Essentials of Biology

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Chapter 2 & 3
Lecture Outline

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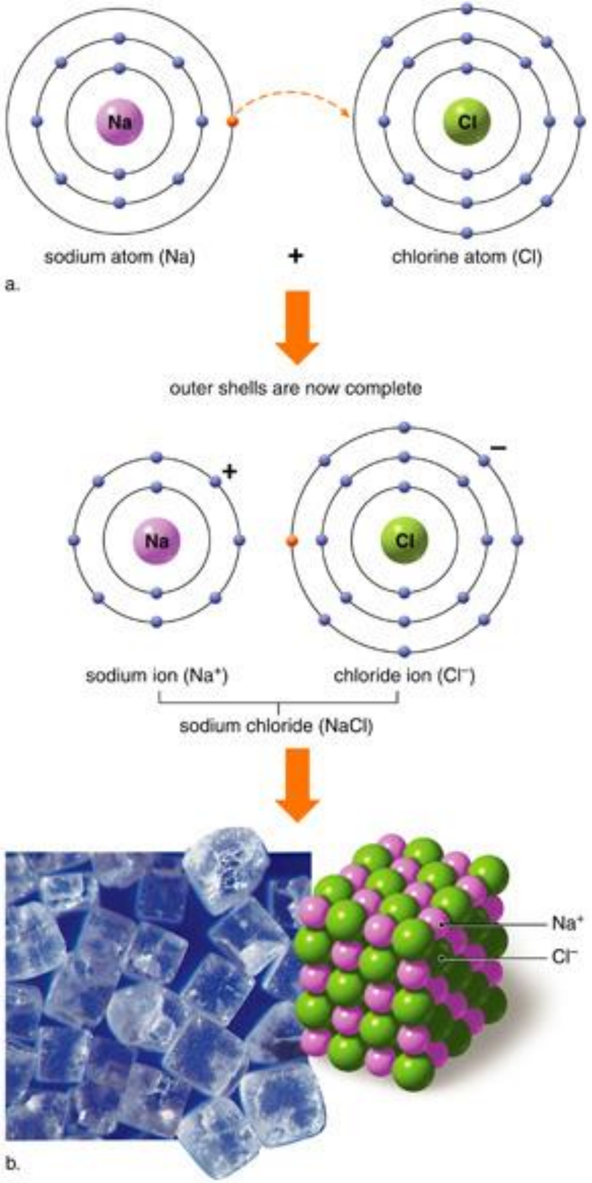
The chemistry of Organic Molecules

- A group of atoms bonded to one another form a molecule.
- If the molecule has more than one type of element present it is a compound.
- Different types of bonds hold molecules and compounds together.

Types of Chemical Bonds (cont.)

- Charged atoms, or ions, can form when atoms lose or gain electrons.
- Positive and negative ions are attracted to one another and bond together in ionic bonds.
- A salt is a dry solid composed of atoms connected by ionic bonds.

Types of Chemical Bonds (cont.)

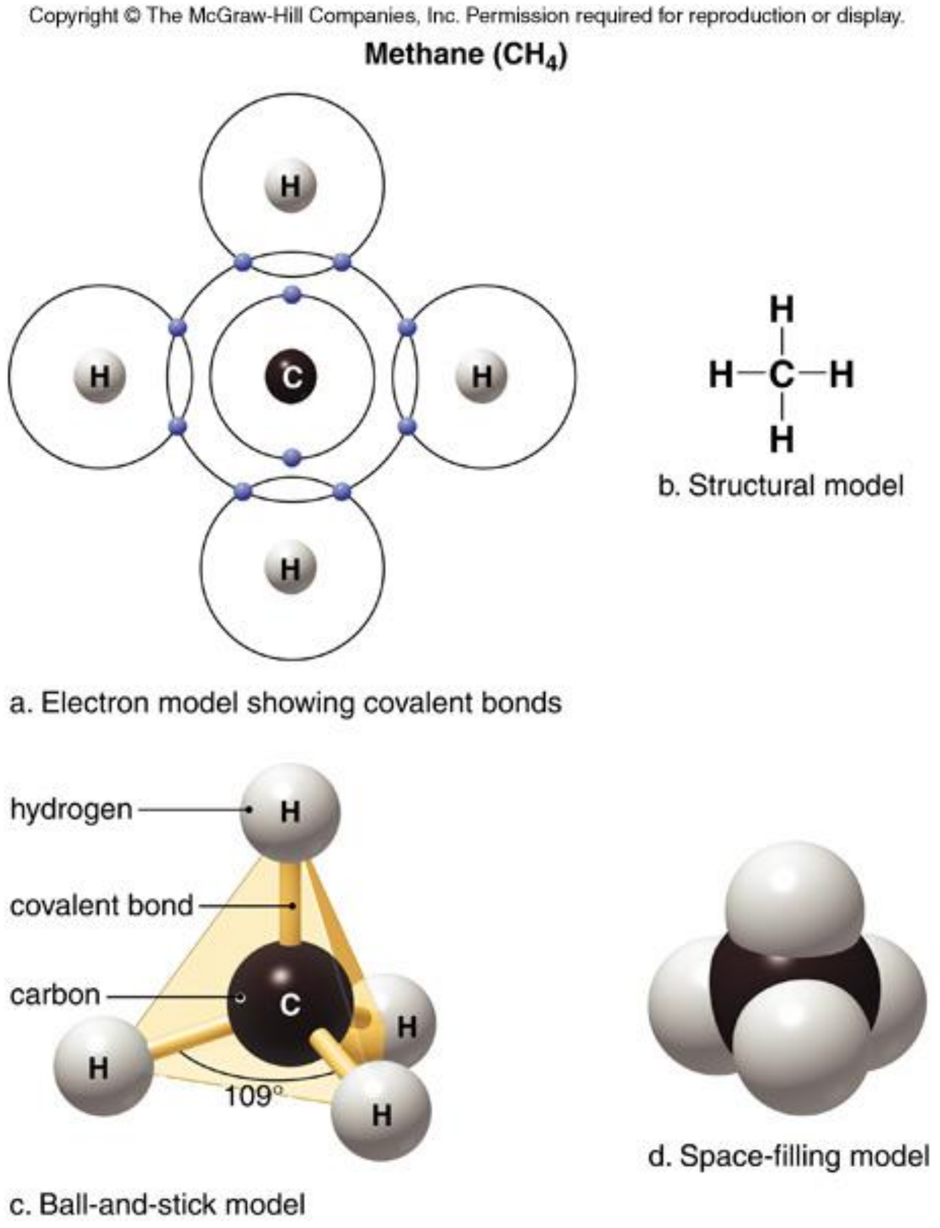


Types of Chemical Bonds (cont.)

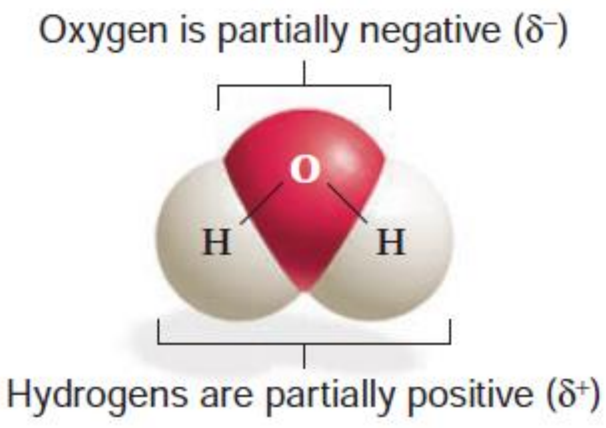
- A covalent bond results when two atoms share electrons, thereby completing their valence shells.

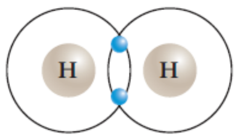
- When molecules contain covalent bonds, the structure of the molecule can be drawn with a formula or model.

Types of Chemical Bonds (cont.)

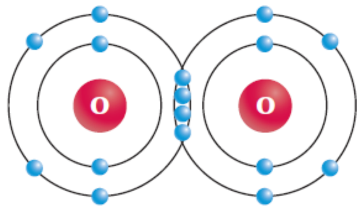


- Atoms differ in their electronegativity, or their affinity for electrons in a covalent bond.
- If electrons are equally shared by the atoms in the bond, the bond is called non-polar bond. While unequal sharing of electrons due to differences in electronegativity makes the bond polar bond.
- The unequal sharing of electrons in a molecule such as water makes the molecule polar.
- Polar water molecules are attracted to one another and can form hydrogen bonds.

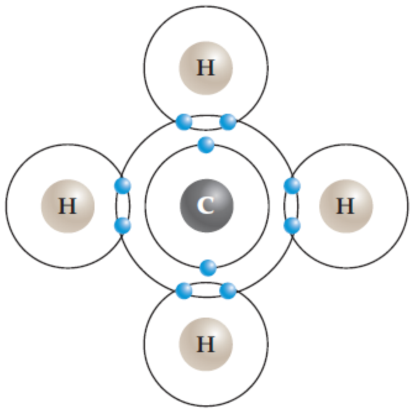


Electron Model	Structural Formula	Molecular Formula
	H—H	H_2

a. Hydrogen gas

Electron Model	Structural Formula	Molecular Formula
	O=O	O_2

b. Oxygen gas

Electron Model	Structural Formula	Molecular Formula
	H | H—C—H | H	CH_4

c. Methane

FIGURE 2.8 Covalently bonded molecules.

In a covalent bond, atoms share electrons, allowing each atom to have a completed outer shell. **a.** A molecule of hydrogen (H_2) contains two hydrogen atoms sharing a pair of electrons. This single covalent bond can be represented in any of the three ways shown. **b.** A molecule of oxygen (O_2) contains two oxygen atoms sharing two pairs of electrons. This results in a double covalent bond. **c.** A molecule of methane (CH_4) contains one carbon atom bonded to four hydrogen atoms.

3.1 Organic Molecules

- Inorganic chemistry can be considered the chemistry of the nonliving world.
- Organic chemistry is the chemistry of the living world.
- To be an organic molecule, the molecule must contain carbon and hydrogen.

3.1 Organic Molecules (cont.)

The Carbon Atom

- Carbon has a total of six electrons, with four in its outer shell.

- To fill this outer shell, carbon atoms share electrons with other elements found in living organisms (the CHNOPS elements).
  - Carbon (C)
  - Hydrogen (H)
  - Nitrogen (N)
  - Oxygen (O)
  - Phosphorus (P)
  - Sulfur (S)

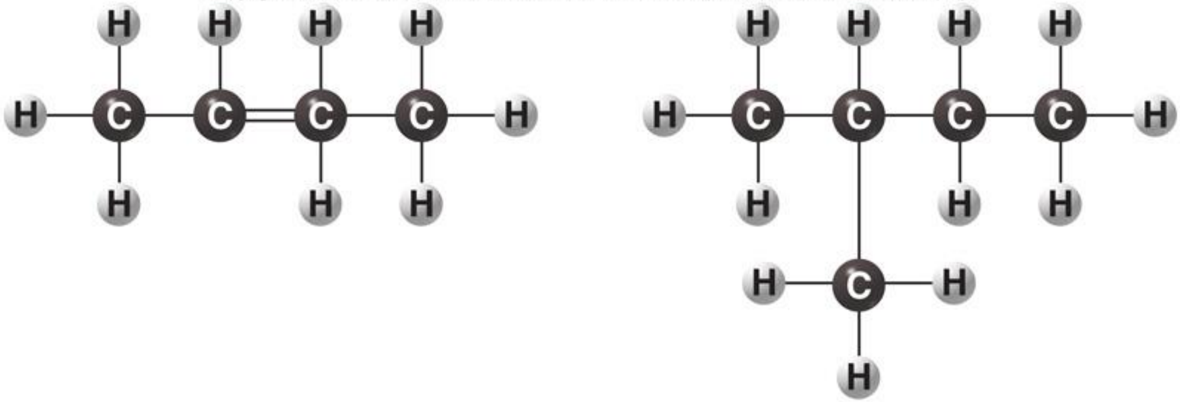
The Carbon Atom (cont.)

- Because the carbon atom's outer shell has four electrons, it can bond with up to four other elements.

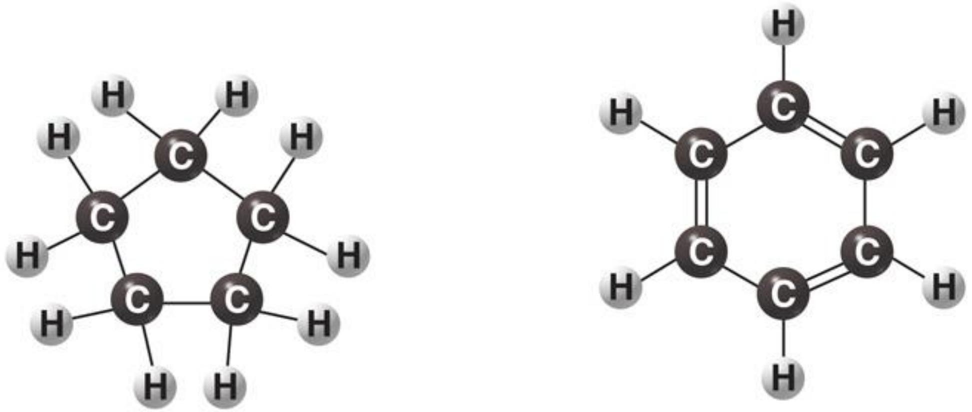
- Carbon atoms frequently bond with other carbon atoms, forming stable chains called hydrocarbons.

- Some carbon molecules, called isomers, have the same number and kinds of atoms but in different arrangements.

The Carbon Atom (cont.)



