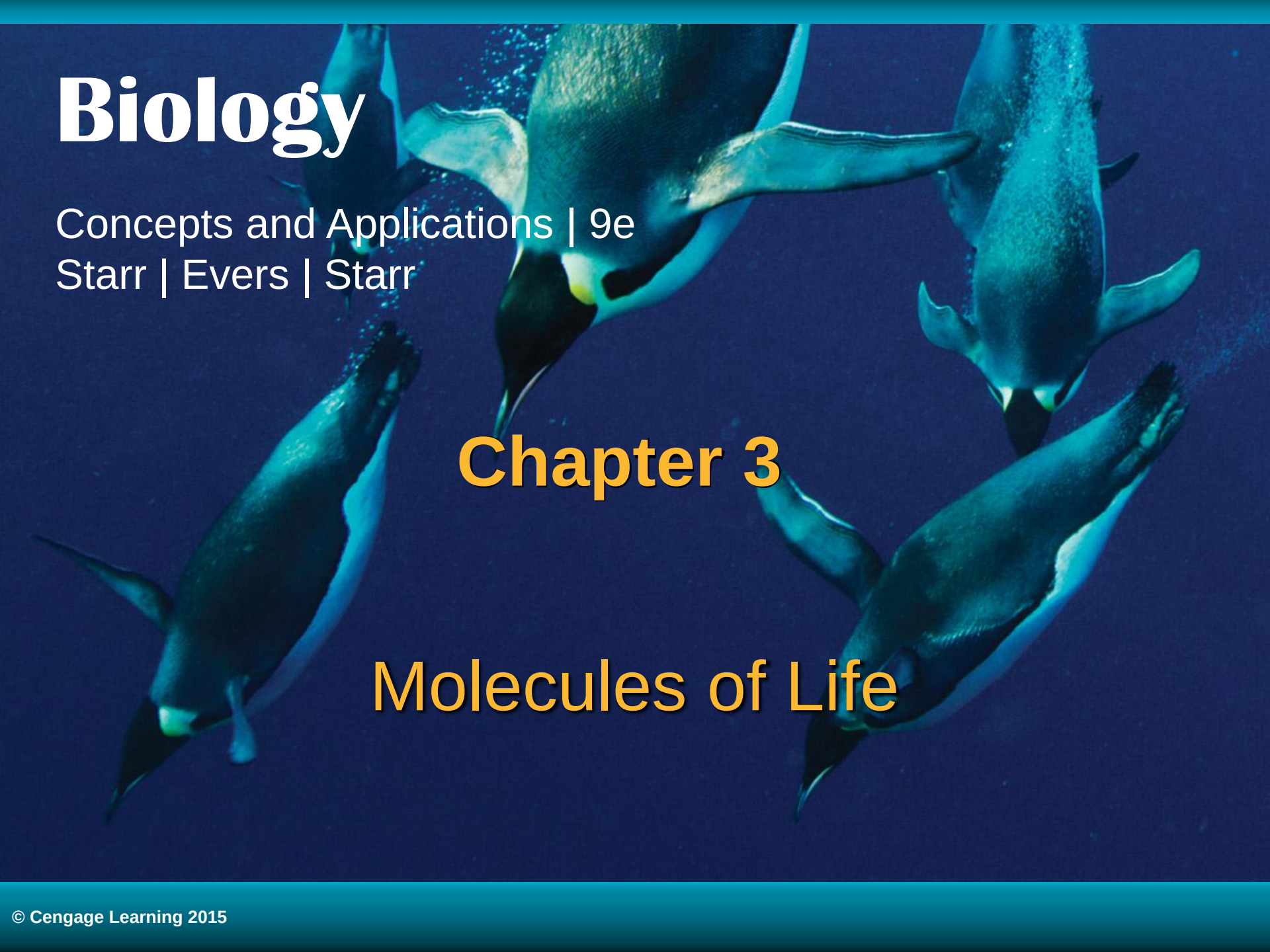

Biology

Concepts and Applications | 9e
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Chapter 3

Molecules of Life

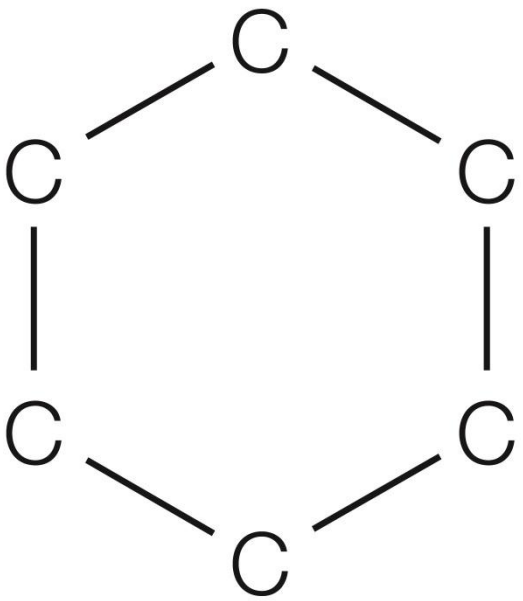
3.1 What Are the Molecules of Life?

- The molecules of life contain a high proportion of carbon atoms:
  - Complex carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids

The Stuff of Life: Carbon (cont'd.)

- The stuff of life: carbon
  - Molecules that have primarily hydrogen and carbon atoms are said to be *organic*
  - Carbon's importance to life arises from its versatile bonding behavior
    - Carbon has four vacancies
  - Many organic molecules have a backbone: a chain of carbon atoms

The Stuff of Life: Carbon (cont'd.)



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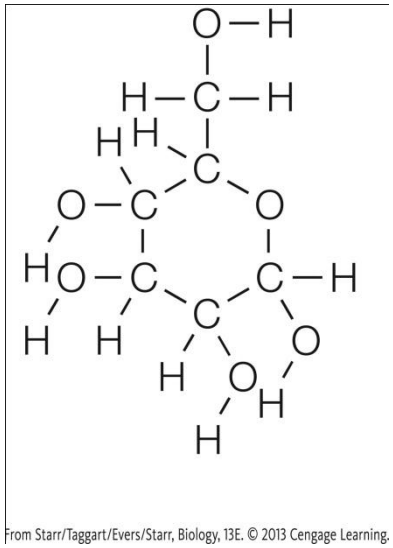
B

The Stuff of Life: Carbon (cont'd.)

A



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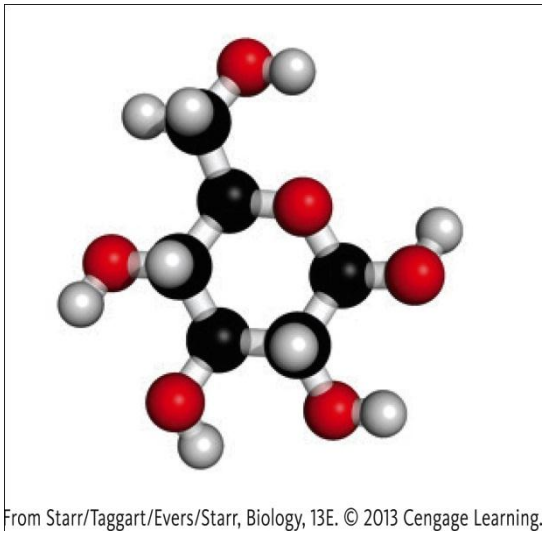

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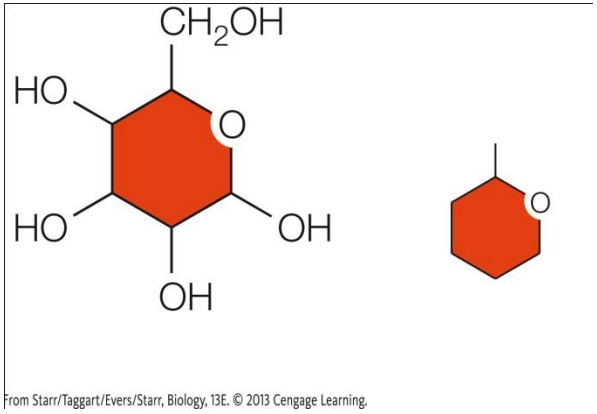

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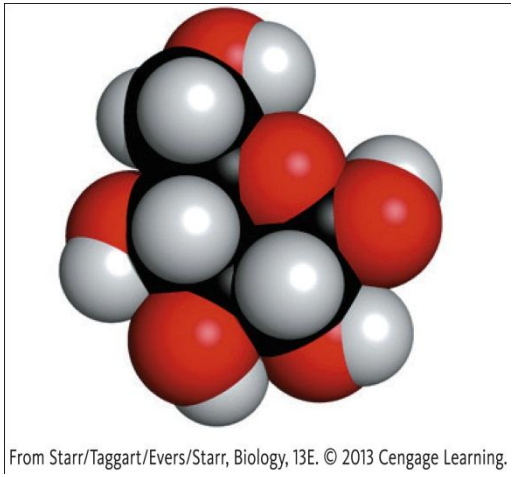

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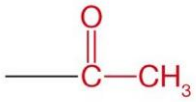
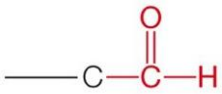
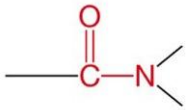
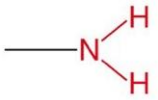
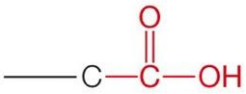
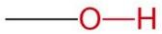
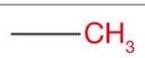
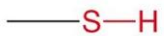
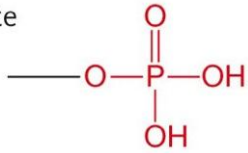
From Structure to Function

- Hydrocarbon: consists only of carbon and hydrogen atoms
- Functional group:
  - An atom (other than hydrogen) or small molecular group bonded to a carbon of an organic compound
  - Imparts a specific chemical property

From Structure to Function (cont'd.)

