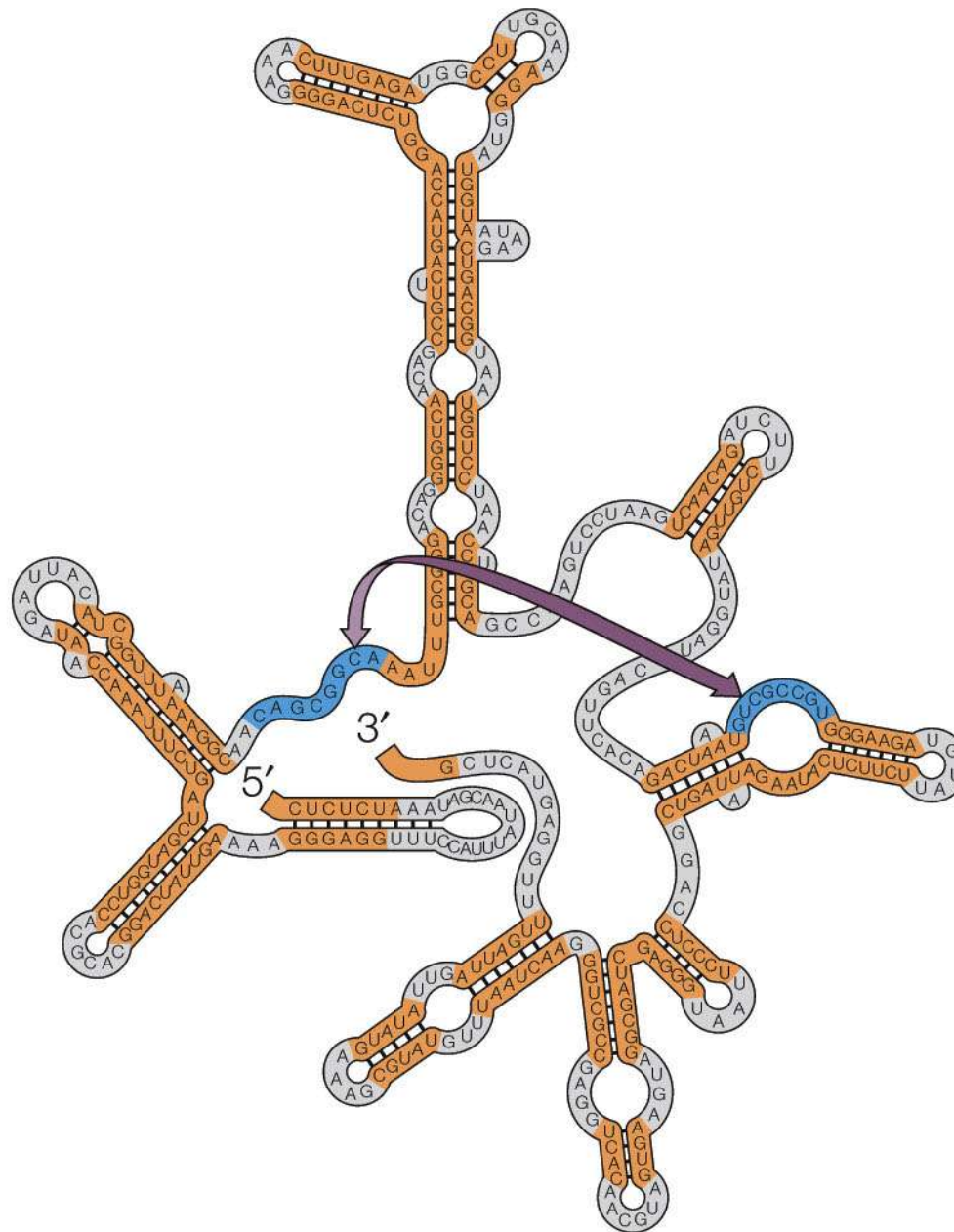


TABLE 3.3**Distinguishing RNA from DNA**

NUCLEIC ACID	SUGAR	BASES
RNA	Ribose	Adenine Cytosine Guanine Uracil
DNA	Deoxyribose	Adenine Cytosine Guanine Thymine

3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

DNA is an *informational molecule*:
information is encoded in the sequences
of bases.