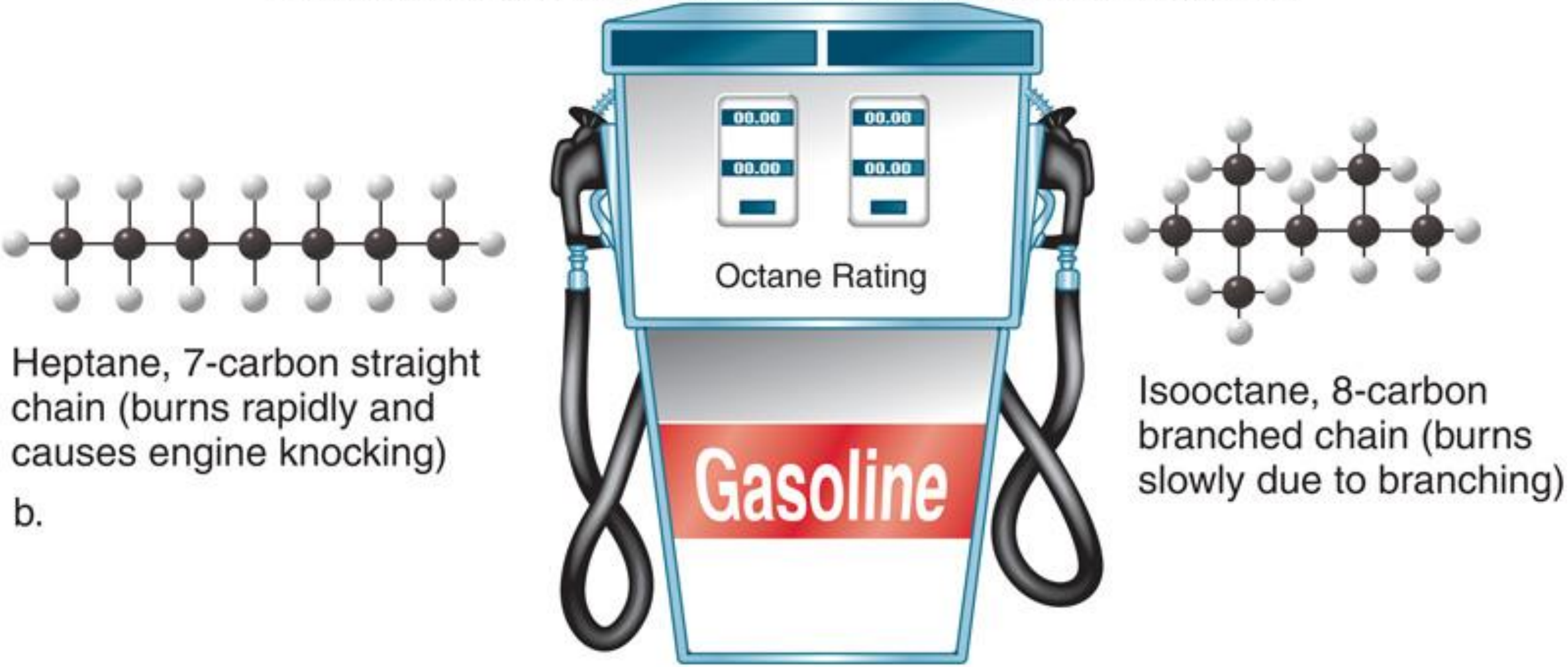
Carbon chains can vary in length, and/or have double bonds, and/or be branched.



Carbon chains can form rings of different sizes and have double bonds.

a.

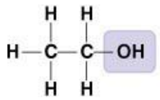
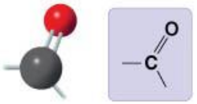
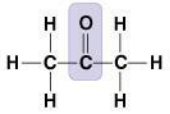
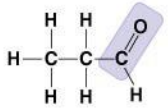
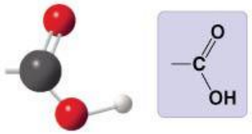
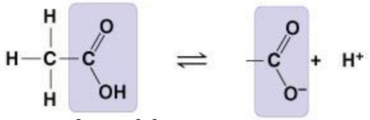
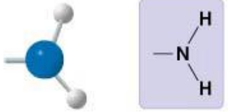
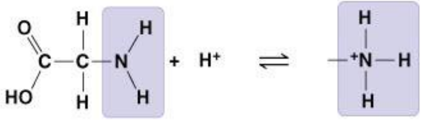
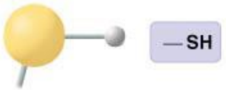
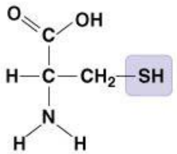
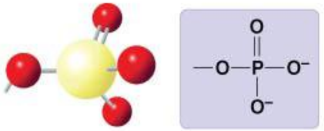
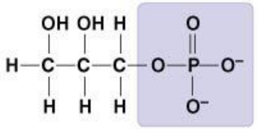
The Carbon Atom (cont.)



The Carbon Skeleton and Functional Groups

- The carbon chain of an organic molecule is called a skeleton or backbone.
- Carbon skeletons can have attached functional groups that determine the reactivity of that molecule.
- Each type of functional group as specific combination of bonded atom that reacts the same way, regardless of the carbon skeleton it is attached to.

- The seven functional groups that are most important in the chemistry of life
  - Hydroxyl group
  - Carbonyl group
  - Carboxyl group
  - Amino group
  - Sulfhydryl group
  - Phosphate group

Chemical Group	Compound Name	Examples
Hydroxyl group (—OH) 	Alcohol	 Ethanol
Carbonyl group (>C=O) 	Ketone Aldehyde	 Acetone  Propanal
Carboxyl group (—COOH) 	Carboxylic acid, or organic acid	 Acetic acid
Amino group ($—NH_2$) 	Amine	 Glycine
Sulfhydryl group (—SH) 	Thiol	 Cysteine
Phosphate group ($—OPO_3^{2-}$) 	Organic phosphate	 Glycerol phosphate

The Carbon Skeleton and Functional Groups (cont.)

Functional Groups

Group	Structure	Found in
Hydroxyl	R—O—H	Alcohols, sugars
Carboxyl	R—C(=O)—O—H	Amino acids, fatty acids
Amino	R—N(—H)—H	Amino acids, proteins
Sulfhydryl	R—S—H	Amino acid cysteine, proteins
Phosphate —P	R—O—P(=O)(—O—H)—O—H	ATP nucleic acids

R = remainder of molecule

The Carbon Skeleton and Functional Groups (cont.)

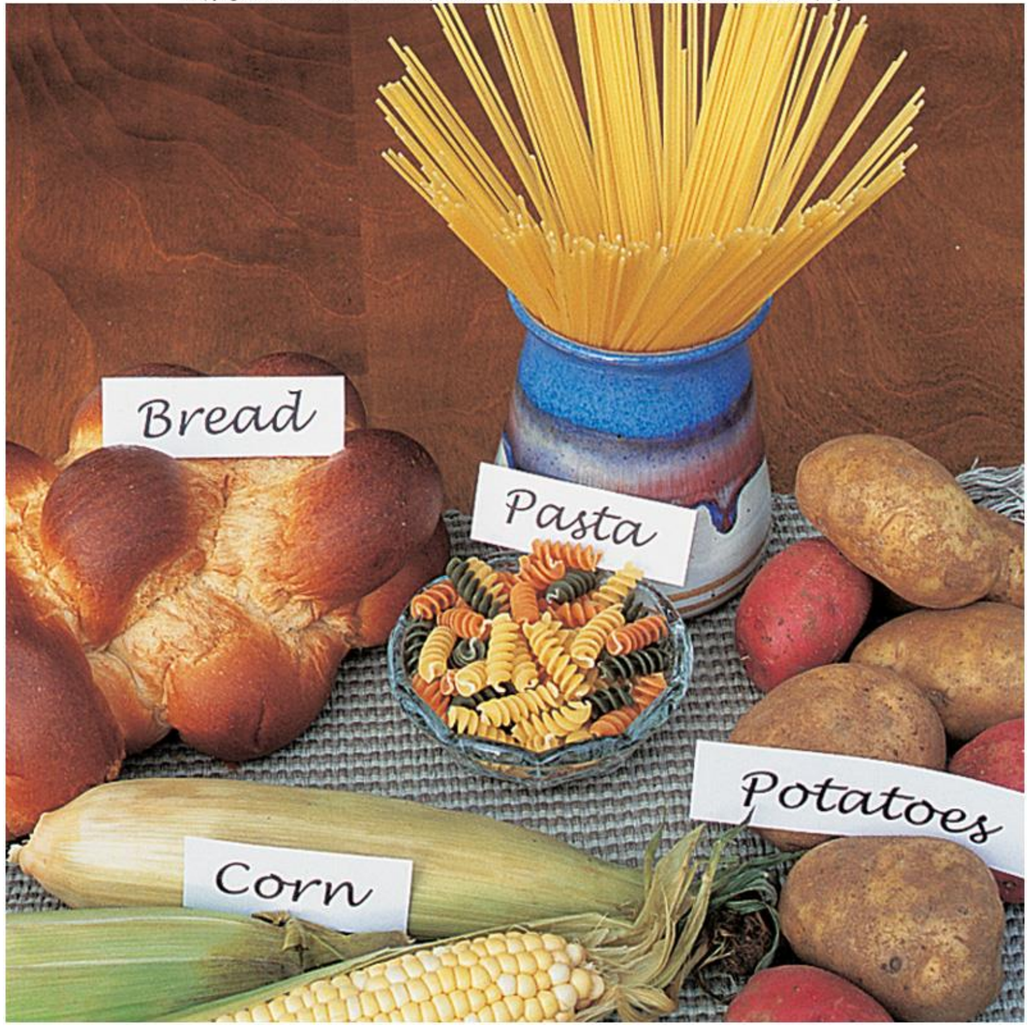
- Functional groups can be found in specific types of organic molecules.
- Hydrocarbons, containing only carbon and hydrogen, are hydrophobic.
- Sugars and alcohols contain polar hydroxyl (OH) groups, making these molecules hydrophilic.
- Organic molecules with carboxyl (COOH) groups are both polar and acidic (i.e., release H^+).
- The attached functional groups determine the polarity and the types of reactions it will undergo.

3.2 The Biomolecules of Cells

- Organic molecules in living organisms are grouped into four categories.
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids

- As your body digests food, these compounds are released and used to assemble the large macromolecules that make up your cells.

3.2 The Organic Molecules of Cells (cont.)



3.2 The Organic Molecules of Cells (cont.)

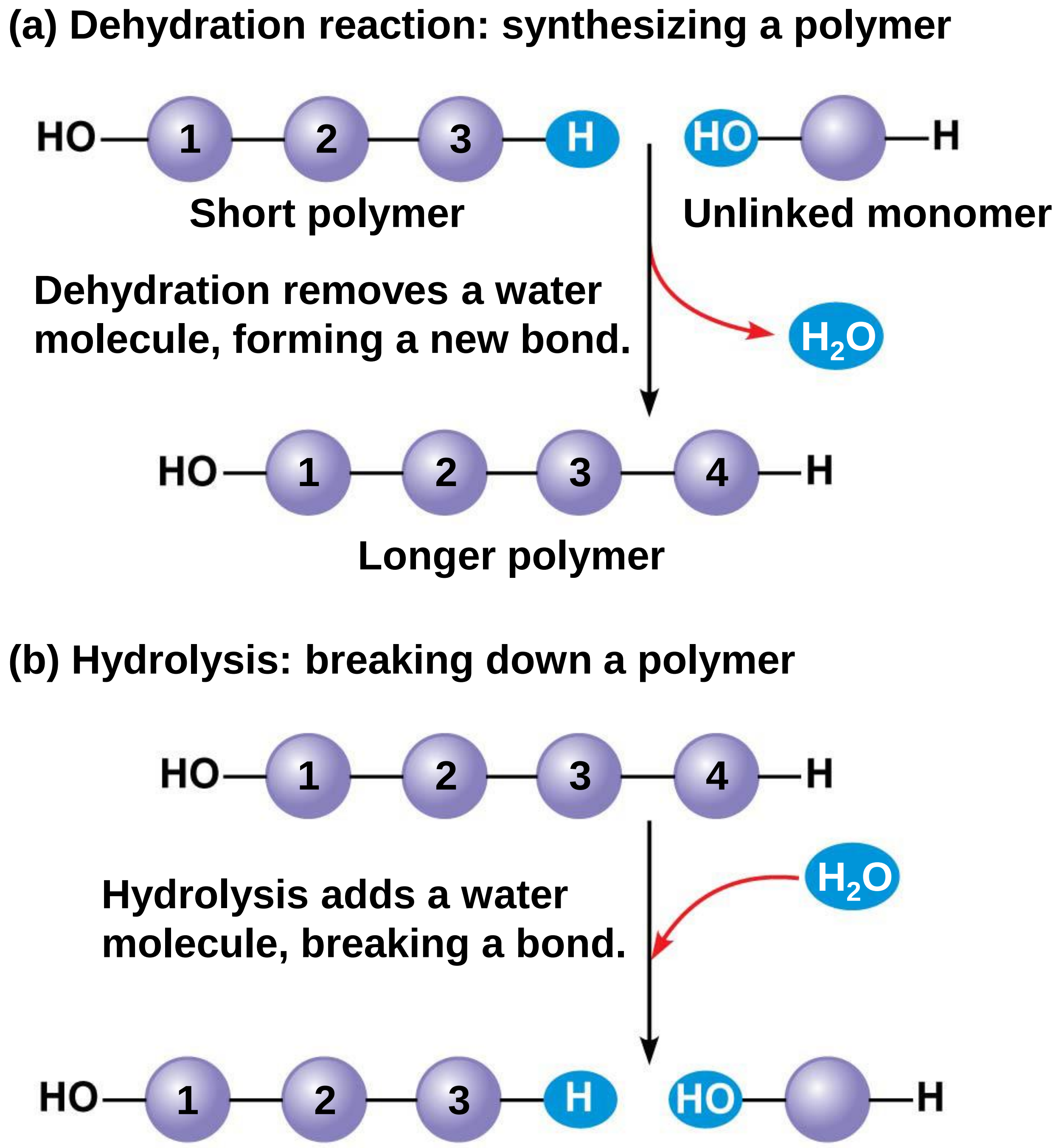
3.2 The Organic Molecules of Cells (cont.)

3.2 The Organic Molecules of Cells (Synthesis and Degradation.)

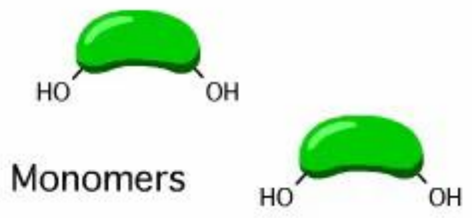
- Macromolecules are constructed by linking together similar types of subunits, called monomers.

- A repeating chain of monomers forms a polymer.
- Macromolecules are synthesized by dehydration reactions.
- Macromolecules are degraded by hydrolysis reactions.
- Enzymes : is a molecule that speed a reaction by bringing reactants together and may participate in the reaction but it is unchanged by it .

Figure 5.2


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

Animation: Polymers



Carbohydrates

- Carbohydrates are typically used by living organisms as a source of energy.

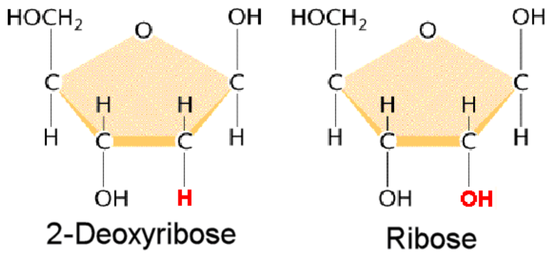
- The term carbohydrate refers to either a single sugar molecule or two sugar molecules bonded together.

