2_ The Molecules of Life

Introduction to Organic Compounds

Carbohydrates

Lipids

Proteins

Nucleic Acids

After completing this topic, you should be able to:

1. **Describe** the importance of carbon to life's molecular diversity.
2. **Define** isomers
3. **Define** macromolecules, monomer and polymer.
4. **Compare** dehydration and hydrolysis reactions.
5. **Explain** how a cell can make a variety of large molecules from a small set of molecules.
6. **Define** monosaccharides, disaccharides, and polysaccharides and explain their functions.
7. **Define** lipids, phospholipids, and steroids and explain their functions.
8. **Describe** the chemical structure of proteins and the importance of proteins to cells.
9. **Describe** the chemical structure of nucleic acids and explain how they relate to inheritance.

Introduction to Organic Compounds

- Properties of carbon
- Functional groups
- Cells make/break large molecules

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

- Almost all the molecules a cell makes are composed of carbon bonded to
  - other carbons
  - atoms of other elements
- Carbon-based molecules are called **organic compounds**
- By sharing electrons, carbon can
  - bond to four other atoms
  - branch in up to four directions

Hydrocarbons

- Methane (CH_4)and other compounds composed of only carbon and hydrogen are called **hydrocarbons**
- Carbon, with attached hydrogens, can form chains of various lengths
- A **carbon skeleton** is a chain of carbon atoms that can differ in length and be
  - straight
  - branched
  - arranged in rings

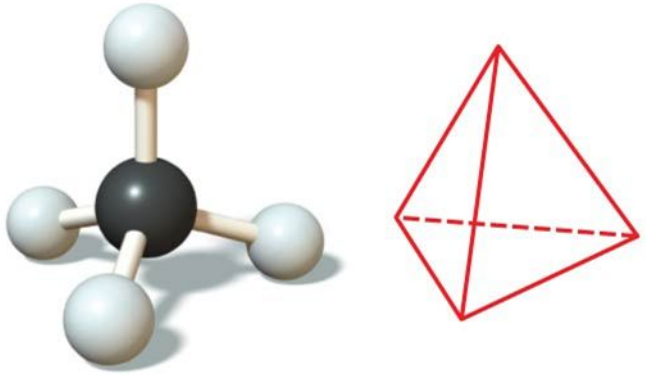
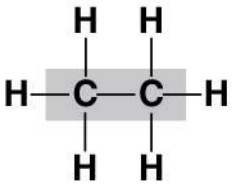
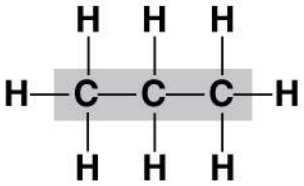


Figure 2.1b

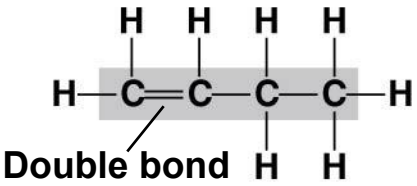


Ethane

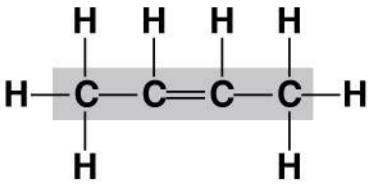


Propane

Length: Carbon skeletons vary in length.

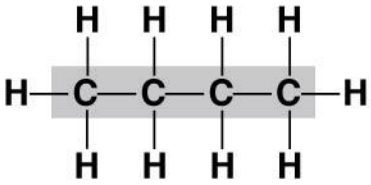


1-Butene

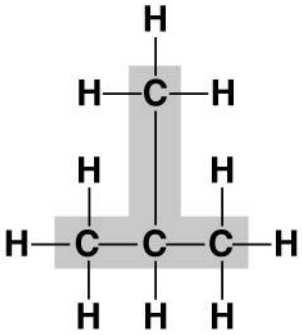


2-Butene

Double bonds: Carbon skeletons may have double bonds, which can vary in location.