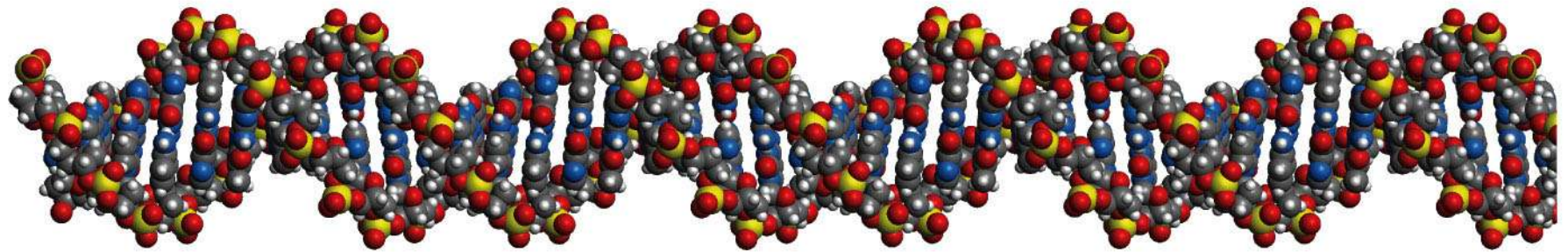
RNA uses the information to determine
the sequence of amino acids in proteins.

3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

The two strands of a DNA molecule form a double helix.

All DNA molecules have the same structure—variation is in the sequence of base pairs.

Figure 3.26 The Double Helix of DNA



3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

DNA carries hereditary information between generations.

Determining the sequence of bases helps reveal evolutionary relationships.

The closest living relative of humans is the chimpanzee.

3.5 What Are the Chemical Structures and Functions of Nucleic Acids?

Other roles for nucleotides:

ATP—energy transducer in biochemical reactions

GTP—energy source in protein synthesis

cAMP—essential to the action of hormones and transmission of information in the nervous system

3.6 How Did Life on Earth Begin?

Origin of life on Earth:

Molecules of life came from
extraterrestrial sources

or

Life resulted from chemical evolution on
Earth

3.6 How Did Life on Earth Begin?

Evidence for extraterrestrial sources:

Meteorites from Mars that have water, small carbon compounds, and magnetite.

Figure 3.27 Was Life Once Here?



3.6 How Did Life on Earth Begin?

Evidence for **chemical evolution**:

Experimentation with an atmosphere
similar to Earth's early atmosphere
(Miller and Urey)

Figure 3.28 Synthesis of Prebiotic Molecules in an Experimental Atmosphere (Part 1)

EXPERIMENT

HYPOTHESIS: Organic chemical compounds can be generated under conditions similar to those that existed on primitive Earth.