TABLE 3.1

Some Functional Groups in Biological Molecules

Group	Structure	Character	Formula	Found in:
acetyl		polar, acidic	$-COCH_3$	some proteins, coenzymes
aldehyde		polar, reactive	—CHO	simple sugars
amide		weakly basic, stable, rigid	—C(O)N—	proteins nucleotide bases
amine		very basic	$-NH_2$	nucleotide bases amino acids
carboxyl		very acidic	—COOH	fatty acids amino acids
hydroxyl		polar	—OH	alcohols sugars
ketone		polar, acidic	—CO—	simple sugars nucleotide bases
methyl		nonpolar	$-CH_3$	fatty acids some amino acids
sulfhydryl		forms rigid disulfide bonds	—SH	cysteine many cofactors
phosphate		polar, reactive	$-PO_4$	nucleotides DNA, RNA phospholipids proteins

From Structure to Function (cont'd.)

- All biological systems are based on the same organic molecules
  - The details of those molecules differ among organisms
- Monomers: subunits of larger molecules
  - Simple sugars, fatty acids, amino acids, and nucleotides
- Polymers: consist of multiple monomers

From Structure to Function (cont'd.)

- Cells build polymers from monomers, and break down polymers to release monomers
  - These processes of molecular change are called chemical *reactions*

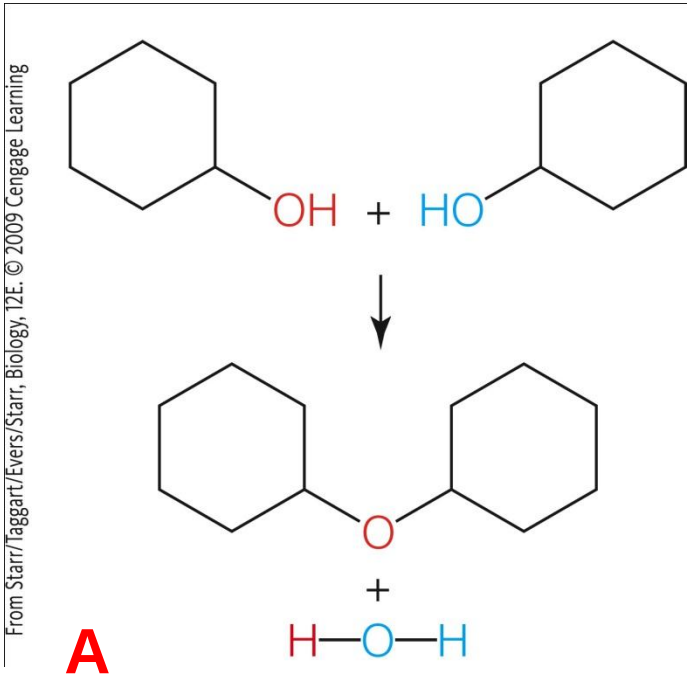
From Structure to Function (cont'd.)

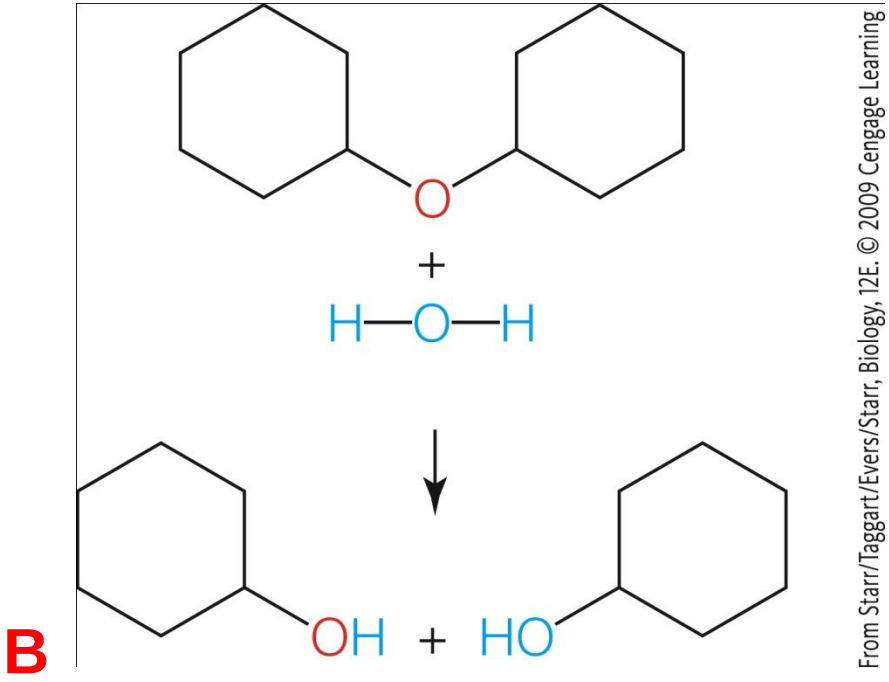
- Metabolism: all enzyme-mediated chemical reactions by which cells acquire and use energy
  - Enzyme: organic molecule that speeds up a reaction without being changed by it

From Structure to Function (cont'd.)

- Condensation: chemical reaction in which an enzyme builds a large molecule from smaller subunits
  - Water is formed during condensation
- Hydrolysis: chemical reaction in which an enzyme uses water to break a molecule into smaller subunits

From Structure to Function (cont'd.)





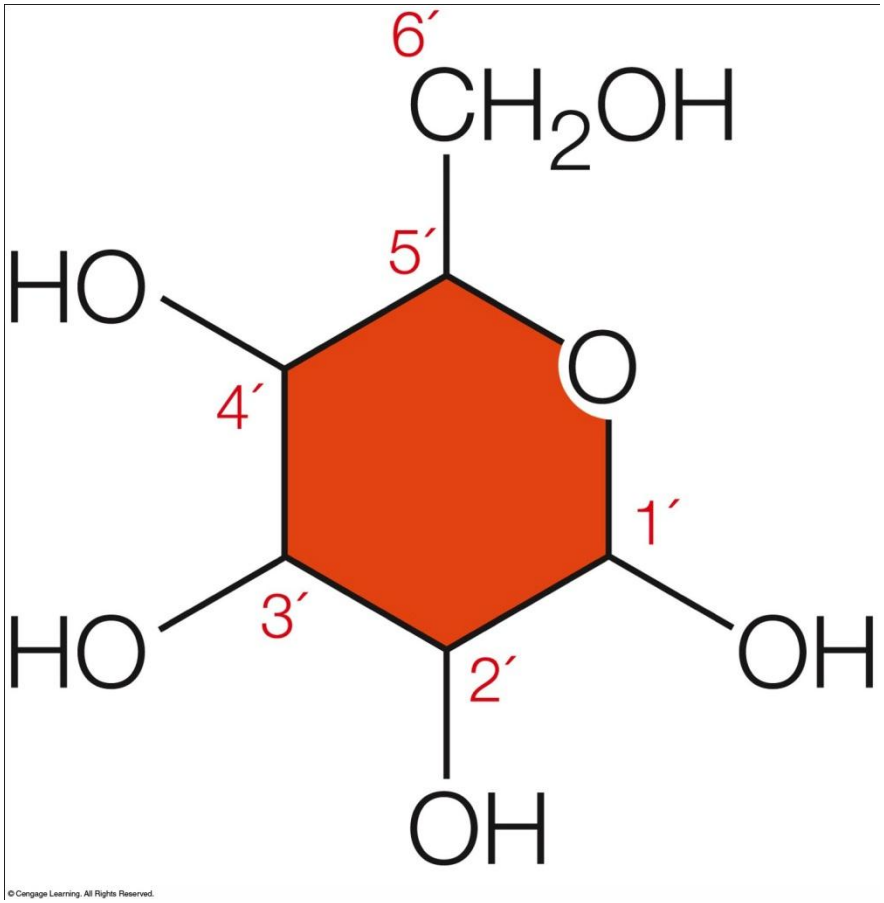
3.2 What Is a Carbohydrate?

- Carbohydrate: organic compound that consist of carbon, hydrogen, and oxygen in a 1:2:1 ratio
- Three main types of carbohydrates in living systems:
  - Monosaccharides
  - Oligosaccharides
  - Polysaccharides

