Biology: Life on Earth

Chapter 3

Molecules of life

Chapter 3 Opener Biology: Life on Earth, 8/e

Chapter 3 Outline

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- 3.6 What Are Nucleic Acids? p. 53

Section 3.1 Outline

- **3.1 Why Is Carbon So Important in Biological Molecules?**
  - Organic/Inorganic Molecules and Functional Groups

Why Is Carbon So Important?

- Organic vs. Inorganic in Chemistry
  - **Organic** refers to molecules containing a carbon skeleton
  - **Inorganic** refers to carbon dioxide and all molecules without carbon

Why Is Carbon So Important?

- Carbon atoms are versatile and can form up to four bonds (single, double, or triple) and rings
- Functional groups in organic molecules confer chemical reactivity and other characteristics

Table 3-1 Important Functional Groups in Biological Molecules

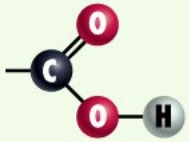
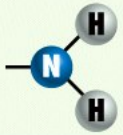
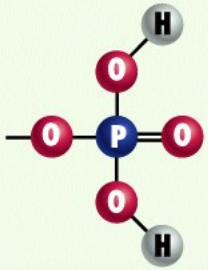
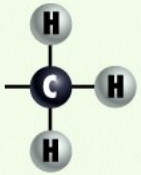
Group	Structure	Properties	Found In
Hydrogen (—H)		Polar or nonpolar, depending on which atom hydrogen is bonded to; involved in dehydration and hydrolysis reactions	Almost all organic molecules
Hydroxyl (—OH)		Polar; involved in dehydration and hydrolysis reactions	Carbohydrates, nucleic acids, alcohols, some acids, and steroids
Carboxylic acid (—COOH)		Acidic; involved in peptide bonds	Amino acids, fatty acids
Amino ($—NH_2$)		Basic; may bond an additional H^+, becoming positively charged; involved in peptide bonds	Amino acids, nucleic acids
Phosphate ($—H_2PO_4$)		Acidic; links nucleotides in nucleic acids; energy-carrier group in ATP	Nucleic acids, phospholipids
Methyl ($—CH_3$)		Nonpolar; tends to make molecules hydrophobic	Many organic molecules; especially common in lipids

Table 3-1 Biology: Life on Earth, 8/e

Section 3.2 Outline

- **3.2 How Are Organic Molecules Synthesized?**
  - Biomolecules Are Joined or Broken Through Dehydration or Hydrolysis

Organic Molecule Synthesis

- Biomolecules are **polymers** (chains) of subunits called **monomers**

Organic Molecule Synthesis

- Monomers are joined together through **dehydration synthesis**
  - An H and an OH are removed, resulting in the loss of a water molecule (H_2O)

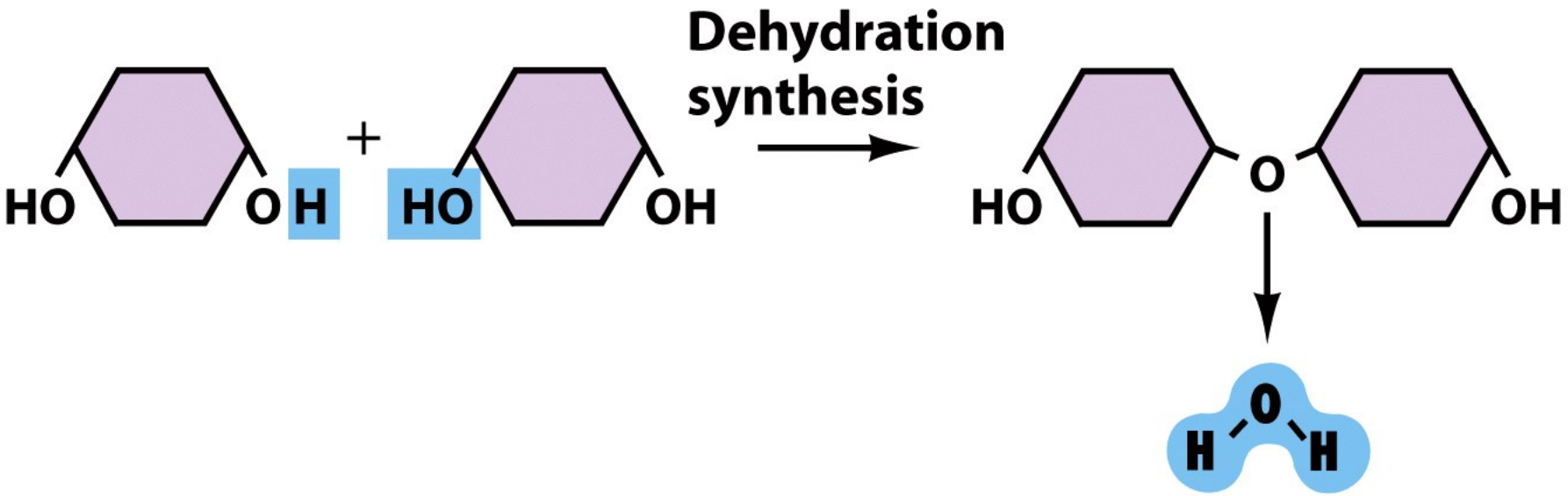


Figure 3-1 Biology: Life on Earth, 8/e

Organic Molecule Synthesis

- Polymers are broken apart through **hydrolysis** (“water cutting”)
  - Water is broken into H and OH and used to break the bond between monomers

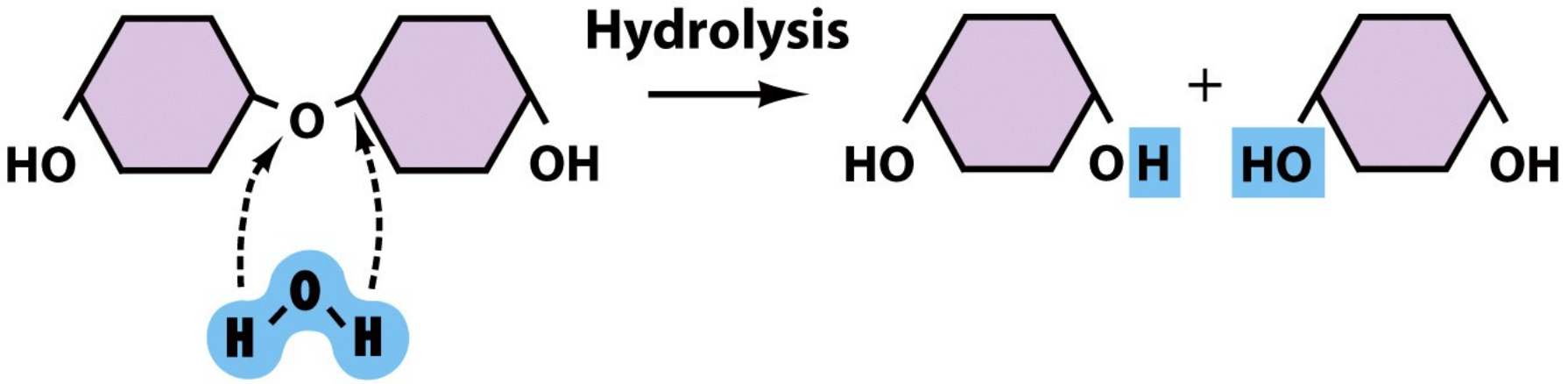


Figure 3-2 Biology: Life on Earth, 8/e

Organic Molecule Synthesis

- All biological molecules fall into one of four categories
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic Acids

Table 3-2 The Principal Biological Molecules

Class of Molecule	Principal Subtypes	Example	Function
Carbohydrate: Usually contains carbon, oxygen, and hydrogen, in the approximate formula $(CH_2O)n$	*Monosaccharide*: Simple sugar with the formula $C_6H_{12}O_6$	Glucose	Important energy source for cells; subunit of polysaccharides
	Disaccharide: Two monosaccharides bonded together	Fructose	Energy-storage molecule in fruits and honey
		Sucrose	Principal sugar transported throughout bodies of land plants
	Polysaccharide: Many monosaccharides (usually glucose) bonded together	Starch	Energy storage in plants
		Glycogen	Energy storage in animals
		Cellulose	Structural material in plants
Lipid: Contains high proportion of carbon and hydrogen; usually nonpolar and insoluble in water	*Triglyceride:* Three fatty acids bonded to glycerol	Oil, fat	Energy storage in animals, some plants
	Wax: Variable numbers of fatty acids bonded to long-chain alcohol	Waxes in plant cuticle	Waterproof covering on leaves and stems of land plants
	Phospholipid: Polar phosphate group and two fatty acids bonded to glycerol	Phosphatidylcholine	Component of cell membranes
	Steroid: Four fused rings of carbon atoms with functional groups attached	Cholesterol	Common component of membranes of eukaryotic cells; precursor for other steroids such as testosterone, bile salts

Table 3-2 part 1 Biology: Life on Earth, 8/e

Table 3-2 The Principal Biological Molecules

Class of Molecule	Principal Subtypes	Example	Function
Protein: Chains of amino acids; contains carbon, hydrogen, oxygen, nitrogen, and sulfur	*Peptide:* Short chain of amino acids	Keratin	Helical protein, principal component of hair
		Silk	Beta-pleated sheet protein produced by silk moths and spiders
	Polypeptide: Long chain of amino acids; also called "protein"	Hemoglobin	Globular protein composed of four subunit peptides; transport of oxygen in vertebrate blood
Nucleic acid: Made of nucleotide subunits containing carbon, hydrogen oxygen, nitrogen, and phosphorus. May consist of a single nucleotide or long chain of nucleotides.	*Long-chain nucleic acids:* polymer of nucleotide subunits	Deoxyribonucleic acid (DNA)	Genetic material of all living cells
		Ribonucleic acid (RNA)	Genetic material of some viruses; in cells, essential in transfer of genetic information from DNA to protein
	Single nucleotides	Adenosine triphosphate (ATP)	Principal short-term energy carrier molecule in cells
		Cyclic adenosine monophosphate (cyclic AMP)	Intracellular messenger

Table 3-2 part 2 Biology: Life on Earth, 8/e

Section 3.3 Outline

- **3.3 What Are Carbohydrates?**
  - There Are Several Monosaccharides with Slightly Different Structures
  - Disaccharides Consist of Two Single Sugars Linked by Dehydration Synthesis
  - Polysaccharides Are Chains of Simple Sugars

What Are Carbohydrates?

- Carbohydrate composition
  - Made of C, H, and O in the ratio of 1:2:1

What Are Carbohydrates?