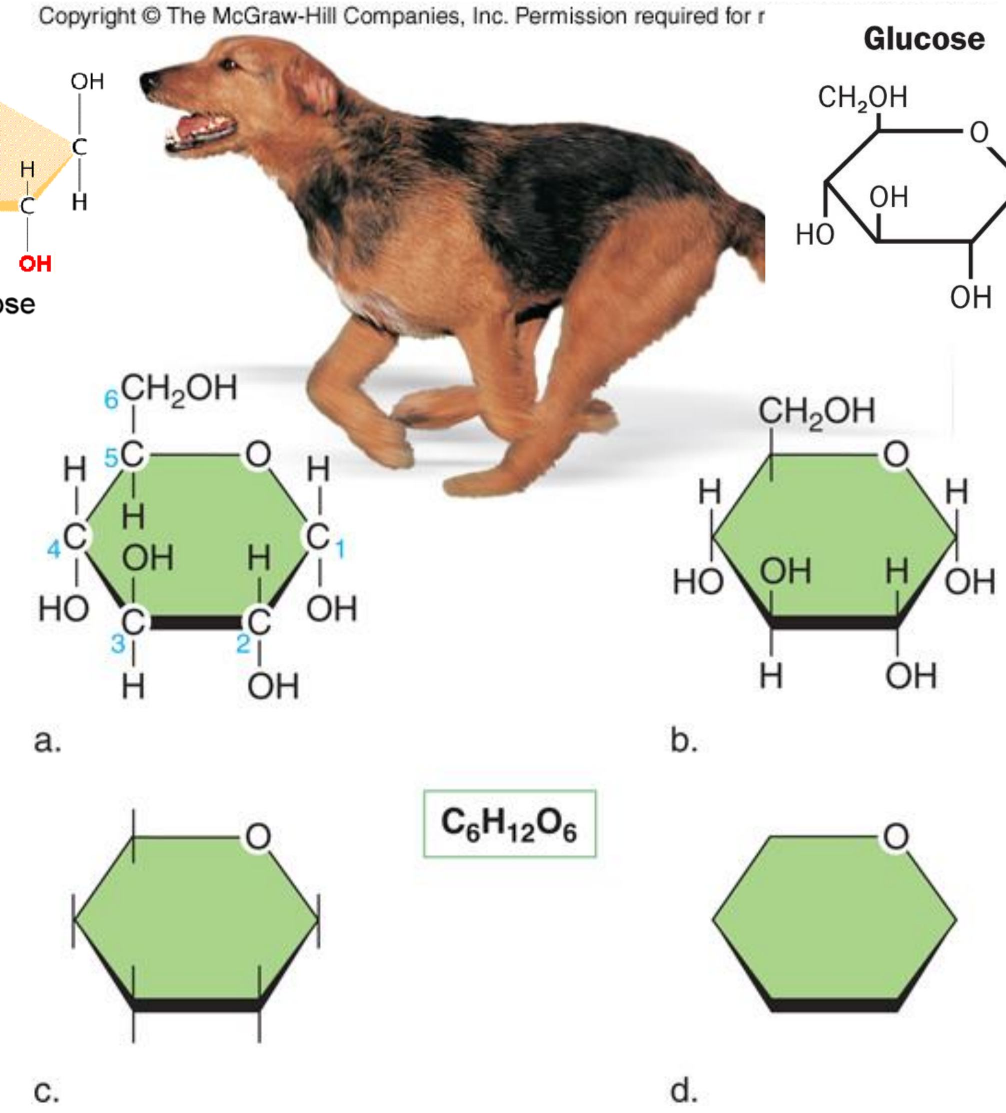
- Glucose is a common sugar molecule used to make carbohydrate polymers.

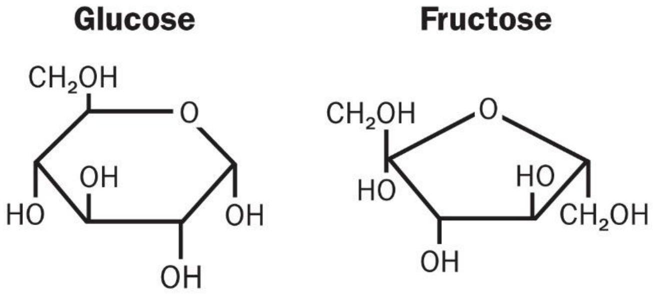
Monosaccharides: Ready Energy

- Monosaccharides are carbohydrates with a single sugar molecule.
- All monosaccharides are multiples of CH_2O
- Functional groups in monosaccharides are carbonyl and hydroxyl.
- Number of carbons in monosaccharide from 3 to 7. They can be classified based on the number of carbons. Hexoses are monosaccharides with 6 carbons, and pentoses are monosaccharides with 5 carbons.
- Glucose is an important monosaccharide in living organisms.
  - Glucose is the energy source of choice.
  - Two important isomers of glucose are fructose and galactose.
- Ribose and deoxyribose are five carbon sugars that are found in RNA and DNA.

Monosaccharides: Ready Energy (cont.)



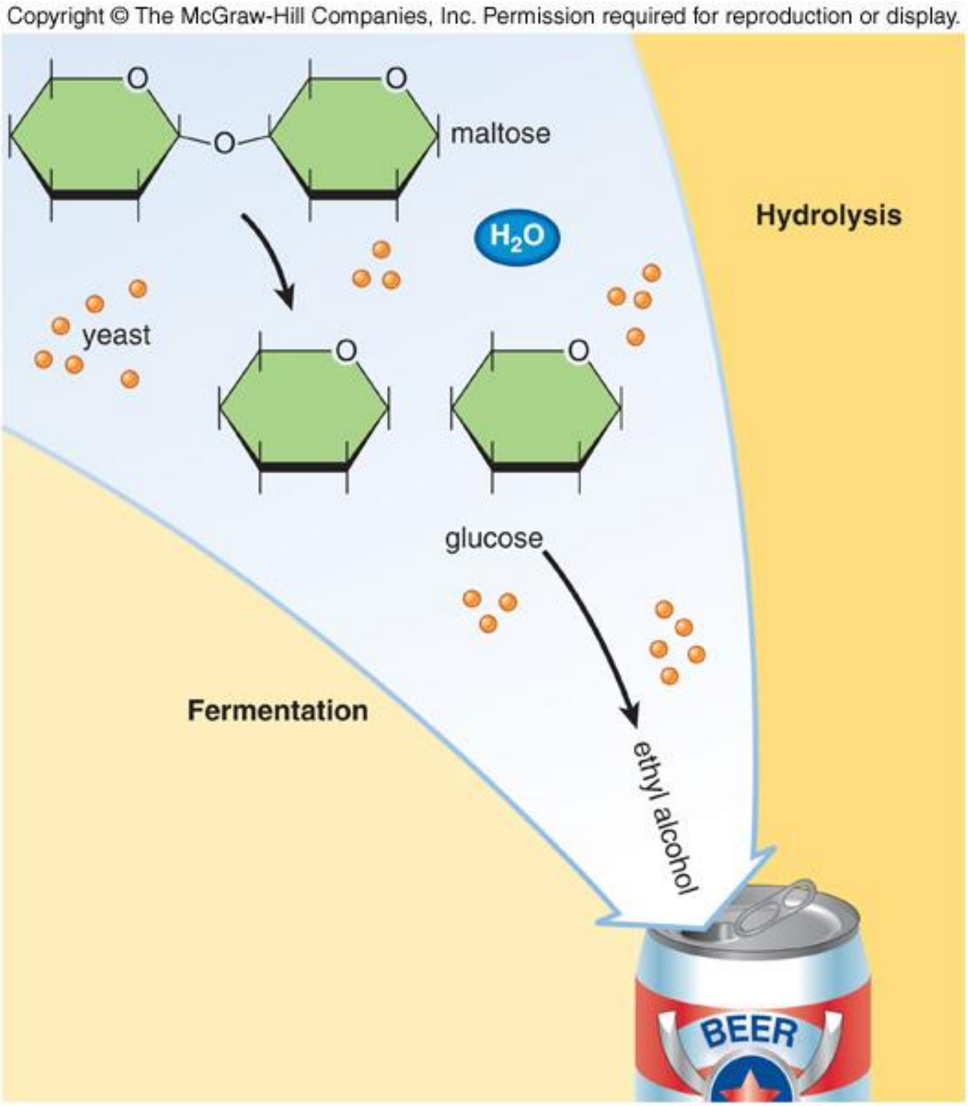


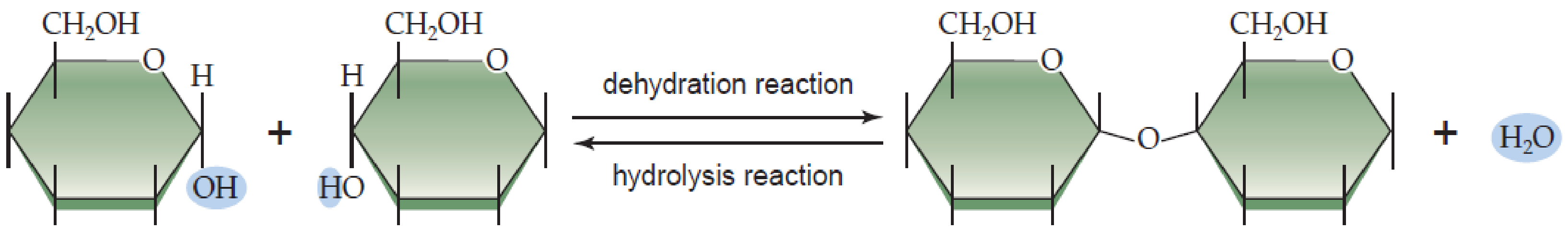


Disaccharides: Varied Uses

- A disaccharide contains two monosaccharides bonded together.(This covalent bond is called a **glycosidic linkage)**
- Joined by dehydration reaction.
- One example is maltose, a disaccharide required for alcohol production during fermentation(two glucose molecules).
- Lactose a milk disaccharide (glucose and galactose).
- Sucrose (table sugar) is another disaccharide(glucose and fructose).

Disaccharides: Varied Uses (cont.)

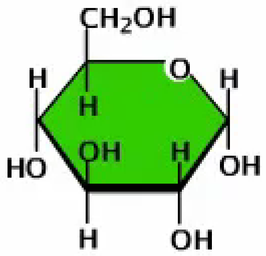




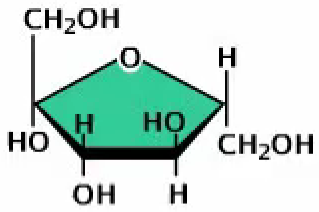
glucose $C_6H_{12}O_6$ + **glucose** $C_6H_{12}O_6$ ⇌ **maltose** $C_{12}H_{22}O_{11}$ + **water**

monosaccharide + monosaccharide ⇌ disaccharide + water

Animation: Disaccharides



Glucose



Fructose

Polysaccharides

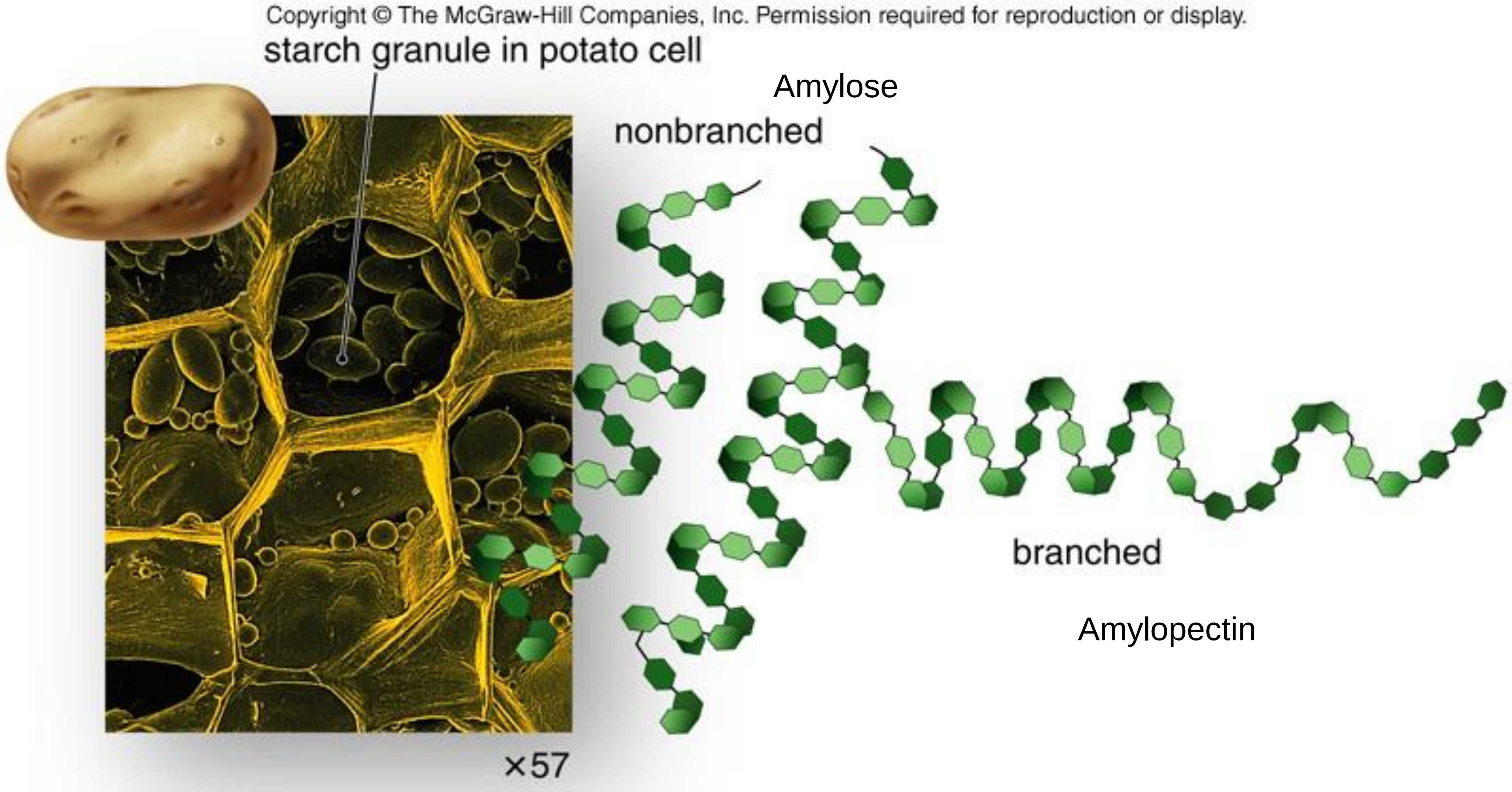
- Polysaccharides are polymers of monosaccharides.