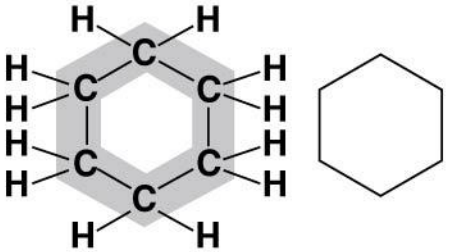


Butane

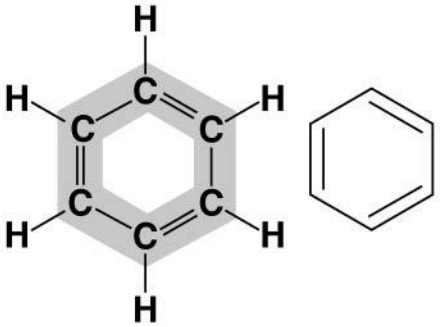


Iso-butane

Branching: Carbon skeletons may be unbranched or branched.



Cyclohexane

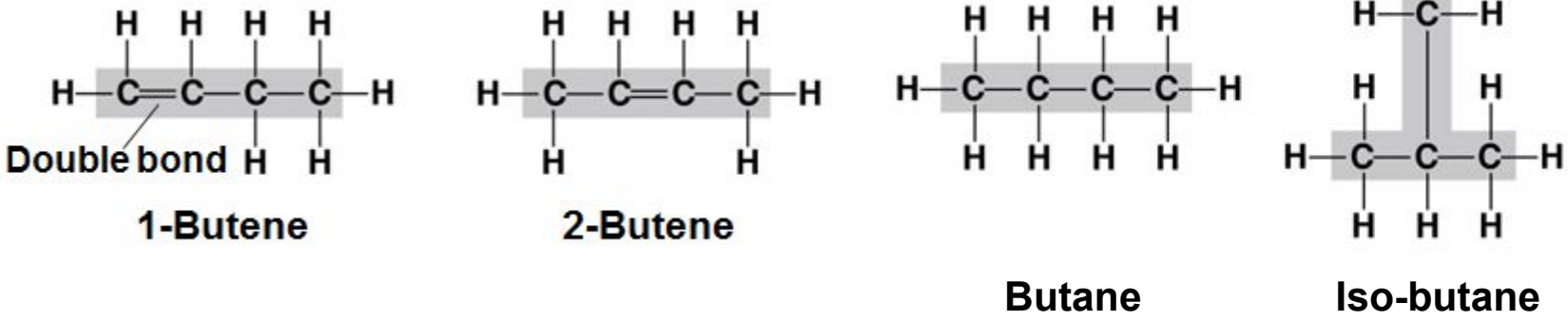


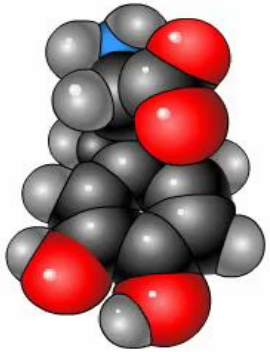
Benzene

Rings: Carbon skeletons may be arranged in rings. (In the abbreviated ring structures, each corner represents a carbon and its attached hydrogens.)

Isomers

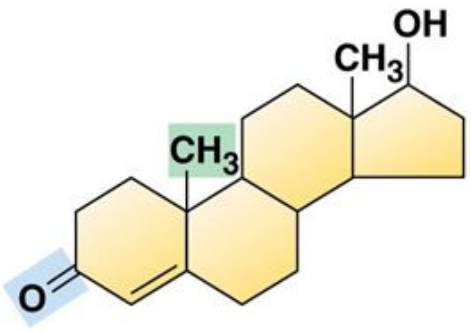
- Compounds with the same formula but different structural arrangements are called **isomers**



