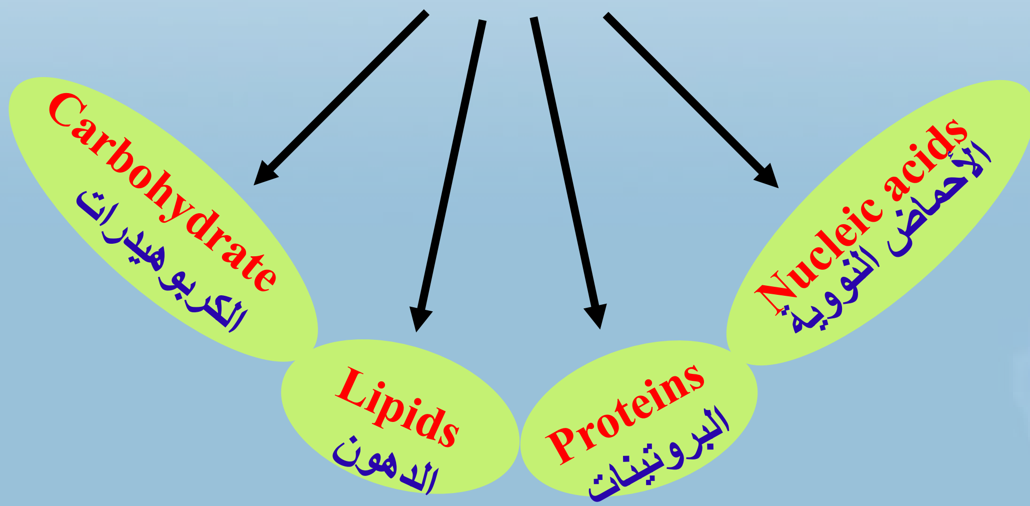
Chapter 3
The Molecules of Cells

INTRODUCTION TO ORGANIC COMPOUNDS (Molecules)

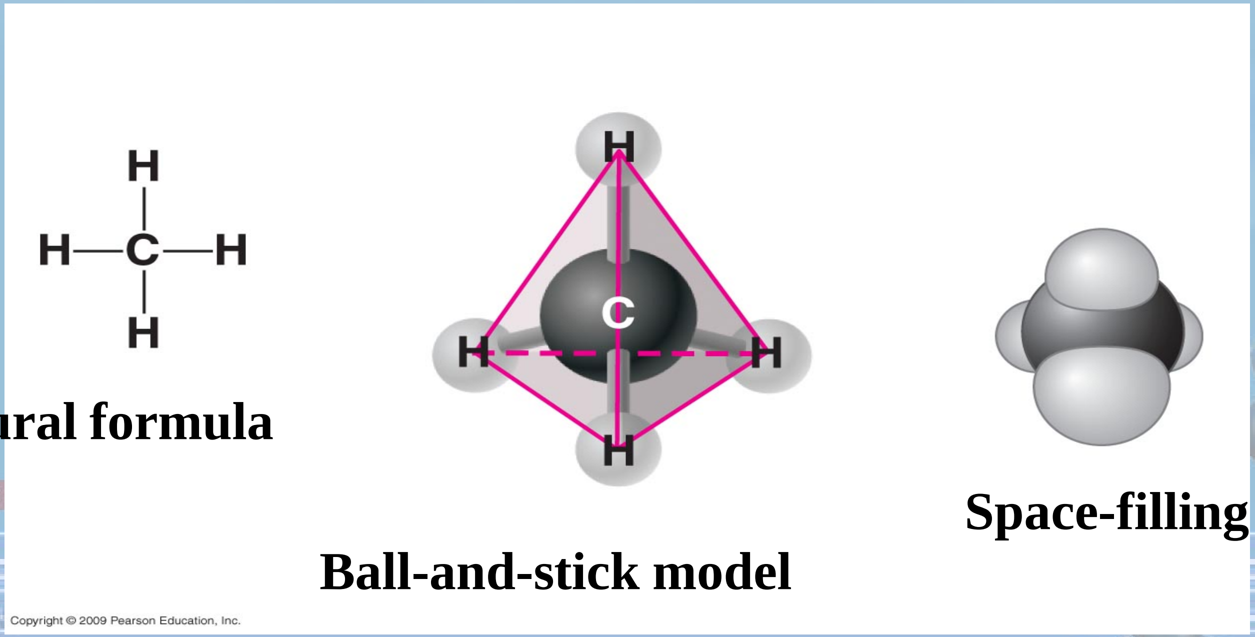


3.1 Life's molecular diversity is based on the properties of carbon

- **Diverse molecules found in cells are composed of carbon bonded to other elements**
- **Carbon-based molecules are called Organic Compounds**
- **By sharing electrons, carbon can bond to four other atoms**
- **By doing so, carbon can branch in up to four directions**

ORGANIC COMPOUNDS (Molecules)

- **Methane (CH_4) is one of the simplest organic compounds**
  - **Four covalent bonds link four hydrogen atoms to the carbon atom**
  - **Each of the four lines in the formula for Methane represents a pair of shared electrons**



Methane

Structural formula

Ball-and-stick model

Space-filling model

The four single bonds of carbon point to the corners of a tetrahedron.

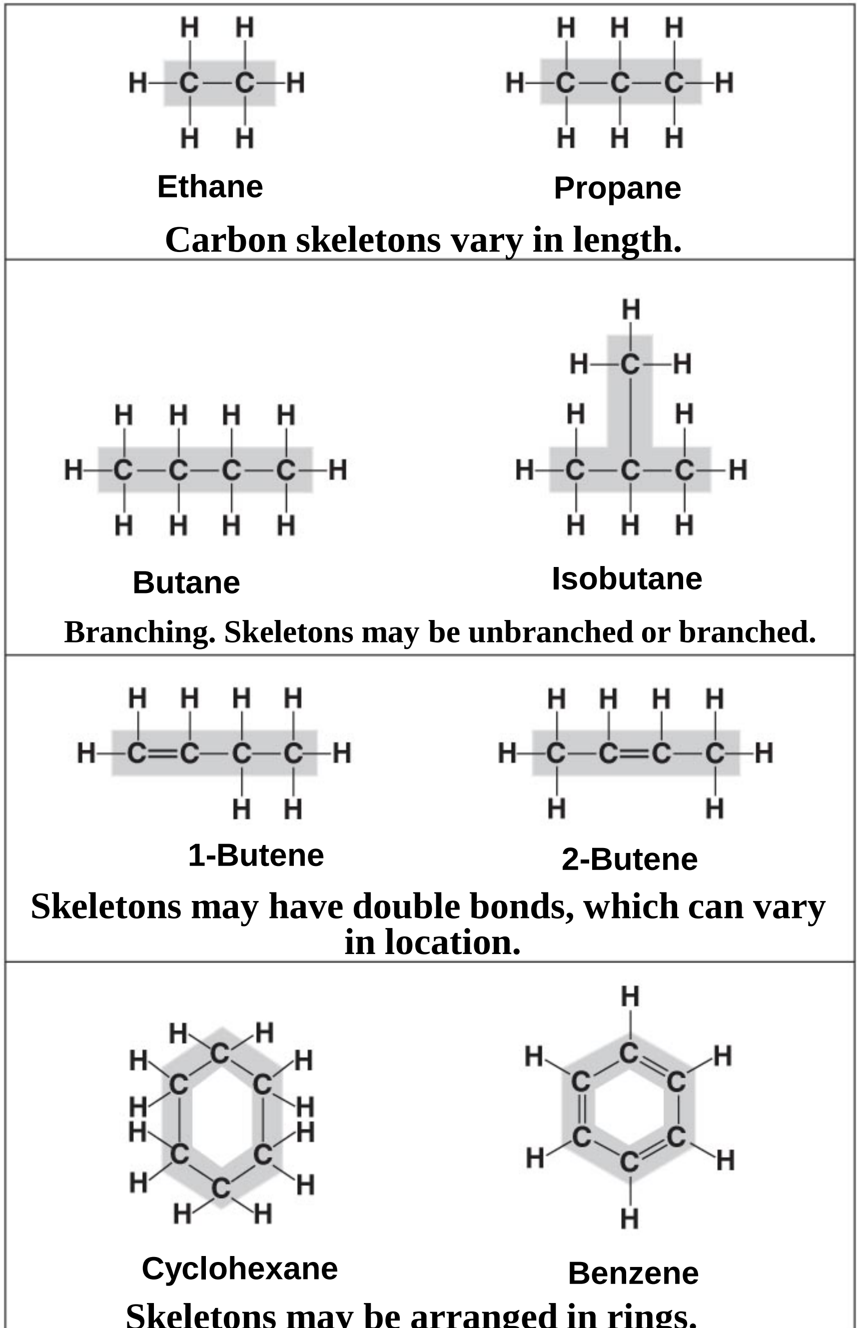
ORGANIC COMPOUNDS (Molecules)

- **Methane and other compounds composed of only carbon and hydrogen are called hydrocarbons**
- **Carbon atoms, with attached hydrogens, can bond together in chains of various lengths**

3.1 Life's molecular diversity is based on the properties of carbon

- A chain of carbon atoms is called a carbon skeleton
- Carbon skeletons can be branched or unbranched
- Therefore, different compounds with the same molecular formula can be produced
- These structures are called ISOMERS

Variations in carbon skeletons
التنوع في الهياكل الكربونية



3.2 Characteristic chemical groups help determine the properties of organic compounds

- An organic compound has unique properties that depend upon
  1. The size and shape of the molecule, and
  2. The groups of atoms (functional groups) attached to it.