Simple Sugars

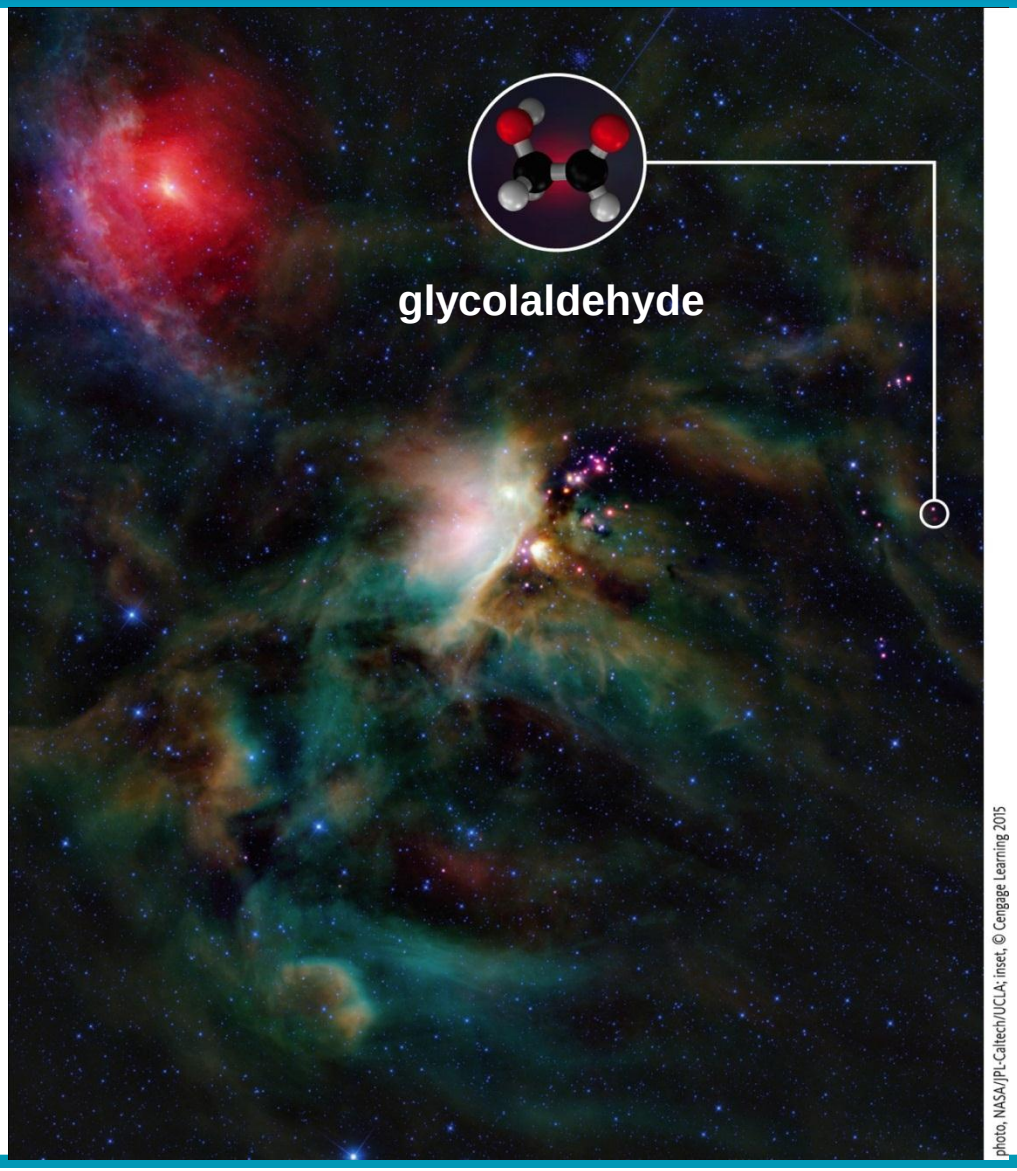
- Monosaccharides (one sugar) are the simplest type of carbohydrates
- Common monosaccharides have a backbone of five or six carbon atoms
  - Examples:
    - Glucose has six carbon atoms
    - Five-carbon monosaccharides are components of the nucleotide monomers of DNA and RNA

Simple Sugars (cont'd.)



glucose

Simple Sugars (cont'd.)



Simple Sugars (cont'd.)

- Cells use monosaccharides for cellular fuel
  - Breaking the bonds of sugars releases energy that can be harnessed to power other cellular processes
- Monosaccharides are also used as:
  - Precursors for other molecules
  - Structural materials to build larger molecules

Polymers of Simple Sugars

- Oligosaccharides are short chains of covalently bonded monosaccharides
- Disaccharides consist of two monosaccharide monomers
  - Examples:
    - Lactose: composed of glucose + galactose
    - Sucrose: composed of glucose + fructose

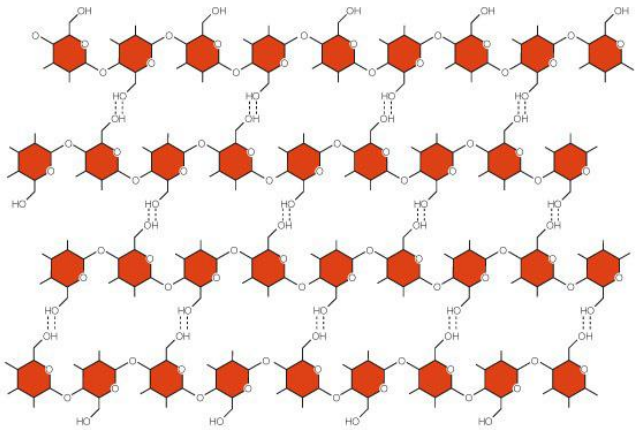
Polymers of Simple Sugars (cont'd.)

- Polysaccharides: chains of hundreds or thousands of monosaccharide monomers
- Most common polysaccharides:
  - Cellulose
  - Starch
  - Glycogen

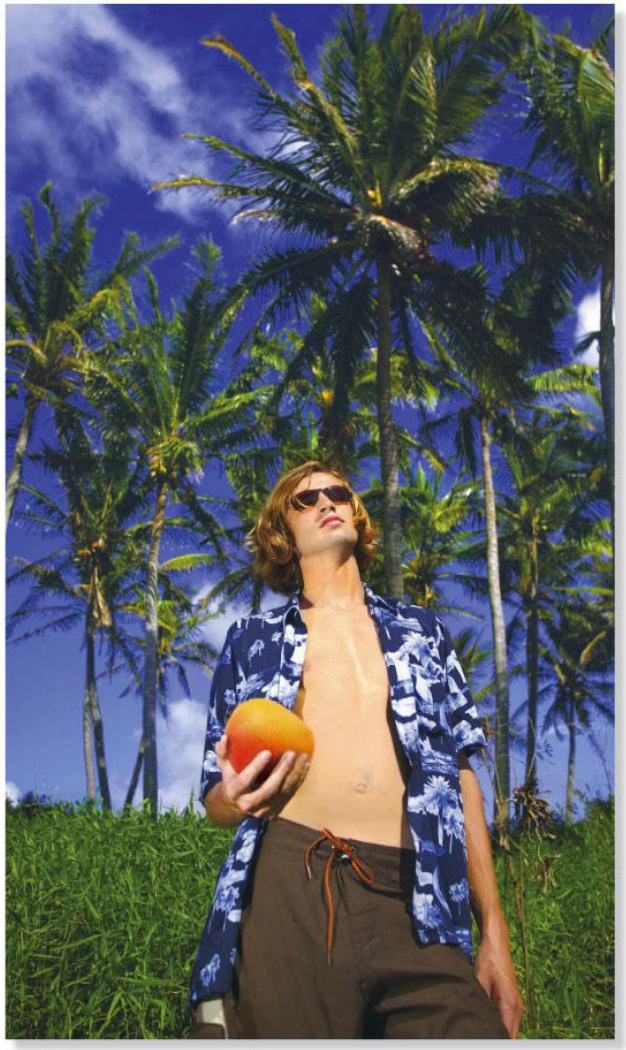
Polymers of Simple Sugars (cont'd.)

- Cellulose
  - Main structural component of plants
  - Tough and insoluble
  - Composed of chains of glucose monomers stretched side by side and hydrogen-bonded at many —OH groups

Polymers of Simple Sugars (cont'd.)



A Cellulose



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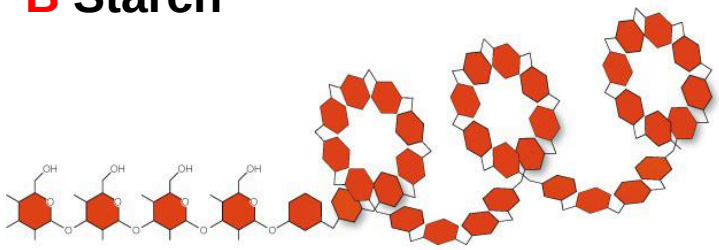
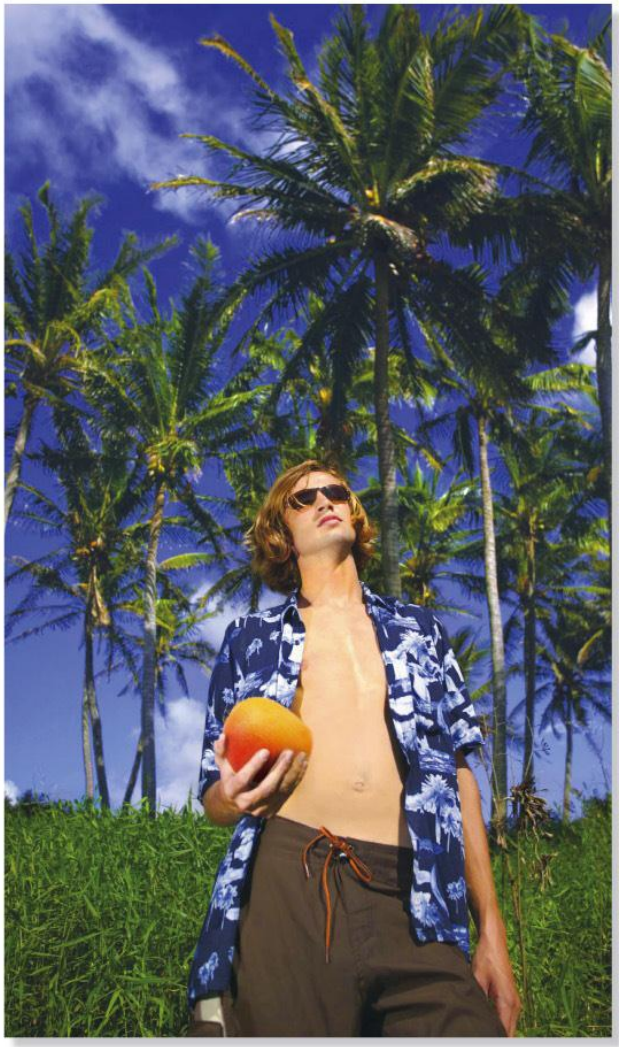
Polymers of Simple Sugars (cont'd.)

- Starch
  - Main energy reserve in plants
  - Stored roots, stems, leaves, seeds, and fruits
  - Composed of a series of glucose monomers that form a chain that coils up

Polymers of Simple Sugars (cont'd.)