- Some polysaccharides function as short term energy storage molecules.
  – Plants store glucose as starch.
  – Animals store glucose as glycogen.
- Other polysaccharides function as structural molecules.
  – Cellulose in plants, chitin in fungi and animals, and peptidoglycan in bacteria.

Polysaccharides as Energy Storage Molecules

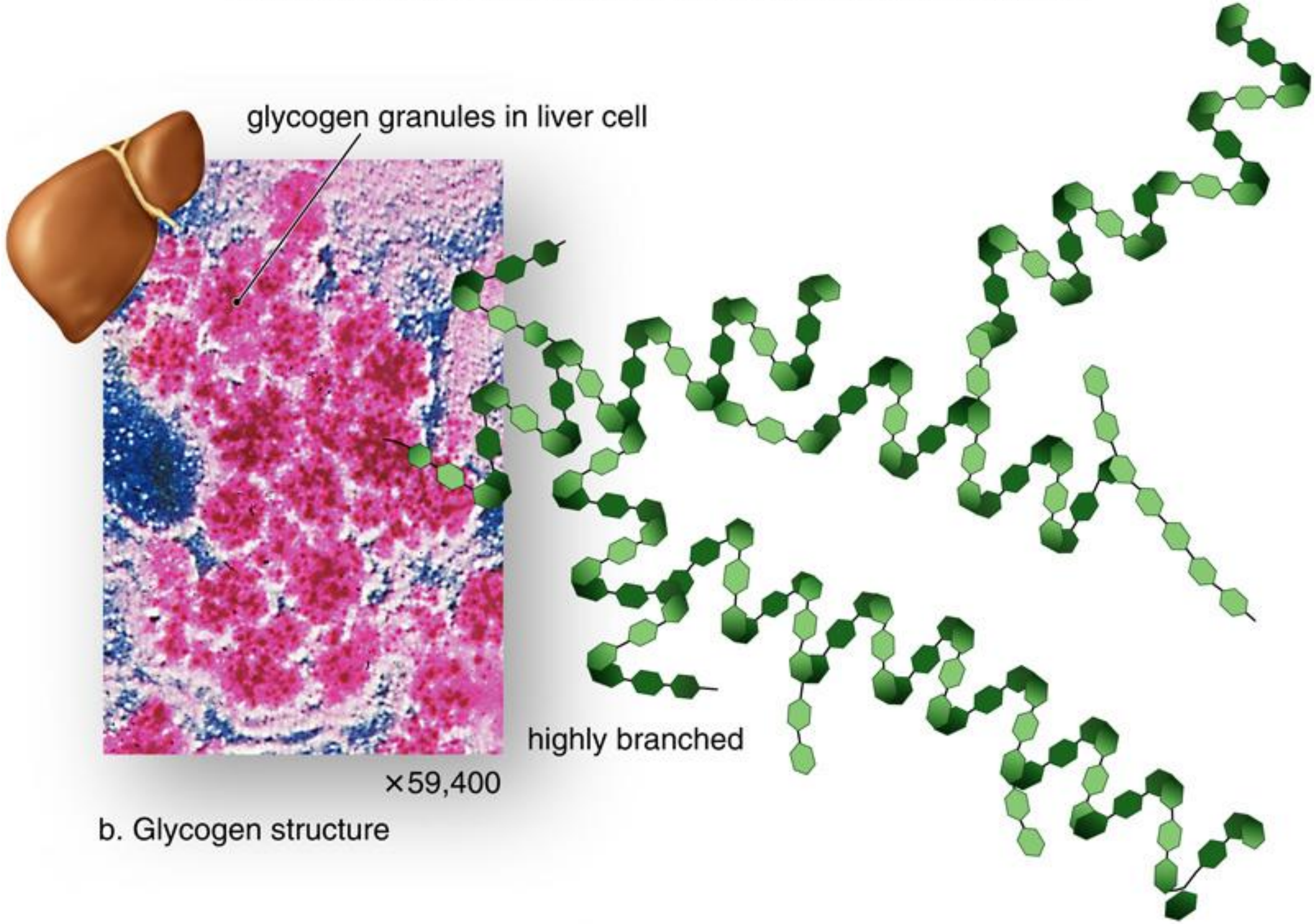
- When organism requires energy, the polysaccharide is broken down to release sugar molecules.
- Starch in plants exists in two forms: amylose (nonbranched) and amylopectin (branched). Both have helical structure.
- Glycogen in animals in liver cells and muscles. Its highly branched and has helical shape.
- Polysaccharides are not highly soluble in water.

Polysaccharides as Energy Storage Molecules (cont.)



a. Starch structure

Polysaccharides as Energy Storage Molecules (cont.)



b. Glycogen structure

Polysaccharides as Structural Molecules

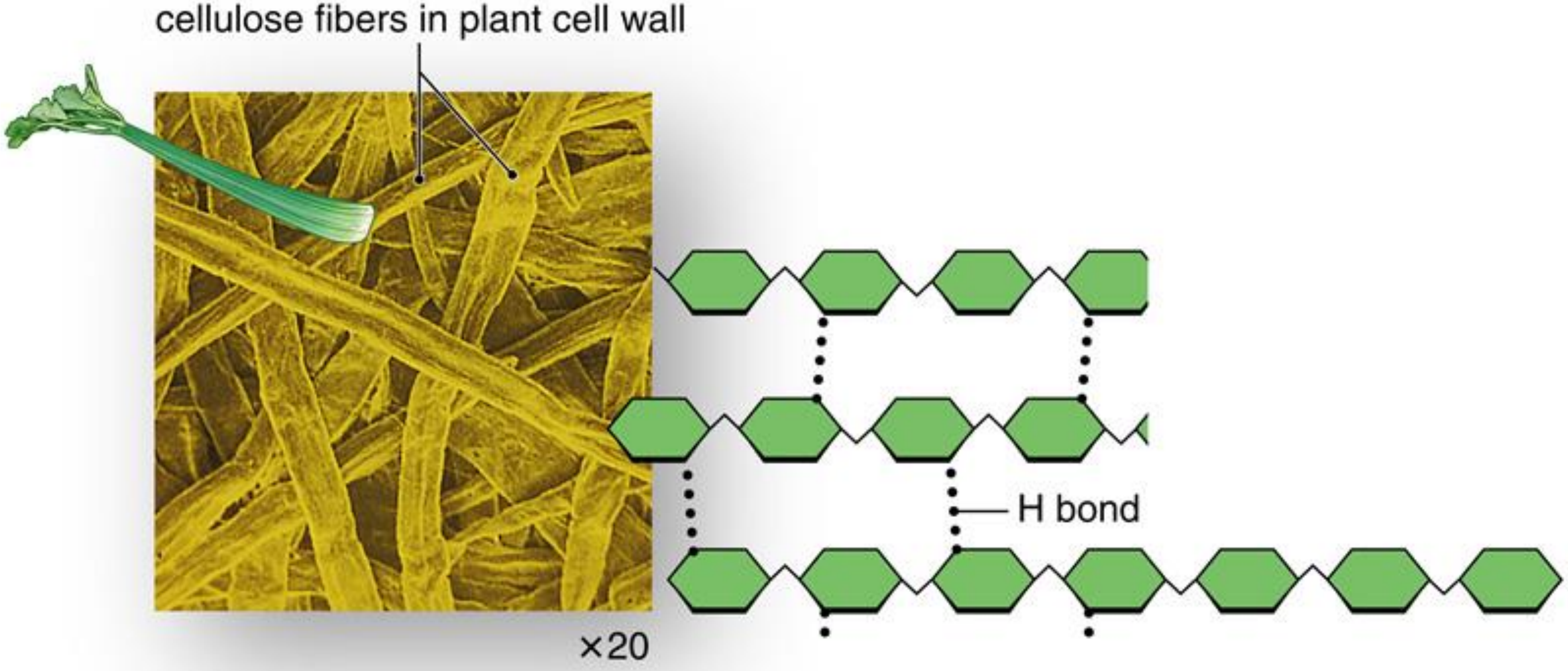
- Monomer is different for each type.
- Monomer of cellulose is glucose.
- Monomer of chitin is sugar with Nitrogen atom.
- Monomer of peptidoglycan is complex and has amino acid.

Polysaccharides as Structural Molecules

- Cellulose is the most abundant polysaccharide on earth because it comprises the cell walls of plants, which gives strength and support to the cell. Its not water soluble. Only microorganisms can digest cellulose. Animals can’t.

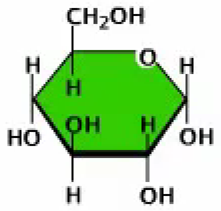
- Chitin is a polysaccharide that forms the exoskeleton of crabs, lobsters, and insects. It has antibacterial and antiviral properties so humans used it in surgical sutures material.

Polysaccharides as Structural Molecules (cont.)



c. Cellulose structure

Animation: Polysaccharides



Lipids

- Lipids are a diverse group of macromolecules that are insoluble in water. Lipids are not polymers.
- Fats and oils are well-known lipids used for energy storage and other purposes.
- Phospholipids are components of the membranes that surround cells.
- Steroids, which have a different structure from most lipids, are used as hormones and for other purposes.

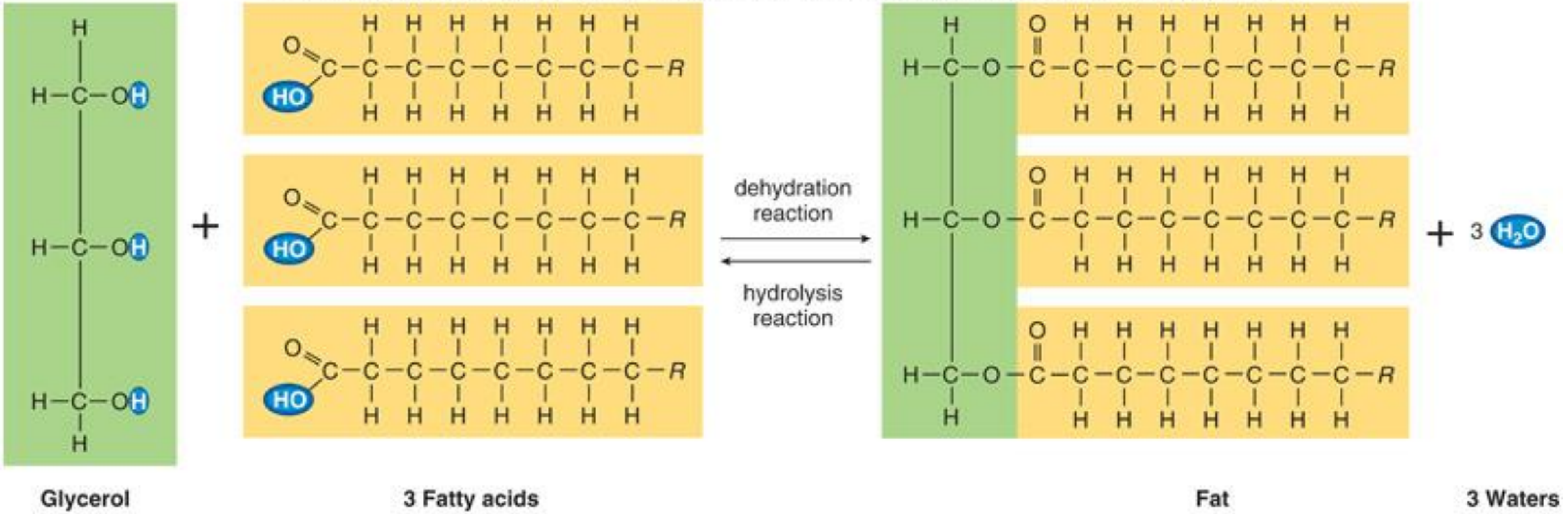
Wax, long chain alcohol and long chain fatty acid

Lipids (cont.)

Triglycerides: Long-term Energy Storage

- Triglycerides includes both fats and oils.
- Fats and oils contain two subunits.
  - Glycerol is an alcohol with three polar –OH groups.
  - Fatty acids are long chain hydrocarbons with a –COOH (carboxyl) group at the end.
- A fat or oil is formed when a dehydration reaction adds three fatty acids to the –OH groups of glycerol and broken down by hydrolysis reactions.
- Since three fatty acids are attached to a glycerol, fats and oils are often called triglycerides.

Fats and Oils: Long-term Energy Storage (cont.)

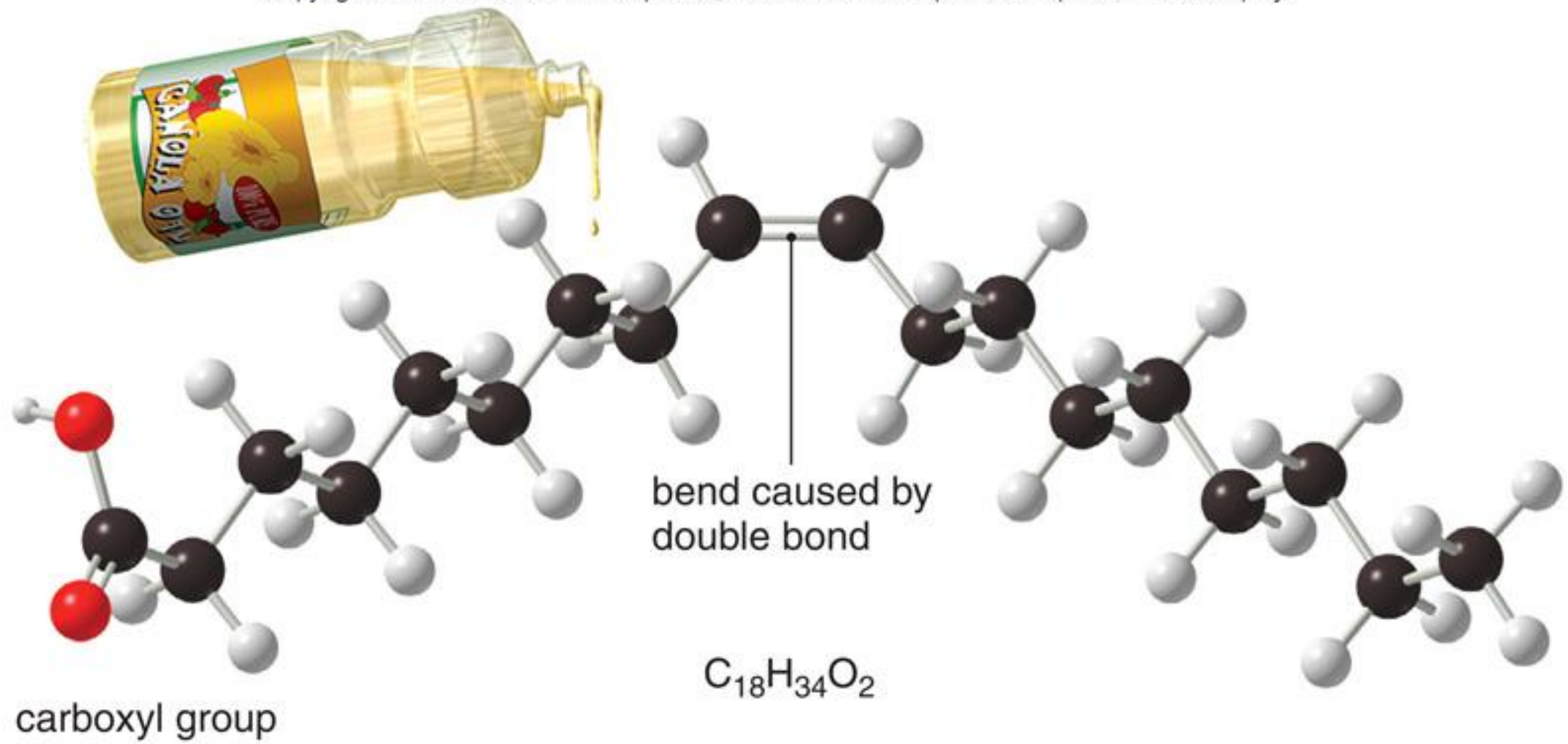


Fatty Acids

- Most fatty acids contain 16 or 18 carbon atoms.
  - Saturated fatty acids have no double bonds between carbon atoms.
  - Unsaturated fatty acids have at least one double bond between carbon atoms.
- Oils tend to contain unsaturated fatty acids while fats like butter tend to contain saturated fatty acids.
- Oils melt at lower temperature than fats, oils are often liquid at room temperature while fats are often solid at room temperature. This is because the double bonds in unsaturated fatty acids (that are found in oils) result in a kink that prevents close packing between hydrocarbon chains.