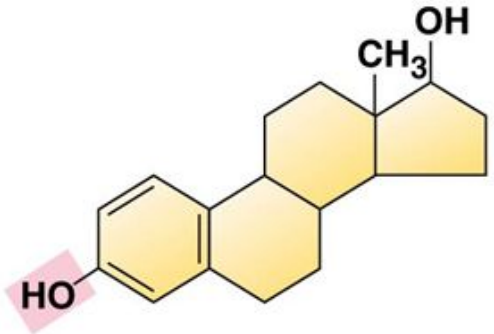


Functional Groups:
A few chemical groups are key to the functioning of biological molecules

- The unique properties of an organic compound depend on
  - the size and shape of its carbon skeleton
  - the groups of atoms that are attached to that skeleton
- The sex hormones testosterone and estradiol (a type of estrogen) differ only in the groups of atoms highlighted below



Male hormone

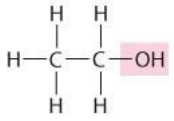
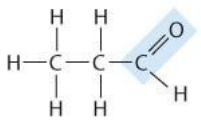
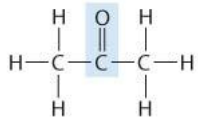
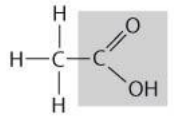
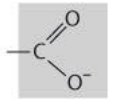
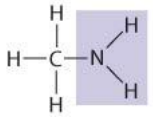
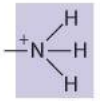
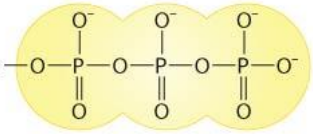
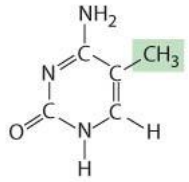


Female hormone

Table 2.2

- The first five groups are called **functional groups**; they affect a molecule's function in a characteristic way
- These five groups are polar, so compounds containing them are typically **hydrophilic** (water-loving) and soluble in water
- A sixth group, the **methyl group**
  - consists of a carbon bonded to three hydrogen atoms
  - is nonpolar and not reactive
  - still affects molecular shape and thus function

TABLE 3.2 IMPORTANT CHEMICAL GROUPS OF ORGANIC COMPOUNDS

Chemical Group	Examples
Hydroxyl group —OH	 Alcohol
Carbonyl group C=O	 Aldehyde  Ketone
Carboxyl group —COOH	 Carboxylic acid  Ionized
Amino group —NH_2	 Amine  Ionized
Phosphate group —OPO_3^{2-}	Adenosine  Organic phosphate
Methyl group —CH_3	 Methylated compound

Cells make large molecules from a limited set of small molecules

- There are **four classes** of molecules important to organisms:

1. carbohydrates
2. lipids
3. proteins
4. nucleic acids

- 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 or similar building blocks strung together
  - The building blocks of polymers are called **monomers**

Dehydration and Hydrolysis

- Monomers are linked together to form polymers through **dehydration reactions**, which remove water
- Polymers are broken apart by **hydrolysis**, the addition of water
- These reactions are mediated by **enzymes**, specialized macromolecules that speed up chemical reactions in cells
- A cell makes a large number of polymers from a small group of monomers For example,
  - **Proteins** are made from 20 different **amino acids**
  - **DNA (nucleic acids)** is built from 4 kinds of monomers called **nucleotides**