- A functional group affects a biological molecule's function in a characteristic way

3.2 Characteristic chemical groups help determine the properties of organic compounds

- Compounds containing functional groups are hydrophilic (water-loving)
- This means that they are soluble in water, which is a necessary prerequisite for their roles in water-based life

3.2 Characteristic chemical groups help determine the properties of organic compounds

- The functional groups are

  - **Hydroxyl group** — consists of a hydrogen bonded to an oxygen
  - **Carbonyl group** — a carbon linked by a double bond to an oxygen atom
  - **Carboxyl group** — consists of a carbon bonded to a hydroxyl group and double-bonded to an oxygen
  - **Amino group** — composed of a nitrogen bonded to two hydrogen atoms and a carbon skeleton
  - **Phosphate group** — consists of a phosphorus atom bonded to four oxygen atoms

3.3 Cells make a huge number of large molecules from a small set of small molecules

- **There are four classes of biological molecules**
  1. Carbohydrates
  2. Proteins
  3. Lipids
  4. Nucleic acids

ORGANIC COMPOUNDS (Molecules)

- **The four classes of biological molecules contain very large molecules**
  - **They are often called macromolecules because of their large size**
  - **They are also called polymers because they are made from identical building blocks strung together**
  - **The building blocks are called monomers**

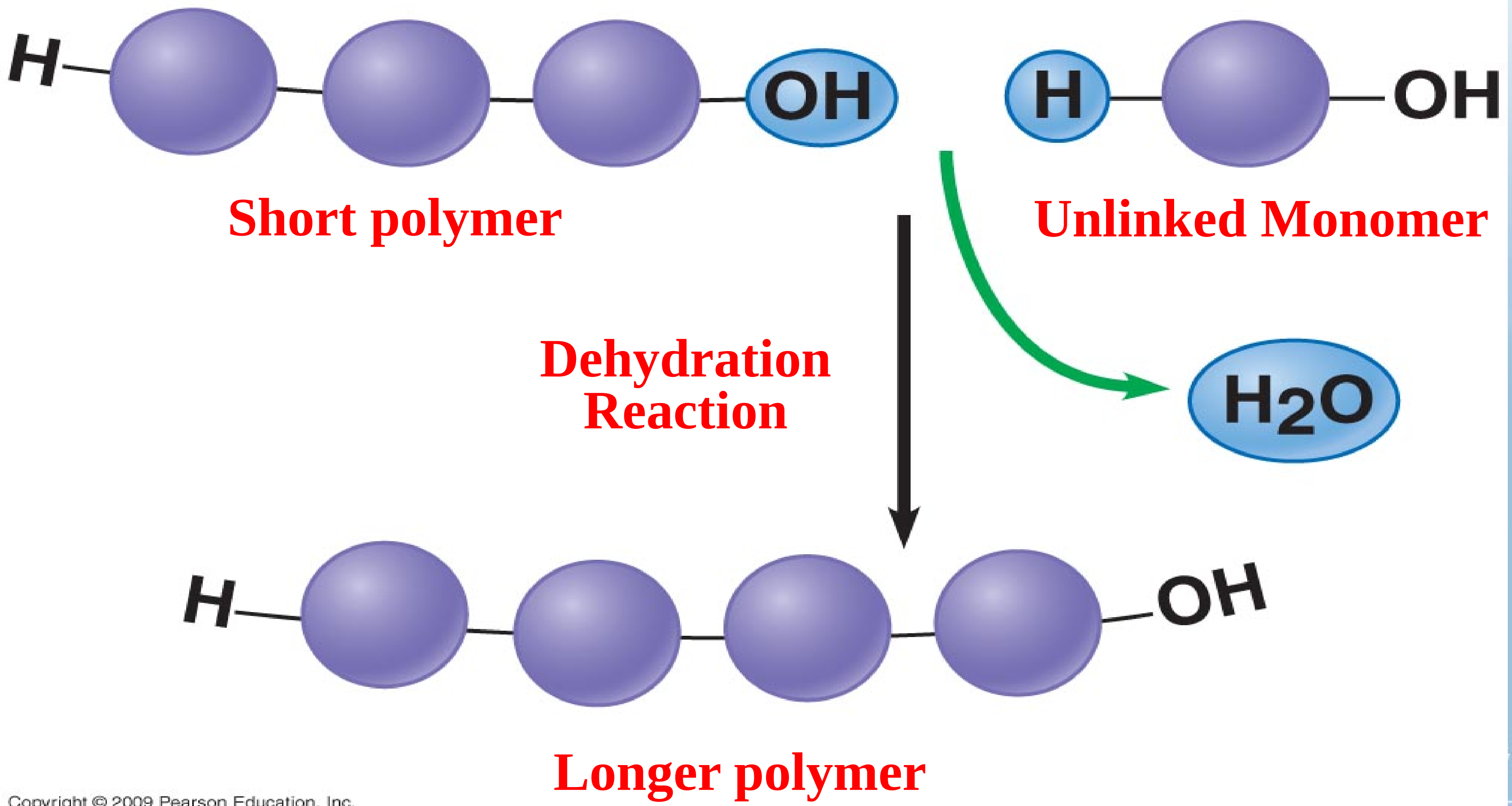
ORGANIC COMPOUNDS (Molecules)

- **Monomers are linked together to form polymers through dehydration reactions, which remove water**
- **Polymers are broken apart by hydrolysis, the addition of water**
- **All biological reactions of this sort are mediated by enzymes, which speed up chemical reactions in cells**

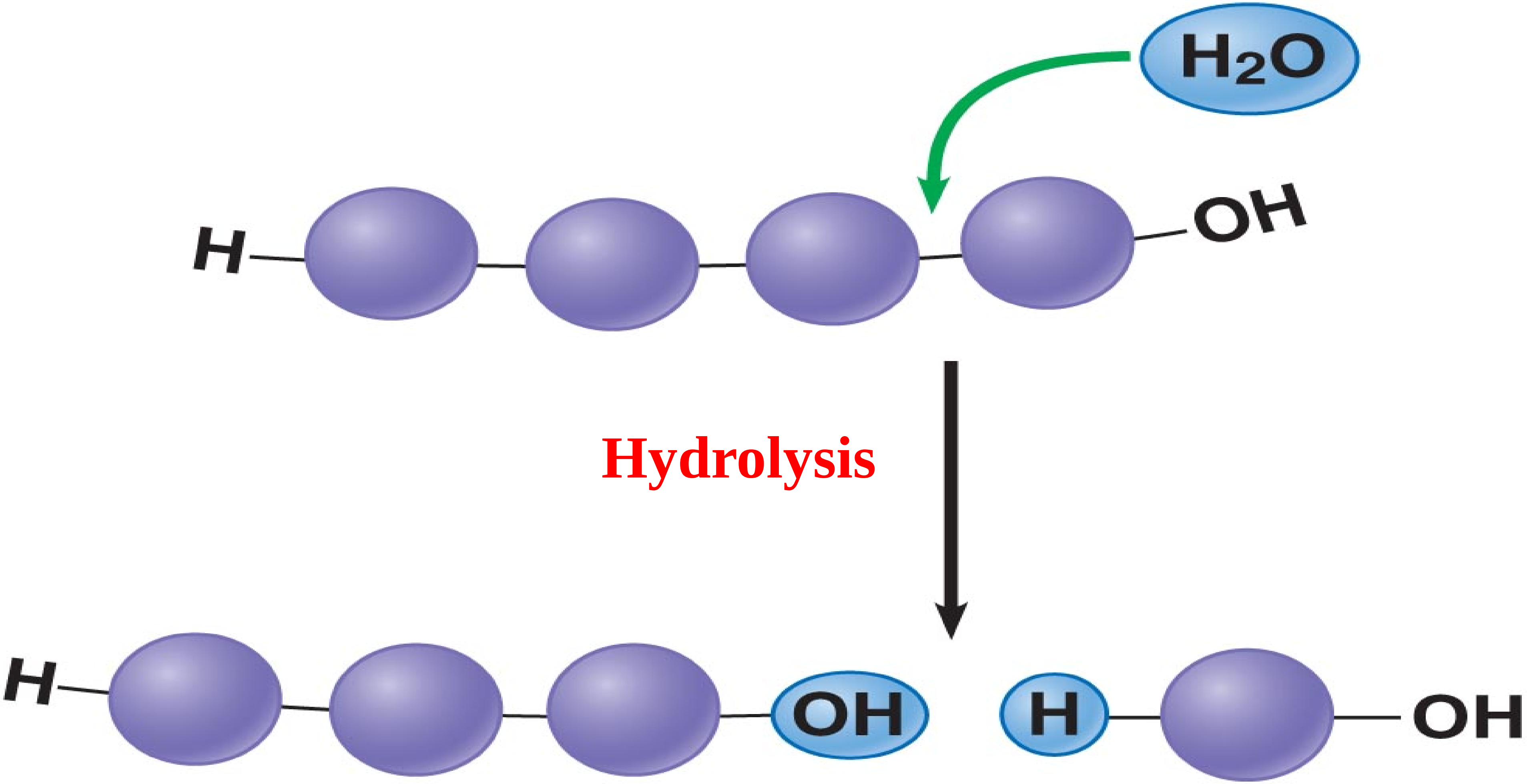
PLAY

Animation: Polymers

Dehydration reactions build a polymer chain



Hydrolysis breaks a polymer chain



CARBOHYDRATES

ORGANIC COMPOUNDS (Molecules)

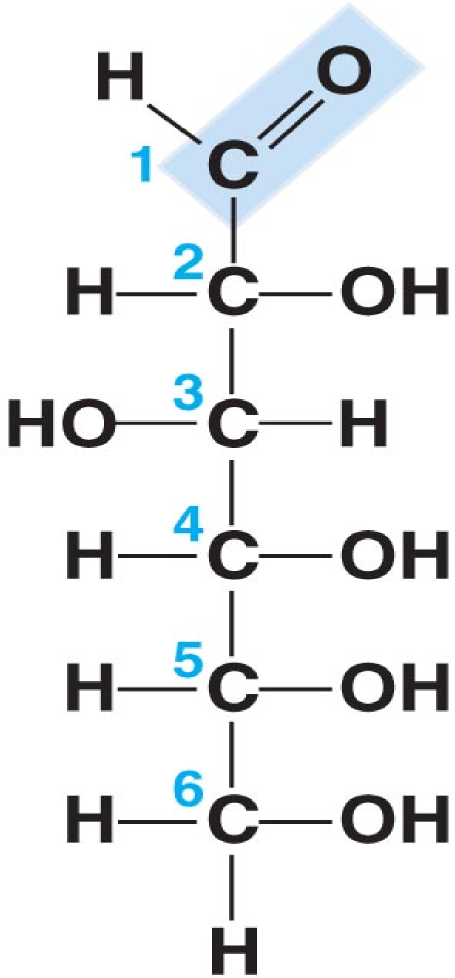
Monosaccharides are the simplest carbohydrates

- Carbohydrates range from small sugar molecules (monomers) to large polysaccharides
- Sugar monomers are monosaccharides, such as glucose and fructose
- These can be hooked together to form the polysaccharides

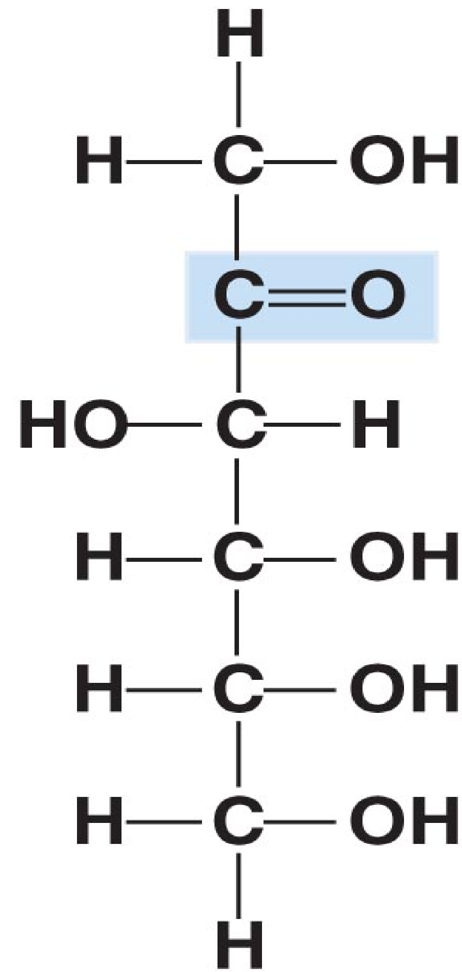
ORGANIC COMPOUNDS (Molecules)

- **The carbon skeletons of monosaccharides vary in length**
  - **Glucose and fructose are six carbons long**
  - **Others have three to seven carbon atoms**
- **Monosaccharides are the main fuels for cellular work**
  - **Monosaccharides are also used as raw materials to manufacture other organic molecules**