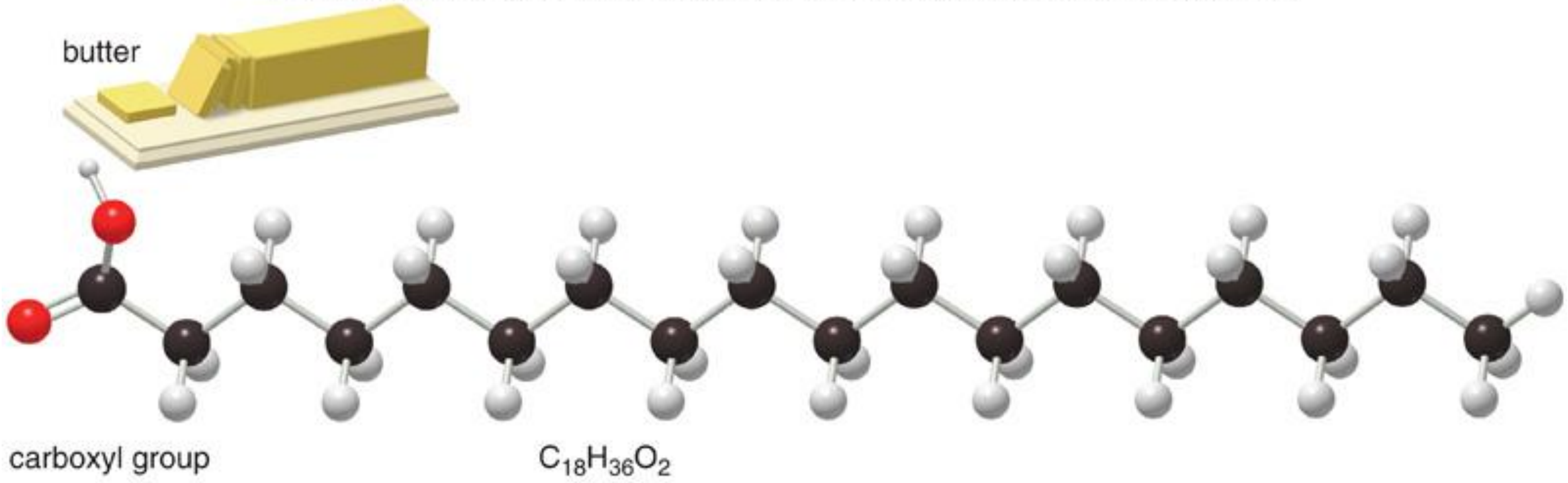
- Triglycerides are used for long-term energy storage. When compared to carbohydrates, fat stores more energy than glycogen.
- The saturation of fats affects human health.
  - Saturated fats such as *trans* fats contribute to heart disease.
  - Unsaturated oils, such as monounsaturated and polyunsaturated oils, can have a protective effect against atherosclerosis.

Fatty Acids (cont.)



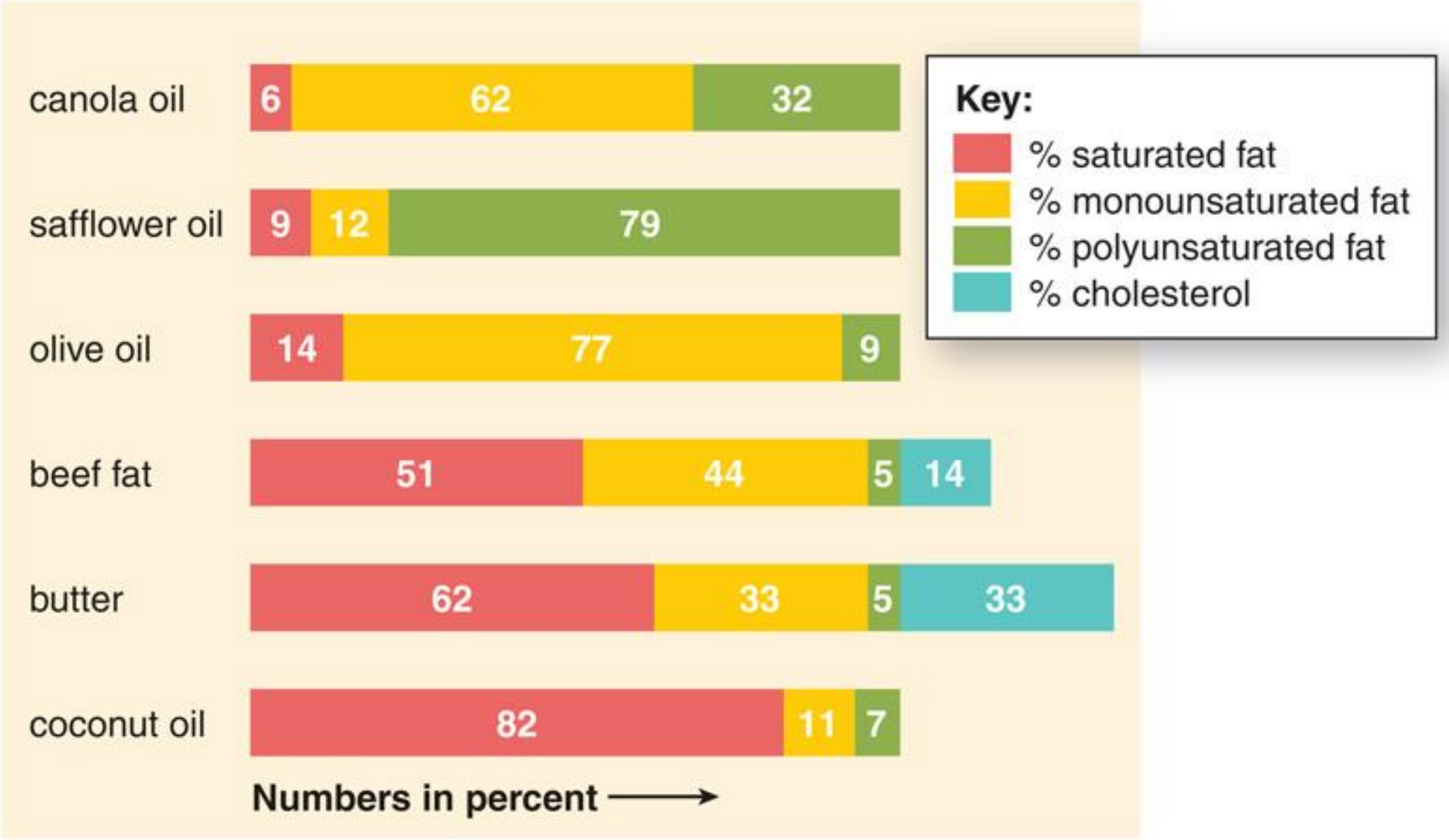
a. Oleic acid, a monounsaturated fatty acid (one double bond) found in canola oil.

Fatty Acids (cont.)



b. Stearic acid, a saturated fatty acid (no double bonds) found in butter.

Fatty Acids (cont.)



c. Percentages of saturated and unsaturated fatty acids in fats and oils.

Phospholipids: Membrane Components

- Phospholipids are lipids that contain a polar, hydrophilic phosphate group.

- They are constructed like fats: glycerol with fatty acids, but instead of the third fatty acid there is a phosphate group attached to glycerol.

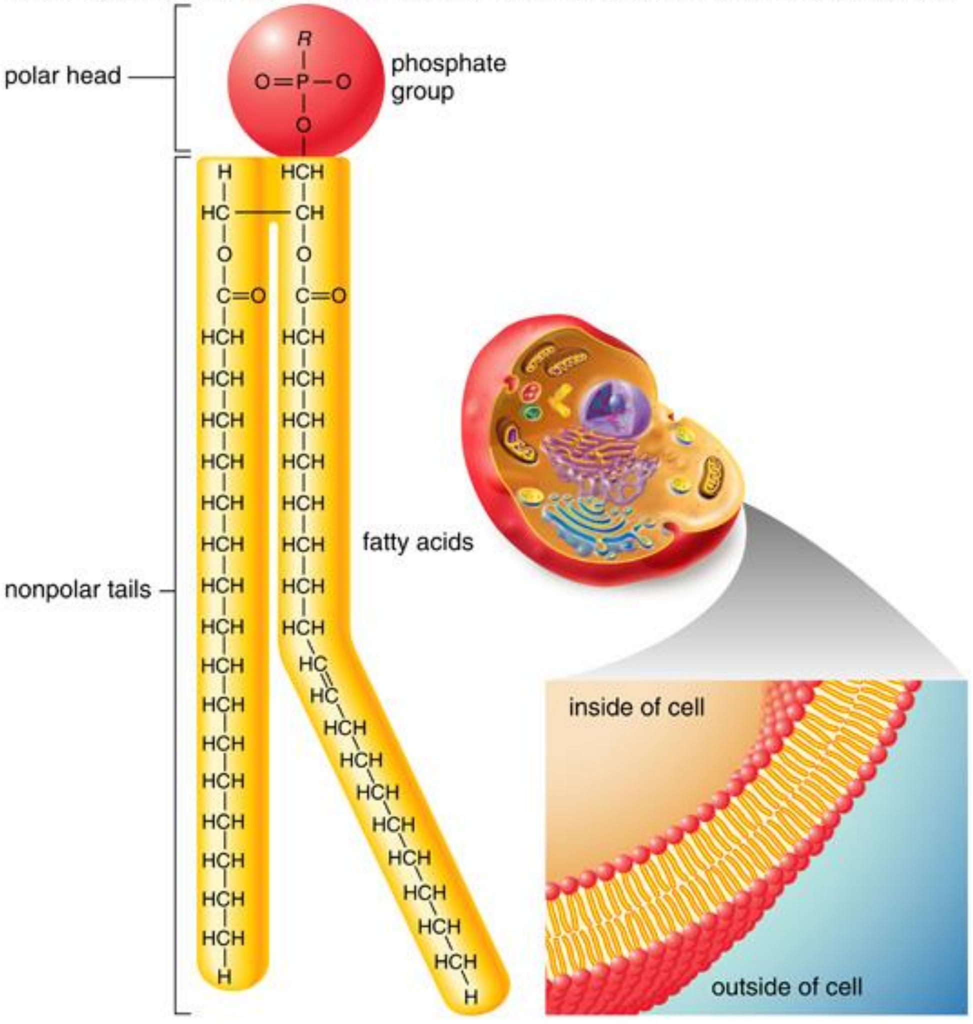
- The structure of phospholipid is described as hydrophilic head and two hydrophobic tails.

- In watery media, the hydrophilic phosphate groups are oriented towards the water.

- Phospholipids can form bilayers that separate two compartments of water. In bilayer, the heads project outward and tails inward.

- Phospholipids comprise the membranes that surround cells and internal structures within cells.

Phospholipids: Membrane Components (cont.)



a. Phospholipid structure

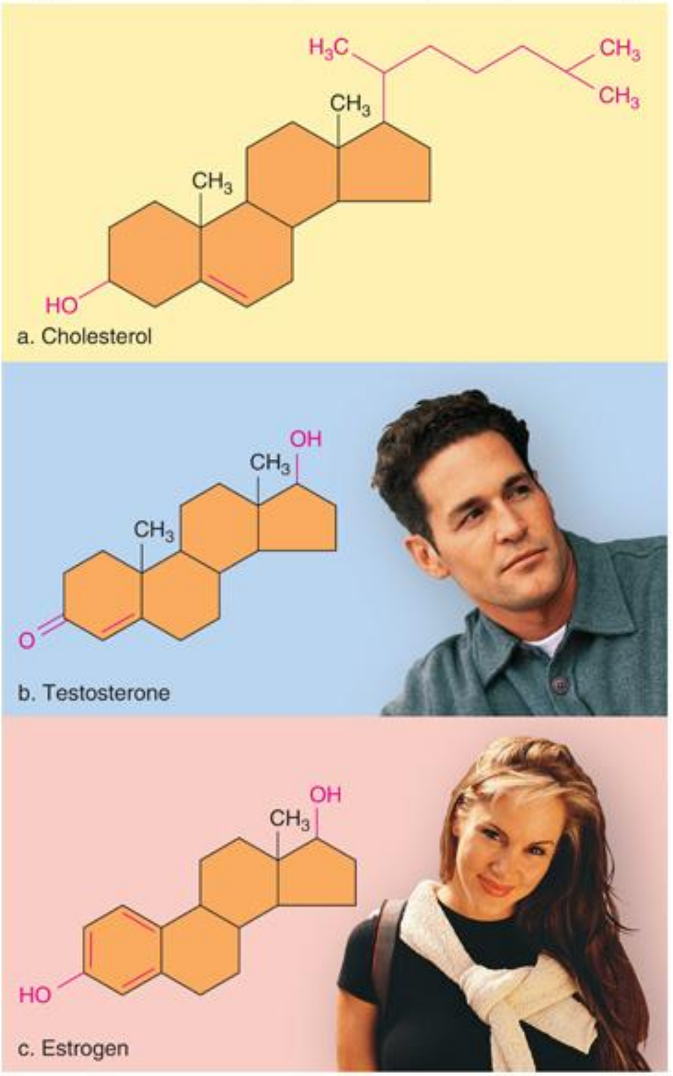
b. Plasma membrane of a cell

Steroids: Four Fused Rings

- Steroids are lipids that have four fused hydrocarbon rings with different functional groups attached.