Figure 2.3-1

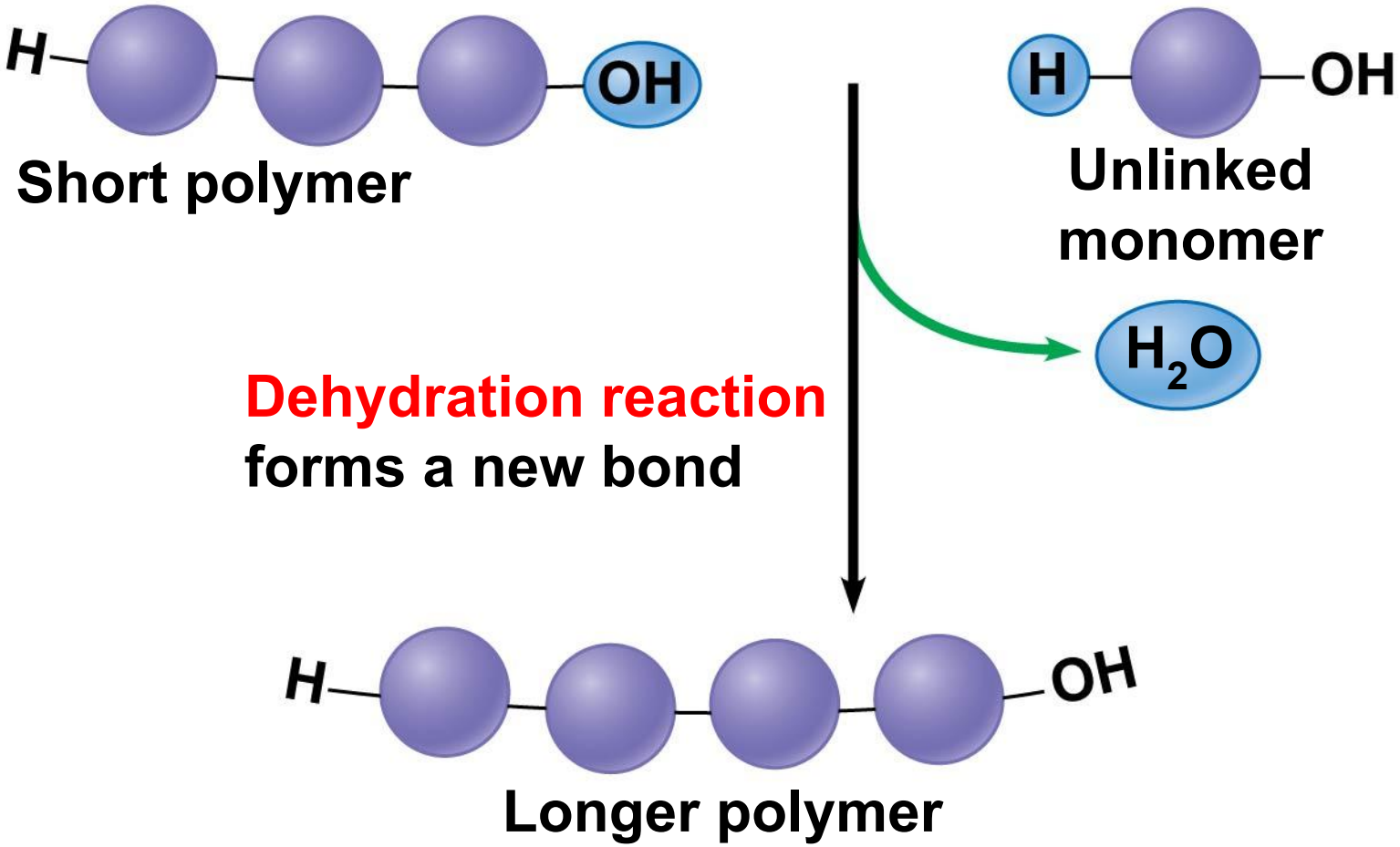