B Starch





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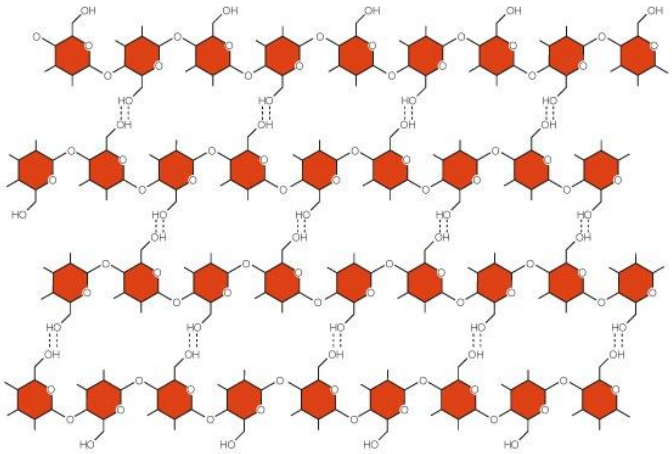
Polymers of Simple Sugars (cont'd.)

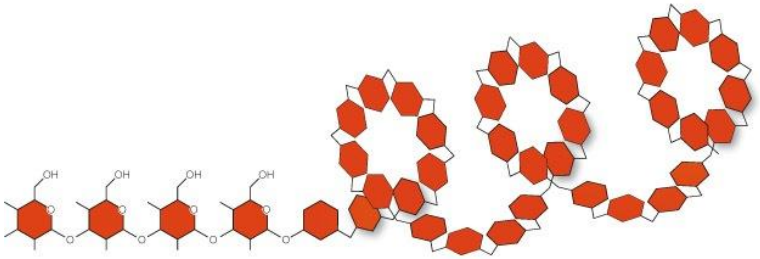
- Glycogen
  - Main energy reserve in animals
  - Very abundant in muscle and liver cells
  - Highly branched chains of glucose monomers

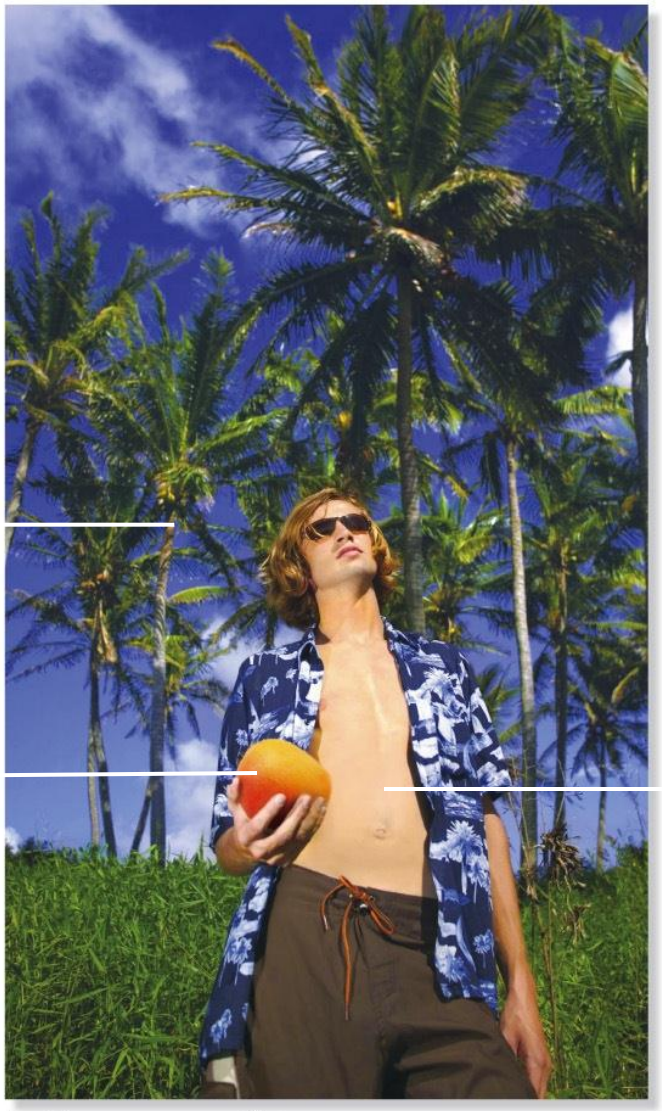
Polymers of Simple Sugars (cont'd.)



A Cellulose

B Starch





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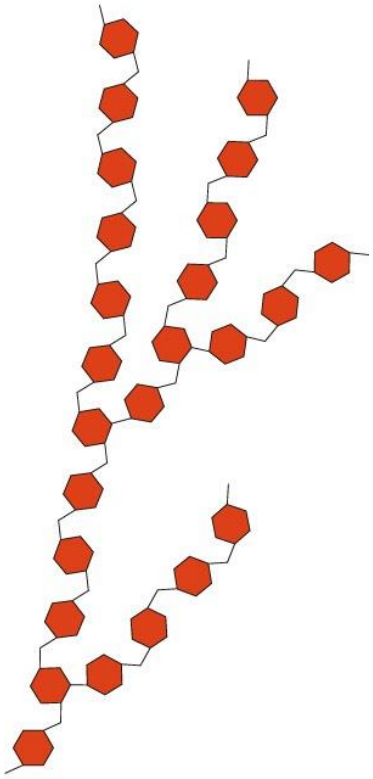


C Glycogen

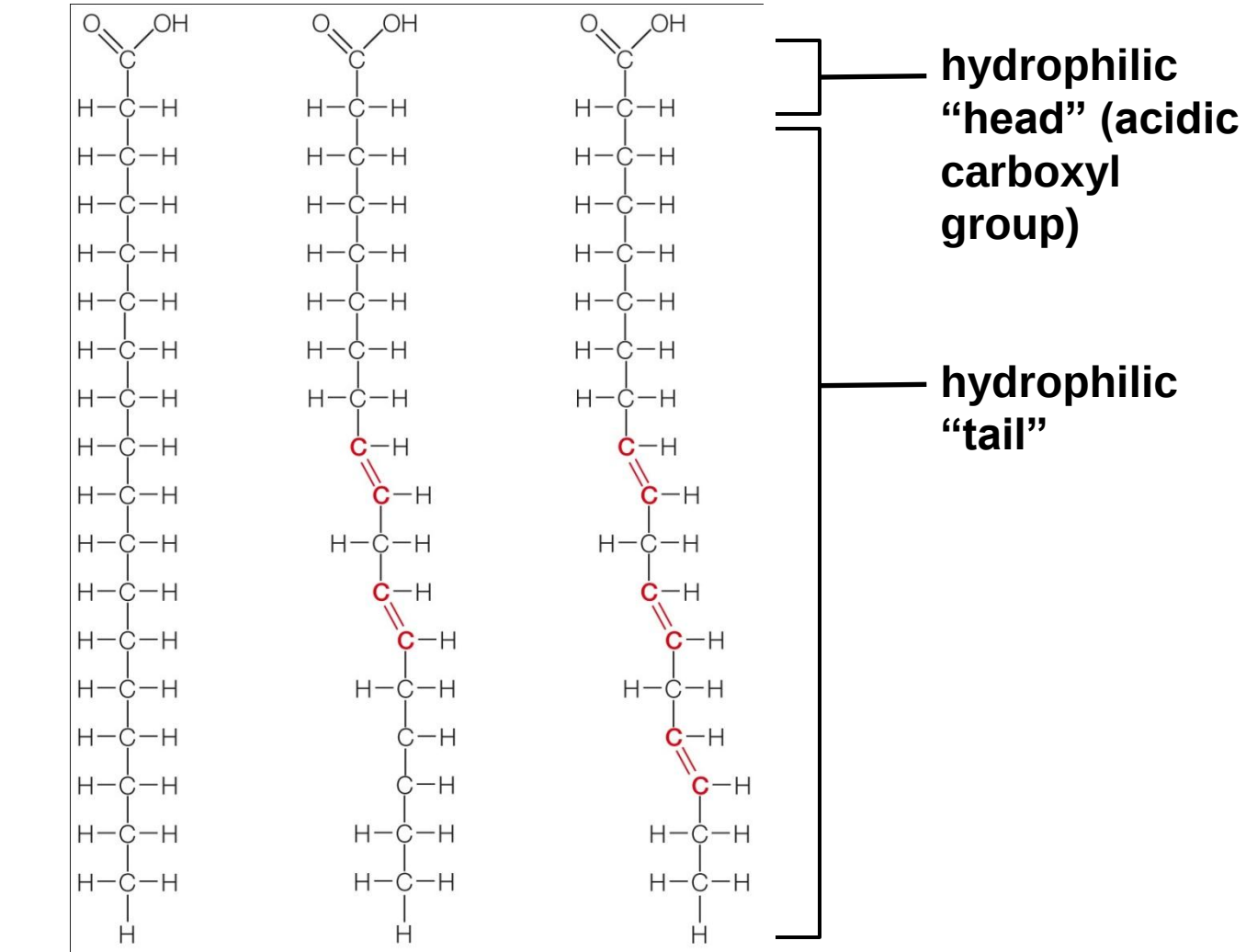
3.3 What Are Lipids?

- Lipids: fatty, oily, or waxy organic compounds
- Many lipids incorporate fatty acids: consist of a long hydrocarbon “tail” with a carboxyl group “head”
  - The tail is hydrophobic
  - The head is hydrophilic

What Are Lipids? (cont'd.)

- Saturated fatty acids have only single bonds linking the carbons in their tails
  - Flexible and wiggle freely
- Unsaturated fatty acids have some double bonds linking the carbons in their tails
  - Flexibility is limited

What Are Lipids? (cont'd.)