- Cholesterol, found in animal cell membranes, and is the precursor for the sex hormones testosterone (male sex hormone) and estrogen (female sex hormone).
- Estrogen-like hormone is also found in plants.
- An anabolic steroid is a synthetic testosterone.

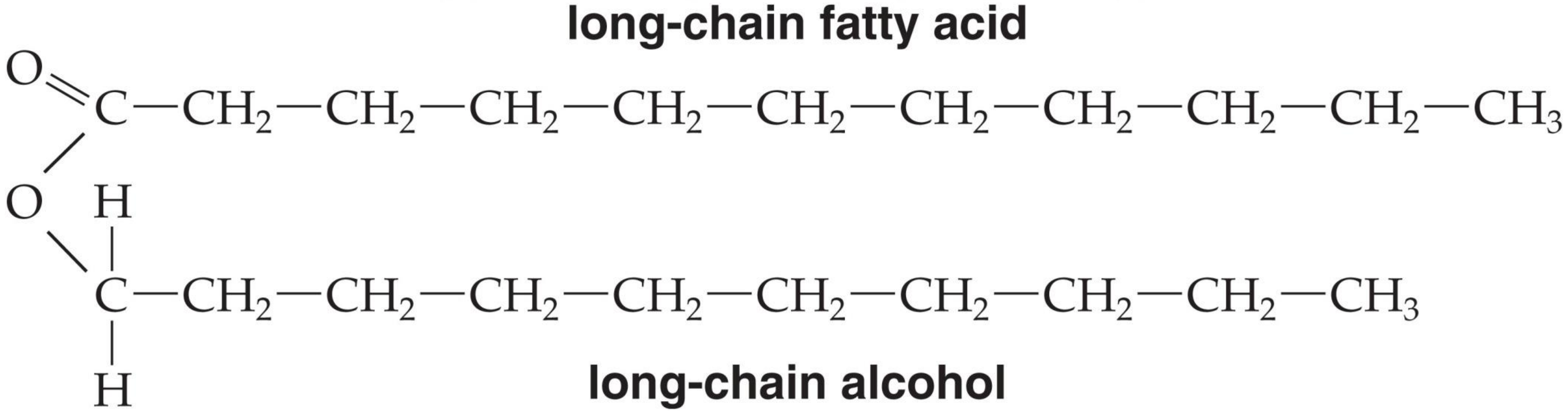
Steroids: Four Fused Rings (cont.)



WAX

- They are molecules made of one long alcohol and one long fatty acid.
- Its solid at room temperature.
- They are waterproof and resistant to degradation.
- Found in plants as part of the protective cuticle layer, and in animals in skin and ear canal.
- Wax has many industrial uses.

WAX


long-chain fatty acid
O
C—CH2—CH2—CH2—CH2—CH2—CH2—CH2—CH2—CH2—CH3
O H
C—CH2—CH2—CH2—CH2—CH2—CH2—CH2—CH2—CH3
H
long-chain alcohol

Proteins

- Proteins have important functions in cells.

1- Metabolism: enzymes that bring reactants together and speed up the chemical reactions in organisms at body temperature.

2- Support: some proteins such as keratin and collagen have structural roles.

3- Transport: channel and carrier proteins in plasma membrane allow substances to enter and exit cell. Other proteins such as hemoglobin are responsible for the transport of oxygen in the blood.

Proteins (cont.)

4- Defense: Proteins form the antibodies of the immune system that defend the body from disease.

5- Regulation: Proteins such as insulin are hormones that regulate cellular function.

6- Motion: Contractile proteins such as actin and myosin allow parts of cells to move and muscles to contract.

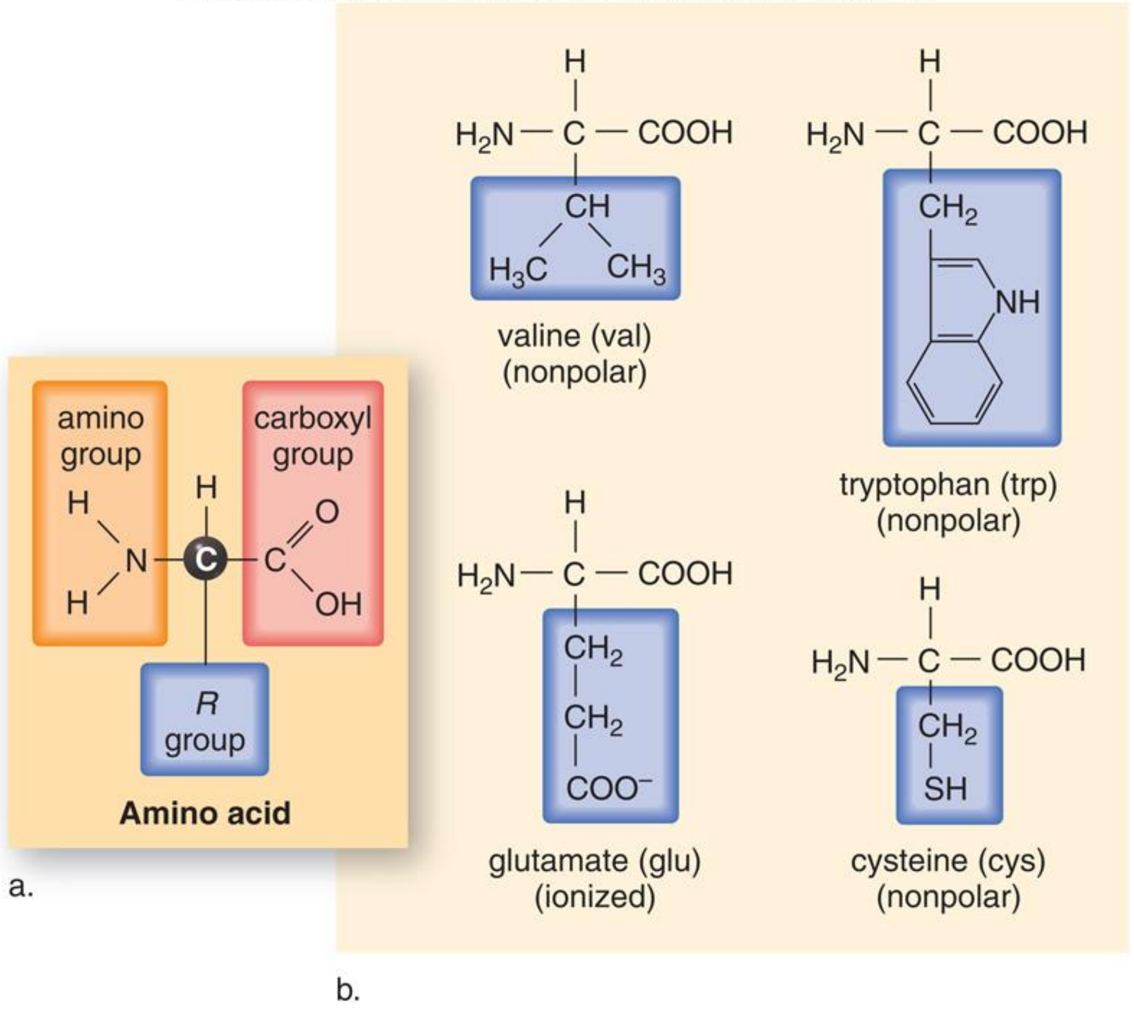
Amino Acids: Subunits of Proteins

- Amino acids are the subunits (monomer) of proteins.

- Amino acids have a central carbon with three elements to their structure.
  - An amino ($–NH_2$) group
  - A carboxyl (–COOH) group
  - The *R* (Residual) group

- The *R* groups vary and make each amino acid unique. Some R groups are nonpolar, some are polar, and some are ionized.

Amino Acids: Subunits of Proteins (cont.)



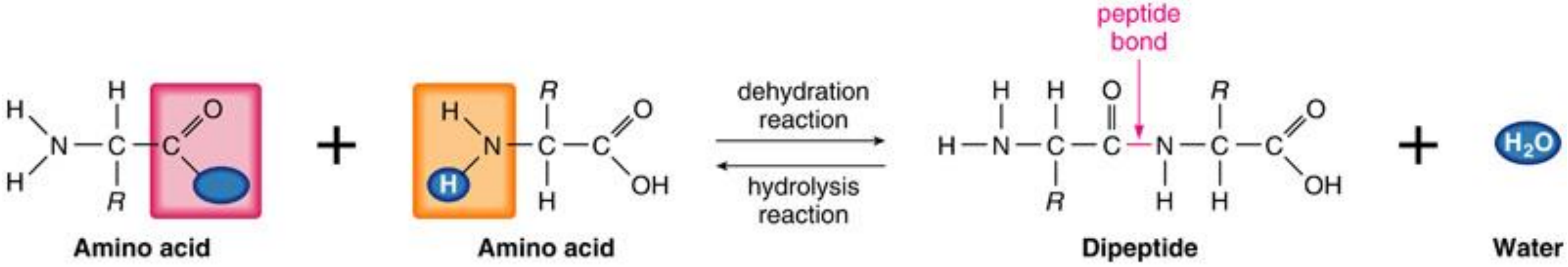
Peptides

- The carboxyl group of one amino acid can be linked to the amino group of another amino acid to form a covalent peptide bond, in a dehydration reaction. The backbone of the polypeptide doesn't involve the R groups.

- Two or more amino acids linked together form a peptide.

- A chain of many amino acids joined by peptide bonds is a polypeptide.
- A protein may contain one or more polypeptide chains.

Peptides (cont.)



Shape of Proteins

- A protein can have up to four levels of structure:
- Primary structure.
- Secondary structure.
- Tertiary structure.
- Quaternary structure.
- A protein's sequence of amino acids is called its primary structure. The bond involved is the peptide bond.
- With 20 different amino acids, there is a tremendous variety of protein primary structures that can be made.

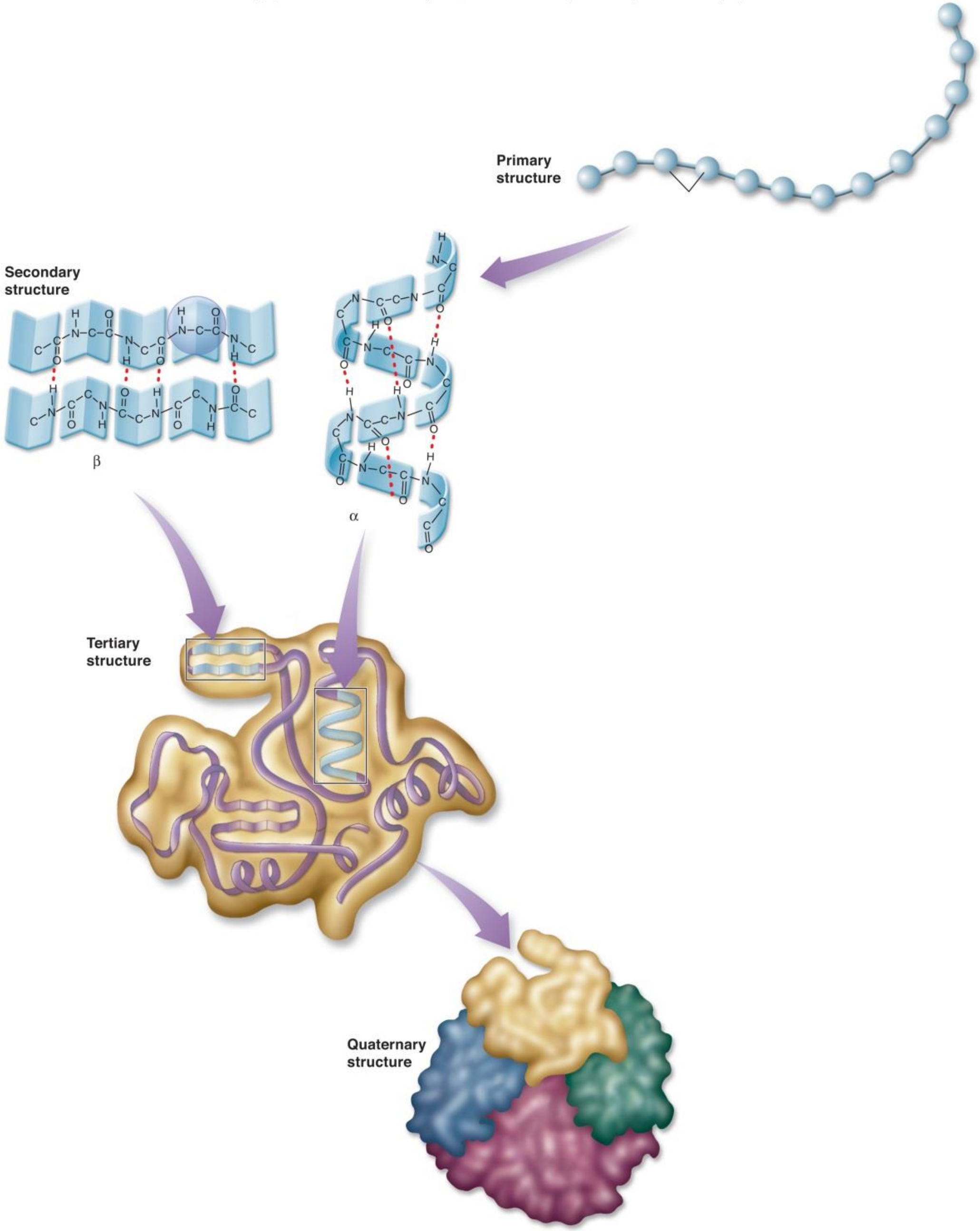
Shape of Proteins (cont.)

- The primary structure of a protein can fold or coil in particular ways to achieve a secondary structure by hydrogen bond between atoms of the back bone.
  - The polypeptide can coil in a spiral α-helix shape.
  - The polypeptide can fold to form a β-pleated sheet.