- Carbohydrates are important energy sources for most organisms (Short term)
- Most small carbohydrates are water-soluble due to the polar OH functional groups

Monosaccharides

- Basic monosaccharide structure
  - Backbone of 3-7 carbon atoms
  - Many –OH and –H functional groups
  - Usually found in a ring form in cells

Monosaccharides

- Example monosaccharides
  - Glucose ($C_6H_{12}O_6$): the most common

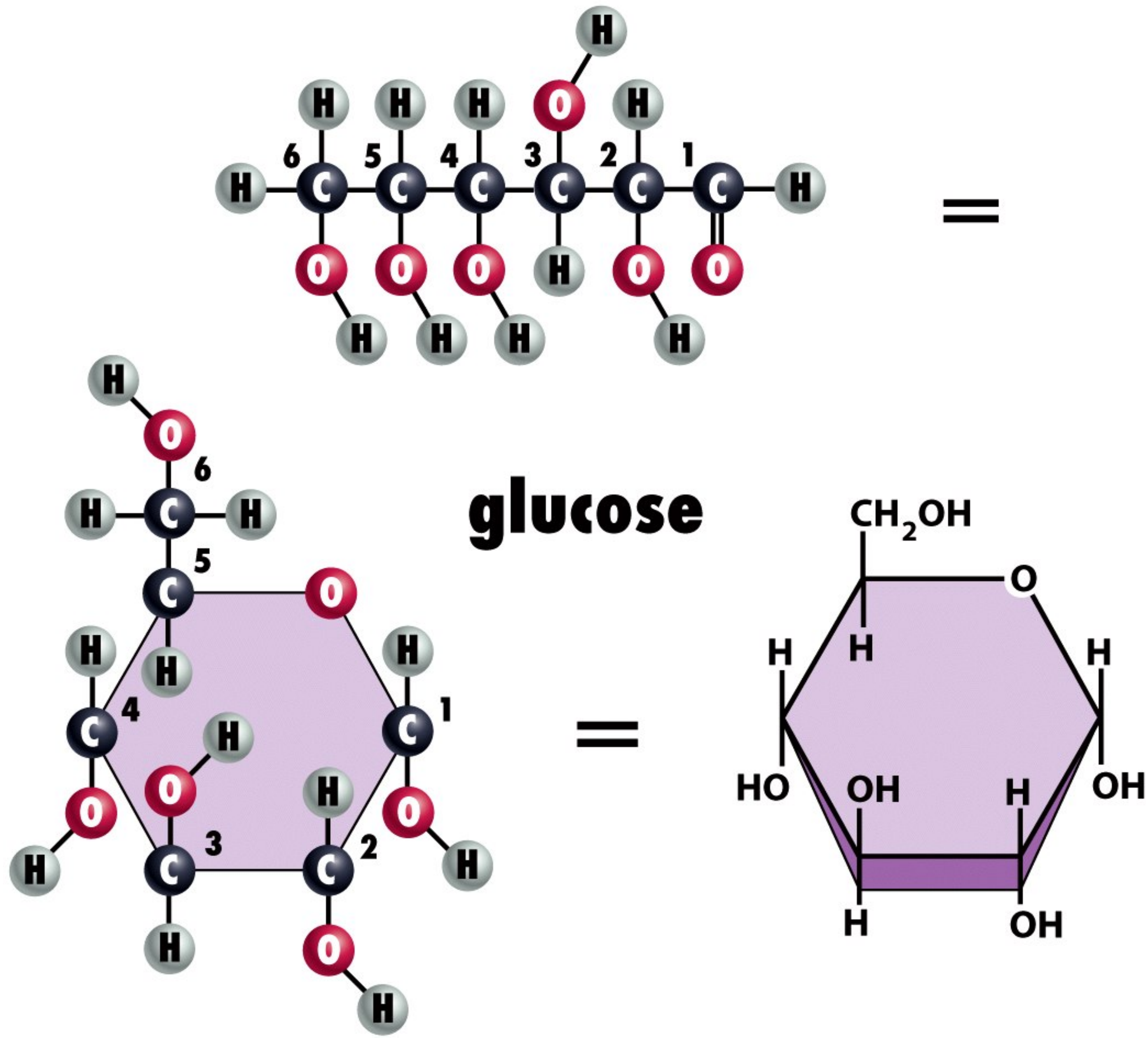
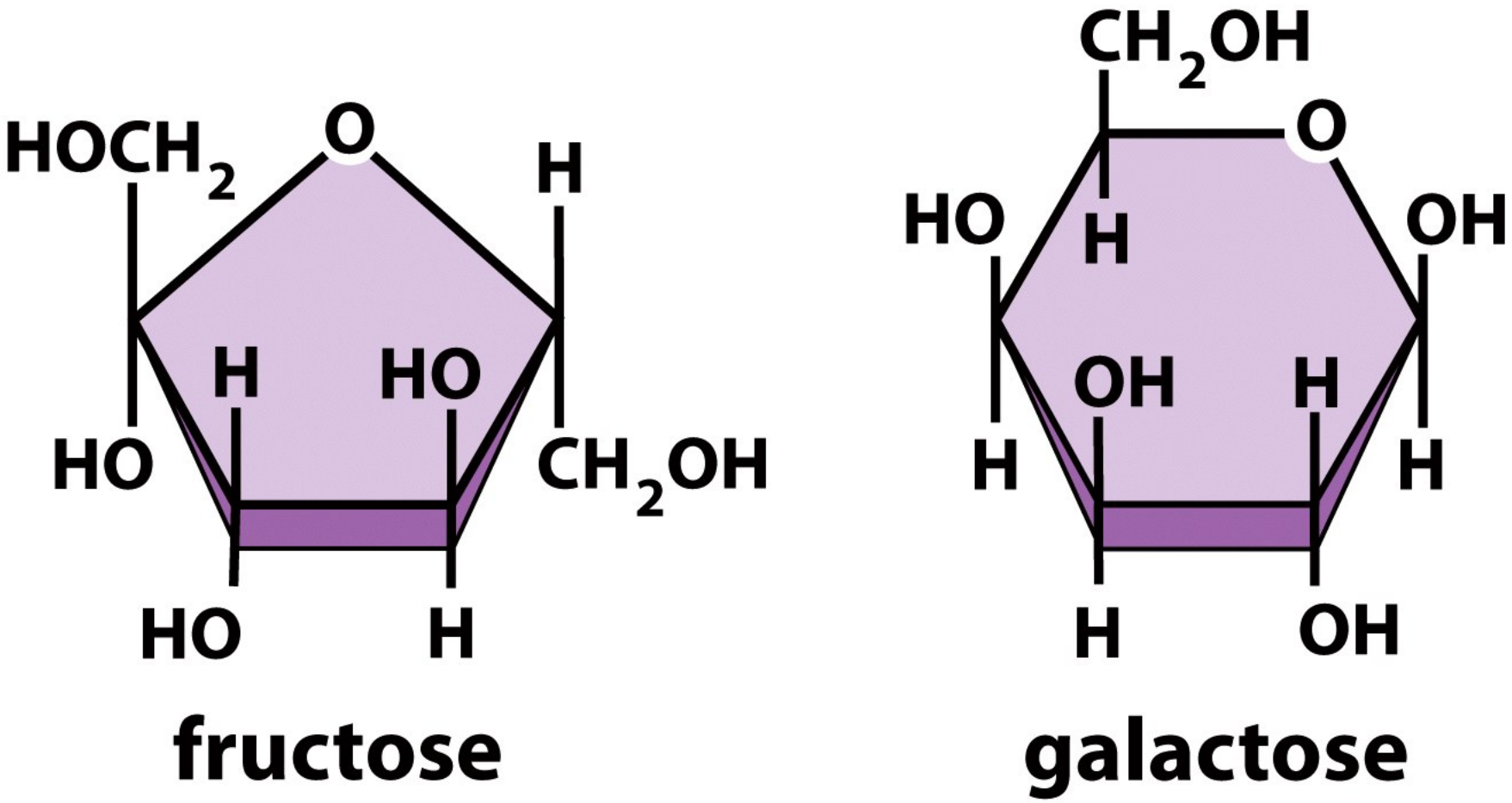


Figure 3-4 Biology: Life on Earth, 8/e

Monosaccharides

- Example monosaccharides continued
  - Fructose (found in corn syrup and fruits)
  - Galactose (found in lactose)



fructose

galactose

Figure 3-5 Biology: Life on Earth, 8/e

Monosaccharides

- Fate of monosaccharides inside a cell
  - Some broken down to free their chemical energy
  - Some are linked together by dehydration synthesis (storage)

Disaccharides

- Disaccharides are two-part sugars
  - Sucrose (table sugar) = glucose + fructose
  - Lactose (milk sugar) = glucose + galactose
  - Maltose (malt sugar)= glucose + glucose

Polysaccharides

- Monosaccharides are linked together to form chains (polysaccharides)
- Storage polysaccharides
  - Starch (polymer of glucose)
    - Formed in roots and seeds as a form of glucose storage (plants)
  - Glycogen (polymer of glucose)
    - Found in liver and muscles (animals)

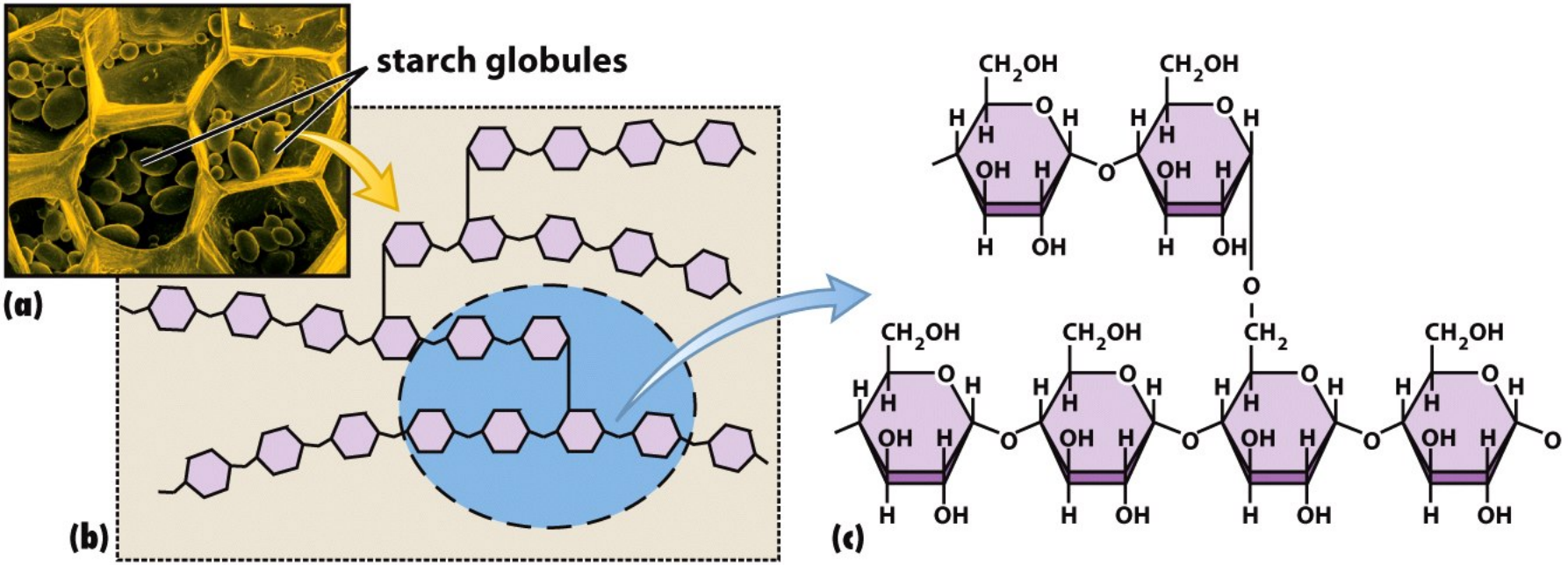


Figure 3-8 Biology: Life on Earth, 8/e

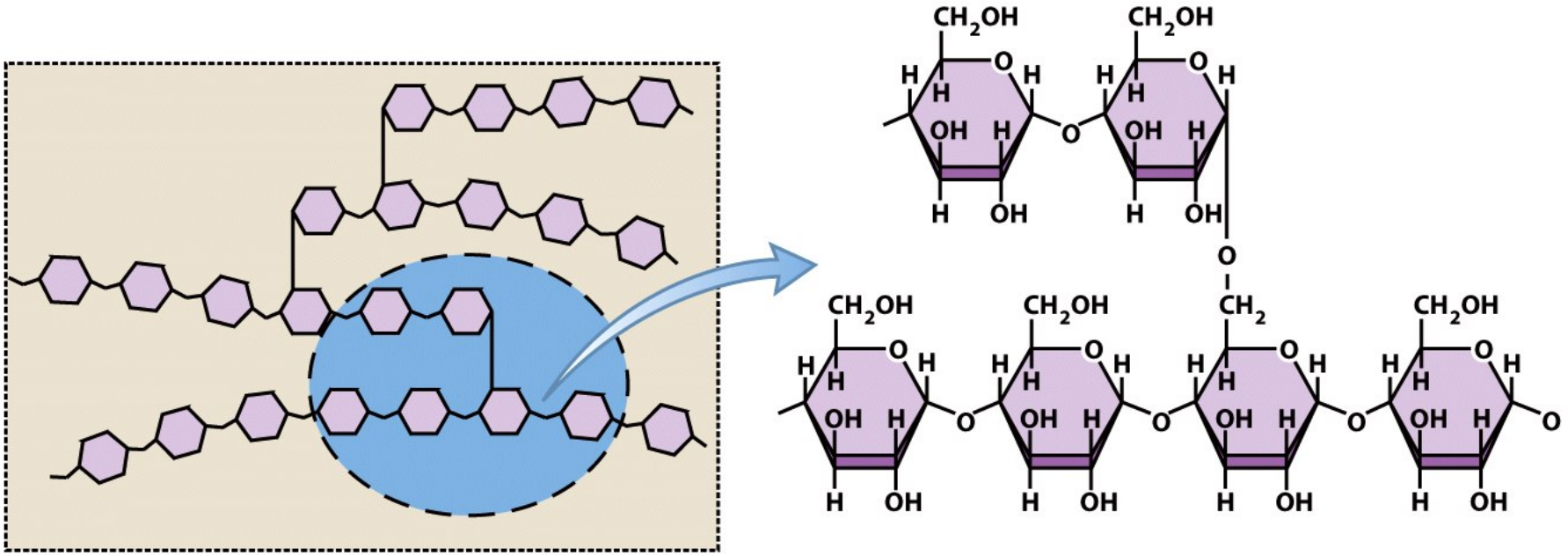


Figure 3-8 part 2 Biology: Life on Earth, 8/e

Polysaccharides

- Structural polysaccharides
  - Cellulose (polymer of glucose)
  - Found in the cell walls of plants
    - Indigestible for most animals due to orientation of bonds between glucoses