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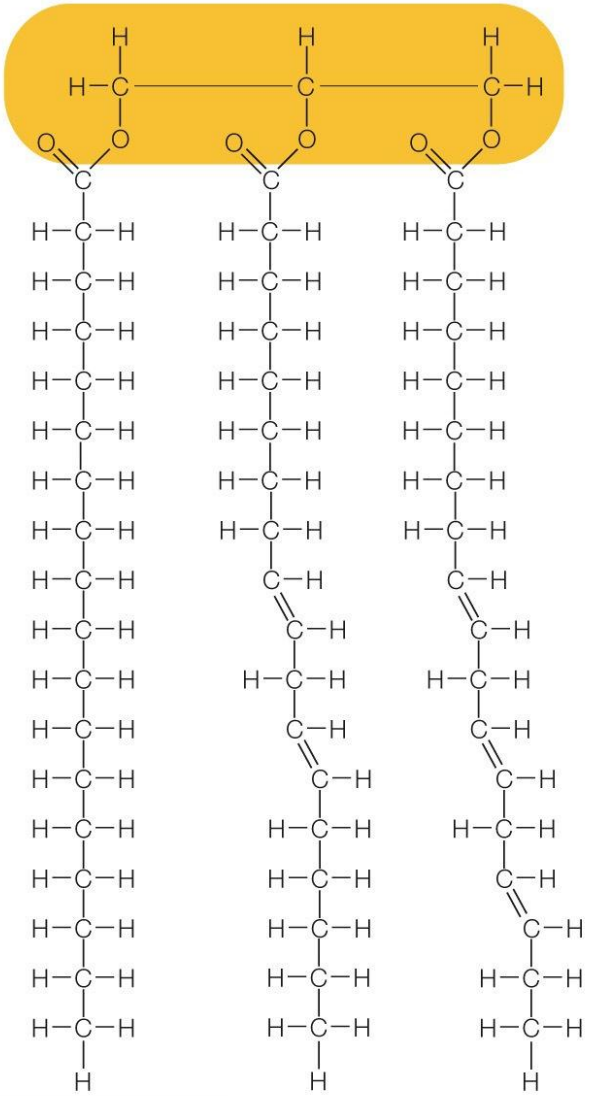
Fats

- Fats: lipid that consists of a glycerol molecule with one, two, or three fatty acid tails
- Triglyceride: a fat with three fatty acid tails
  - Saturated fats: triglycerides with saturated fatty acid tails; solid at room temperature
  - Unsaturated fats: triglycerides with unsaturated fatty acid tails; liquid at room temperature

Fats (cont'd.)



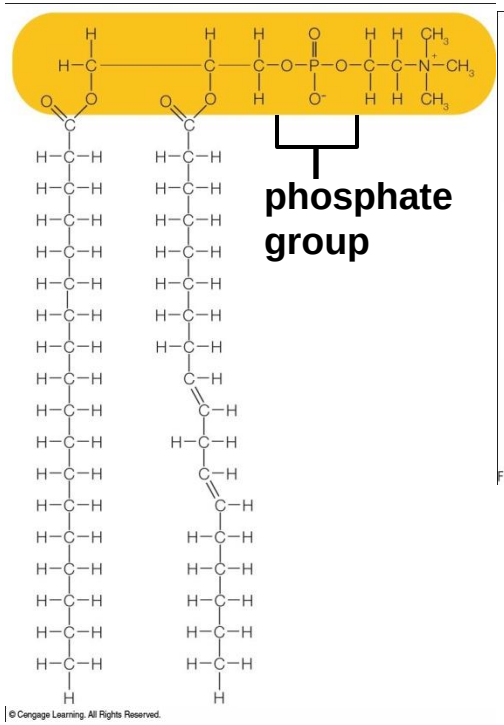
Phospholipids

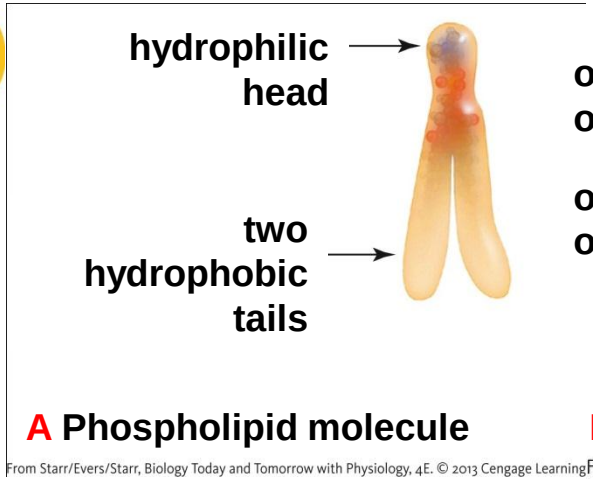
- Phospholipid: main component of cell membranes
  - Contains phosphate group in hydrophilic head and two nonpolar fatty acid tails

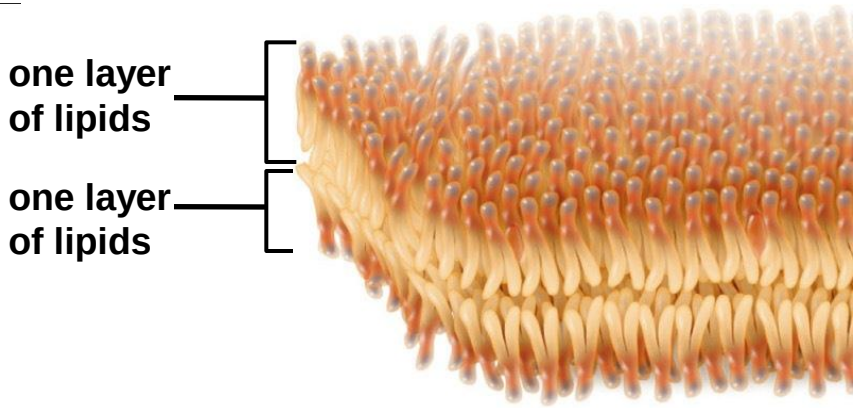
Phospholipids (cont'd.)

- In a cell membrane, phospholipids are arranged in two layers called a *lipid bilayer*
  - One layer of hydrophilic heads are dissolved in cell's watery interior
  - Other layer of hydrophilic heads are dissolved in the cell's fluid surroundings
  - Hydrophobic tails are sandwiched between the hydrophilic heads

Phospholipids (cont'd.)







A Phospholipid molecule

B A lipid bilayer

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B

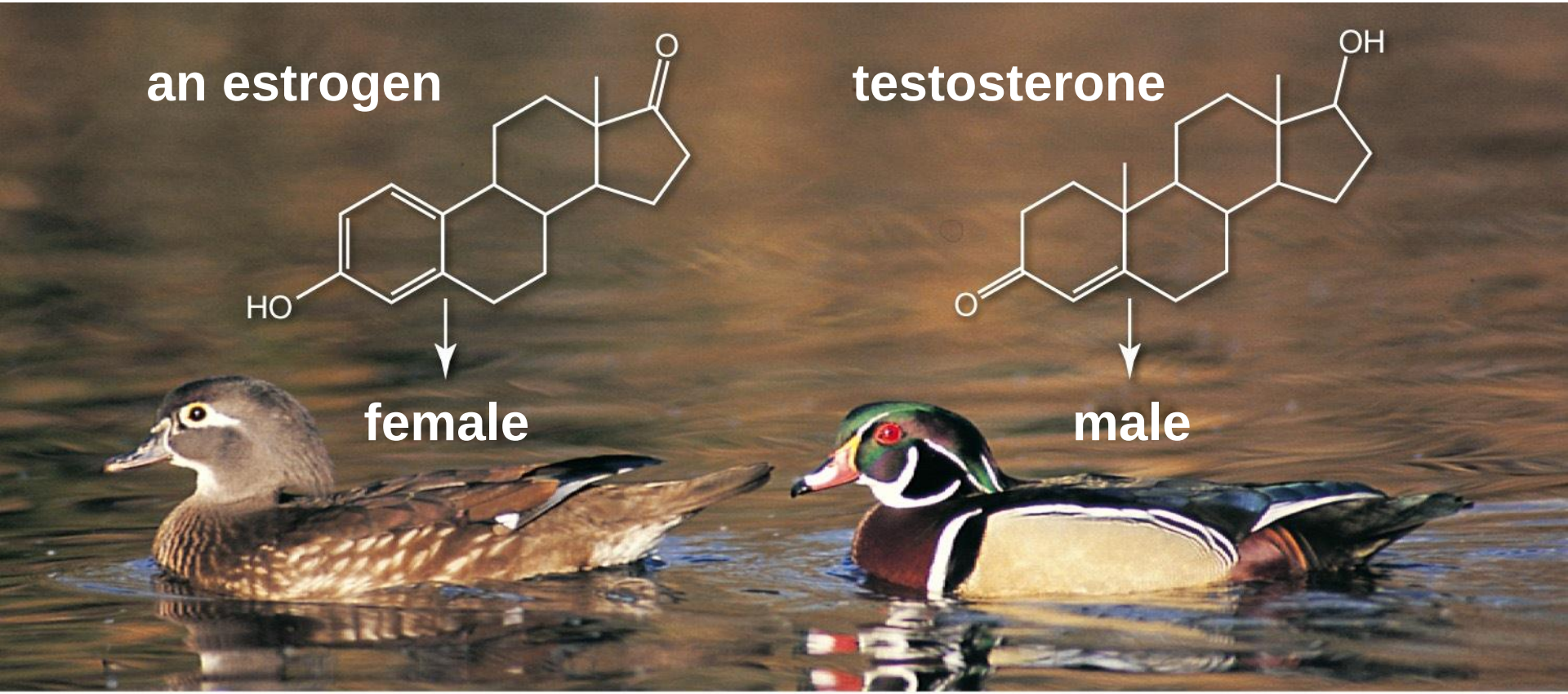
Waxes

- Wax: complex, varying mixture of lipids with long fatty acid tails bonded to alcohols or carbon rings
- Molecules pack tightly, so waxes are firm and water-repellent
  - Plants secrete waxes to restrict water loss and keep out parasites and other pests
  - Other types of waxes protect, lubricate, and soften skin and hair

Steroids

- Steroids: lipids with no tails
  - Contain a rigid backbone that consists of twenty carbon atoms arranged in a characteristic pattern of four rings
- Functional groups attached to the rings define the type of steroid
- Examples: estrogen and testosterone
  - Dictates many sex characteristics

Steroids (cont'd.)