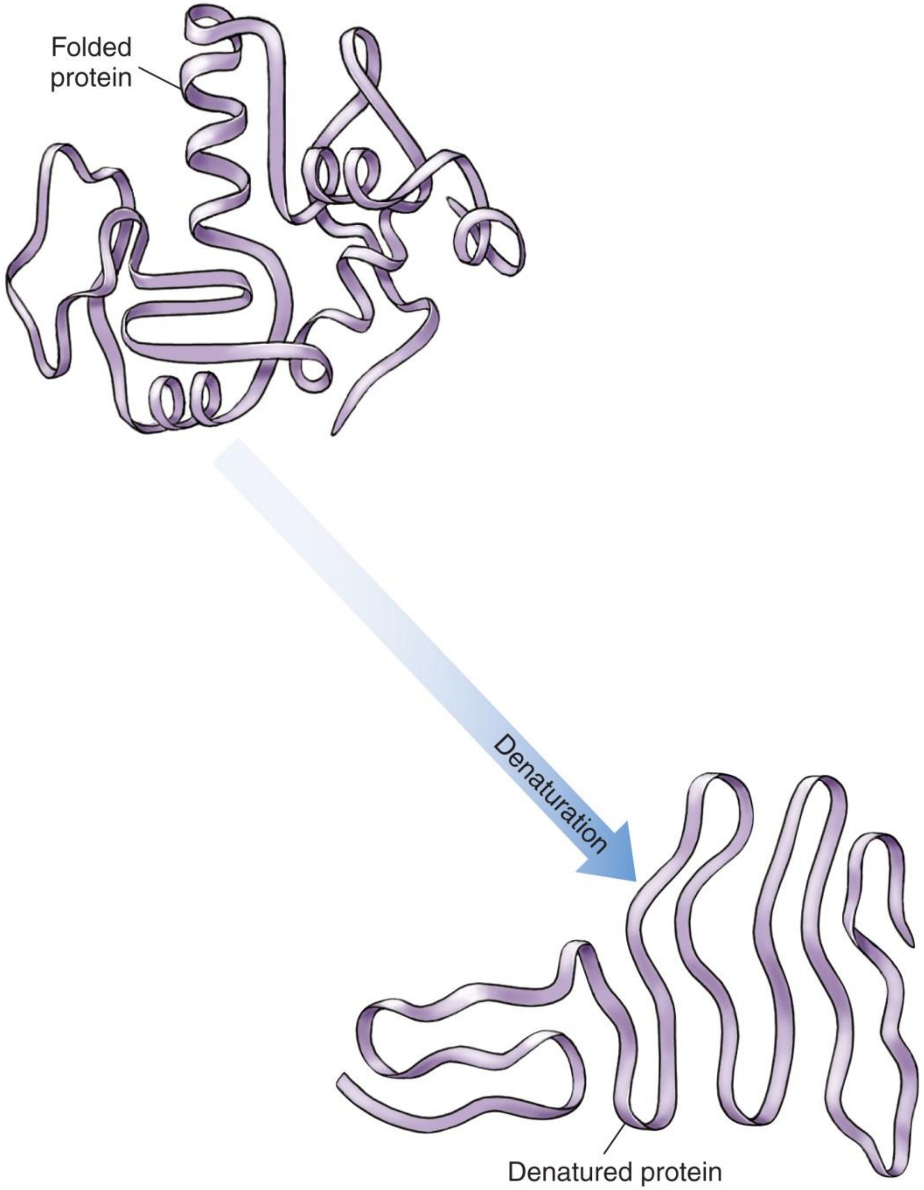
- Fibrous proteins such as the keratin in fingernails are structural proteins with secondary structure.

Shape of Proteins (cont.)

- When the secondary structure of a protein is folded and twisted into a rounded, three-dimensional shape it forms the tertiary structure by hydrogen bond, ionic bond, covalent bond and hydrophobic interaction between atoms of the R groups.
- Globular proteins, including enzymes, have tertiary structure.
- Proteins that consist of more than one polypeptide have quaternary structure.
- When a enzyme loses these levels of structure it is said to have been denatured.



Primary structure
Secondary structure
β
α
Tertiary structure
Quaternary structure


Folded protein
Denaturation
Denatured protein

Protein Folding Disease

- Proteins cant function properly unless they fold into their correct 3D shape.
- Cells contain “chaperone proteins” which help new proteins fold into their normal shape, and correct misfolding of existing proteins.
- Human diseases that are linked to misfolded proteins include mad cow disease, Alzheimers and cystic fibrosis.

Nucleic Acids

- DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) are the nucleic acids in cells.
- Nucleic acids are polymers of nucleotides.
- Nucleotides have three components.
  - A phosphate group ($–PO_4^-$)
  - A 5-carbon sugar (pentose)
  - A nitrogen-containing base

Nucleic Acids (cont.)

- The 5-carbon sugar differs between DNA and RNA.
  - Ribose is the sugar found in RNA.
  - Deoxyribose is the sugar found in DNA.

- There are four possible nitrogen-containing bases in DNA or RNA.
  - The bases in DNA are thymine, adenine, cytosine and guanine.
  - The bases in RNA are uracil, adenine, cytosine, and guanine.

Nucleic Acids (cont.)

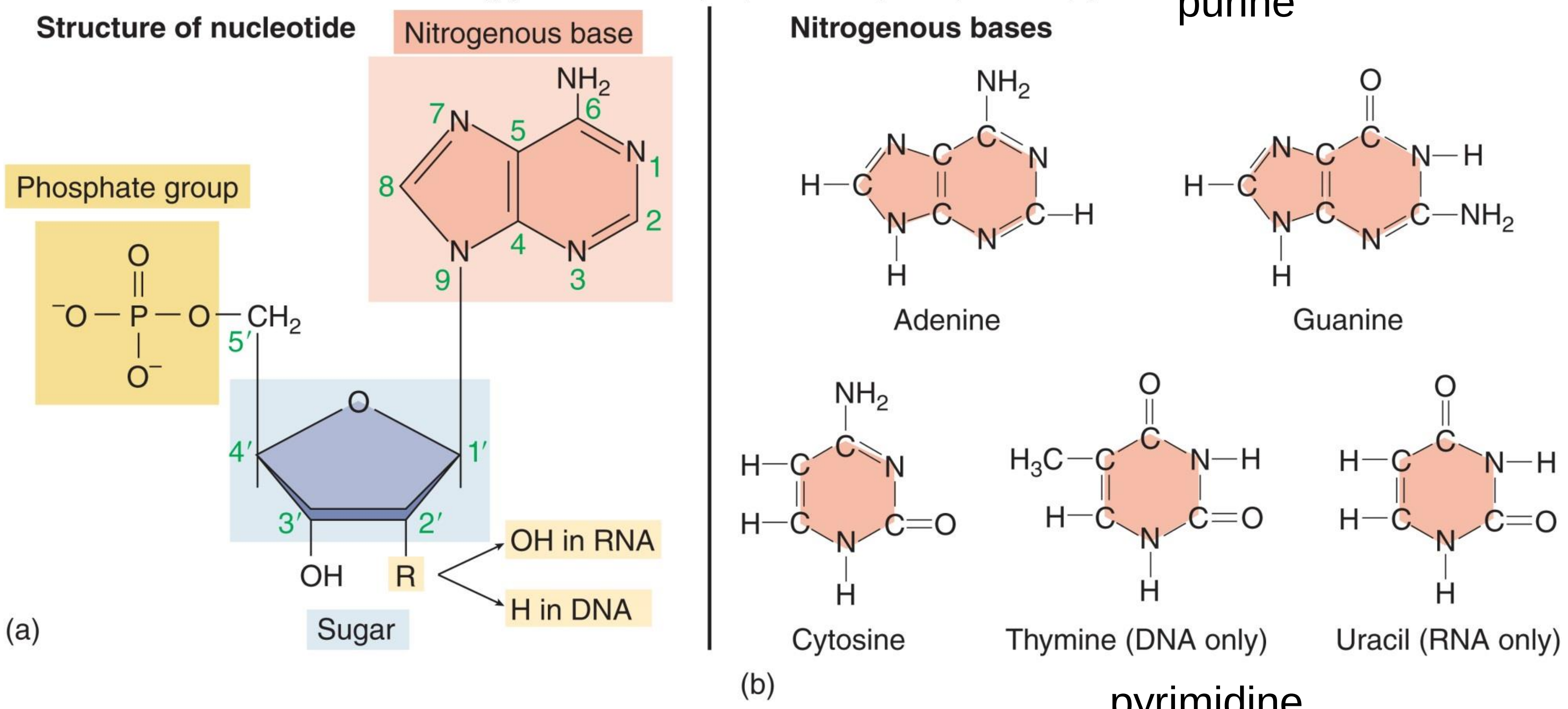
- The phosphate groups and sugars of nucleotides are linked by dehydration reaction to form the backbone of a DNA or RNA molecule.

- The nitrogen-containing bases show specific complementary base pairing.
  - In DNA or RNA, guanine is always paired with cytosine.
  - In DNA, thymine is always paired with adenine.
  - In RNA, uracil is always paired with adenine.

- DNA is a double helix formed from two spiral strands, while RNA is usually a single strand.

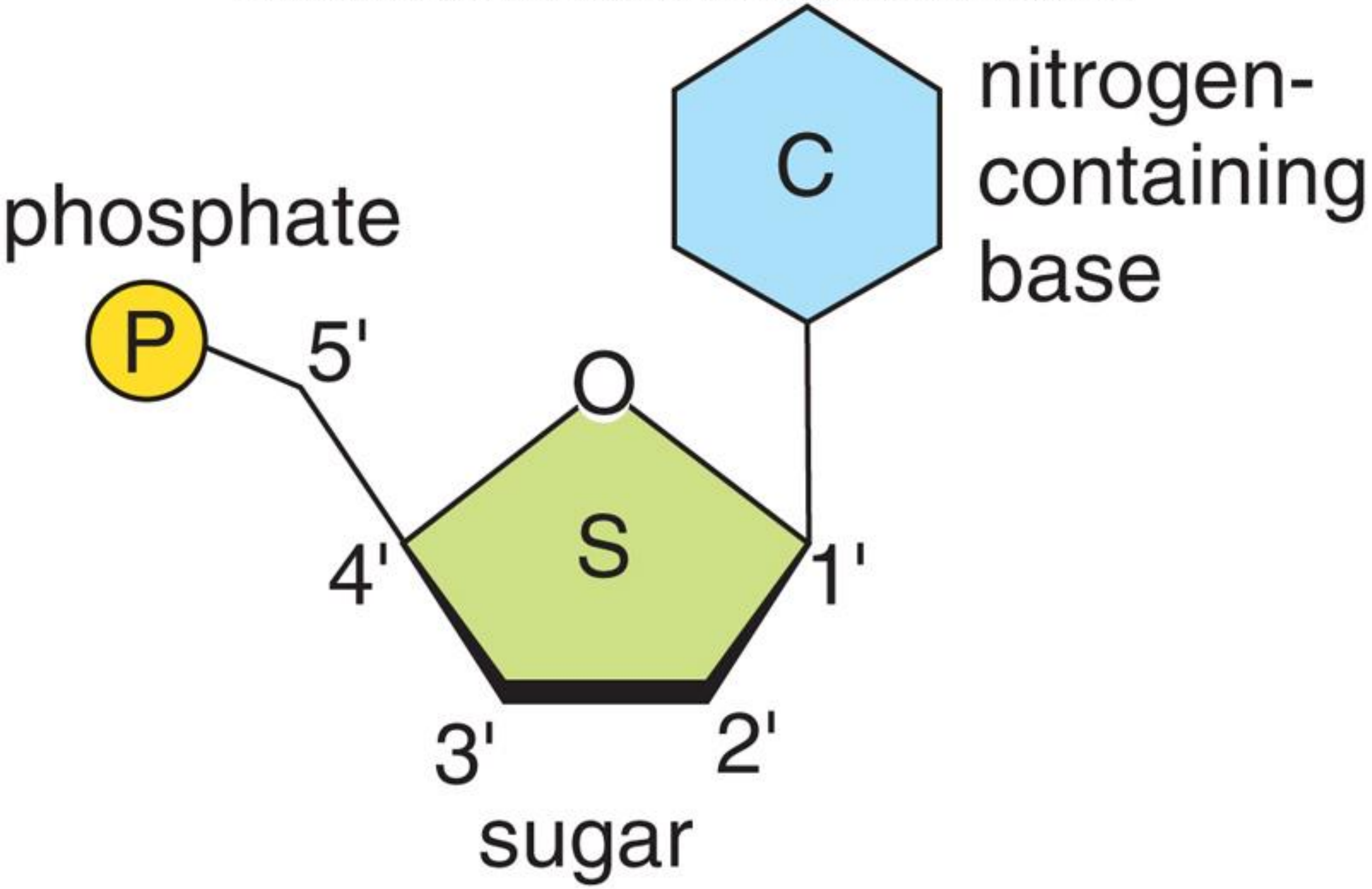
Fig. 3.9

purine



pyrimidine

Nucleic Acids (cont.)