Structures of glucose and fructose ($C_6H_{12}O_6$)



Glucose
(an aldose)



Fructose
(a ketose)

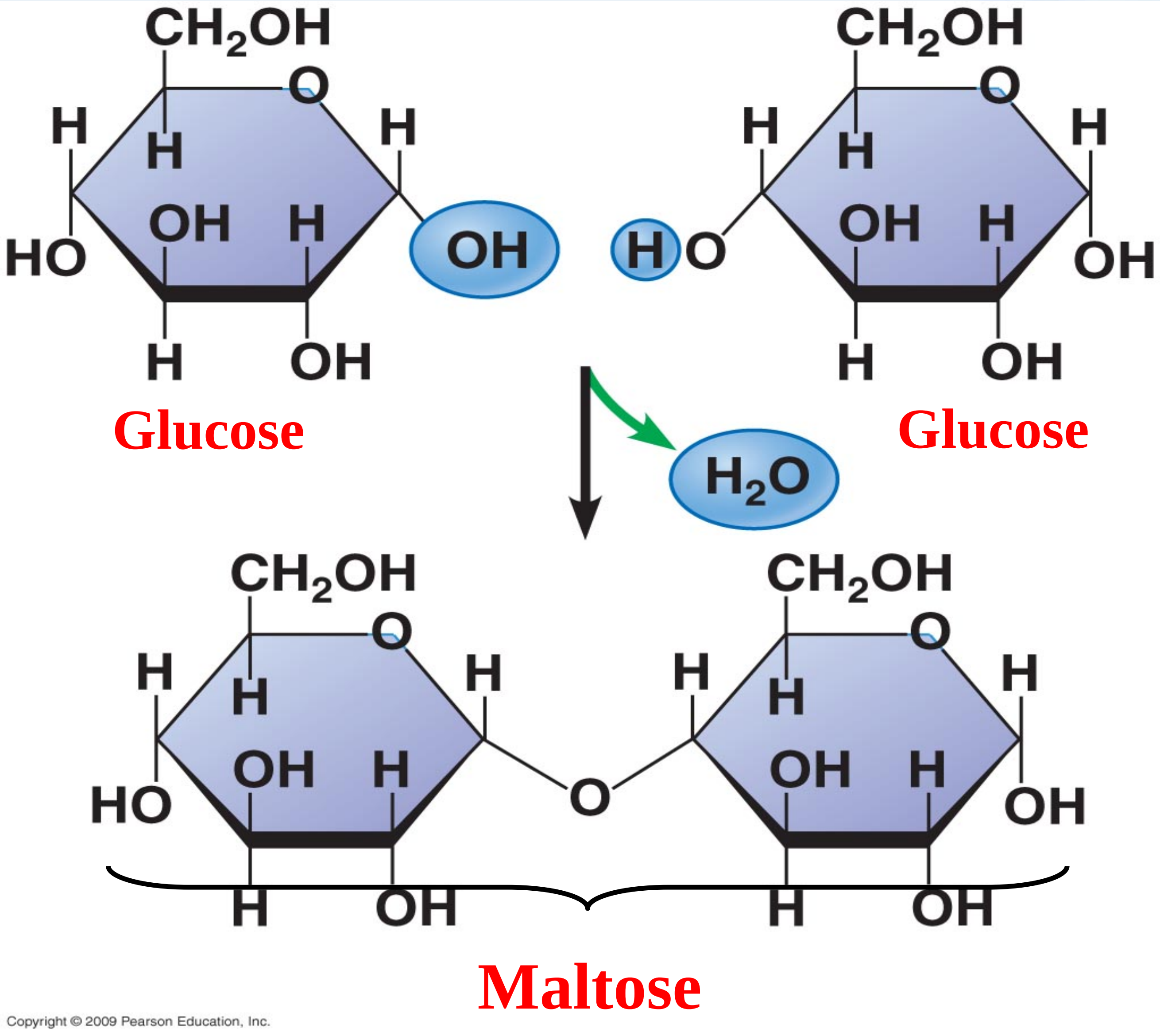
ORGANIC COMPOUNDS (Molecules)

Cells link two single sugars to form disaccharides

- **Two monosaccharides (monomers) can bond to form a disaccharide in a dehydration reaction**
- **An example is glucose monomer bonding to a fructose monomer to form sucrose, a common disaccharide**

PLAY Animation: Disaccharides

Disaccharide formation by a dehydration reaction

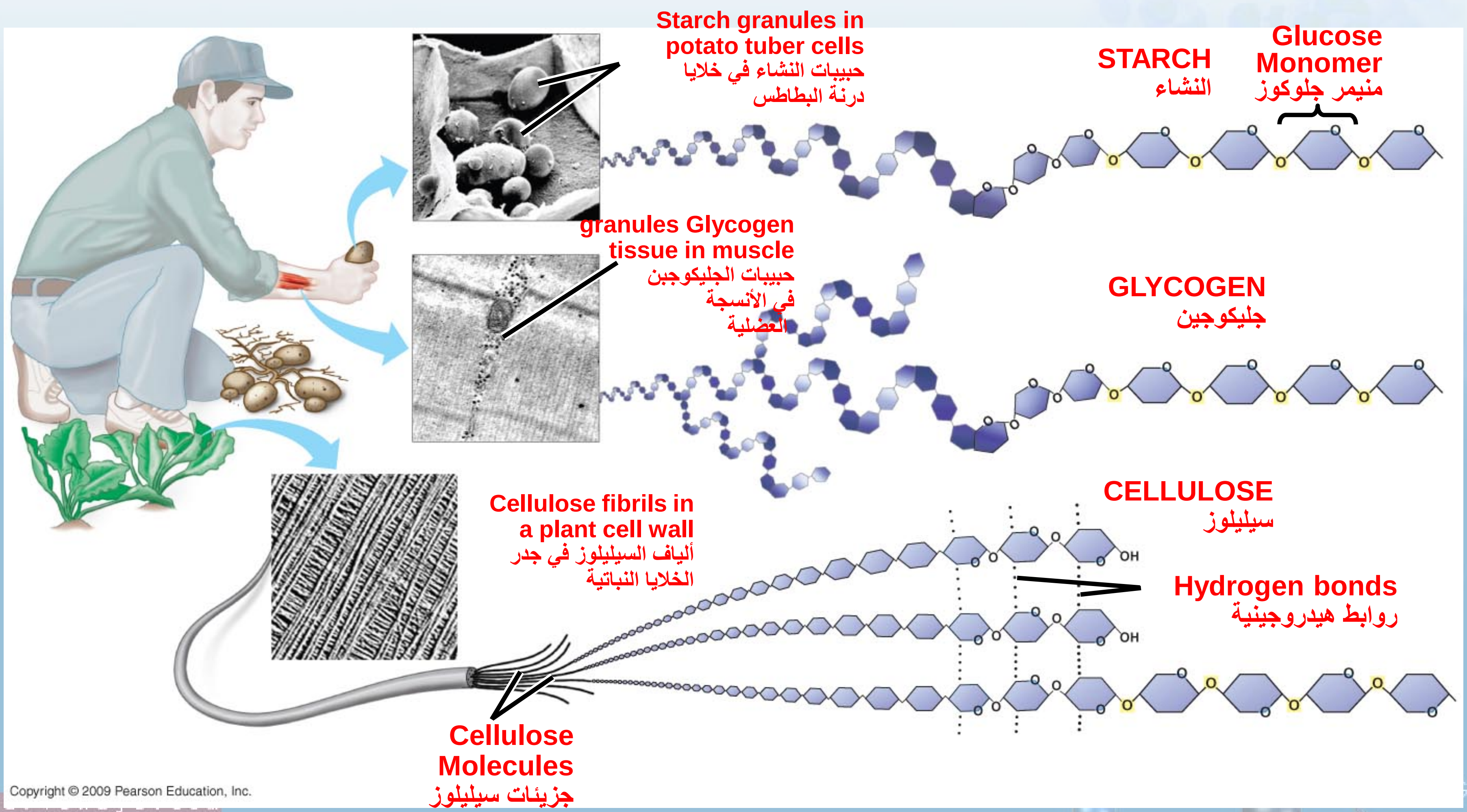


ORGANIC COMPOUNDS (Molecules)

Polysaccharides are long chains of sugar units

- **Starch** is a storage polysaccharide composed of glucose monomers and found in plants
- **Glycogen** is a storage polysaccharide composed of glucose, which is hydrolyzed by animals when glucose is needed
- **Cellulose** is a polymer of glucose that forms plant cell walls
- **Chitin** is a polysaccharide used by insects and crustaceans to build an exoskeleton

Polysaccharides



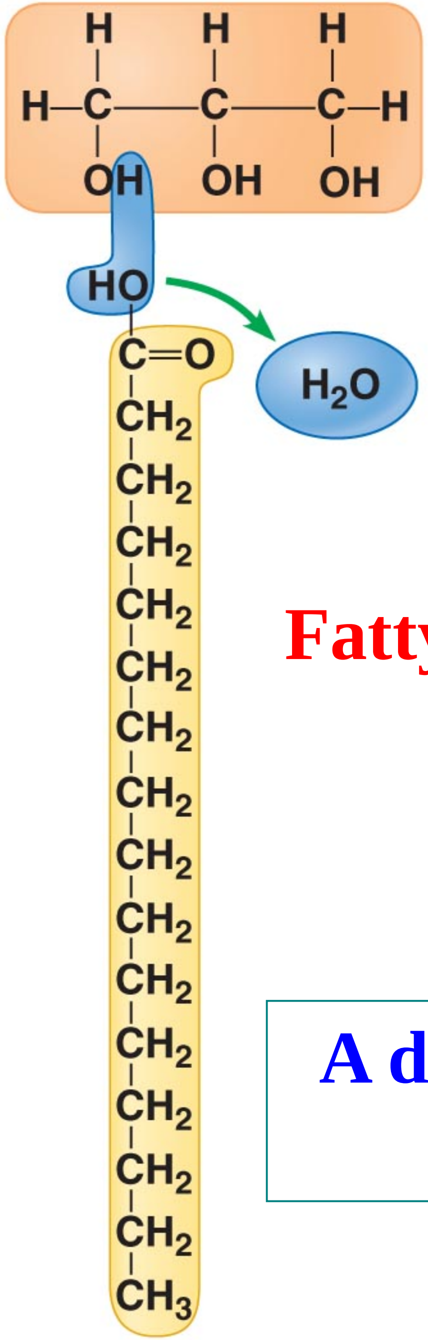
LIPIDS

اللبيدات (الشحوميات)

True Fats	Phospholipids	Steroids
الدهون الحقيقية	اللبيدات (الدهون) الفسفورية	الاستيرويدات