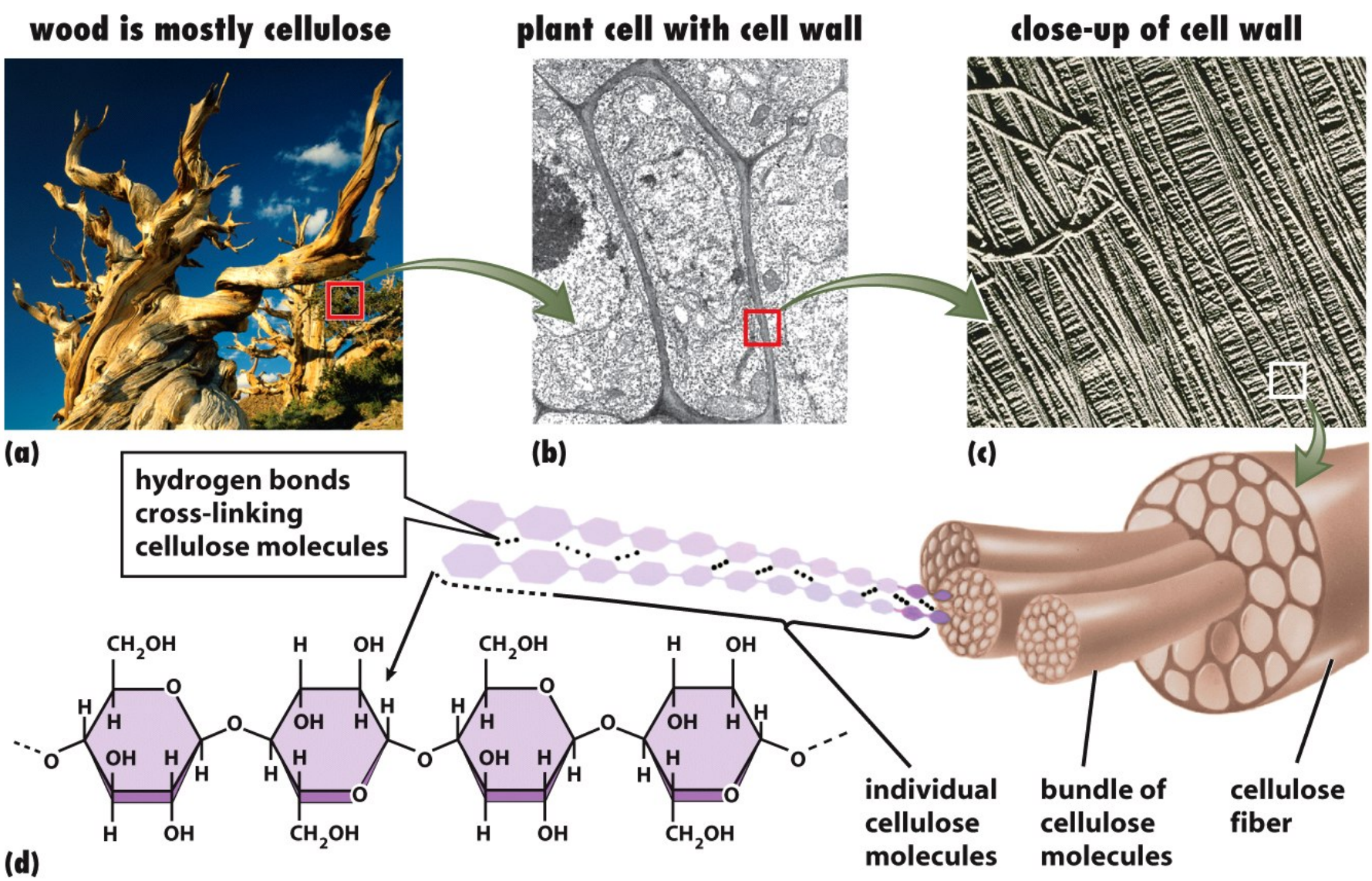


Figure 3-9 Biology: Life on Earth, 8/e

wood is mostly cellulose

Figure 3-9a Biology: Life on Earth, 8/e

plant cell with cell wall

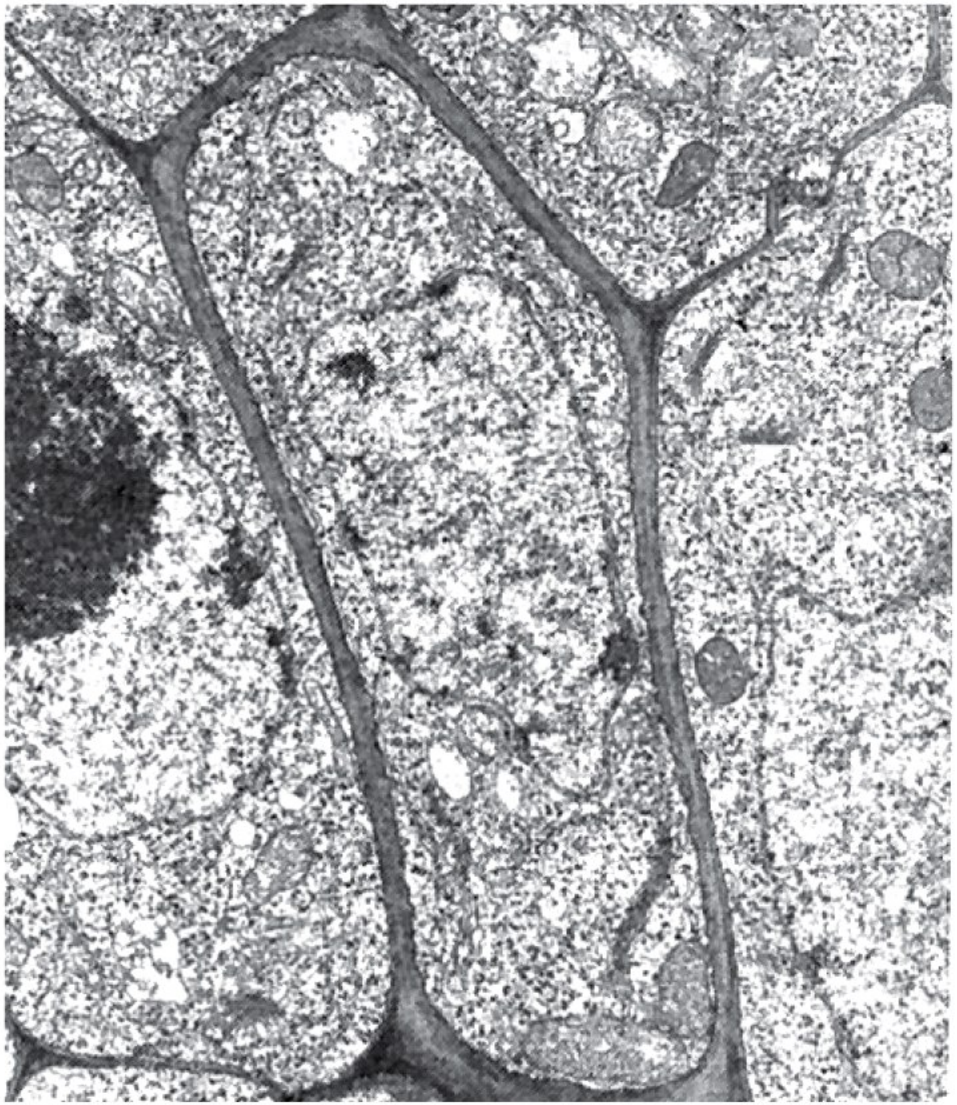


Figure 3-9b Biology: Life on Earth, 8/e

close-up of cell wall

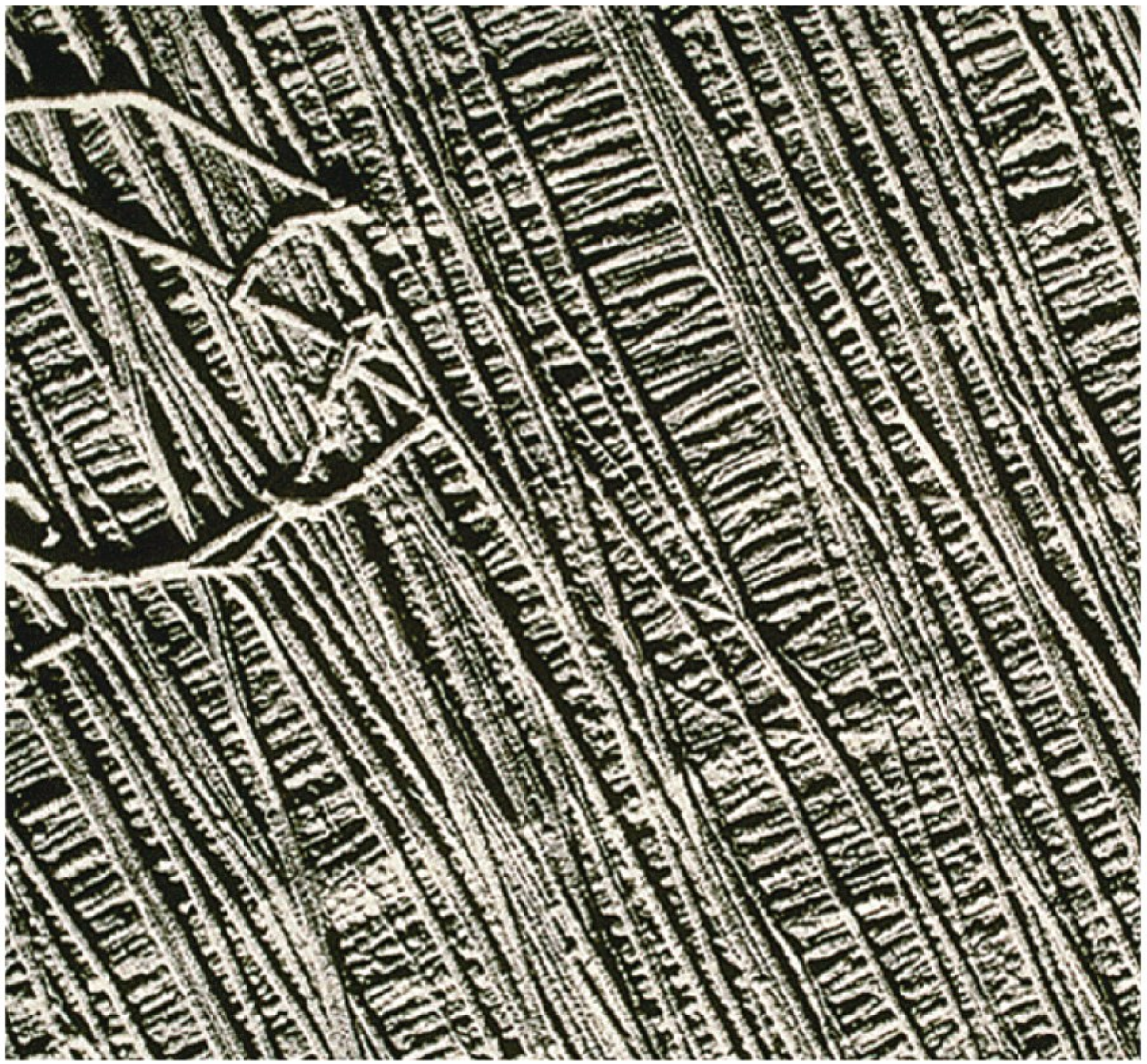


Figure 3-9c Biology: Life on Earth, 8/e

Polysaccharides

- Structural polysaccharides continued
  - Chitin (polymer of modified glucose units)
    - Found in the outer coverings of insects, crabs, and spiders
    - Found in the cell walls of many fungi