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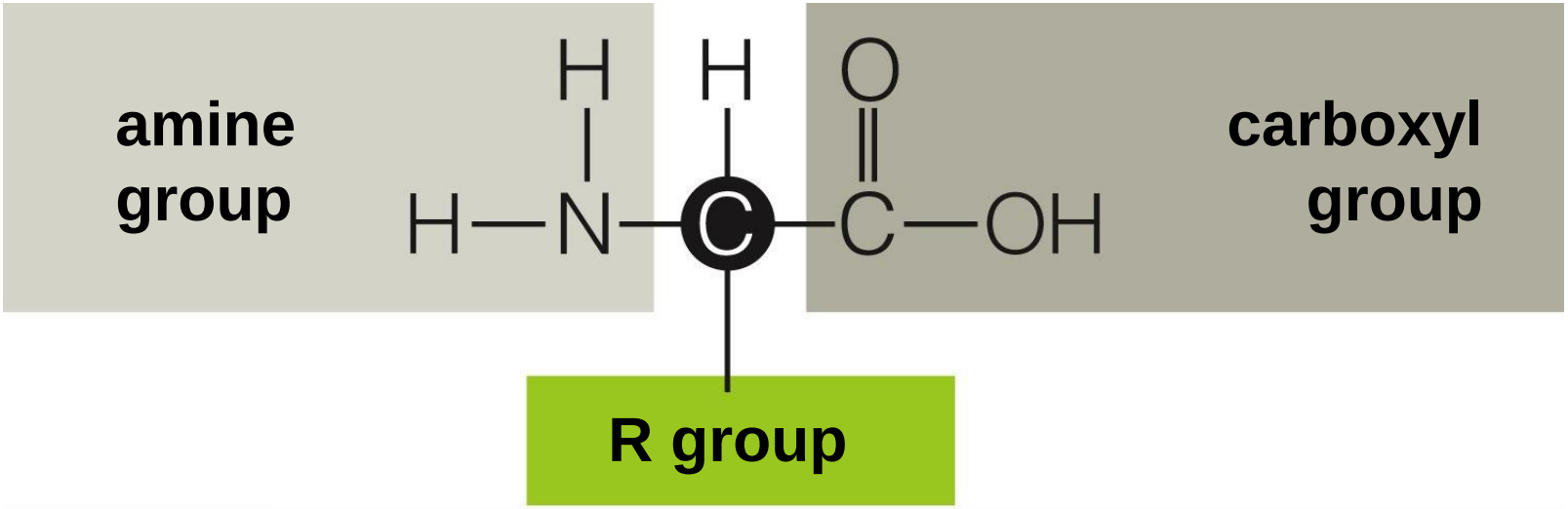
3.4 What Are Proteins?

- Amino acid subunits
  - Cells can make thousands of different proteins from only twenty kinds of monomers called *amino acids*
  - An amino acid contains:
    - An amine group (—NH_2)
    - A carboxyl group (—COOH, the acid)
    - A side chain called an “R group”; defines the kind of amino acid

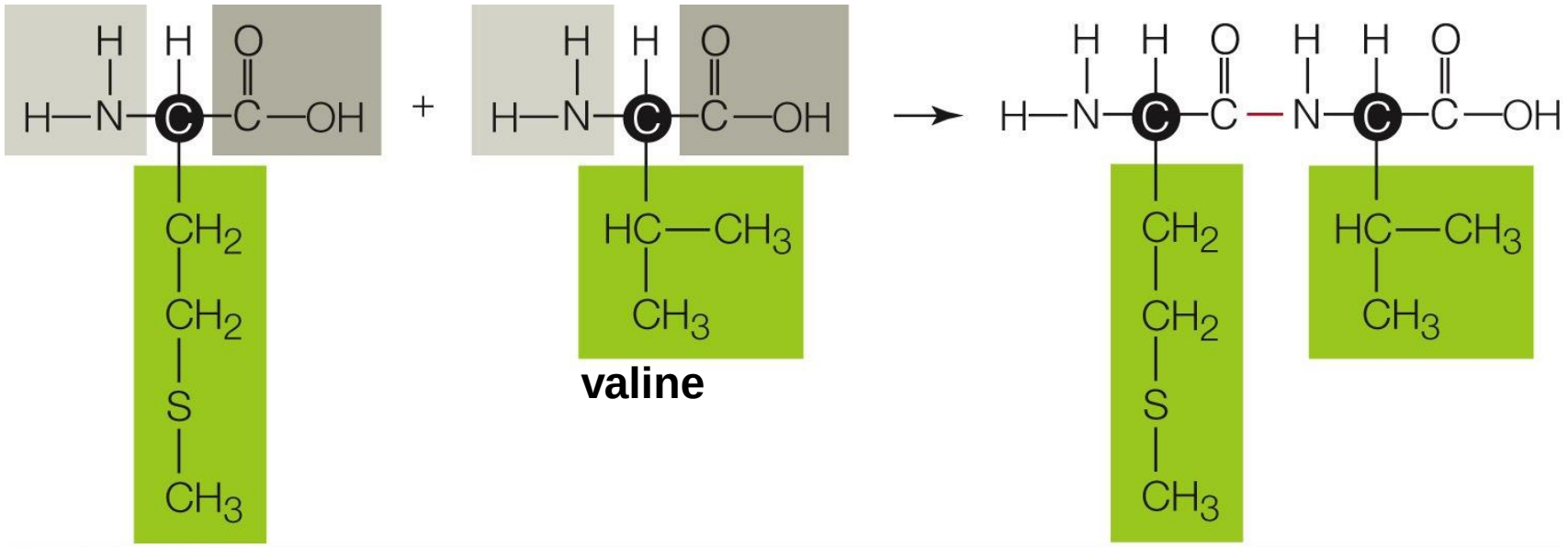
Amino Acid Subunits (cont'd.)



Amino Acid Subunits (cont'd.)

- The covalent bond that links amino acids in a protein is called a *peptide bond*
- A short chain of amino acids is called a *peptide*
  - As the chain lengthens, it becomes a *polypeptide*
- *Proteins* consist of polypeptides that are hundreds or even thousands of amino acids long

Amino Acid Subunits (cont'd.)



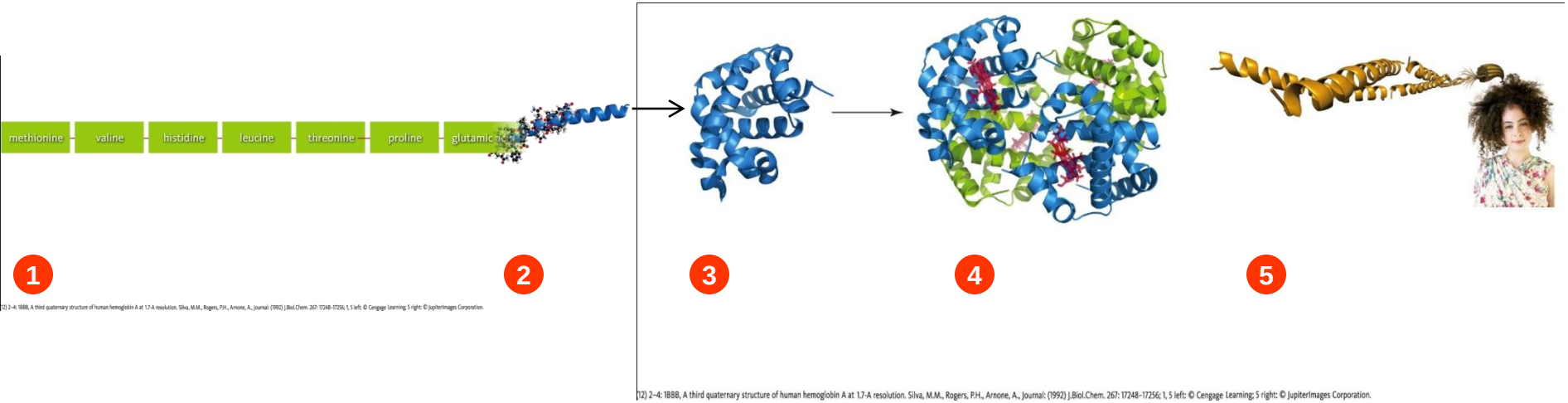
Structure Dictates Function

- Proteins function in movement, defense, and cellular communication
  - Example: enzymes
- A protein's biological activity arises from and depends on its structure

Structure Dictates Function (cont'd.)

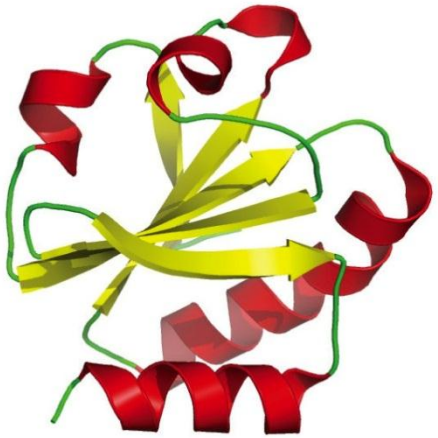
- Primary structure: linear series of amino acids; defines the type of protein
- Secondary structure: polypeptide chain that forms twists and folds
- Tertiary structure: nonadjacent regions of protein adjoin to create compact domains
- Quaternary structure: two or more polypeptide chains that are closely associated or covalently bonded together

Structure Dictates Function (cont'd.)