a. Nucleotide

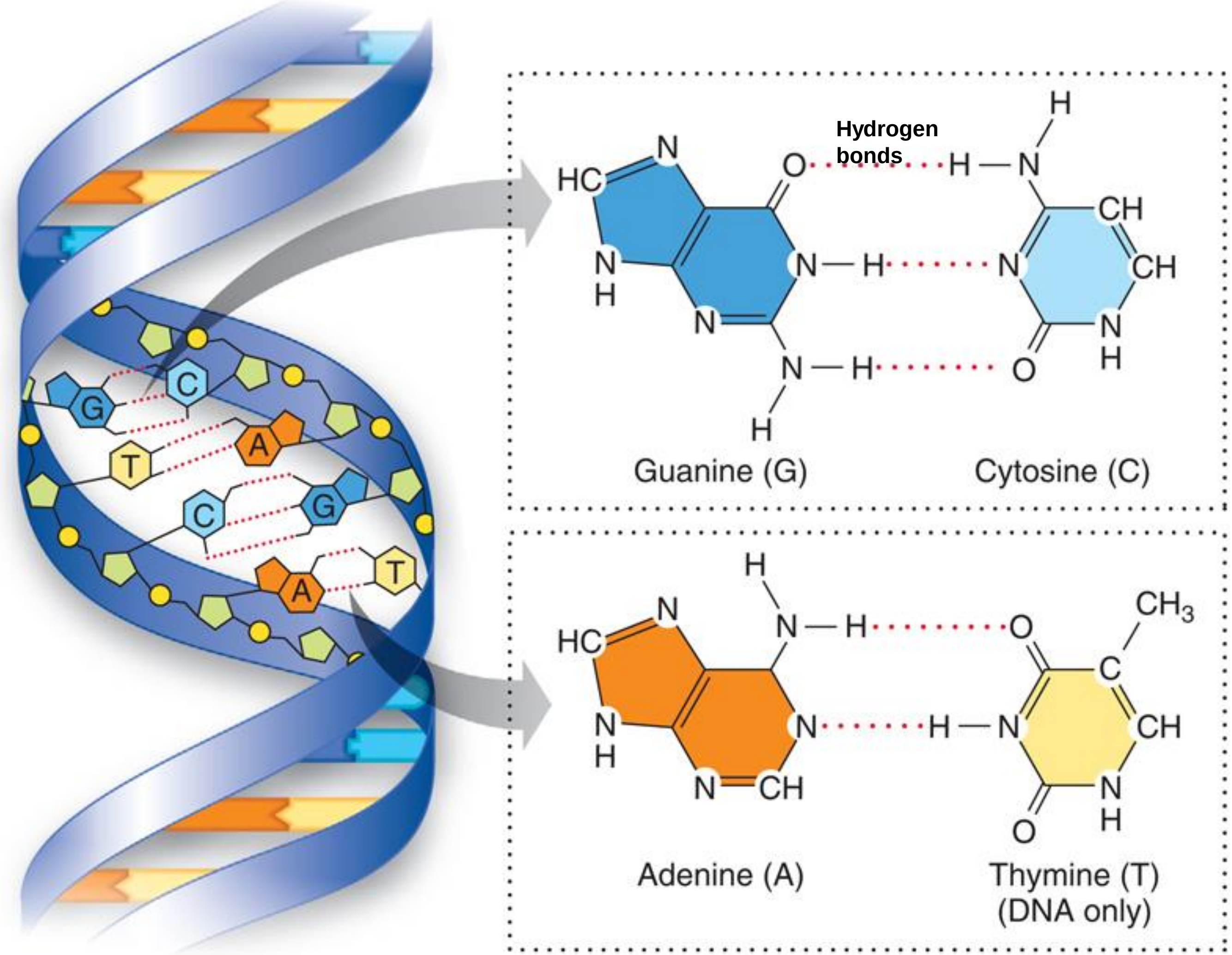
Table 3.3

TABLE 3.3

DNA Structure Compared to RNA Structure

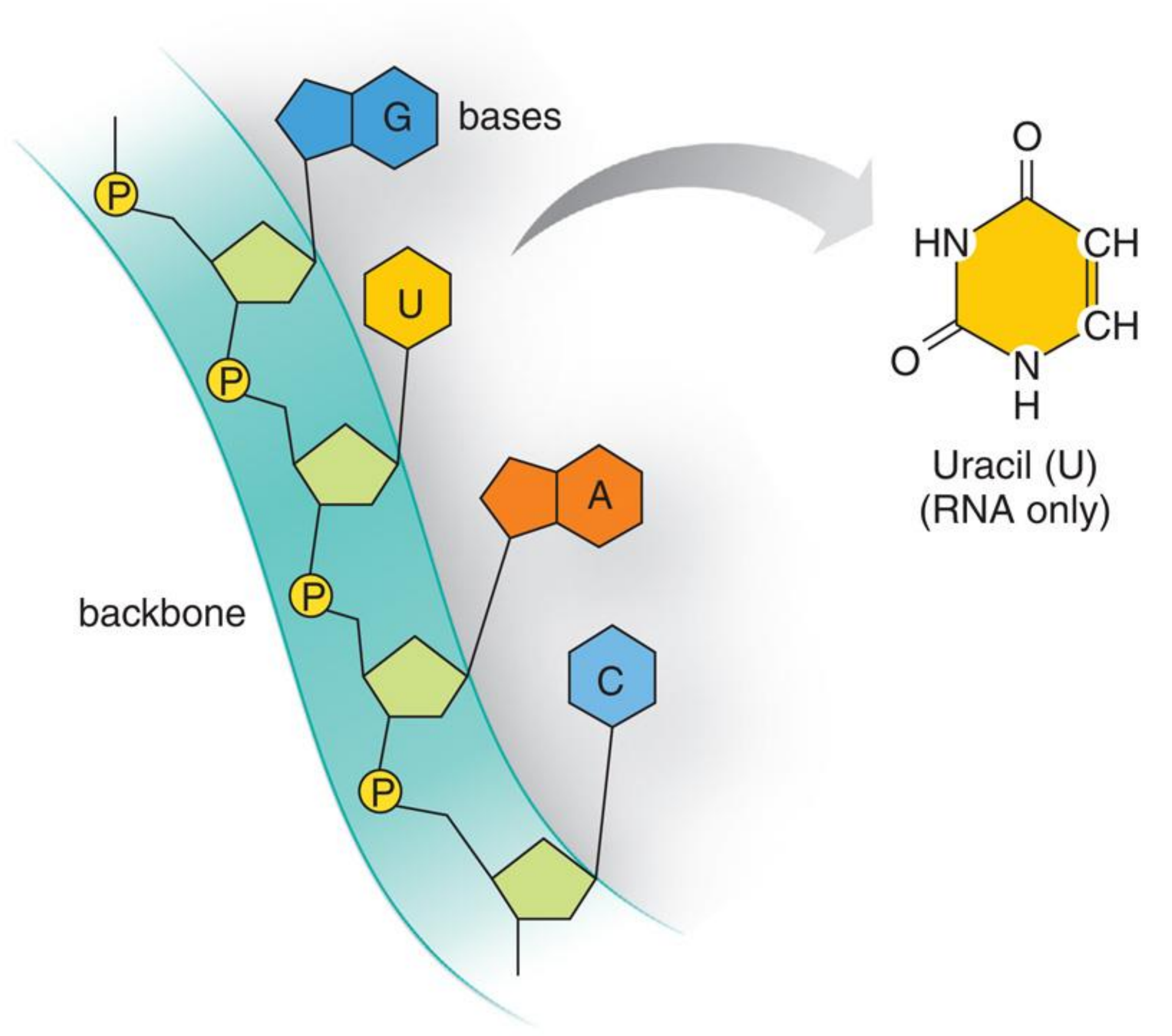
	DNA	*RNA*
Sugar	Deoxyribose	Ribose
Bases	Adenine, guanine, thymine, cytosine	Adenine, guanine, uracil, cytosine
Strands	Double stranded with base pairing	Single stranded
Helix	Yes	No

Nucleic Acids (cont.)



b. DNA structure with base pairs: G with C and A with T

Nucleic Acids (cont.)

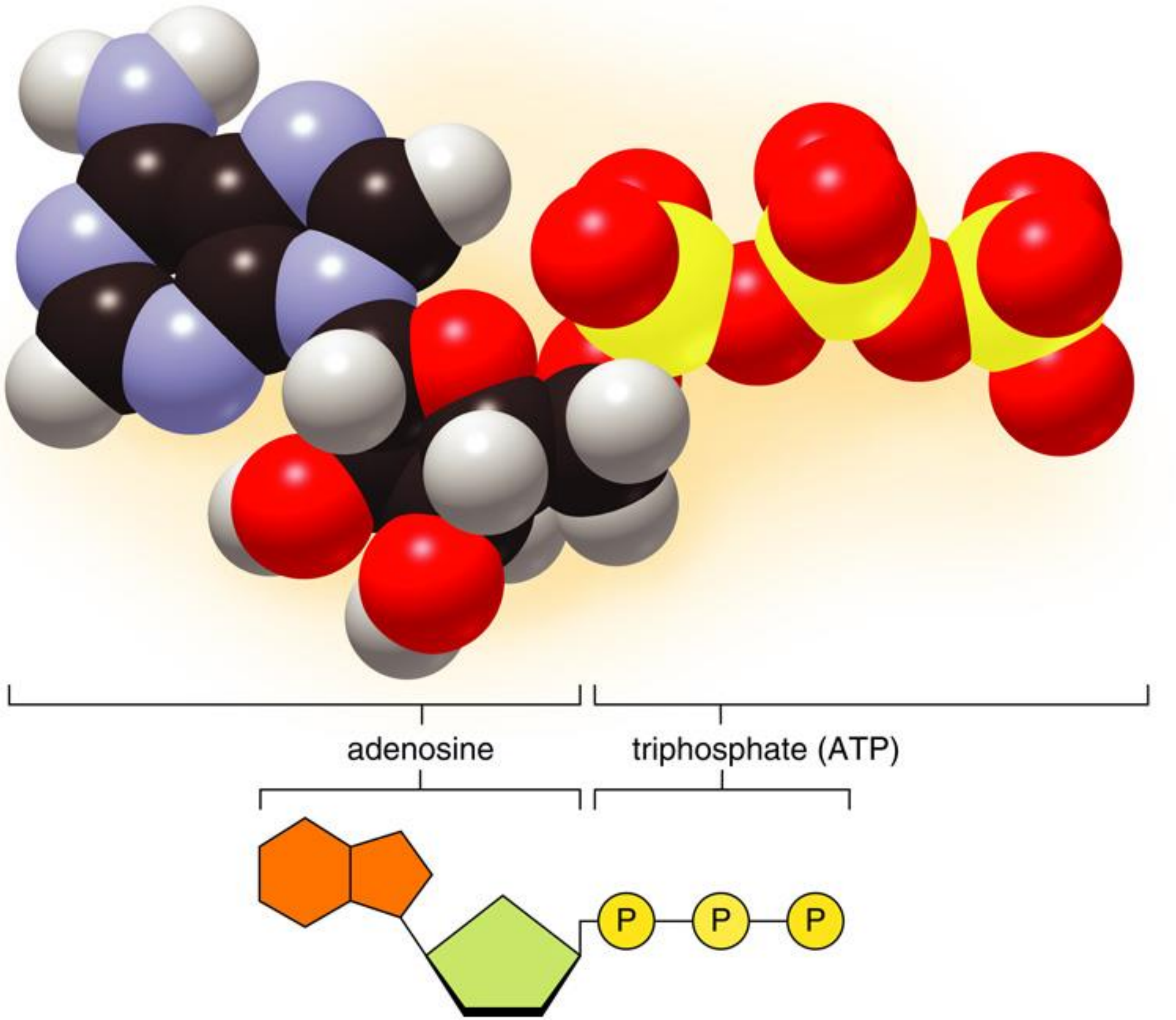


c. RNA structure with bases G, U, A, C

ATP: Adenosine Triphosphate

- It’s a nucleotide made of adenine+ Pentose sugar+ three phosphate groups.
- It’s a high-energy molecule because the last two phosphate bonds are unstable and easily broken.
- When cell hydrolyzes ATP, it releases ADP, a phosphate group and energy. This energy is used in the cell for energy requiring processes.

Structure of ATP (cont.)



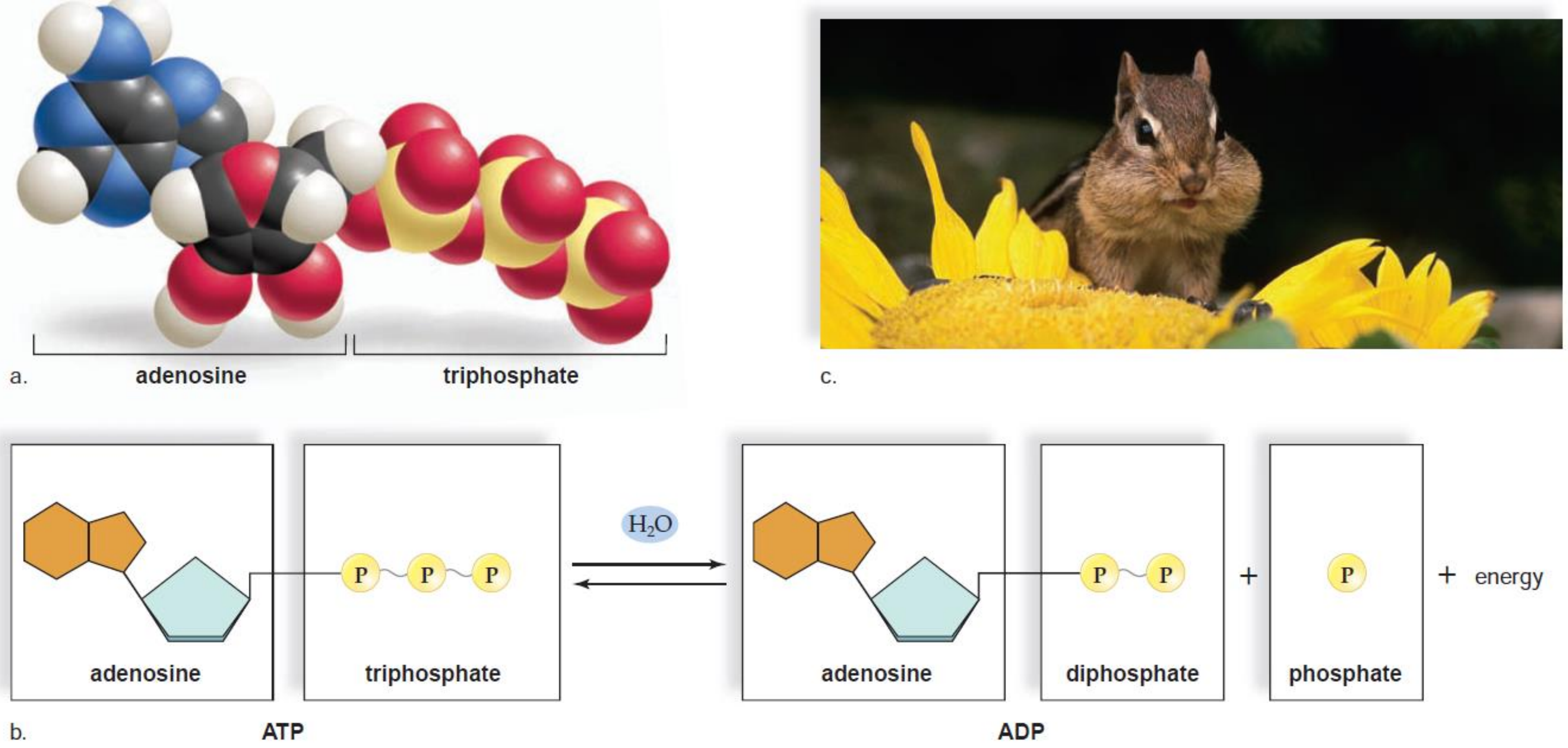


FIGURE 3.22 ATP.

ATP, the universal energy currency of cells, is composed of adenosine and three phosphate groups. **a.** Space-filling model of ATP. **b.** When cells require energy, ATP becomes ADP + Ⓟ, and energy is released. **c.** The breakdown of ATP provides the energy that an animal, such as a chipmunk, uses to acquire food and make more ATP.

Use and Production of ATP (cont.)