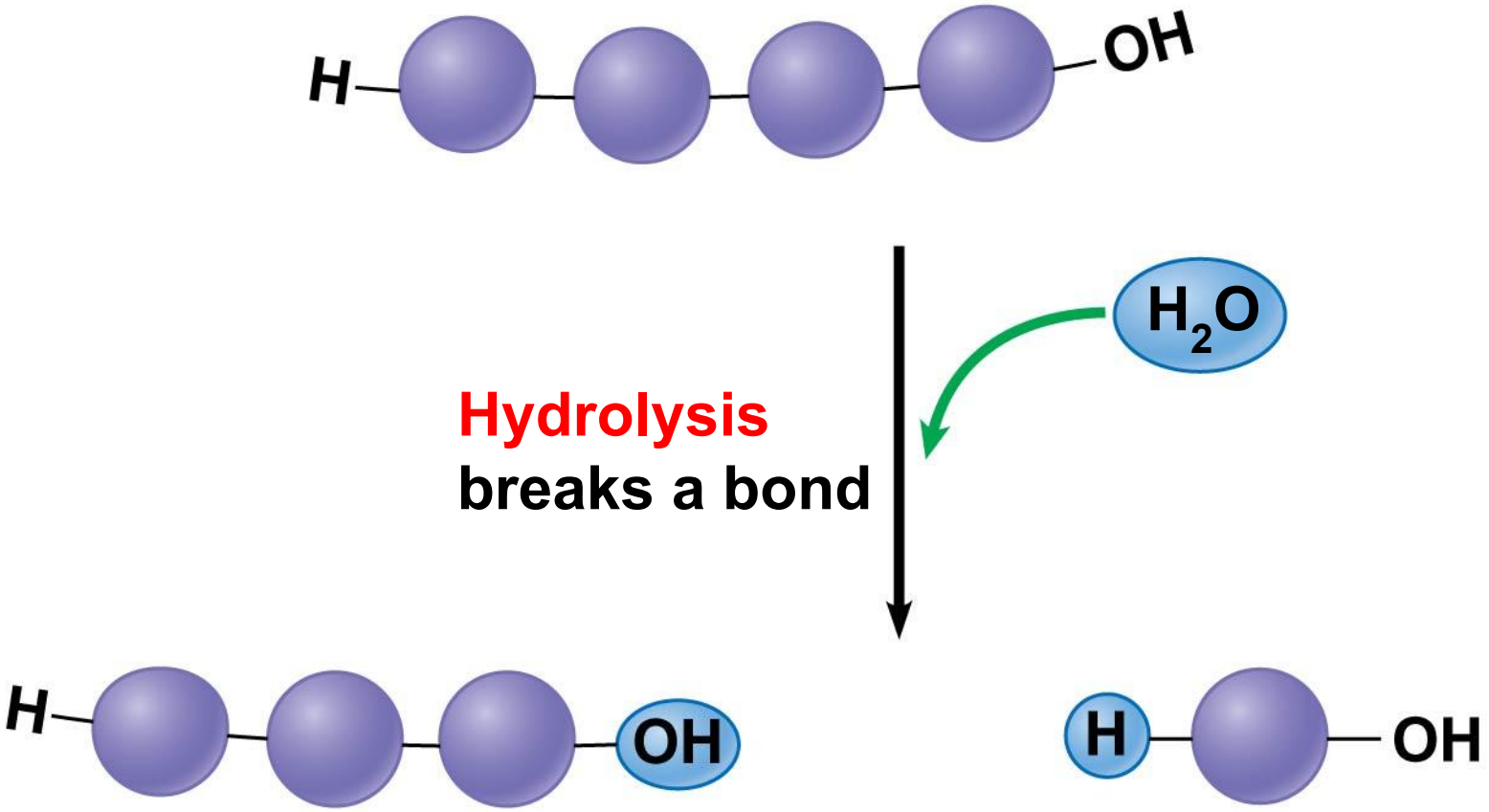