METHOD

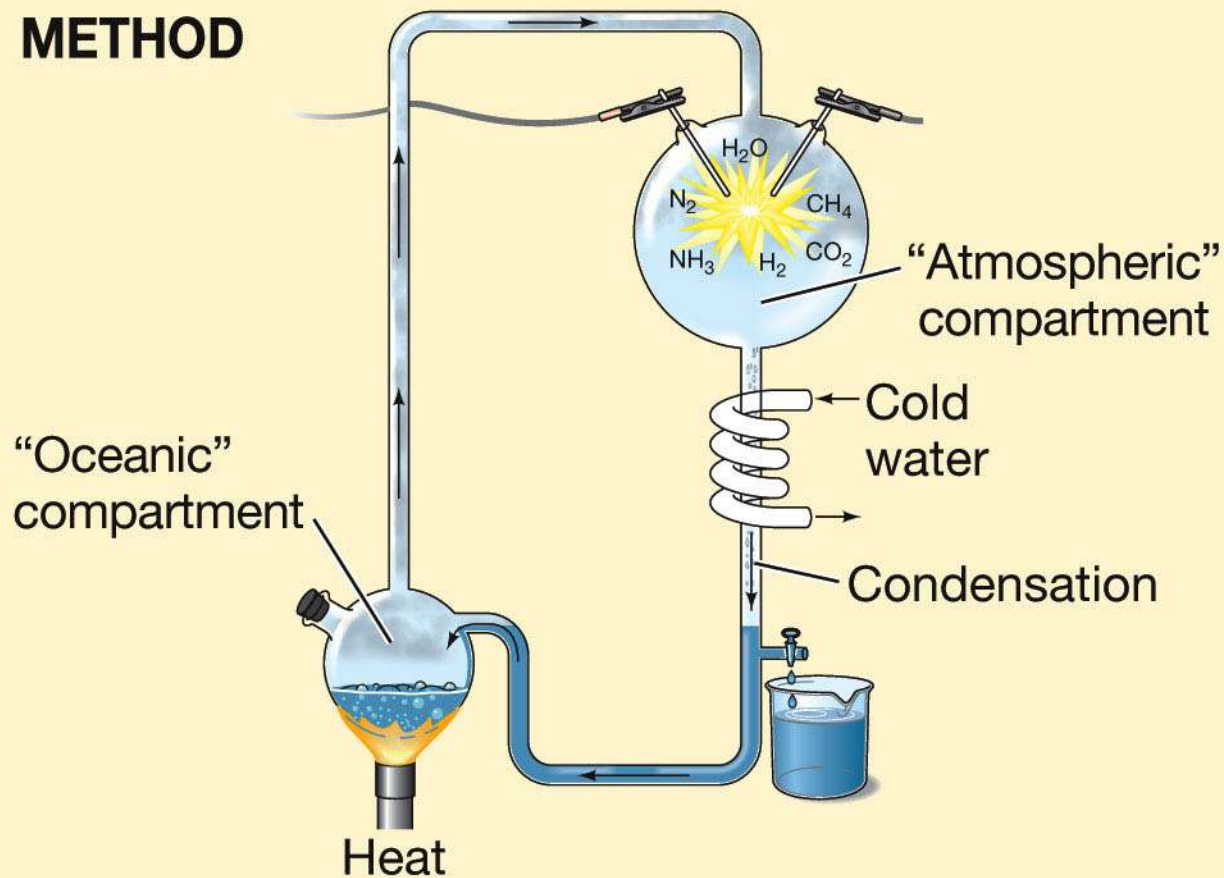


Figure 3.28 Synthesis of Prebiotic Molecules in an Experimental Atmosphere (Part 2)

EXPERIMENT

RESULTS

The compounds react in water, eventually forming purines, pyrimidines, and amino acids.

CONCLUSION: The chemical building blocks of life