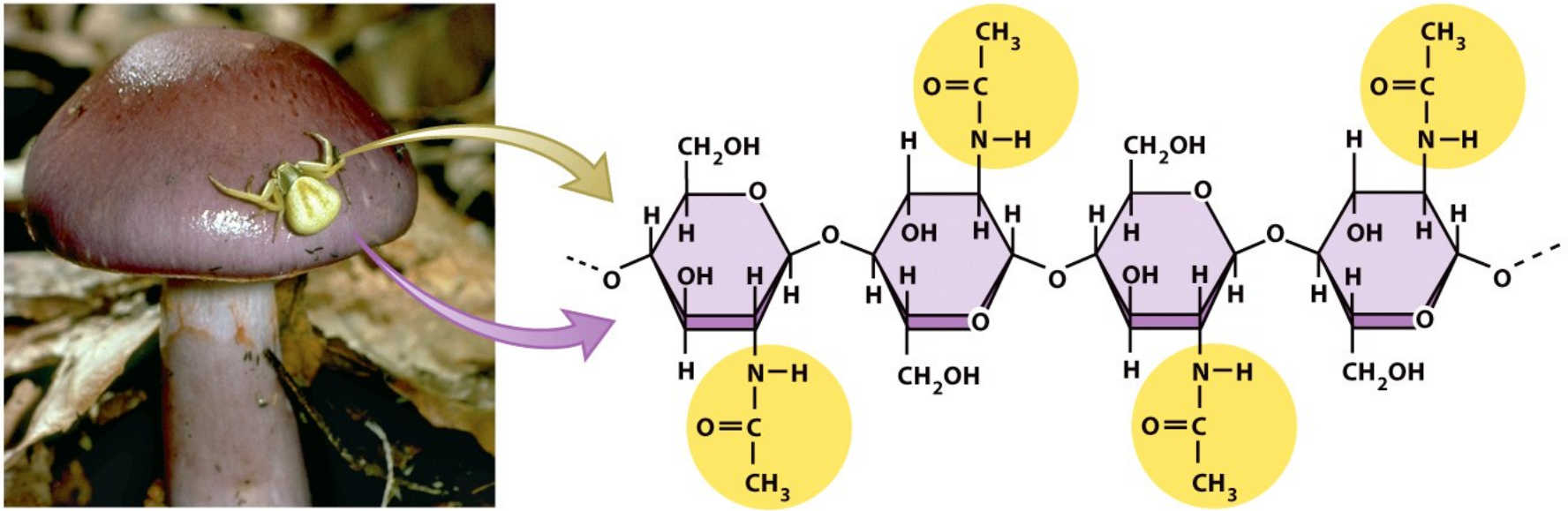


Figure 3-10 Biology: Life on Earth, 8/e

Figure 3-10 part 1 Biology: Life on Earth, 8/e

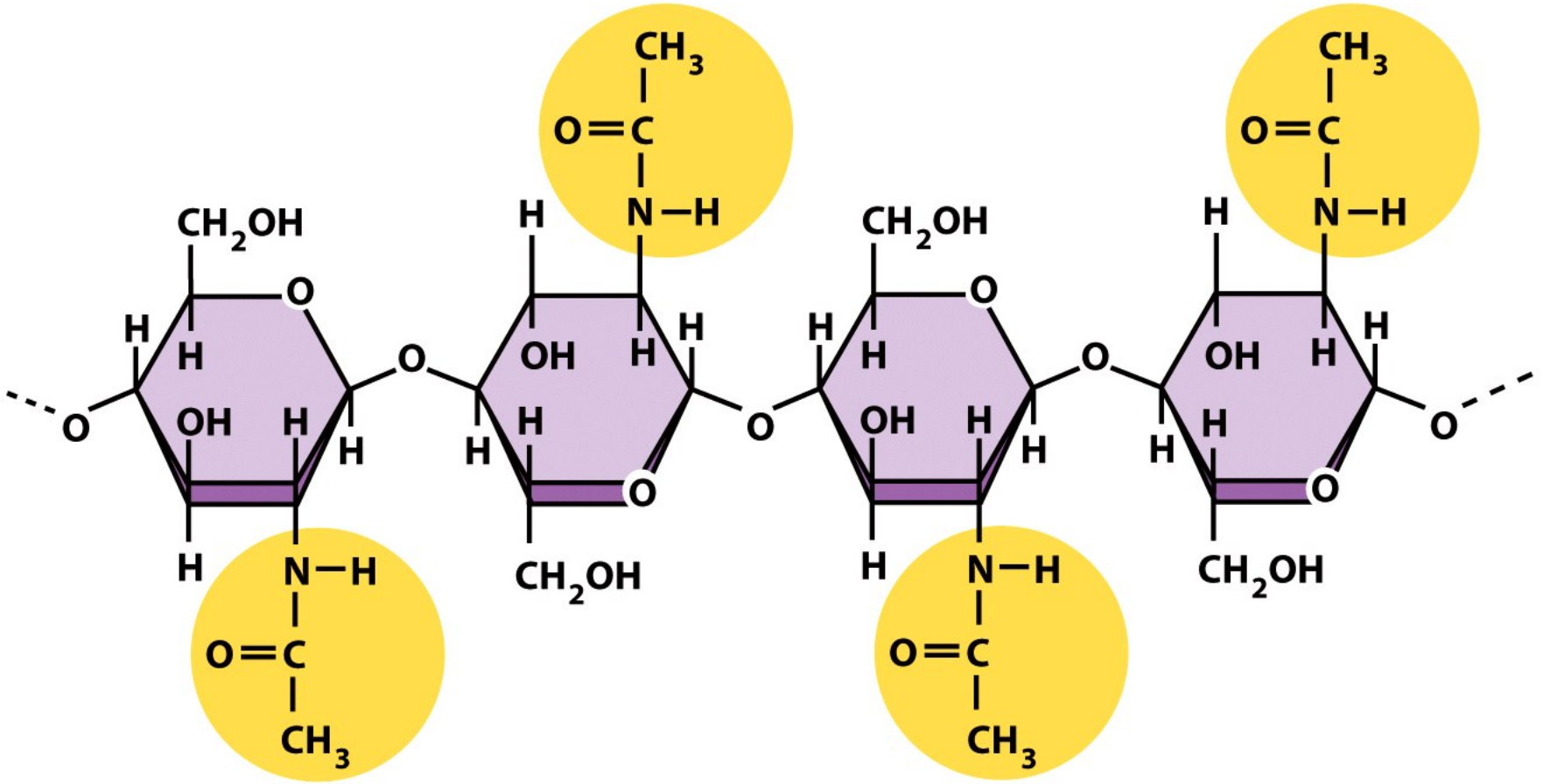


Figure 3-10 part 2 Biology: Life on Earth, 8/e

What Are Lipids?

- All lipids contain large chains of nonpolar hydrocarbons
- Most lipids are therefore hydrophobic and water insoluble

What Are Lipids?

- Lipids are diverse in structure and serve in a variety of functions
  - Energy storage
  - Waterproofing
  - Membranes in cells
  - Hormones

Oils, Fats, and Waxes

- Made of one or more fatty acid subunits
- Fats and oils
  - Formed by dehydration synthesis
    - 3 fatty acids + glycerol → triglyceride

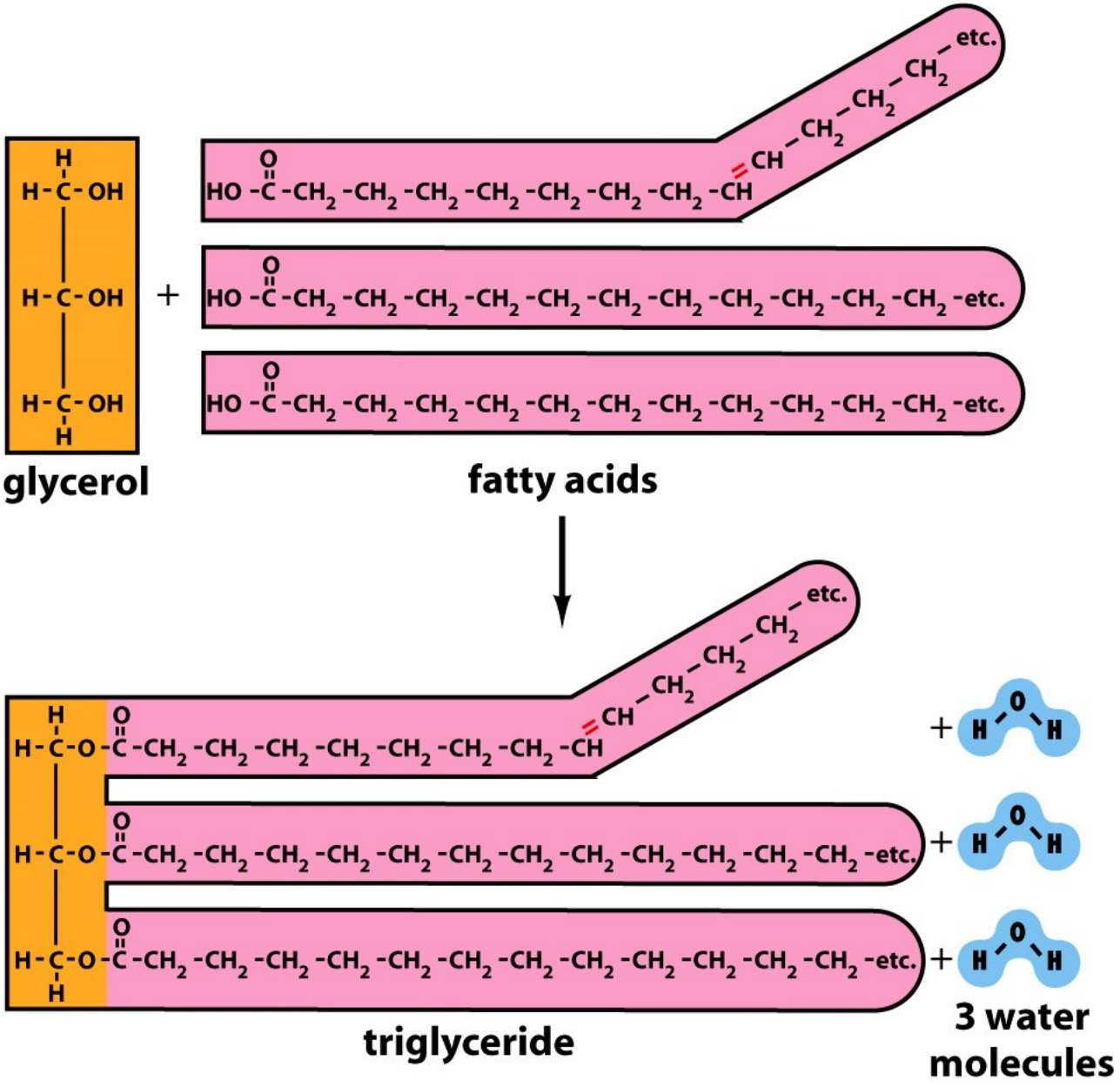


Figure 3-11 Biology: Life on Earth, 8/e

Oils, Fats, and Waxes

- Fats and oils used for long-term energy storage
  - Fats and oils possess a high density of stored chemical energy