Figure 2.3-2



Carbohydrates

- Monosaccharide
- Disaccharide
- Polysaccharide

Monosaccharides: the simplest carbohydrates

- **Carbohydrates** range from small sugar molecules (monomers) to large polysaccharides
- Sugar monomers are **monosaccharides**, such as those found in
  - fructose
  - glucose
  - Honey (mixture of different compounds with monosaccharides being the major component)

Monosaccharides can be hooked together by dehydration reactions to form

- more complex sugars
- Polysaccharides

The carbon skeletons of monosaccharides vary in length

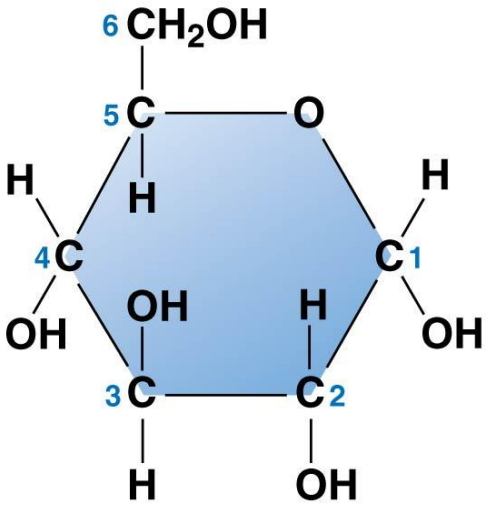
- Glucose and fructose are six carbons long
- Others have three to seven carbon atoms

Monosaccharides are

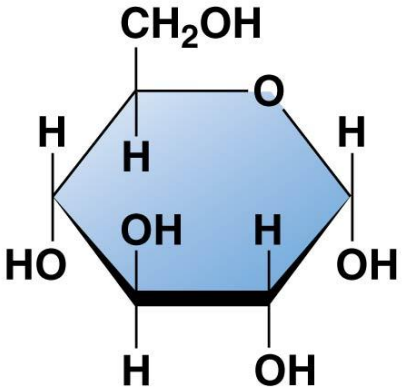
- the main fuels for cellular work
- used as raw materials to manufacture other organic molecules

- Many monosaccharides form rings

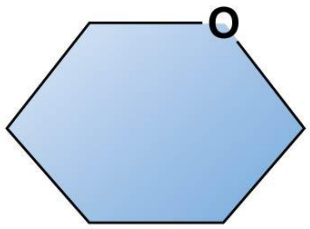
- The ring diagram may be
  - abbreviated by not showing the carbon atoms at the corners of the ring