could have been generated in the probable atmosphere of early Earth.

3.6 How Did Life on Earth Begin?

Conditions in which polymers would be synthesized:

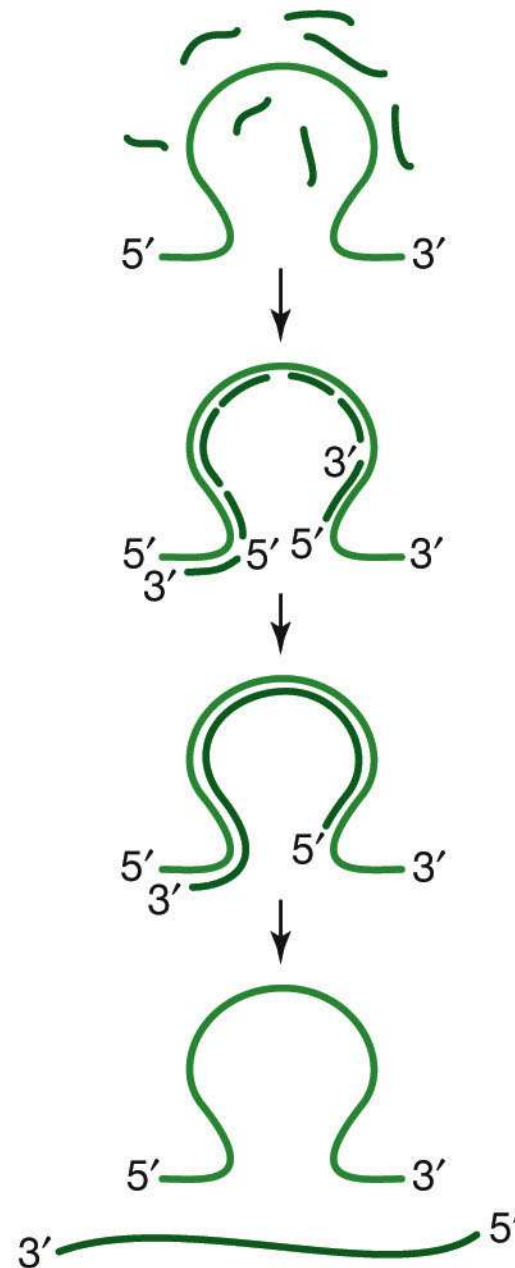
- Solid mineral surfaces
- Hydrothermal vents—metals as catalysts
- Hot pools at ocean edges