Fat

Figure 3-12a Biology: Life on Earth, 8/e

Oils, Fats, and Waxes

- Fat solidity is due to single or double carbon bonds
  - Fats that are solid at room temperature are ***saturated*** (carbon chain has as many hydrogen atoms as possible, and mostly or all C-C bonds), e.g. beef fat

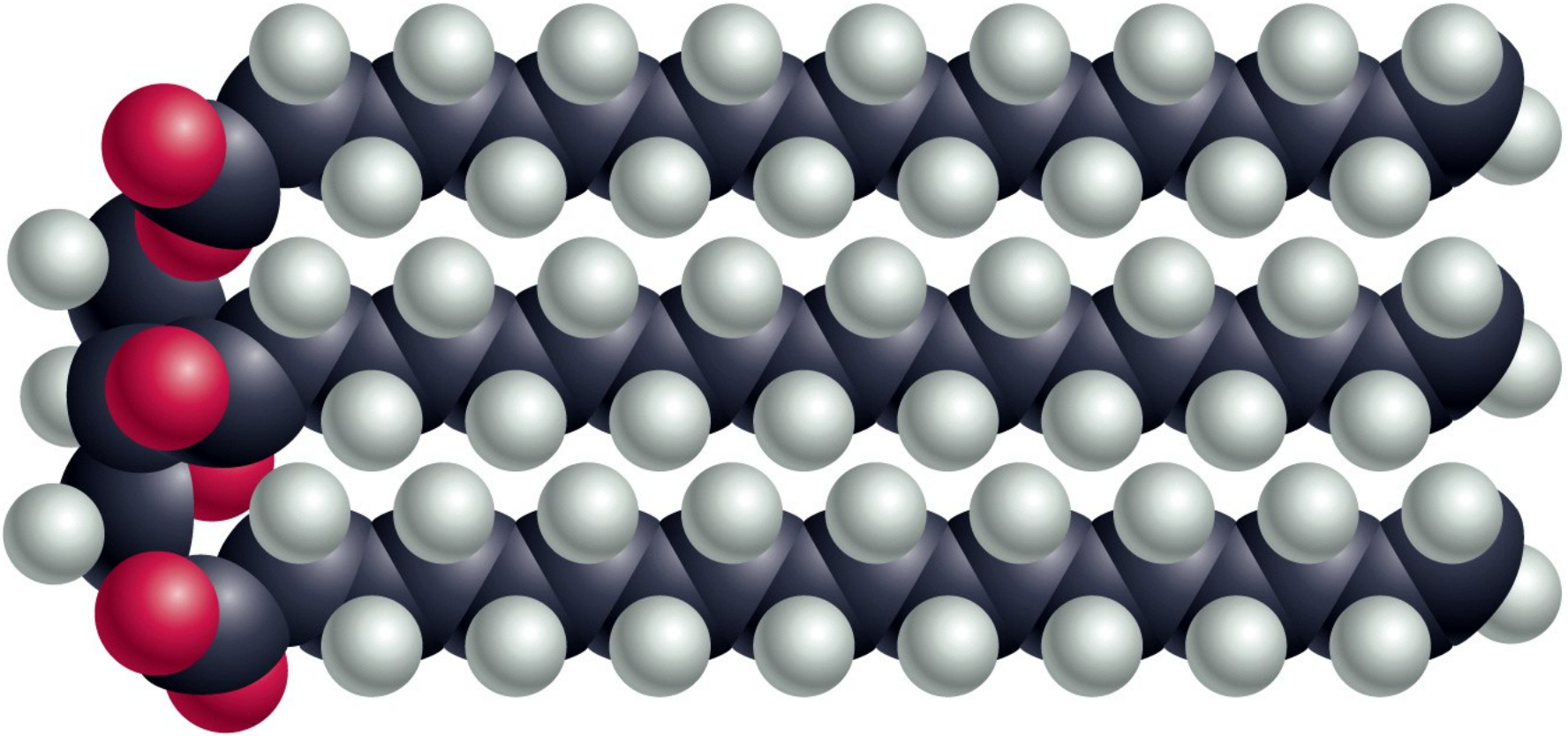


Figure 3-13 Biology: Life on Earth, 8/e

Oils, Fats, and Waxes

- Fat solidity is due to single or double carbon bonds (continued)
  - Fats that are liquid at room temperature are ***unsaturated*** (fewer hydrogen atoms, many C=C bonds), e.g. corn oil

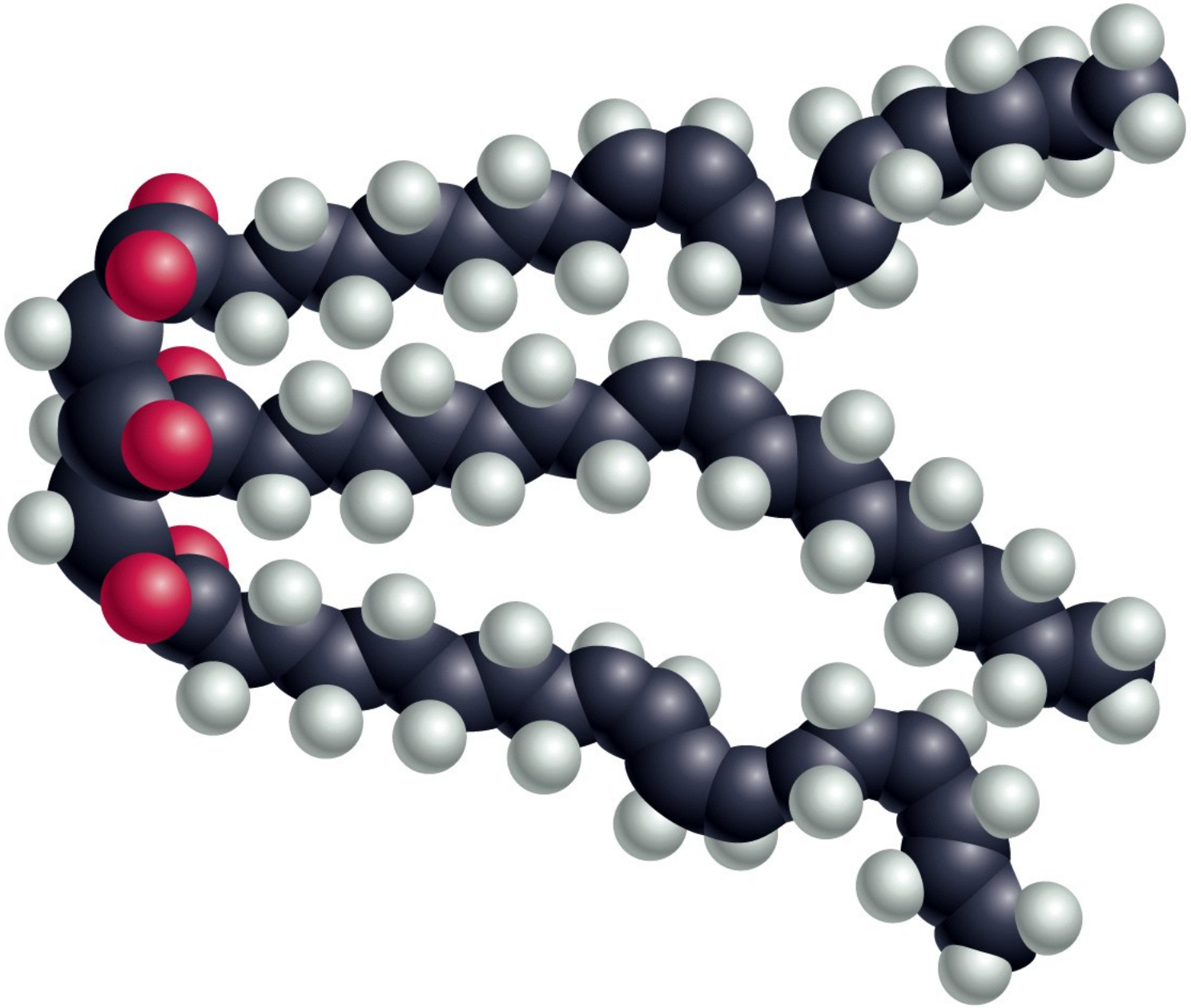


Figure 3-14 Biology: Life on Earth, 8/e

Phospholipids

- **Phospholipids**: form plasma membranes around all cells
- Construction
  - 2 fatty acids + glycerol + a short polar functional group

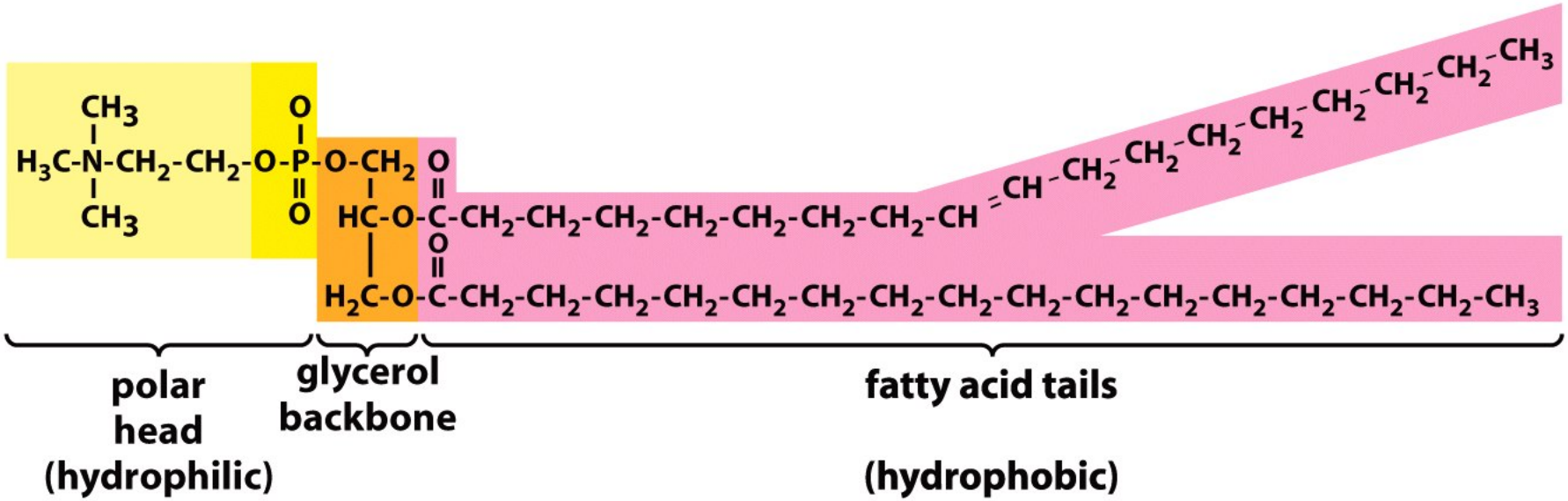


Figure 3-15 Biology: Life on Earth, 8/e

Phospholipids

- Phospholipids have hydrophobic and hydrophilic portions
  - Polar functional groups are water soluble
  - Nonpolar fatty acid “tails” are water insoluble

Oils, Fats, and Waxes

- Waxes are made of a long hydrocarbon chain attached to an alcohol.
- Waxes are highly saturated, solid at room temperature and VERY WATERPROOF.