Structural formula

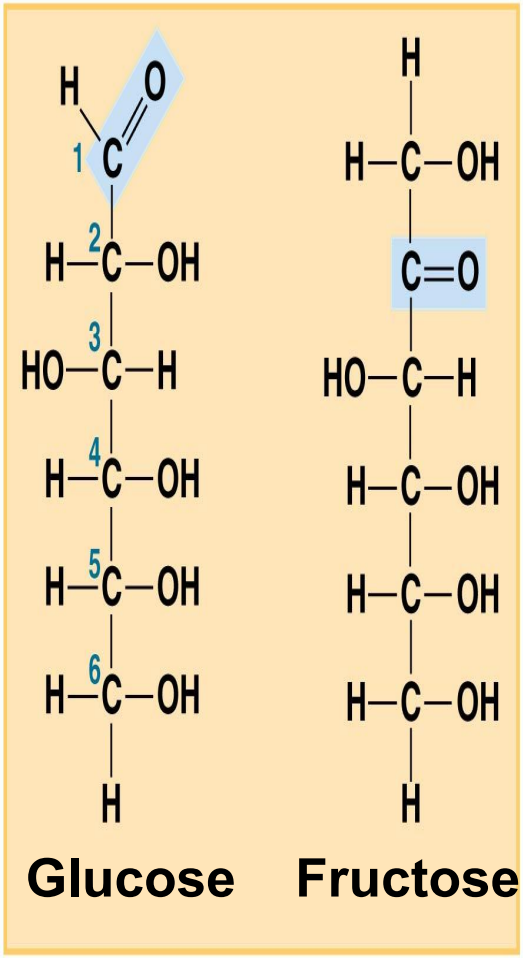


Abbreviated structure



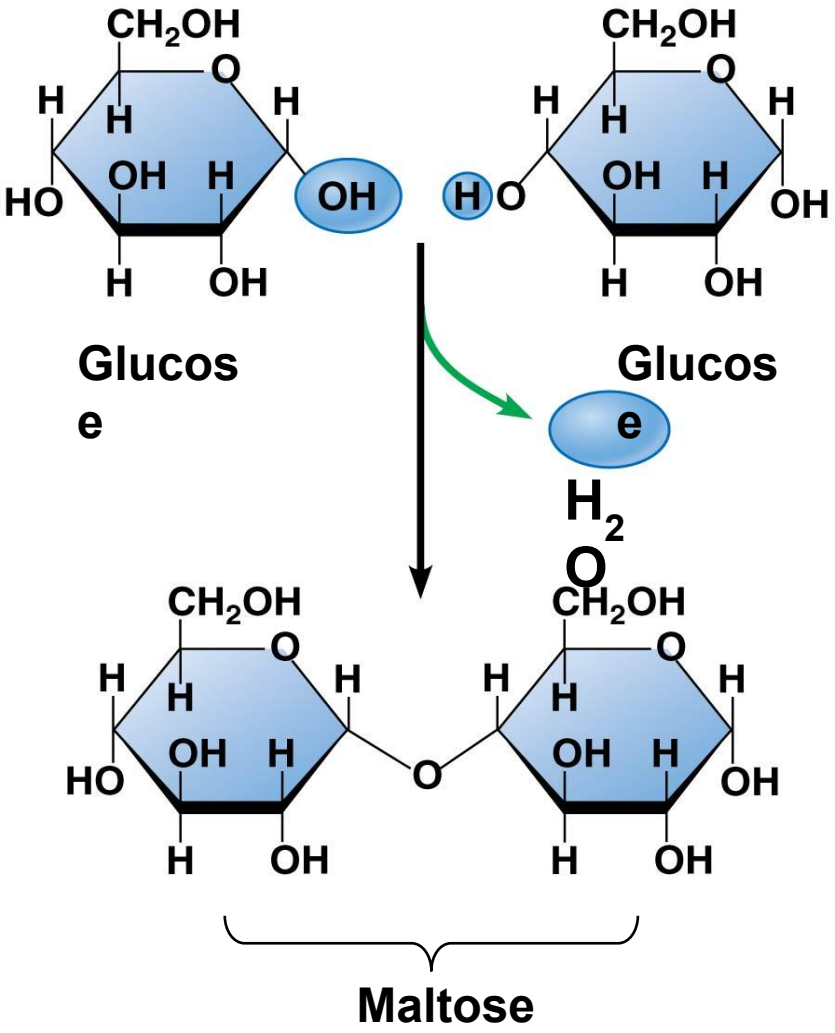
Simplified structure

Isomers



Two monosaccharides are linked to form a disaccharide

- Two monosaccharides (monomers) can bond to form a **disaccharide** in a **dehydration reaction**
- The disaccharide **sucrose** is formed by combining
  - a **glucose** monomer
  - a **fructose** monomer
- The disaccharide **maltose** is formed from **two glucose** monomers



Polysaccharides:

- **Polysaccharides** are macromolecules, polymers composed of thousands of monosaccharides

- Polysaccharides may function as
  - storage molecules
  - structural compounds

- Polysaccharides are usually hydrophilic (water-loving)