3.8 Fats are lipids that are mostly energy-storage molecules

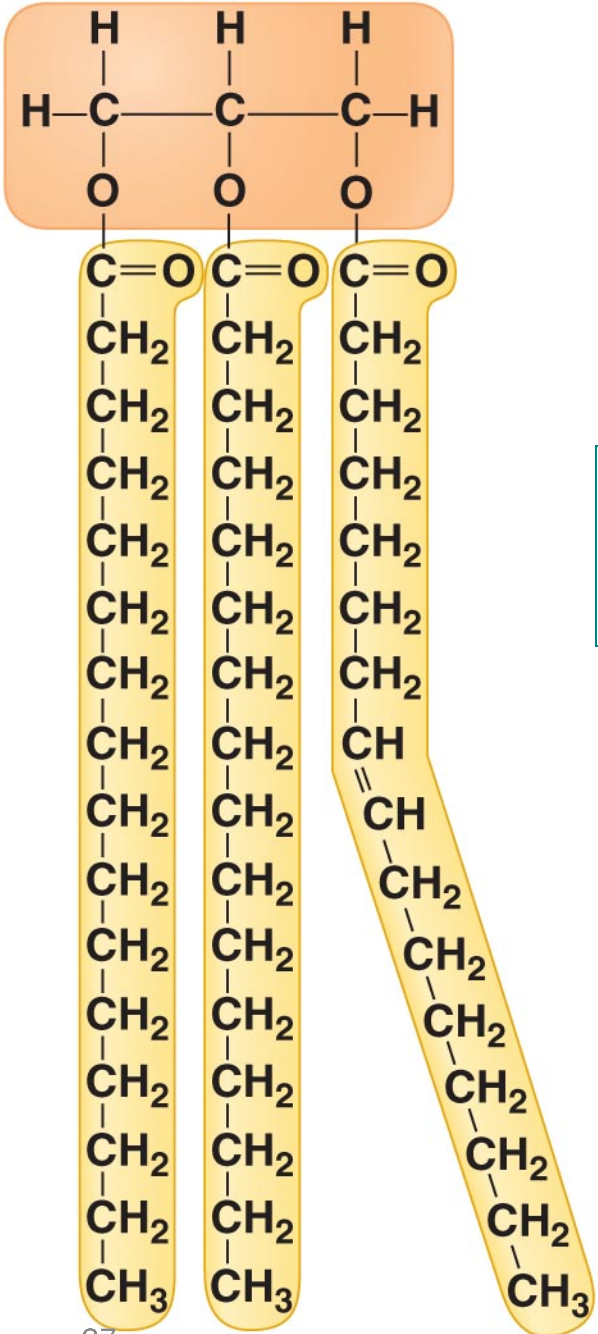
- **Lipids** are water insoluble (hydrophobic, or water fearing) compounds that are important in energy storage
  - They contain twice as much energy as a polysaccharide
- **Fats** are lipids made from glycerol and fatty acids
- Fatty acids link to glycerol by a dehydration reaction
  - A fat contains one glycerol linked to three fatty acids
  - Fats are often called triglycerides because of their structure



Glycerol

Fatty acid

A dehydration reaction linking a fatty acid to glycerol



A fat molecule made from glycerol and three fatty acids

ORGANIC COMPOUNDS (Molecules)

3.8 Fats are lipids that are mostly energy-storage molecules

- Some fatty acids contain double bonds

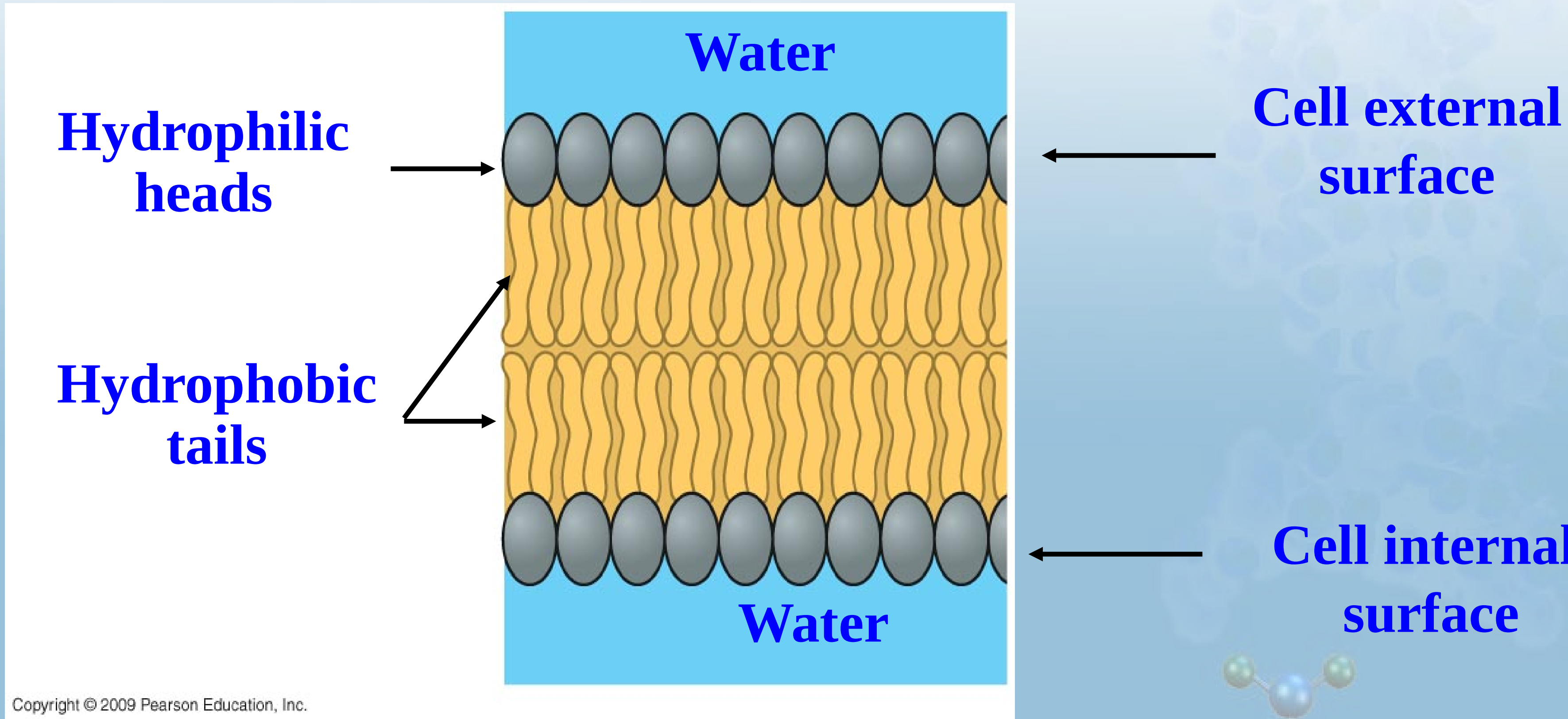
1. This causes kinks or bends in the carbon chain because the maximum number of hydrogen atoms cannot bond to the carbons at the double bond
2. These compounds are called **unsaturated fats** because they have fewer than the maximum number of hydrogens
3. Fats with the maximum number of **hydrogens** are called **saturated fats**

3.9 Phospholipids and steroids are important lipids with a variety of functions

- **Phospholipids** are structurally similar to fats and are an important component of all cells

1. For example, they are a major part of **cell membranes**, in which they cluster into a **bilayer** of phospholipids
2. The **hydrophilic heads** are in contact with the water of the environment and the internal part of the cell
3. The **hydrophobic tails** band in the center of the bilayer

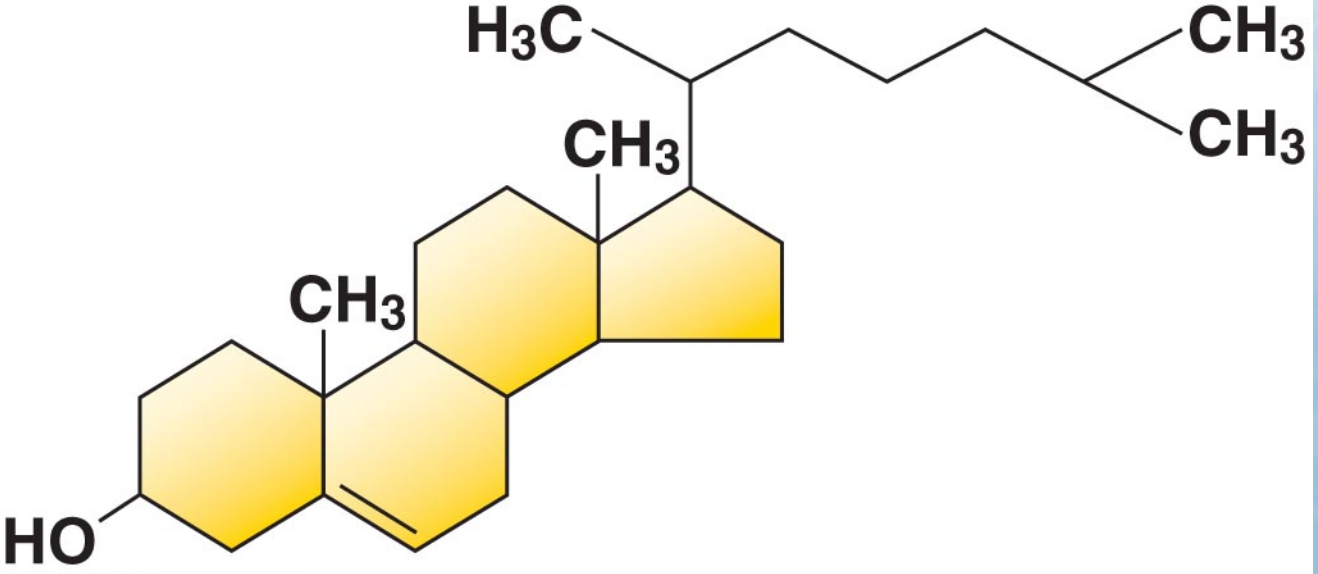
Section of a phospholipid membrane



3.9 Phospholipids and steroids are important lipids with a variety of functions

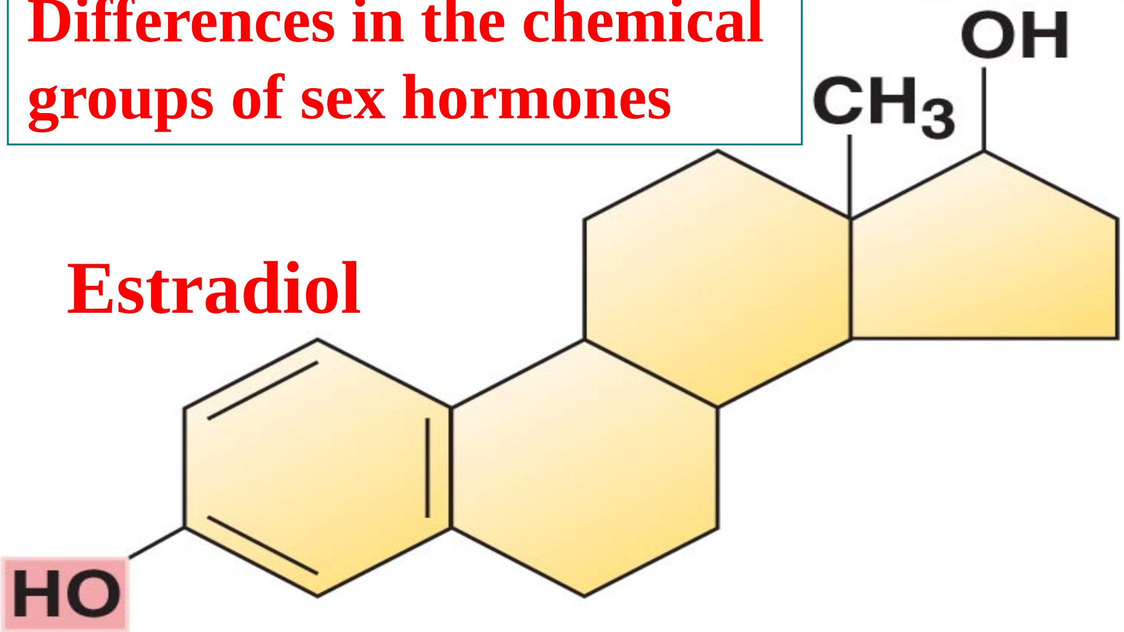
- **Steroids are lipids composed of fused ring structures**
- **Cholesterol is an example of a steroid that plays a significant role in the structure of the Cell Membrane**
- **In addition, cholesterol is the compound from which we synthesize Sex Hormones**