(12) 2–4: 1BBB, A third quaternary structure of human hemoglobin A at 1.7-A resolution. Silva, M.M., Rogers, P.H., Arnone, A., Journal: (1992) J.Biol.Chem. 267: 17248–17256; 1, 5 left: © Cengage Learning; 5 right: © JupiterImages Corporation.

Structure Dictates Function (cont'd.)



A

Castrignanò T, De Meo PD, Cozzetto D, Talamo IG, Tramontano A. (2006). The PMDB Protein Model Database. Nucleic Acids Research, 34: D306-D309.

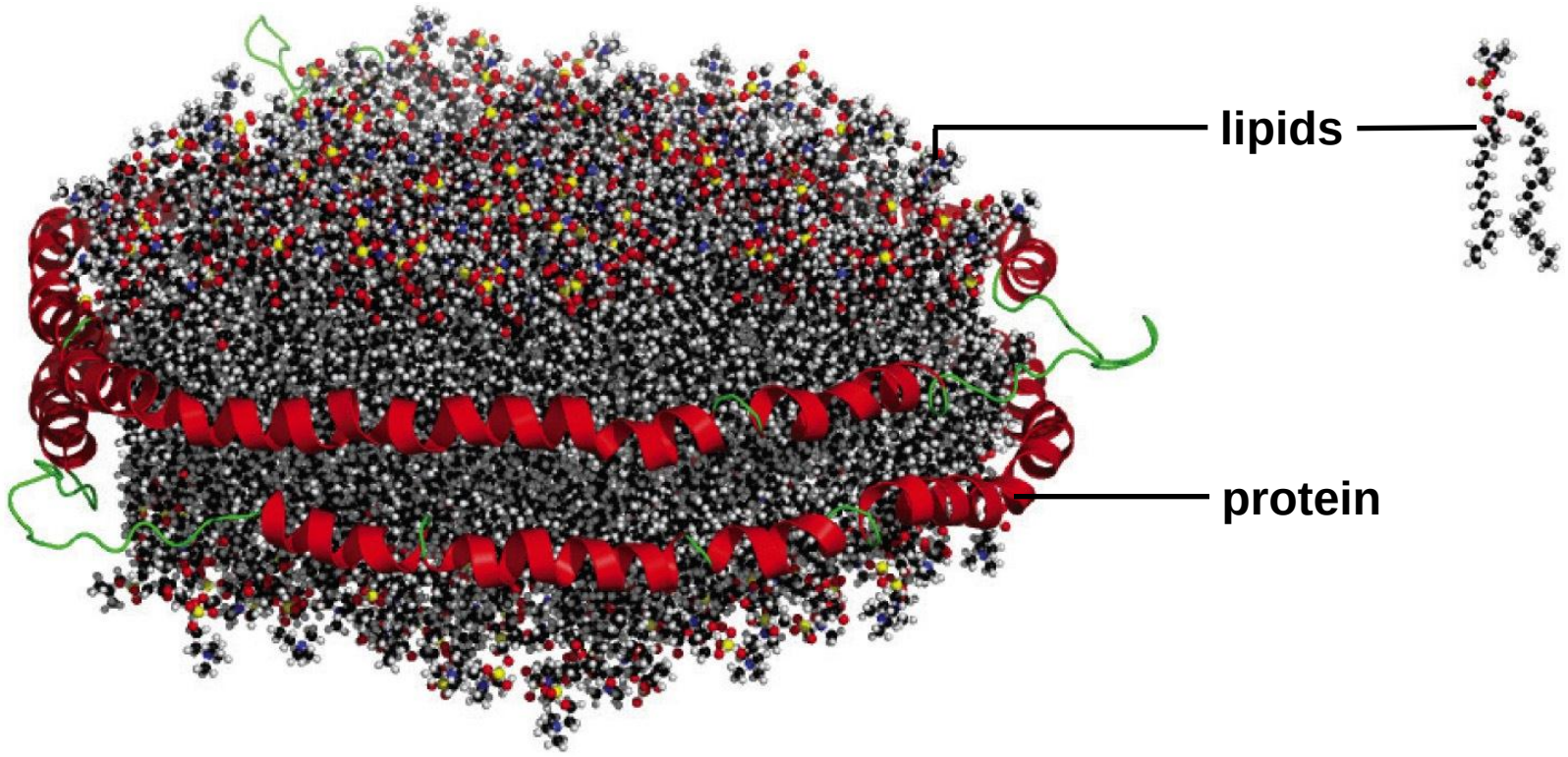
B

pdb ID2W5J, Vollmar, M., Shlieper, D., Winn M., Buechner, C., Groth, G. "Structure of the C14 rotor ring of the proton translocating chloroplast ATP synthase." (2009) *J. Biol. Chem.* 284:18228.

Structure Dictates Function (cont'd.)

- Enzymes often attach sugars or lipids to proteins
  - Examples: glycoproteins and lipoproteins

Structure Dictates Function (cont'd.)



Castrignanò T, De Meo PD, Cozzetto D, Talamo IG, Tramontano A. (2006). The PMDB Protein Model Database. Nucleic Acids Research, 34: D306-D309

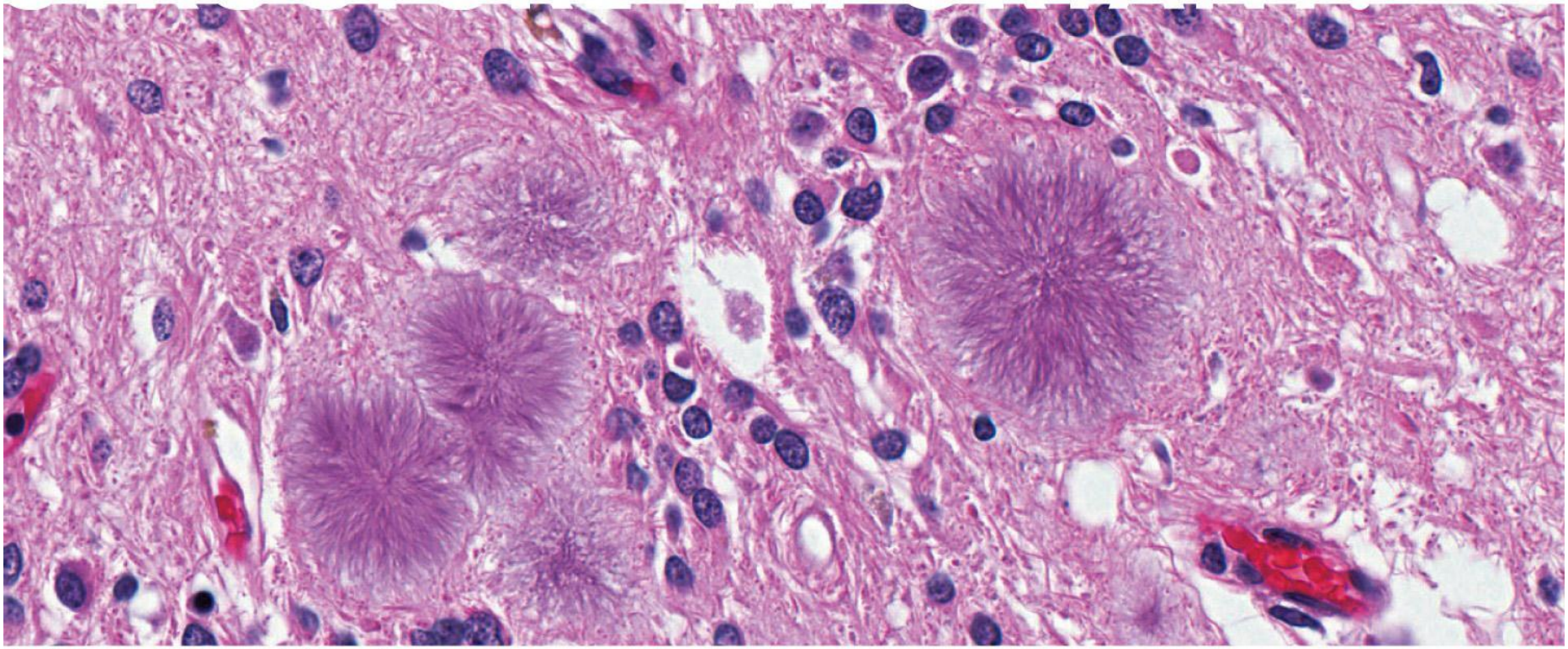
3.5 Why Is Protein Structure Important?

- Heat, some salts, shifts in pH, or detergents can *denature* (unravel) a protein by breaking hydrogen bonds
- Denaturation causes a protein to lose its function

Why Is Protein Structure Important? (cont'd.)

- Misfolding of the glycoprotein PrPC causes a *prion* (infectious protein) to form
- May lead to:
  - Scrapie in sheep
  - Mad cow disease
  - Variant Creutzfeldt–Jakob disease in humans
    - Confusion, memory loss, and lack of coordination

Why Is Protein Structure Important? (cont'd.)