Oils, Fats, and Waxes

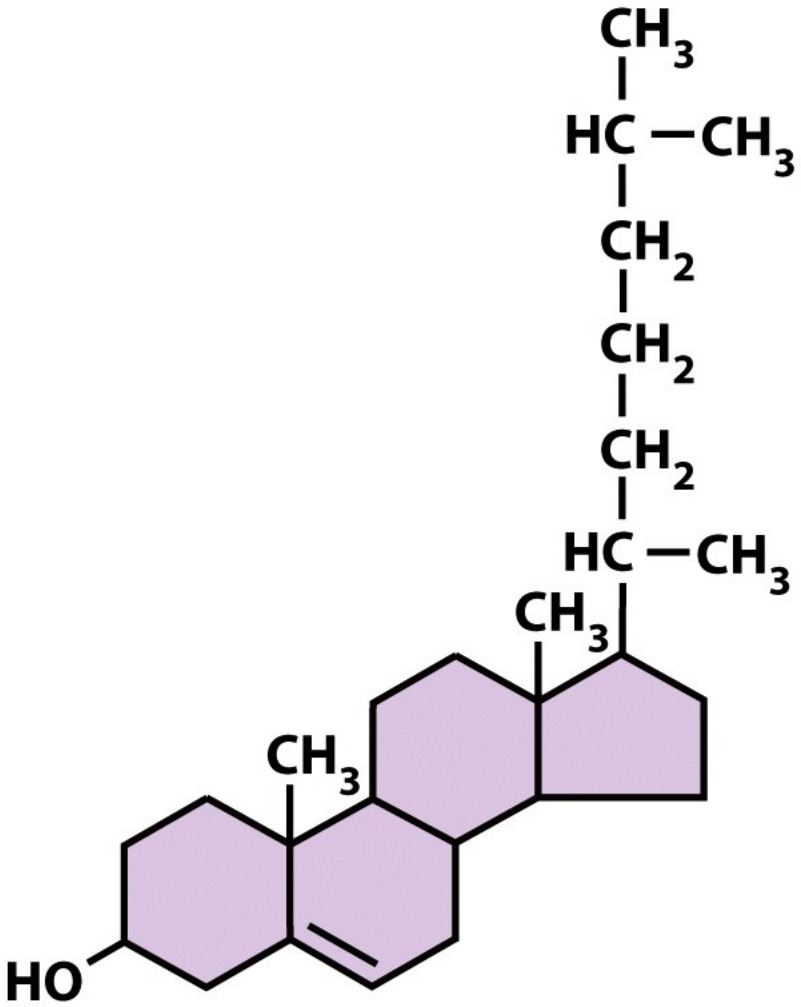
- Waxes form waterproof coatings
  - Leaves and stems of plants, mammal fur, insect exoskeletons
- Used to build honeycomb structures by bees

Wax

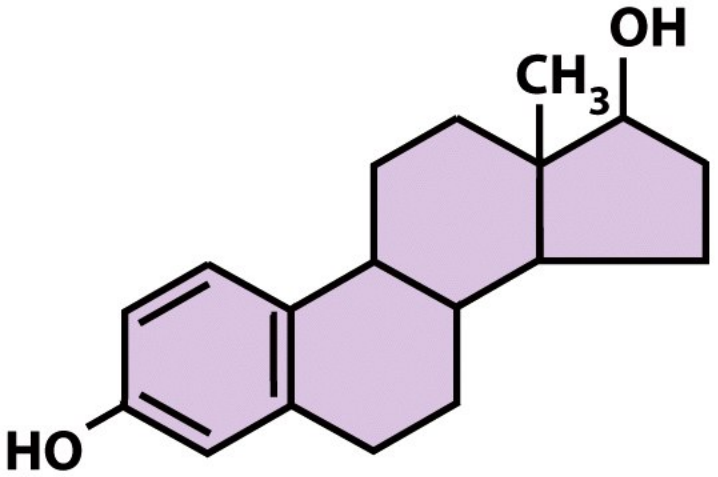
Figure 3-12b Biology: Life on Earth, 8/e

Steroids

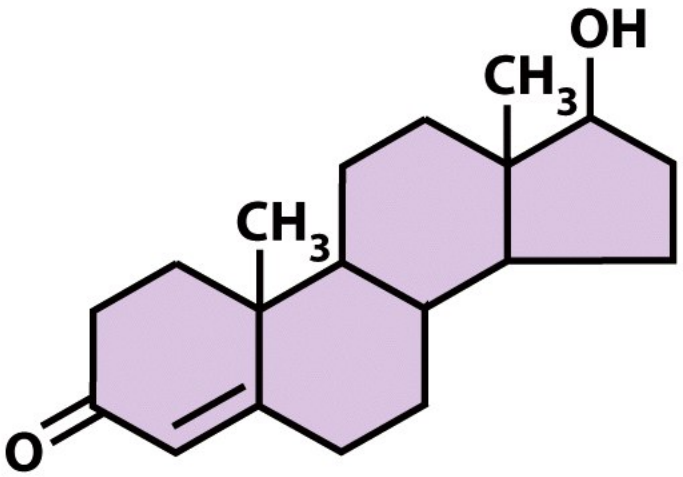
- Steroids are composed of four carbon rings fused together
- Examples of steroids
  - Cholesterol
    - Found in membranes of animal cells
  - Male and female sex hormones



cholesterol



estrogen



testosterone

Figure 3-16 Biology: Life on Earth, 8/e

Hair

Figure 3-17a Biology: Life on Earth, 8/e

Horn

Figure 3-17b Biology: Life on Earth, 8/e

Silk

Figure 3-17c Biology: Life on Earth, 8/e

What Are Proteins?

- Proteins have a variety of functions

Table 3-3 Functions of Proteins

Function	Example
Structure	Collagen in skin; keratin in hair, nails, horns
Movement	Actin and myosin in muscle
Defense	Antibodies in bloodstream
Storage	Albumin in egg white
Signaling	Growth hormone in bloodstream
Catalyzing reactions	Enzymes (Ex.: amylase digests carbohydrates; ATP synthase makes ATP)

Table 3-3 Biology: Life on Earth, 8/e

Amino Acids

- Proteins are formed from chains of amino acids (monomers)
- All amino acids have similar structure
  - All contain amino and carboxyl groups
  - All have a variable “R” group
    - Some R groups are hydrophobic
    - Some are hydrophilic
    - Cysteine R groups can form disulfide bridges

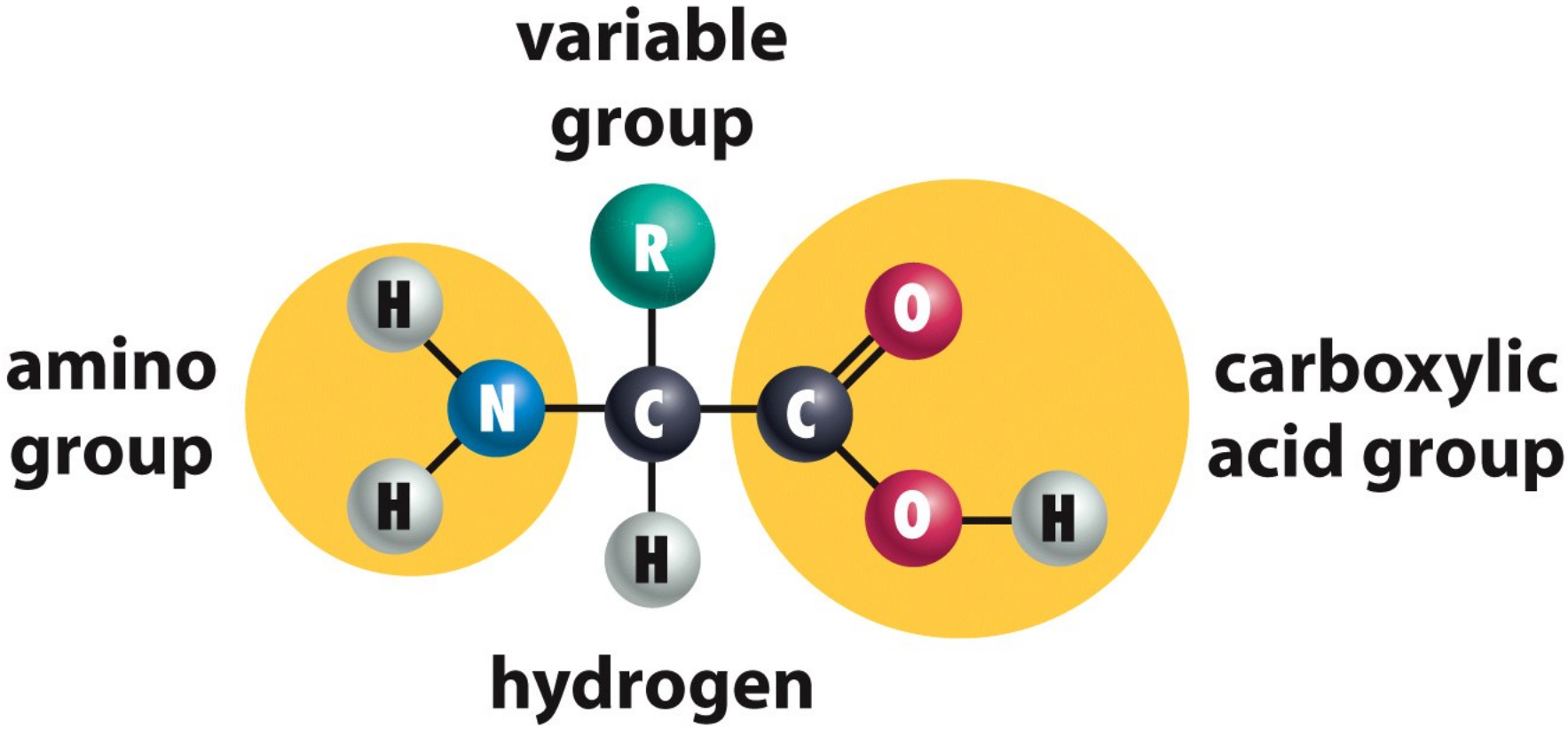


Figure 3-18 Biology: Life on Earth, 8/e

Amino Acids

- The sequence of amino acids in a protein dictates its function

Dehydration Synthesis

- Amino acids are joined to form chains by dehydration synthesis
  - An amino group reacts with a carboxyl group, and water is lost

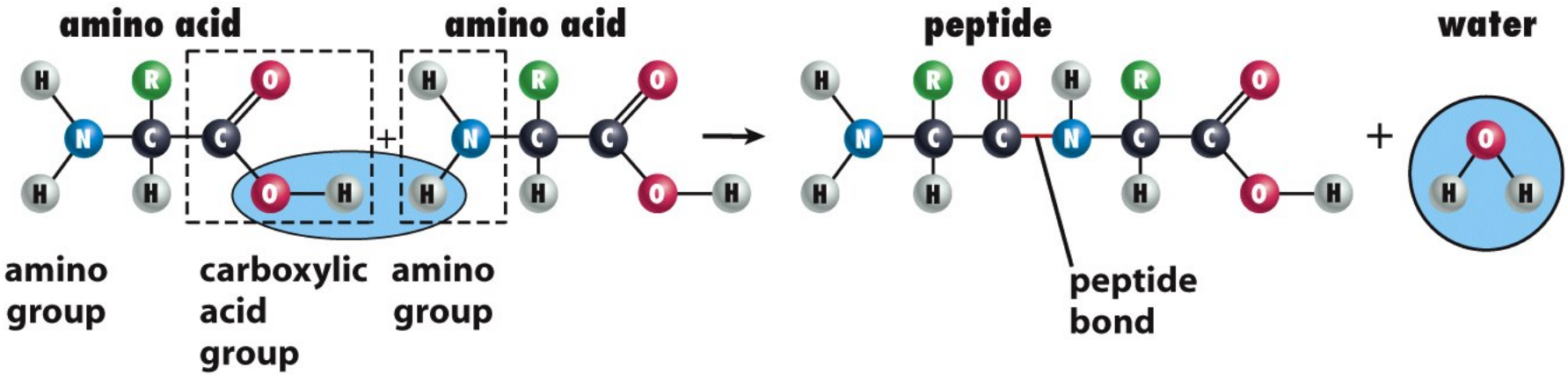


Figure 3-20 Biology: Life on Earth, 8/e

Dehydration Synthesis

- Resultant covalent bond is a **peptide bond**
- Long chains of amino acids are known as **polypeptides** or just **proteins**

Four Levels of Structure

- Proteins exhibit up to four levels of structure
  - **Primary structure** is the sequence of amino acids linked together in a protein
  - **Secondary structures** are helices and pleated sheets
  - **Tertiary structure** refers to complex foldings of the protein chain held together by disulfide bridges, hydrophobic/hydrophilic interactions, and other bonds
  - **Quaternary structure** is found where *multiple* protein chains are linked together