Cholesterol, a steroid

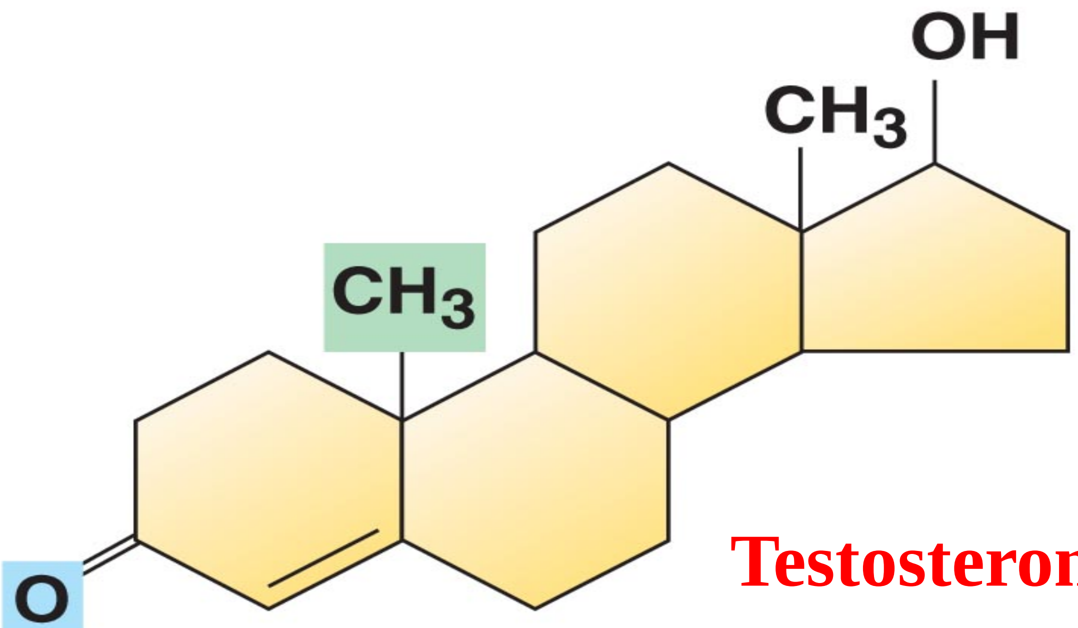


Differences in the chemical groups of sex hormones

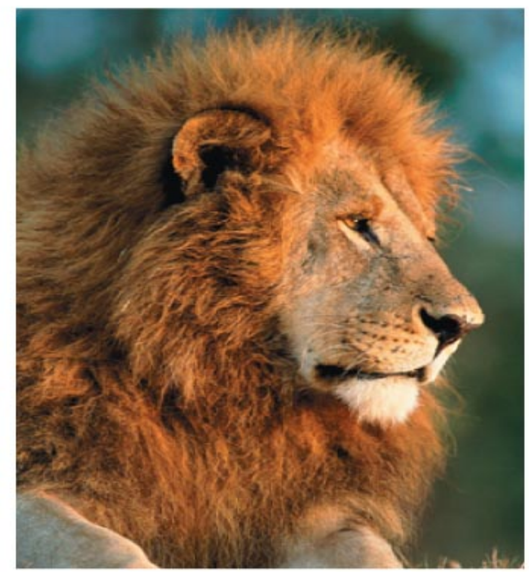
Estradiol



Testosterone



Female lion



Male lion

PROTEINS

3.11 Proteins are essential to the structures and functions of life

- **A protein** is a polymer built from various combinations of 20 amino acid monomers
  - Proteins have unique structures that are directly related to their functions
  - **Enzymes**, proteins that serve as metabolic catalysts, regulate the chemical reactions within cells

ORGANIC COMPOUNDS (Molecules)

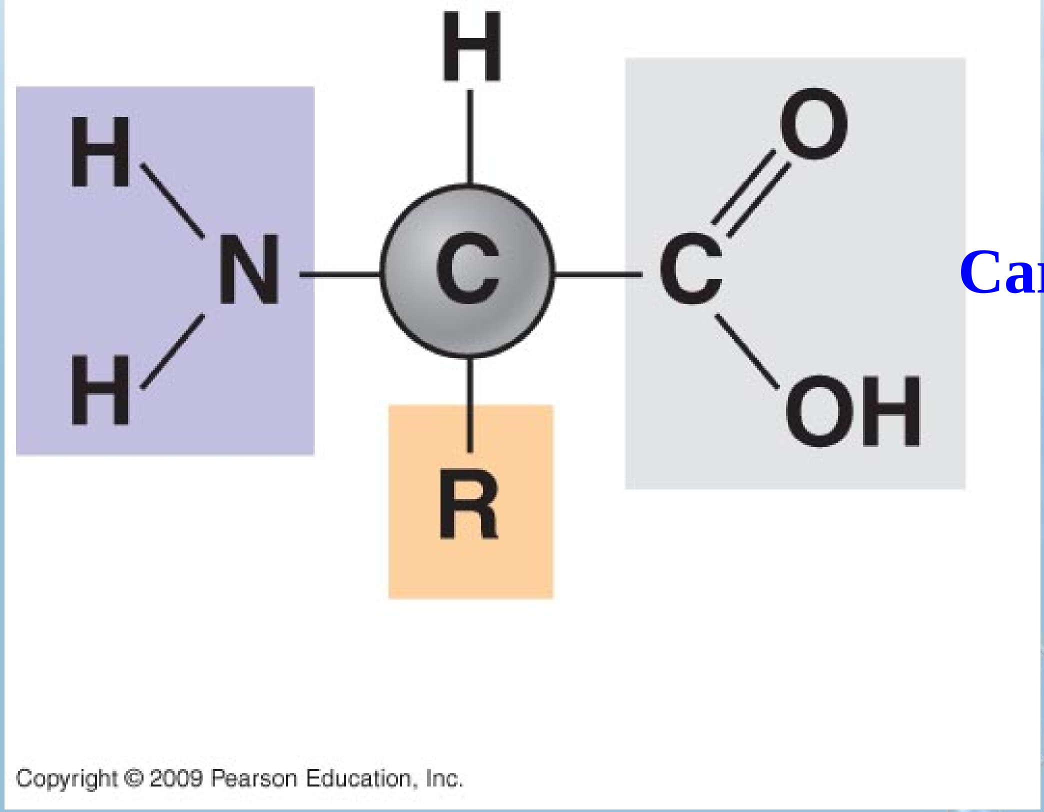
- **Structural proteins provide associations between body parts**
- **Contractile proteins are found within muscle**
- **Defensive proteins include antibodies of the immune system**
- **Signal proteins are best exemplified by the hormones**
- **Receptor proteins serve as antenna for outside signals**
- **Transport proteins carry oxygen**

3.12 Proteins are made from amino acids linked by peptide bonds

- **Amino acids, the building blocks of proteins, have an amino group and a carboxyl group**
- **covalently bonded to a central carbon atom**
  - **Also bonded to the central carbon is a hydrogen atom and some other chemical group symbolized by R**

General structure of an amino acid

Amino Group

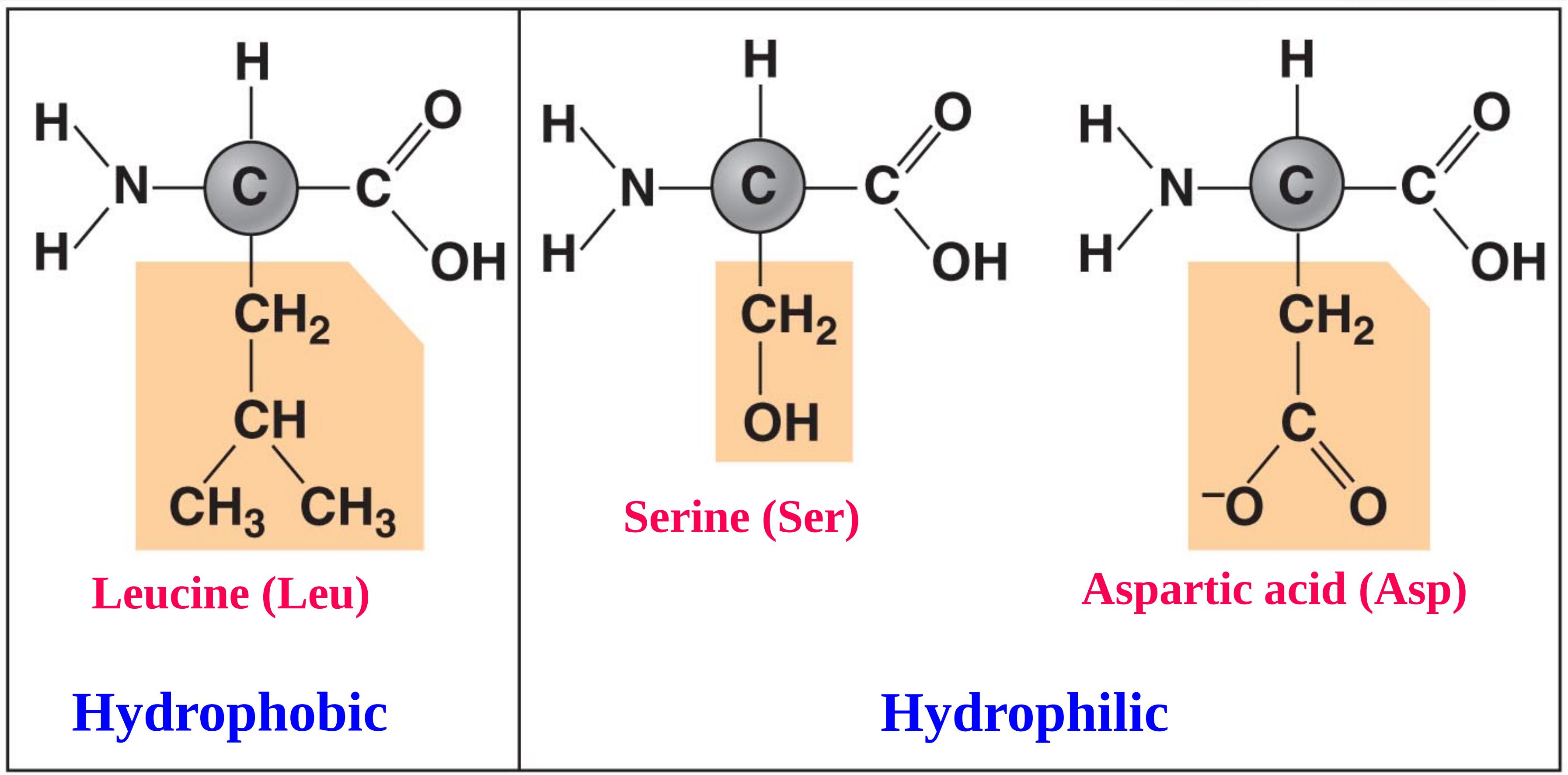


Carboxyl group

ORGANIC COMPOUNDS (Molecules)