3.6 How Did Life on Earth Begin?

Folded RNA molecules can act as catalysts—ribozymes.

RNA may have evolved first, and catalyzed its own replication as well as protein synthesis.

Figure 3.29 An Early Catalyst for Life?



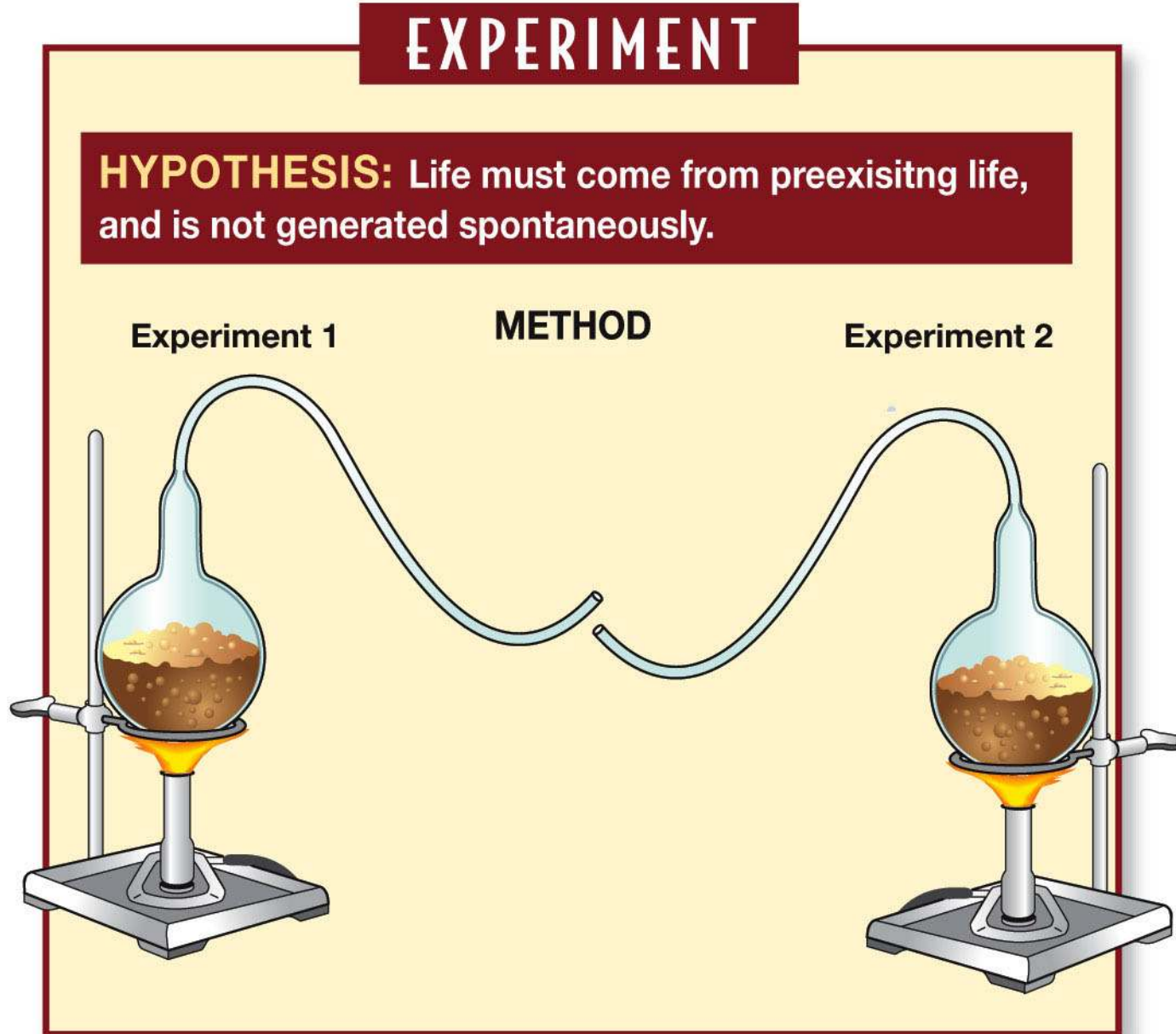
LIFE 8e, Figure 3.29

3.6 How Did Life on Earth Begin?

Classic experiments disproved spontaneous generation—life appearing from inanimate matter.

Redi and Pasteur showed that life arises only from life.

Figure 3.30 Disproving the Spontaneous Generation of Life (Part 1)



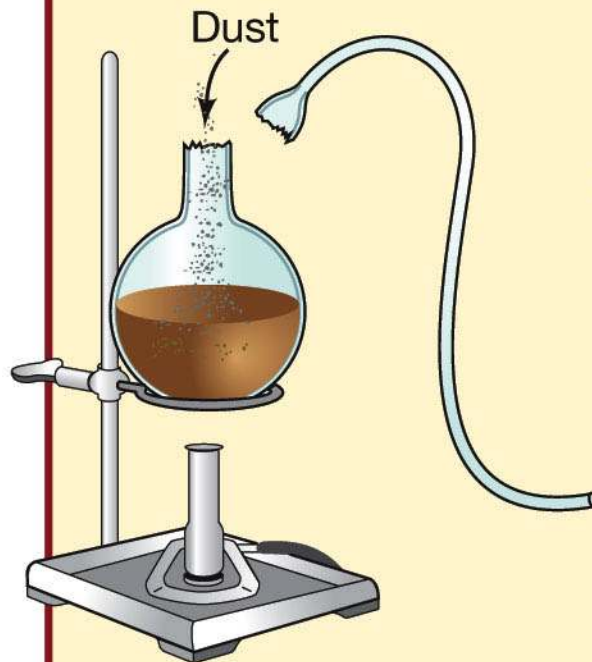
LIFE 8e, Figure 3.30 (Part 1)

Figure 3.30 Disproving the Spontaneous Generation of Life (Part 2)

EXPERIMENT

HYPOTHESIS: Life must come from preexisting life, and is not generated spontaneously.