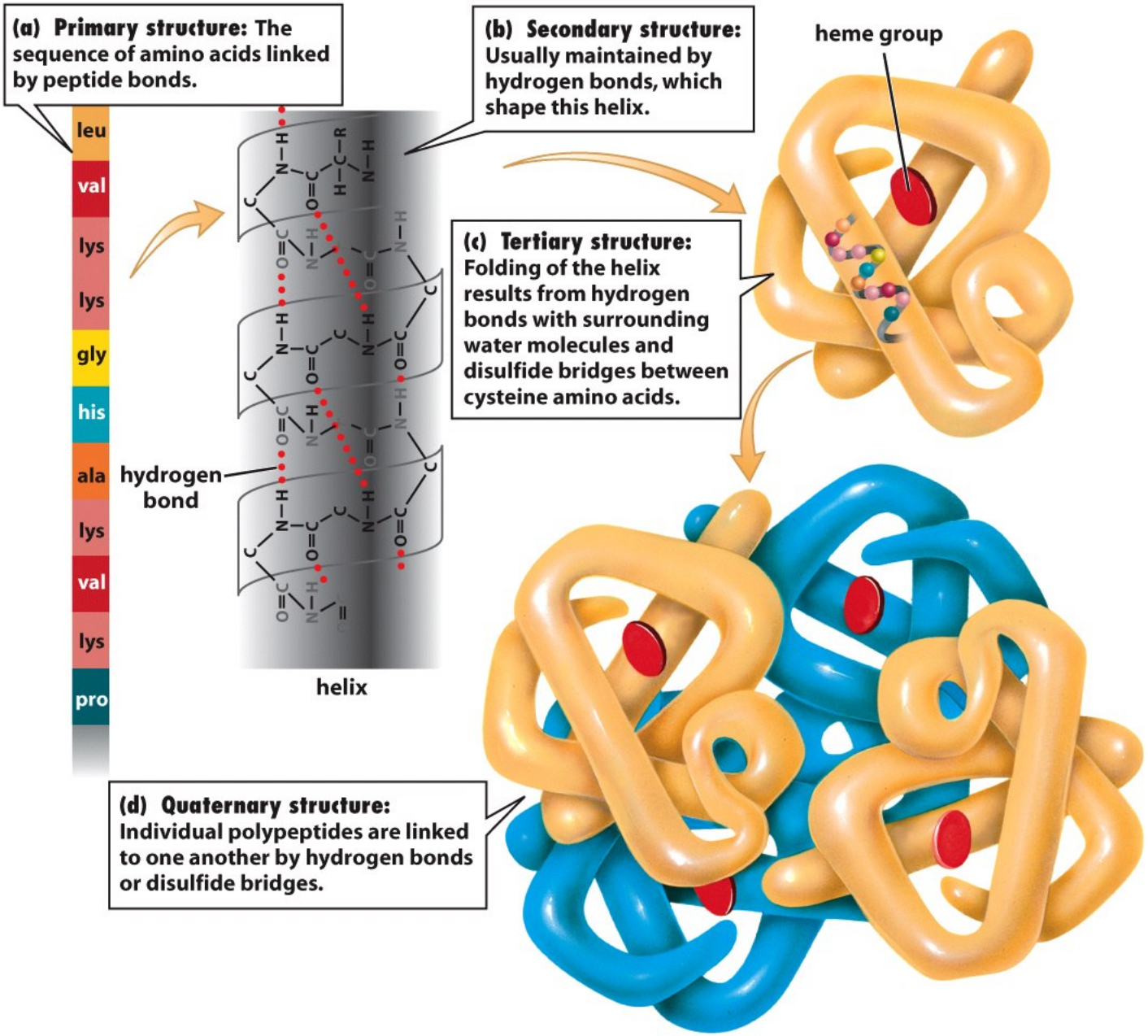


Figure 3-21 Biology: Life on Earth, 8/e

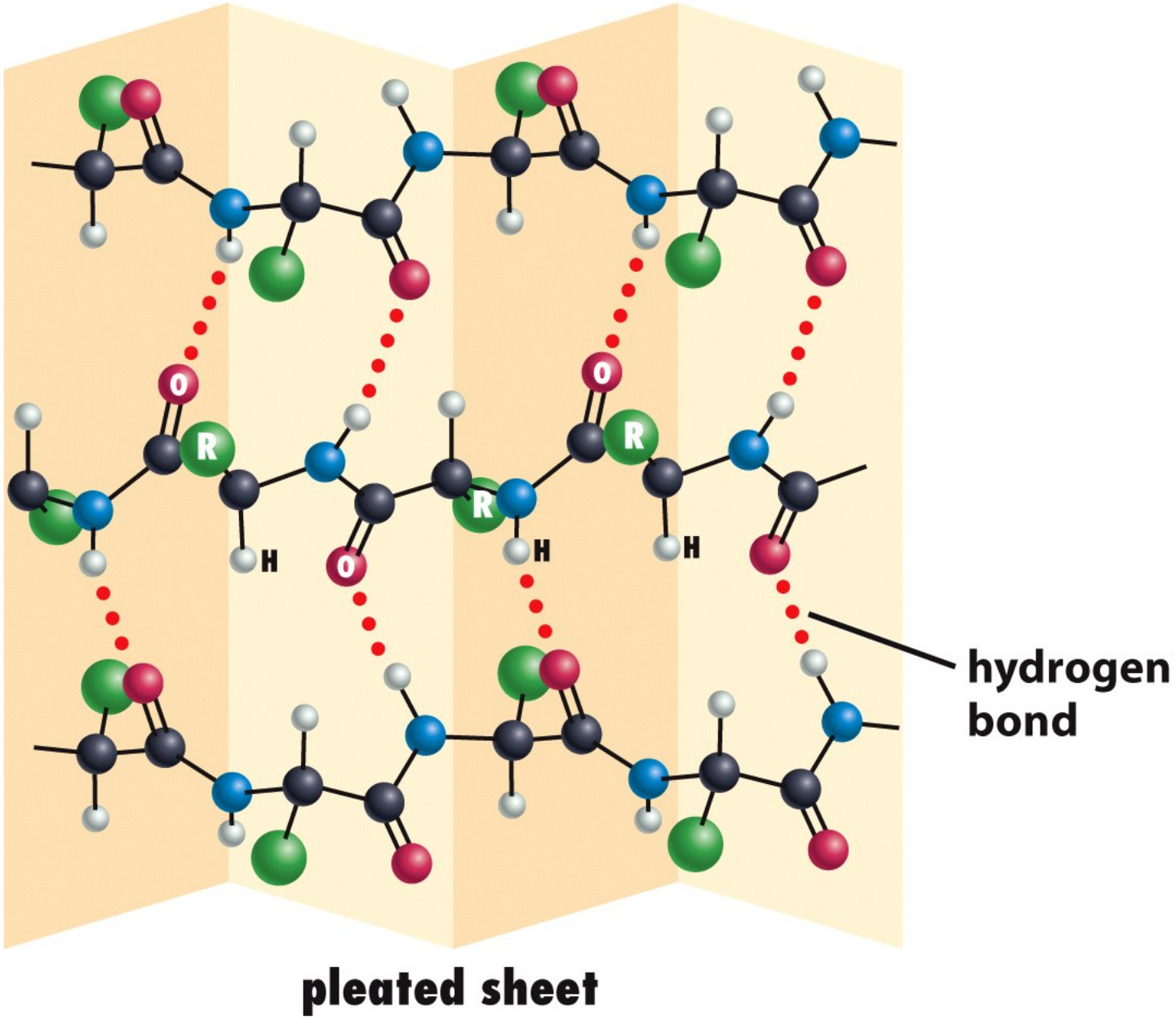


Figure 3-22 Biology: Life on Earth, 8/e

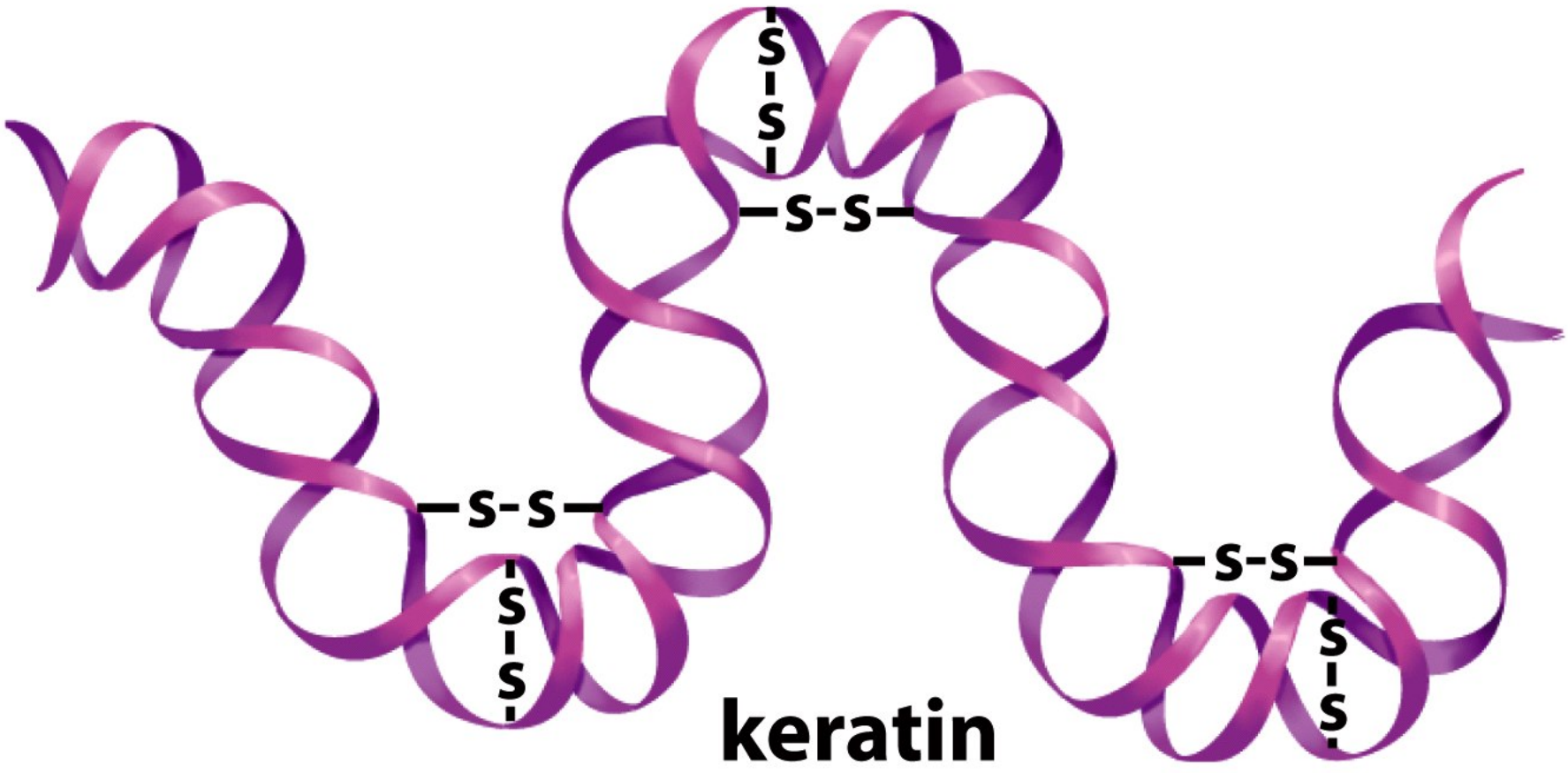


Figure 3-23 Biology: Life on Earth, 8/e

Three Dimensional Structures

- The type, position, and number of amino acids determine the structure and function of a protein
  - Precise positioning of amino acid R groups leads to bonds that determine secondary and tertiary structure
  - Disruption of these bonds leads to **denatured** proteins and loss of function

What Are Nucleic Acids?

- Nucleotides are the monomers of nucleic acid chains

What Are Nucleic Acids?