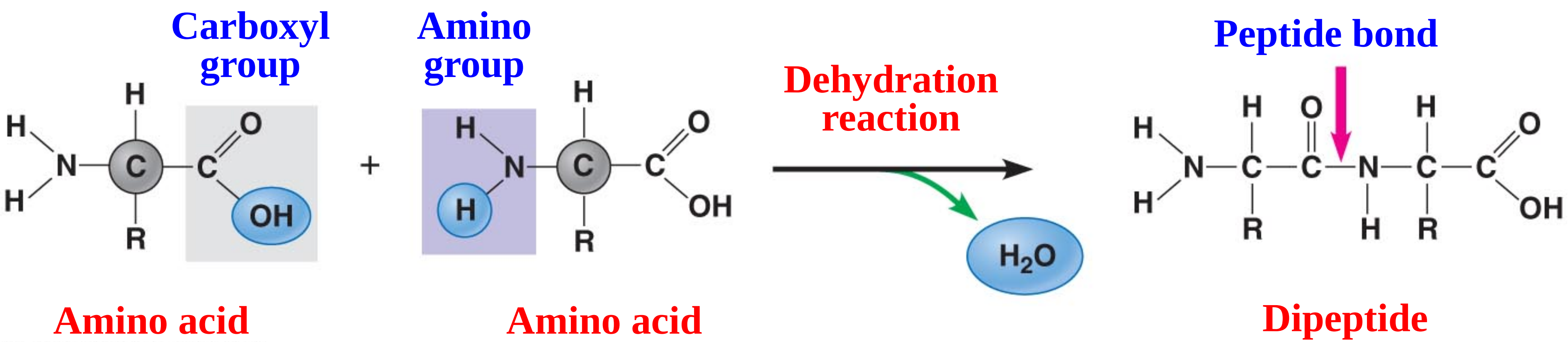
- **Amino acids are classified as hydrophobic or hydrophilic**
  - **Some amino acids have a non-polar R group and are hydrophobic**
  - **Others have a polar R group and are hydrophilic, which means they easily dissolve in aqueous solutions**

Examples of amino acids with hydrophobic and hydrophilic R groups



- **Amino acid monomers are linked together to form polymeric proteins**
  - **This is accomplished by an enzyme-mediated dehydration reaction**
  - **This links the carboxyl group (COOH) of one amino acid to the amino group (NH_2) of the next amino acid. The covalent linkage resulting is called a peptide bond**

Peptide bond formation



3.13 A protein's specific shape determines its function

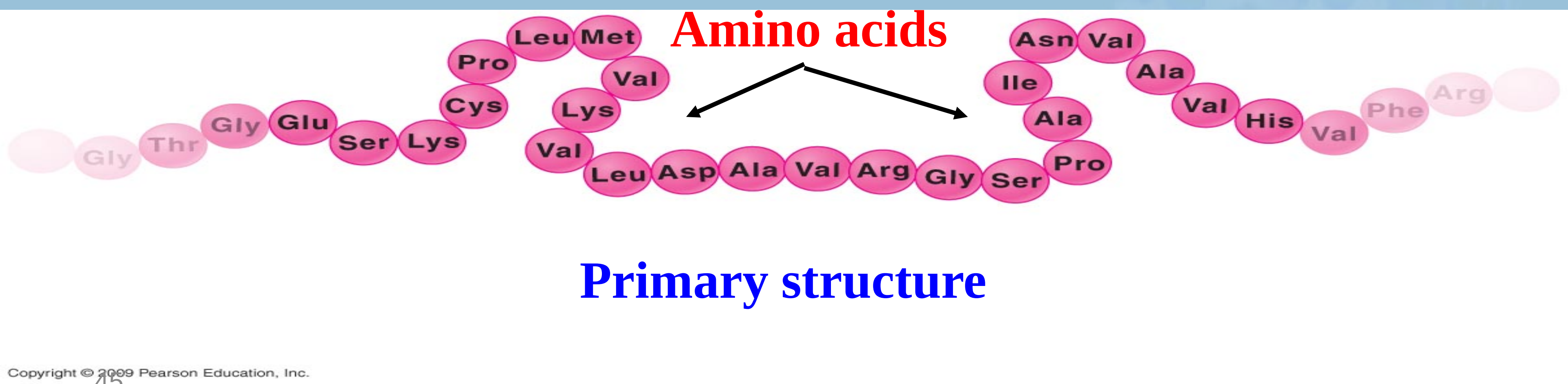
- A polypeptide chain contains hundreds or thousands of amino acids linked by peptide bonds
  - The amino acid sequence causes the polypeptide to assume a particular shape
  - The shape of a protein determines its specific function

3.14 A protein's shape depends on four levels of structure

- A protein can have four levels of structure
  - Primary structure التركيب الاولي
  - Secondary structure التركيب الثانوي
  - Tertiary structure التركيب الثالثي
  - Quaternary structure التركيب الرباعي

3.14 A protein's shape depends on four levels of structure

- The primary structure of a protein is its unique amino acid sequence
  - The correct amino acid sequence is determined by the cell's genetic information
  - The slightest change in this sequence affects the protein's ability to function



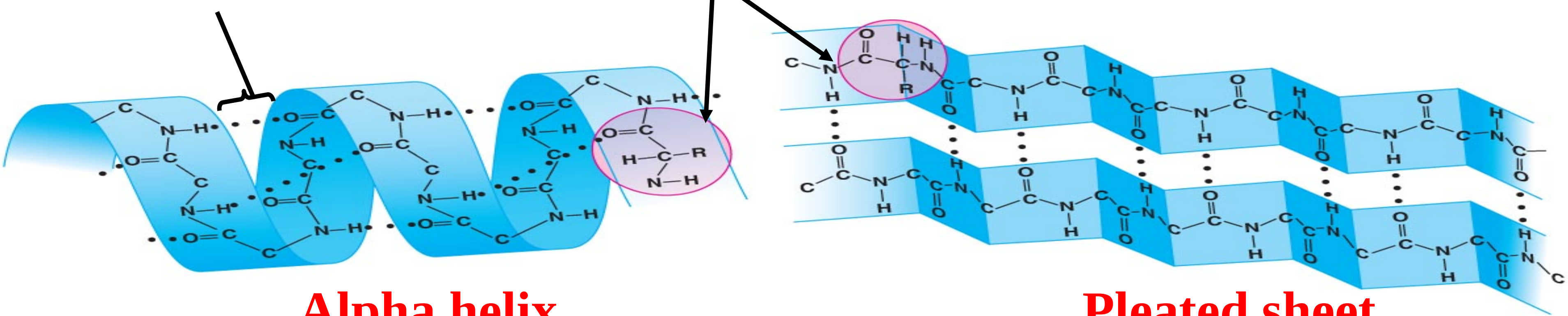
Primary structure

ORGANIC COMPOUNDS (Molecules)

- **Protein secondary structure results from coiling or folding of the polypeptide**
  - **Coiling results in a helical structure called an alpha helix**
  - **Folding may lead to a structure called a pleated sheet**
  - **Coiling and folding result from hydrogen bonding between certain areas of the polypeptide chain**

Hydrogen bond

Amino acids



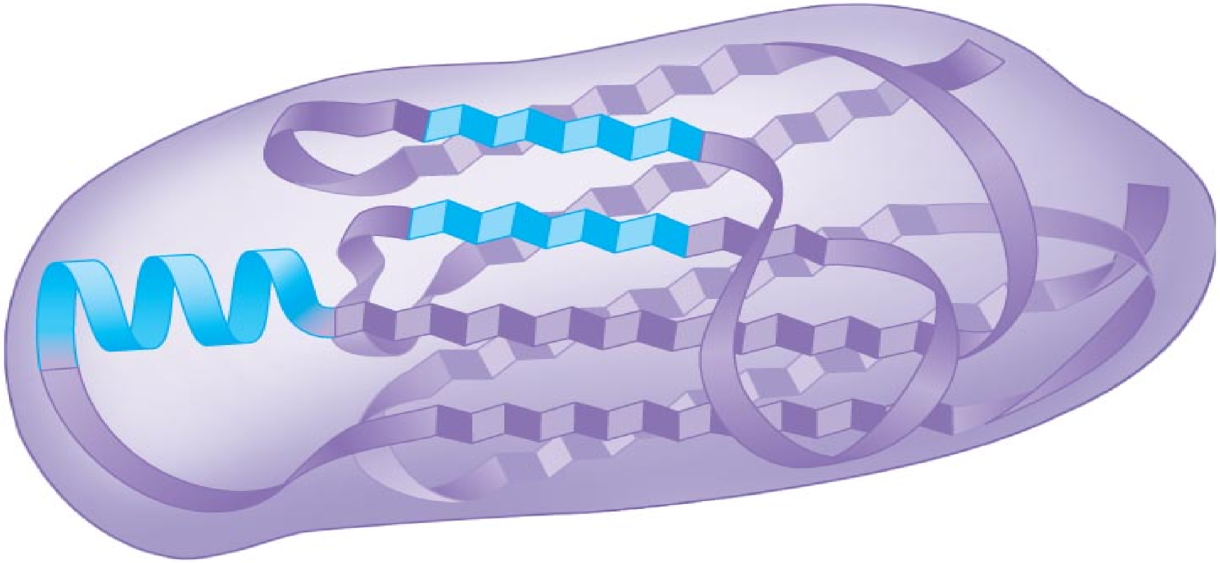
Alpha helix

Pleated sheet

Secondary structure

ORGANIC COMPOUNDS (Molecules)

- **The overall three-dimensional shape of a protein is called its tertiary structure**
  - **Tertiary structure generally results from interactions between the R groups of the various amino acids**
  - **Disulfide bridges are covalent bonds that further strengthen the protein's shape**