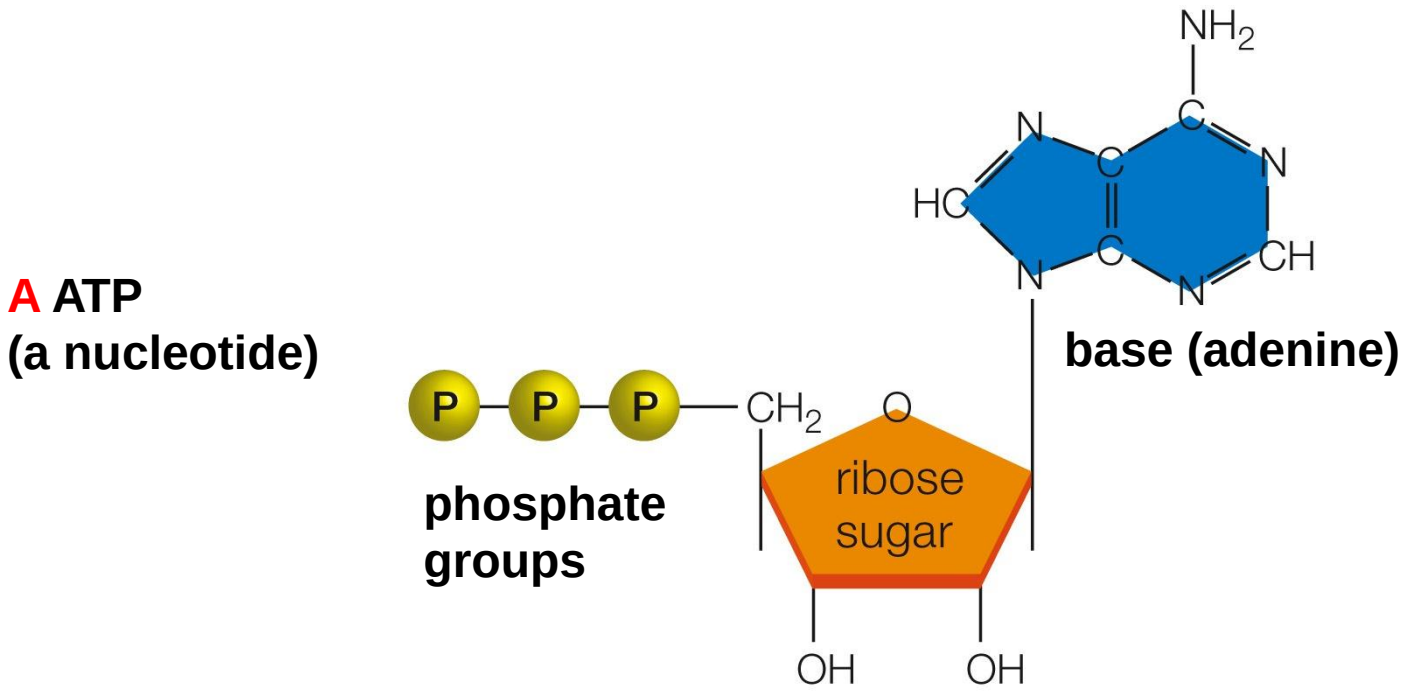


Sherif Zaki, MD PhD, Wun-Ju Shieh, MD PhD; MPH/ CDC

3.6 What Are Nucleic Acids?

- Nucleotide: consists of a sugar with a five-carbon ring bonded to a nitrogen-containing base and one, two, or three phosphate groups
  - Example: ATP (adenosine triphosphate); an energy carrier in cells

What Are Nucleic Acids? (cont'd.)



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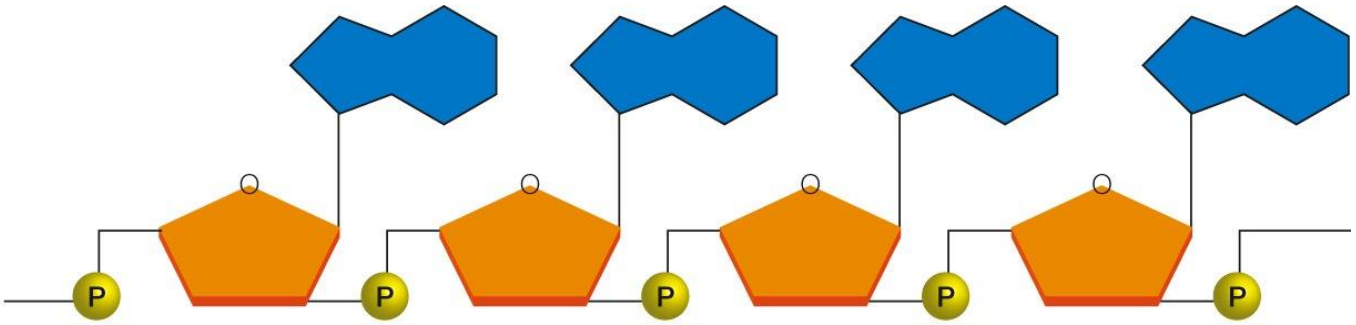
What Are Nucleic Acids? (cont'd.)

- Nucleic acids: chains of nucleotides in which the sugar of one nucleotide is bonded to the phosphate group of the next
  - RNA (ribonucleic acid): single-stranded chain of nucleotides; important for protein synthesis
  - DNA (deoxyribonucleic acid): consists of two chains of nucleotides twisted into a double helix; holds information to build a new cell

What Are Nucleic Acids? (cont'd.)

B RNA
(a nucleic acid)



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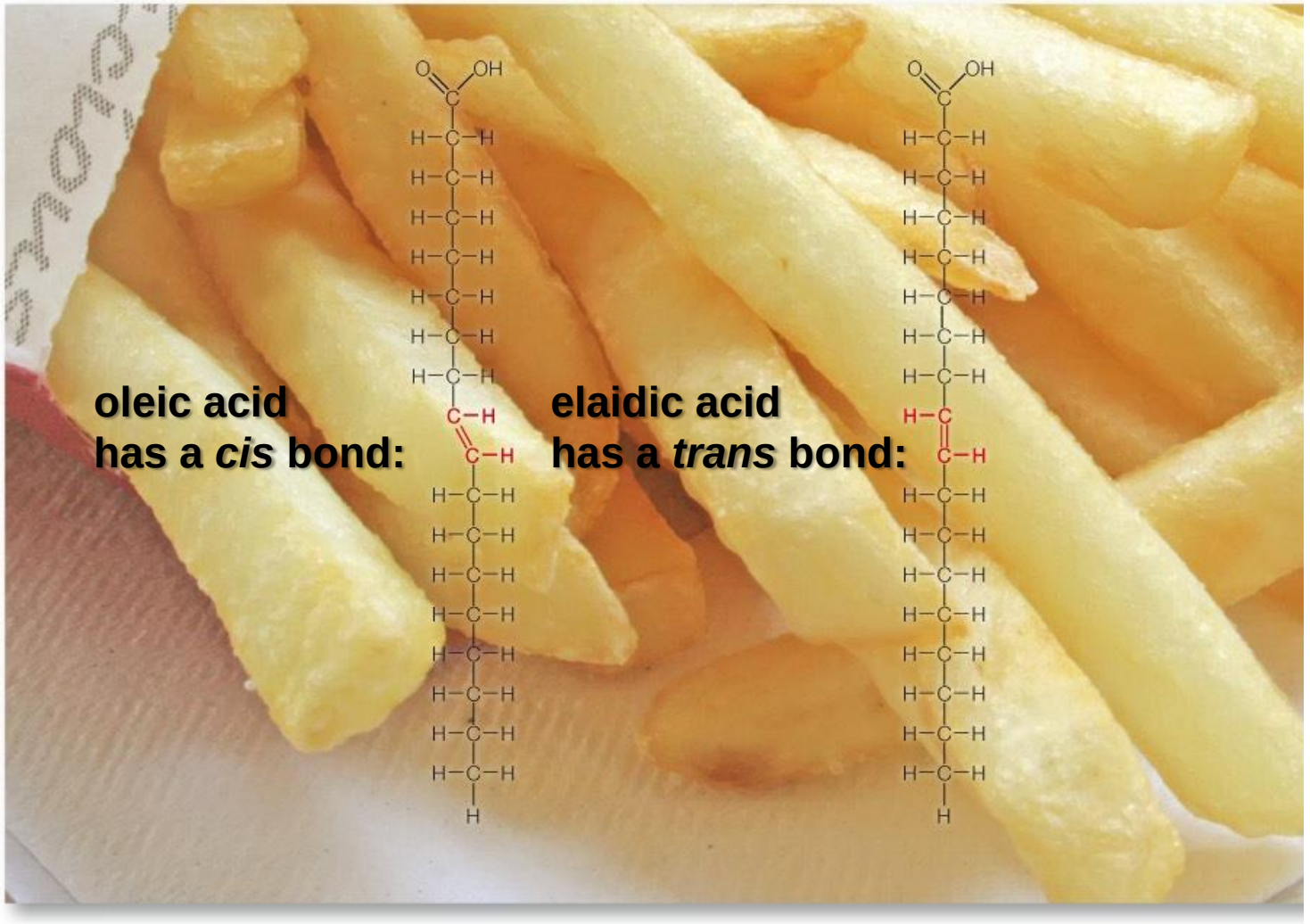
3.7 Application: Fear of Frying

- *Trans* fats have unsaturated fatty acid tails with hydrogen atoms around the double bonds
- Small amounts of *trans* fats occur naturally
- Main source of *trans* fats is an artificial food product called partially hydrogenated vegetable oil
- Hydrogenation: adds hydrogen atoms to oils in order to change them into solid fats

Application: Fear of Frying (cont'd.)



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Application: Fear of Frying (cont'd.)

- In 1908, Procter & Gamble Co. developed partially hydrogenated oil to make candles
- As electricity replaced candles, the company began marketing partially hydrogenated oils as a low cost alternative to lard
- For decades, hydrogenated oils were considered healthier than animal fats

Application: Fear of Frying (cont'd.)

- *Trans* fats raise the level of cholesterol in our blood more than any other fat
- Directly alters the function of our arteries and veins
  - Eating as little as two grams a day of hydrogenated vegetable oil increases a person's risk of atherosclerosis, heart attack, and diabetes