- All nucleotides are made of three parts
  - Phosphate group
  - Five-carbon sugar
  - Nitrogen-containing base

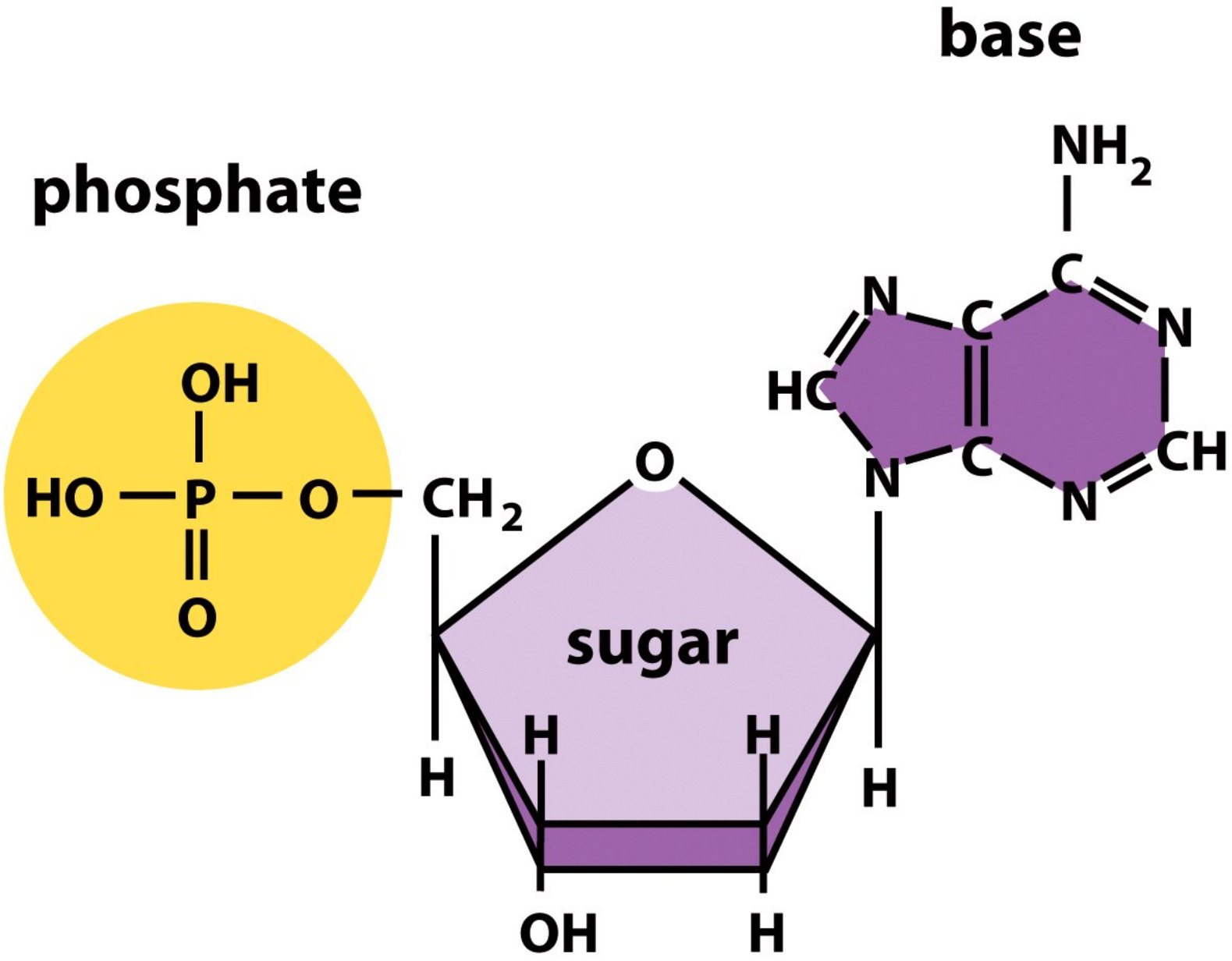


Figure 3-24 Biology: Life on Earth, 8/e

Molecules of Heredity

- Two types of nucleotides
  - **Ribonucleotides** (A, G, C, and U) found in **RNA**
  - **Deoxyribonucleotides** (A, G, C, and T) found in **DNA**

Molecules of Heredity

- Two types of polymers of nucleic acids
  - **DNA** (deoxyribonucleic acid) found in chromosomes
    - Carries genetic information needed for protein construction
  - **RNA** (ribonucleic acid)
    - Copies of DNA used directly in protein construction

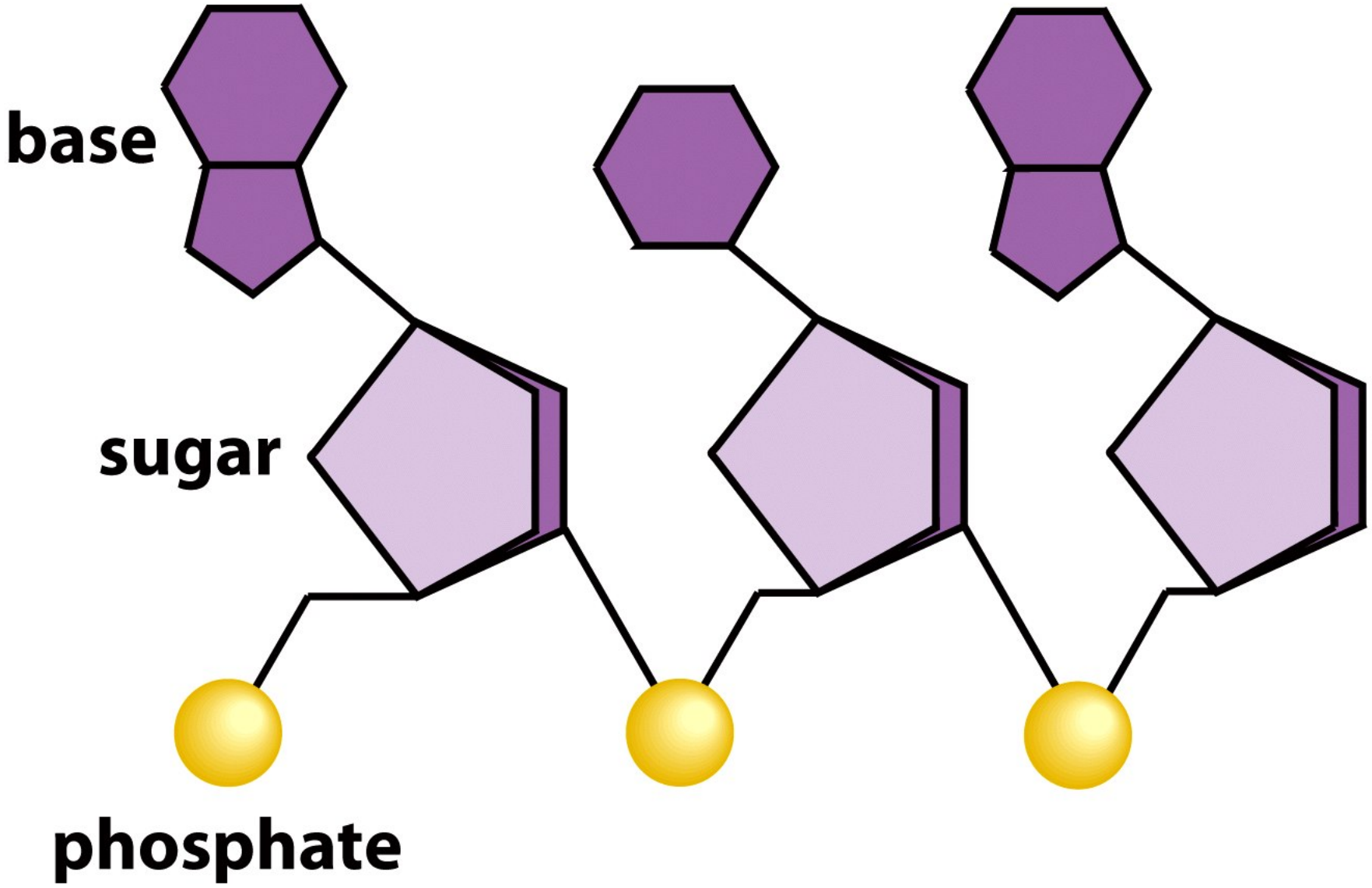


Figure 3-25 Biology: Life on Earth, 8/e

Molecules of Heredity

- Each DNA molecule consists of two chains of nucleotides that form a double helix

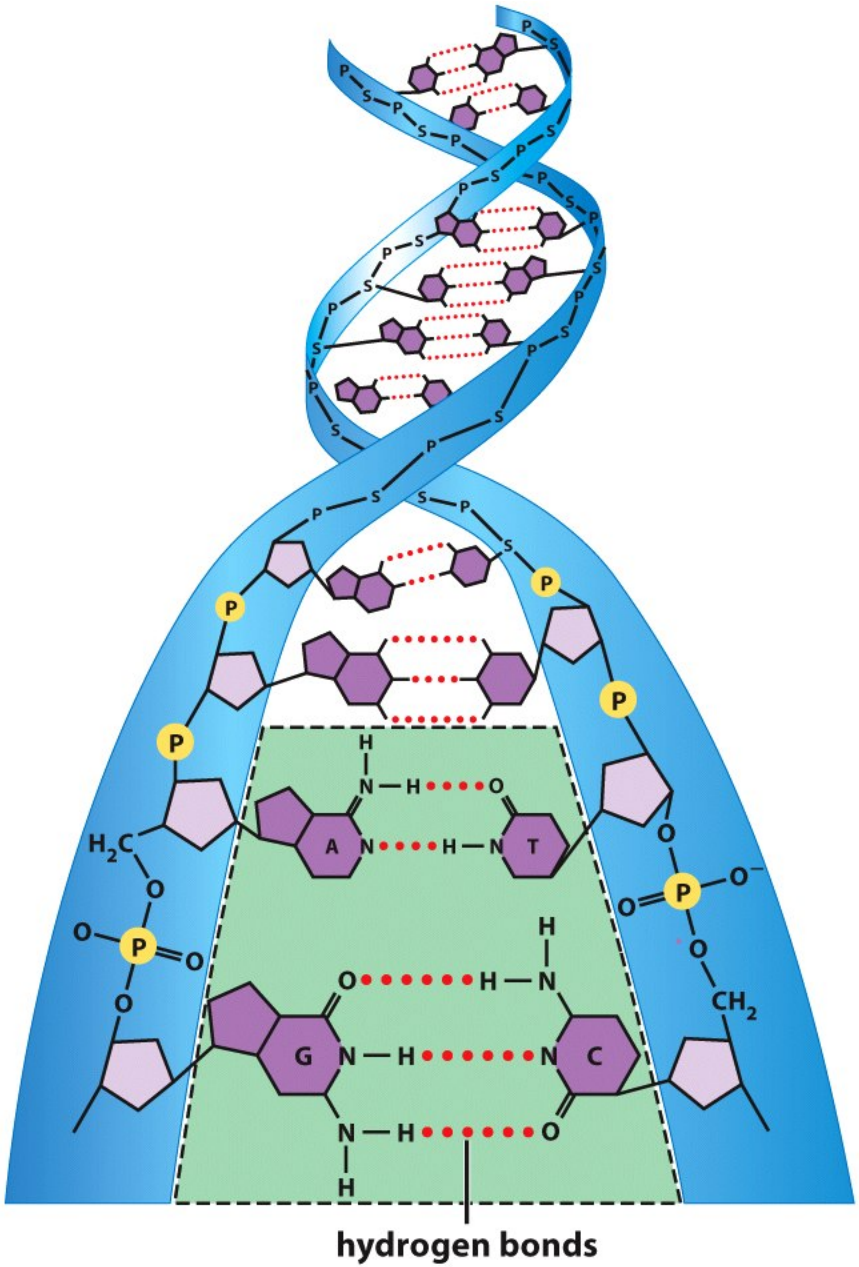


Figure 3-26 Biology: Life on Earth, 8/e