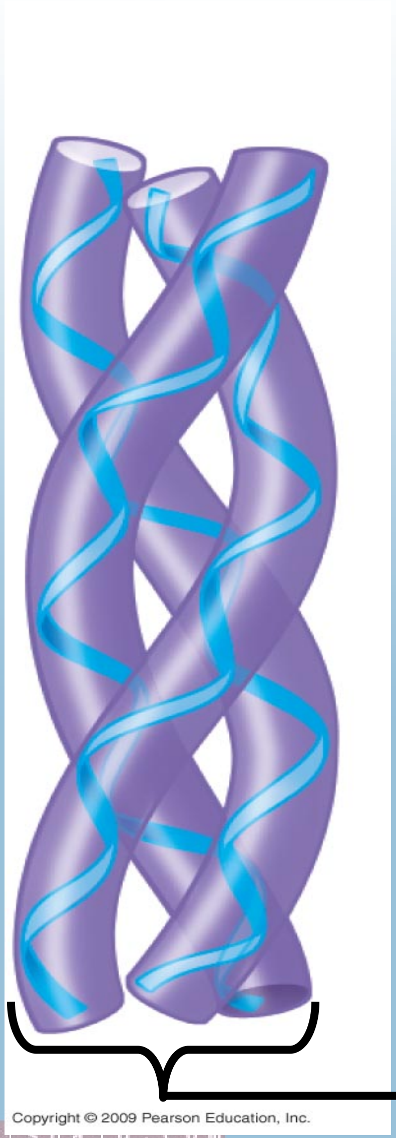
Globular Polypeptide (single subunit of transthyretin)

Tertiary structure

ORGANIC COMPOUNDS (Molecules)

- **Two or more polypeptide chains (subunits) associate providing quaternary structure**
  - **Collagen is an example of a protein with quaternary structure**
  - **Its triple helix gives great strength to connective tissue, bone, tendons and ligaments**

Polypeptide chain (alpha helix)

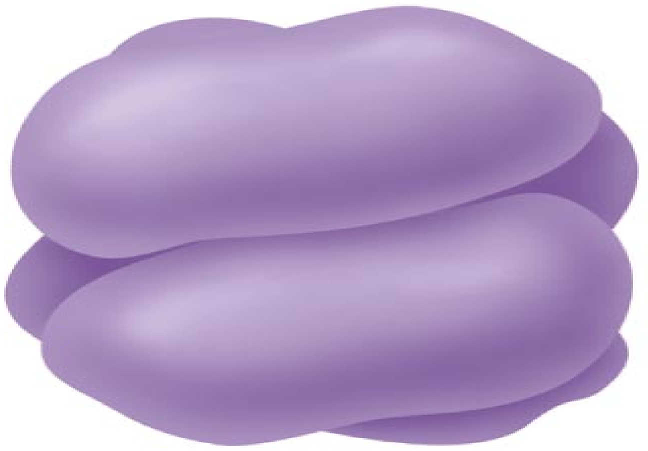


- **Collagen** is a fibrous protein with helical subunits interwind into a larger triple helix.
- This arrangement gives the long fibers great strength

Triple helix

Collagen fiber

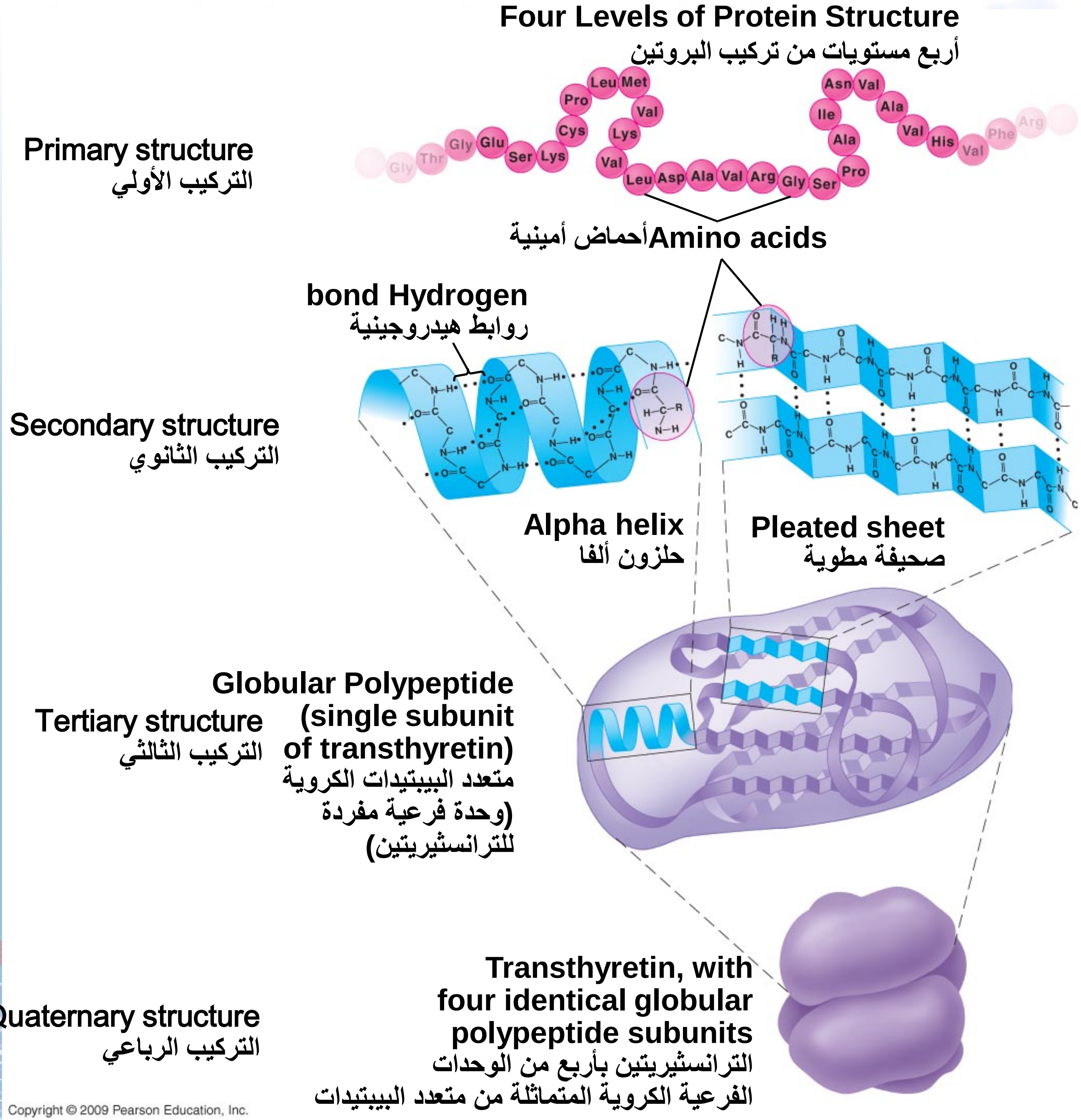
Transthyretin, with four identical globular polypeptide subunits



Quaternary structure

Transthyretin:

A plasma protein consisting of 127 amino acids that binds retinol and thyroxine


Four Levels of Protein Structure
أربع مستويات من تركيب البروتين
Primary structure
التركيب الأولي
Gly Thr Gly Glu Ser Lys Cys Pro Leu Met Val Lys Val Leu Asp Ala Val Arg Gly Ser Pro Ala Ile Asn Val Ala Val His Val Phe Arg
أحماض أمينية Amino acids
bond Hydrogen
روابط هيدروجينية
Secondary structure
التركيب الثانوي
Alpha helix
حلزون ألفا
Pleated sheet
صحيفة مطوية
Tertiary structure
التركيب الثالثي
Globular Polypeptide (single subunit of transthyretin)
متعدد الببتيدات الكروية (وحدة فرعية مفردة للترانسثيريتين)
Quaternary structure
التركيب الرباعي
Transthyretin, with four identical globular polypeptide subunits
الترانسثيريتين بأربع من الوحدات الفرعية الكروية المتماثلة من متعدد الببتيدات
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3.13 A protein's specific shape determines its function

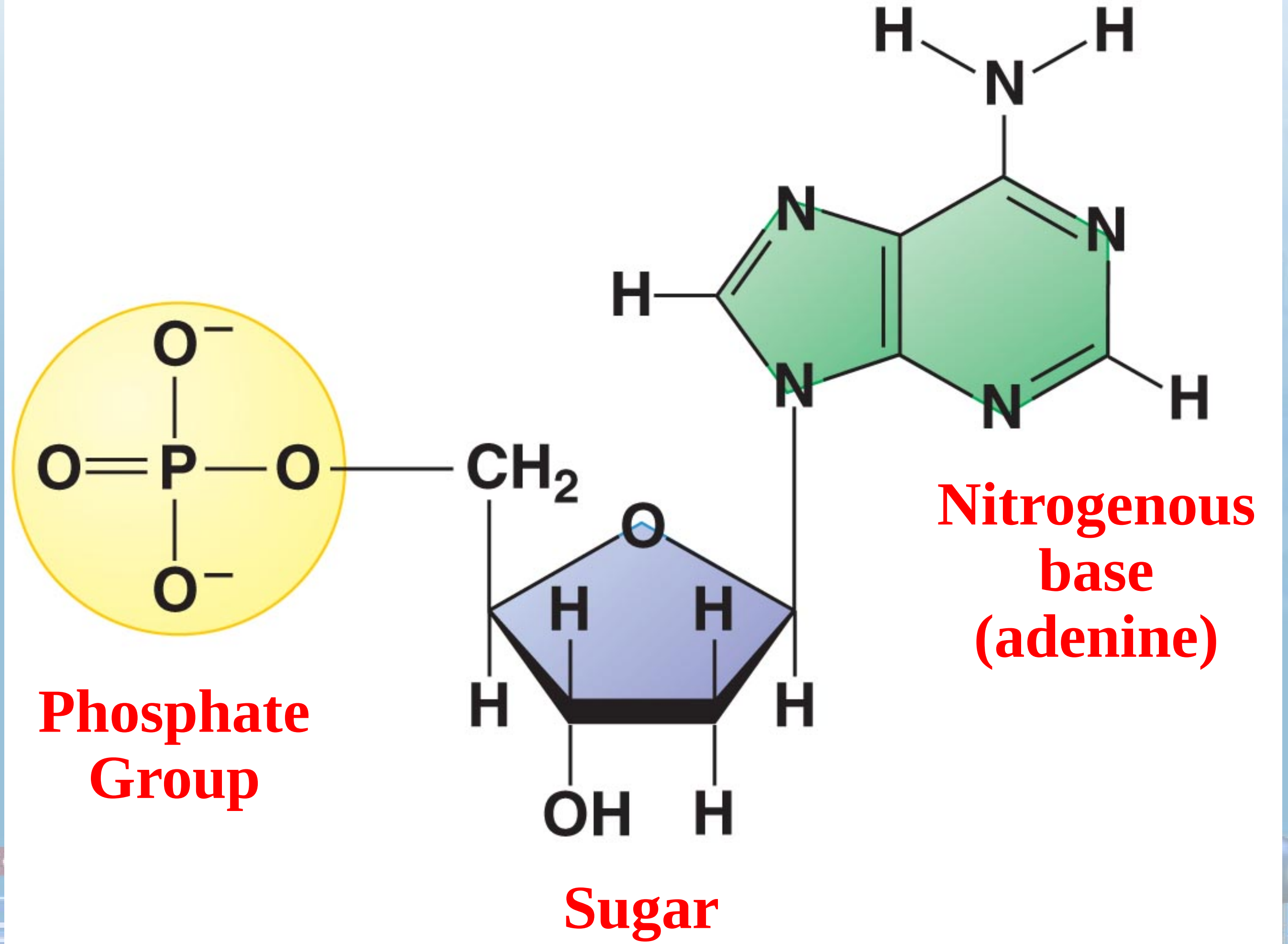
- **If for some reason a protein's shape is altered, it can no longer function**
  - **Denaturation will cause polypeptide chains to unravel and lose their shape and, thus, their function**
  - **Proteins can be denatured by changes in salt concentration and pH**