Experiment 1



METHOD



Experiment 2

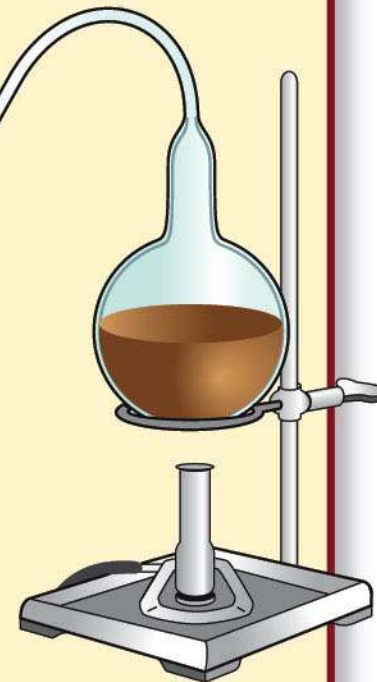
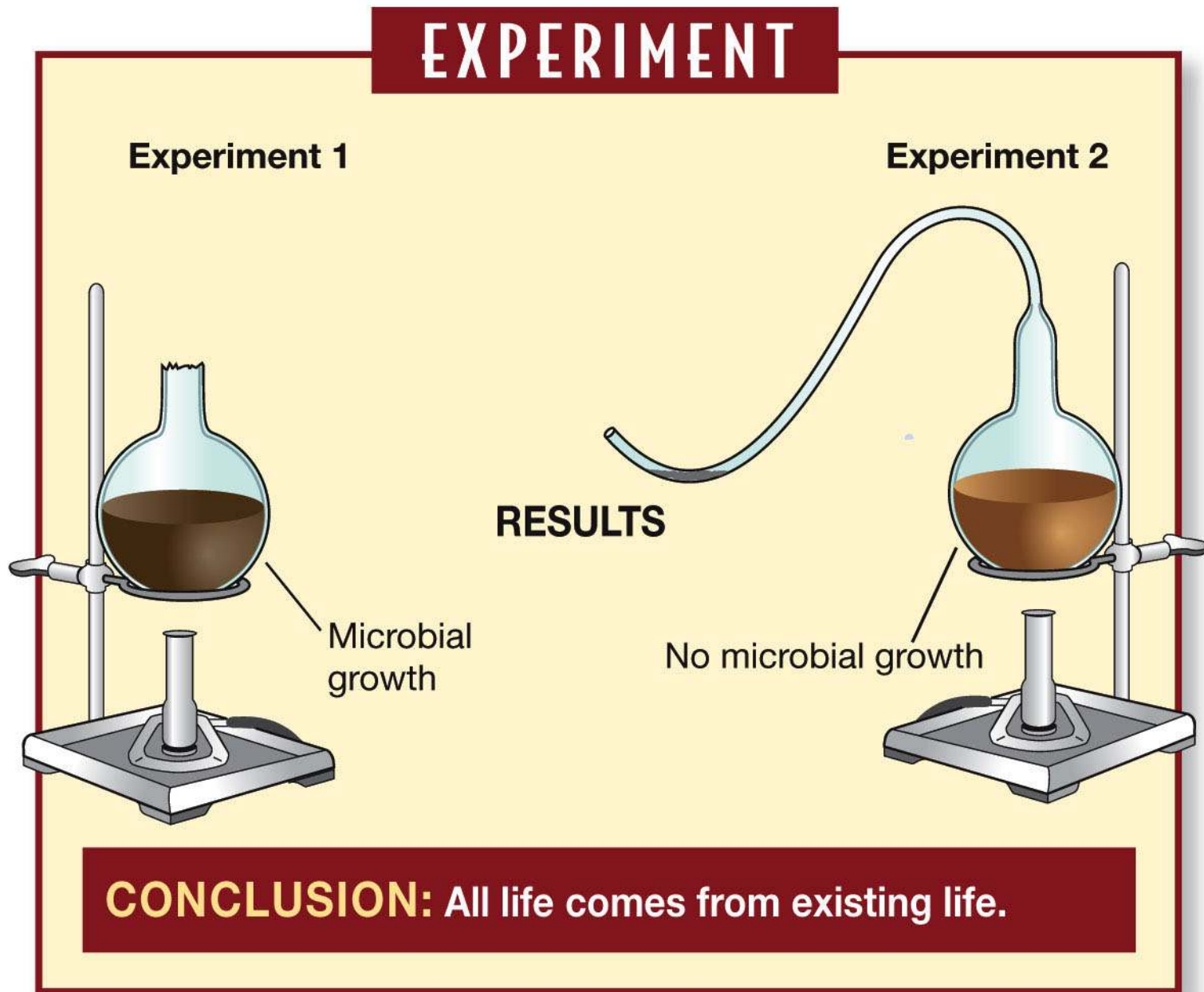


Figure 3.30 Disproving the Spontaneous Generation of Life (Part 3)



3.6 How Did Life on Earth Begin?

Conditions on Earth were very different during the Hadean (pre-biotic) than those of today—when chemical evolution took place.