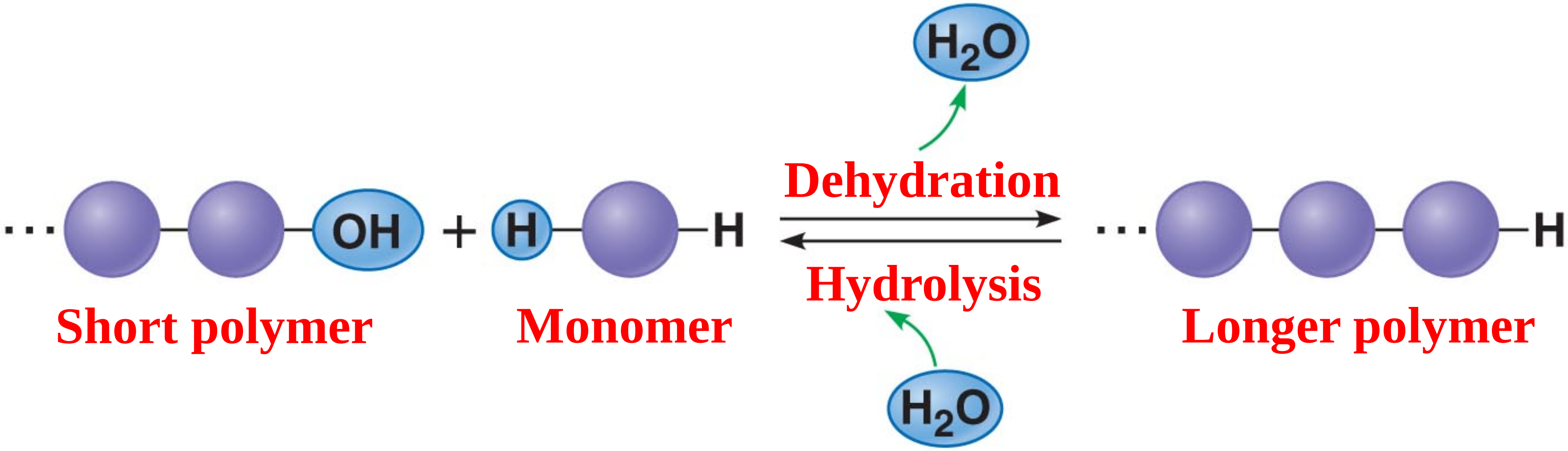
NUCLEIC ACIDS

3.16 Nucleic acids are information-rich polymers of nucleotides

- **DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) are composed of monomers called nucleotides**
  - **Nucleotides have three parts**
    1. **A five-carbon sugar called ribose in RNA and deoxyribose in DNA**
    2. **A phosphate group**
    3. **A nitrogenous base**

Nucleotide, consisting of a phosphate group, sugar, and a nitrogenous base




H_2O
Dehydration
OH
H
H
H
Hydrolysis
Short polymer
Monomer
Longer polymer
H_2O

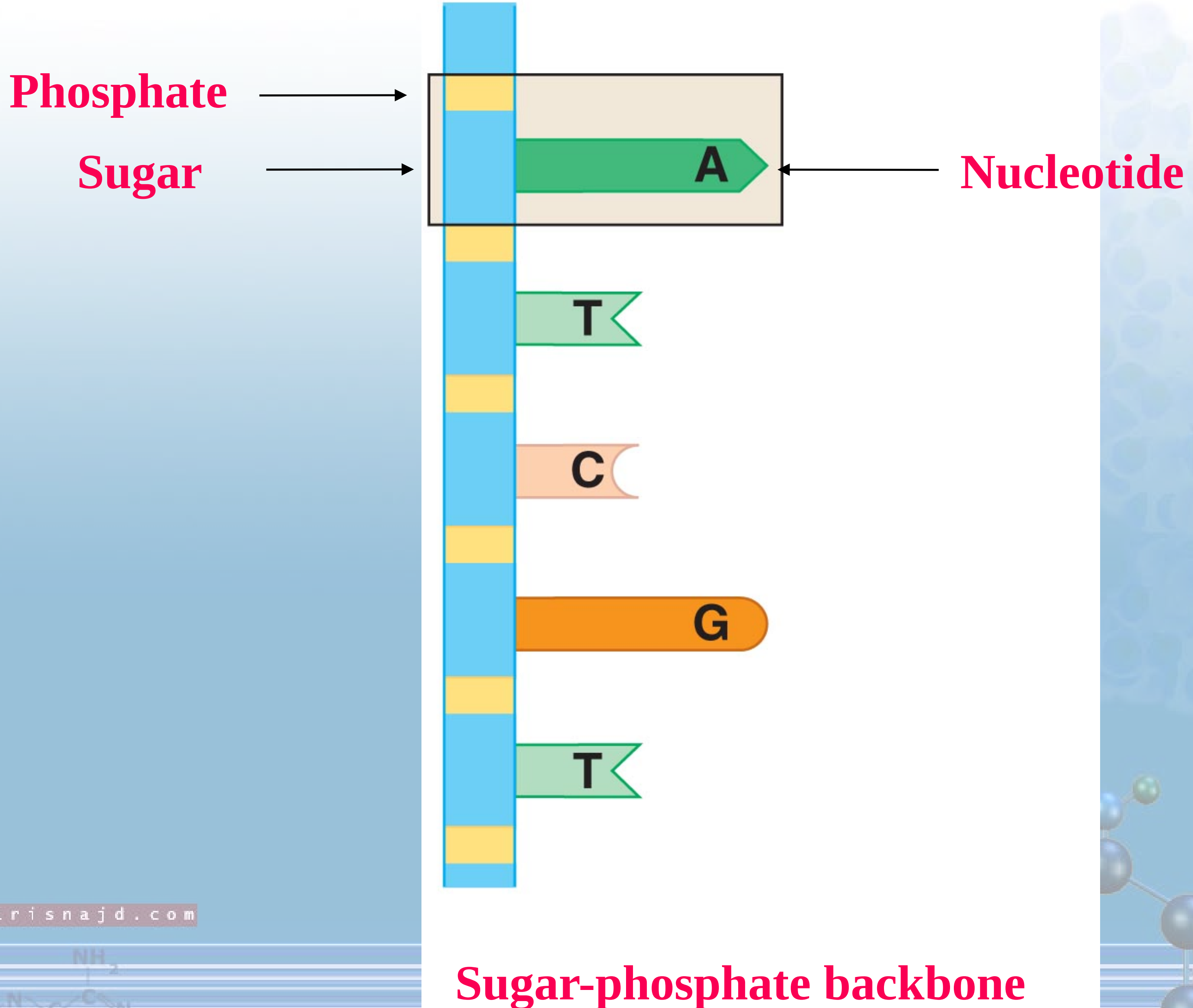
3.16 Nucleic acids are information-rich polymers of nucleotides

- **DNA nitrogenous bases are:**
- **adenine (A), thymine (T), cytosine (C), and guanine (G)**
- **RNA also has A, C, and G, but instead of thymine (T), it has uracil (U)**

3.16 Nucleic acids are information-rich polymers of nucleotides

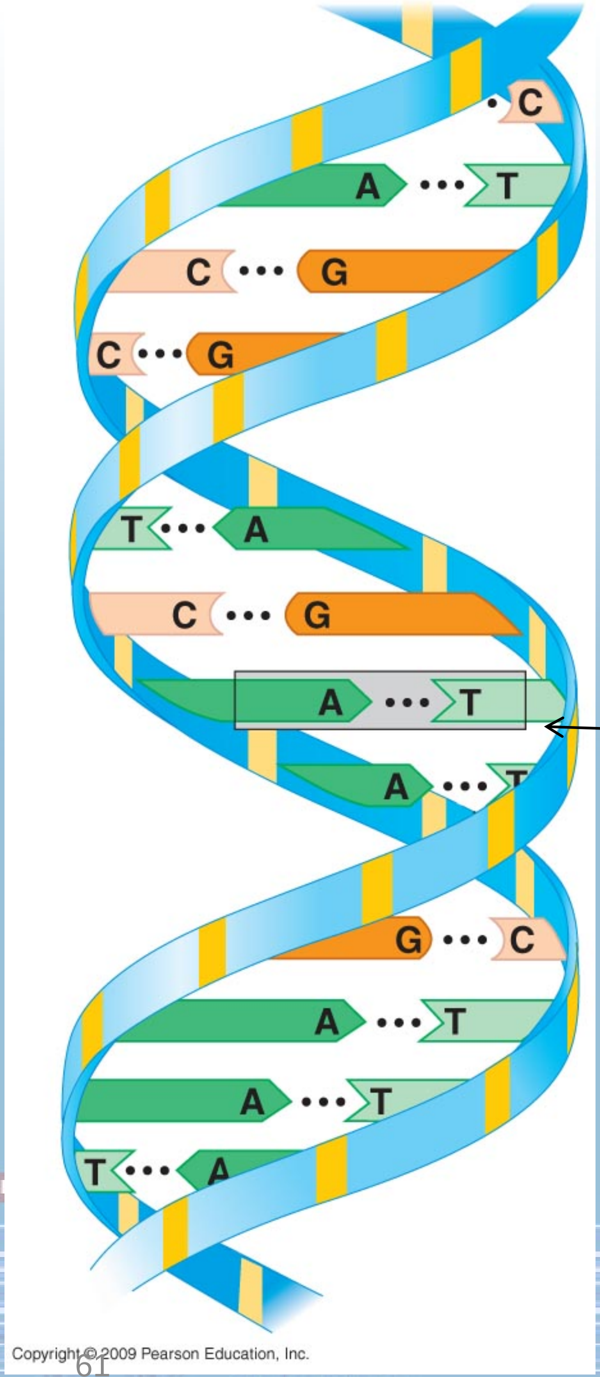
- A nucleic acid polymer is a **polynucleotide**. It is formed when the **phosphate group** of a nucleotide monomer bonds to the **sugar** of the next nucleotide

- The result is a repeating **sugar-phosphate backbone** with protruding **nitrogenous bases**


Phosphate
Sugar
Nucleotide
A
T
C
G
T
Sugar-phosphate backbone

3.16 Nucleic acids are information-rich polymers of nucleotides

- Two polynucleotide strands wrap around each other to form a DNA double helix
  - The two strands are associated because particular bases always hydrogen bond to one another
  - Usually A pairs with T, and C pairs with G, producing base pairs
- RNA is usually a single polynucleotide strand



DNA double helix

Base pair

ORGANIC COMPOUNDS (Molecules)

- A particular nucleotide sequence that can instruct the formation of a polypeptide is called a gene
  - Most DNA molecules consist of millions of base pairs and, consequently, many genes
  - These genes, many of which are unique to the species, determine the structure of proteins and, thus, life’s structures and functions