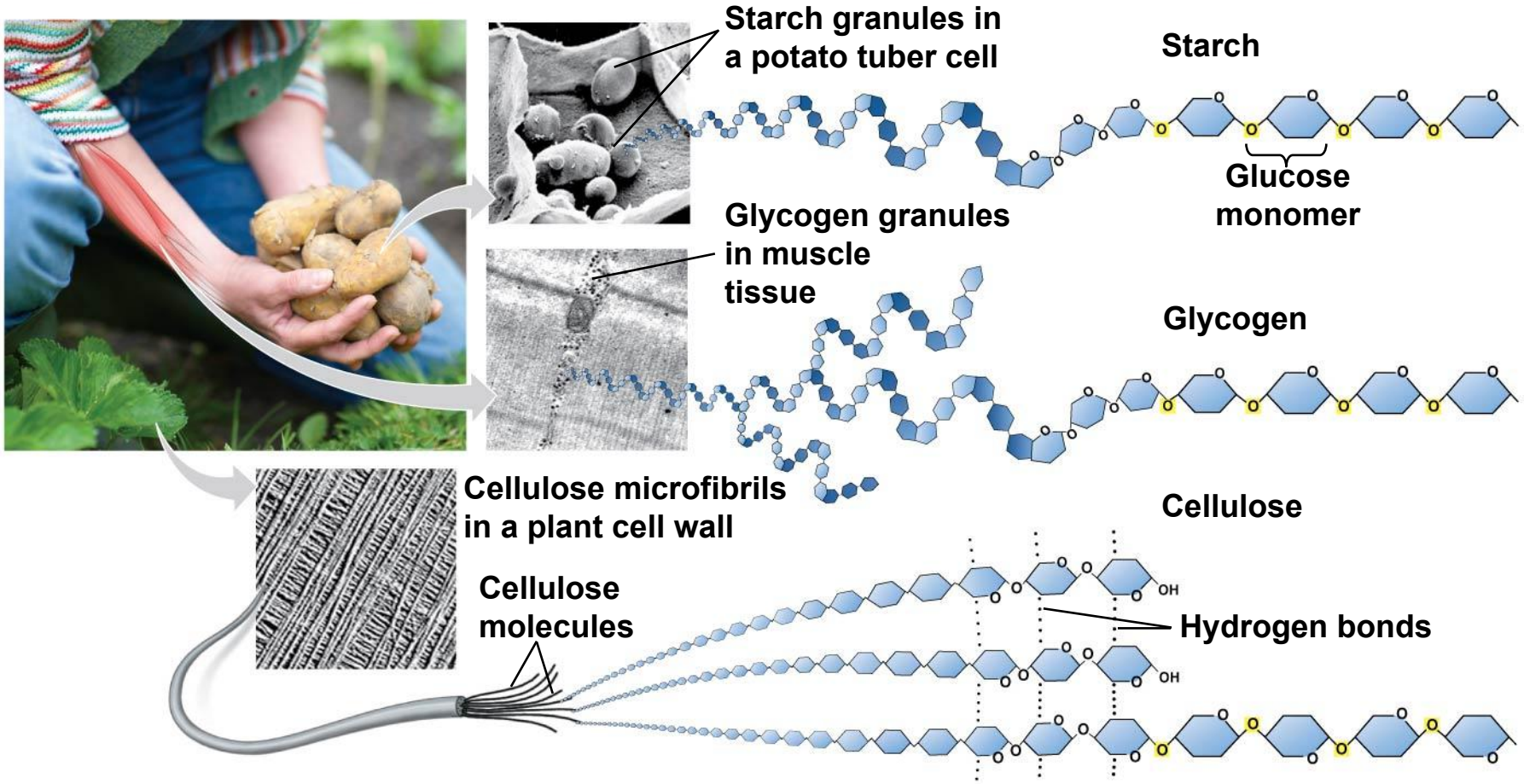
- Bath towels, for example, are often made of cotton, which is mostly cellulose, and therefore water absorbent

Polysaccharides are long chains of sugar units

- **Starch** is
  - composed of glucose monomers
  - used by plants for energy storage
- **Glycogen** is
  - composed of glucose monomers
  - used by animals for energy storage
- **Cellulose**
  - is a polymer of glucose monomers
  - forms plant cell walls
- **Chitin** is
  - used by insects and crustaceans to build an exoskeleton, and found in the cell walls of fungi

Figure 2.6

Starch, glycogen, and cellulose are glucose polymers



Lipids

- Fats
- Phospholipids
- Steroids

Lipids

- are water insoluble (**hydrophobic**, or water-fearing) compounds
- are important in long-term energy storage
- contain twice as much energy as a polysaccharide
- consist mainly of carbon and hydrogen atoms linked by nonpolar covalent bonds

- Lipids differ from carbohydrates, proteins, and nucleic acids in that they are
  - not huge molecules
  - not built from monomers

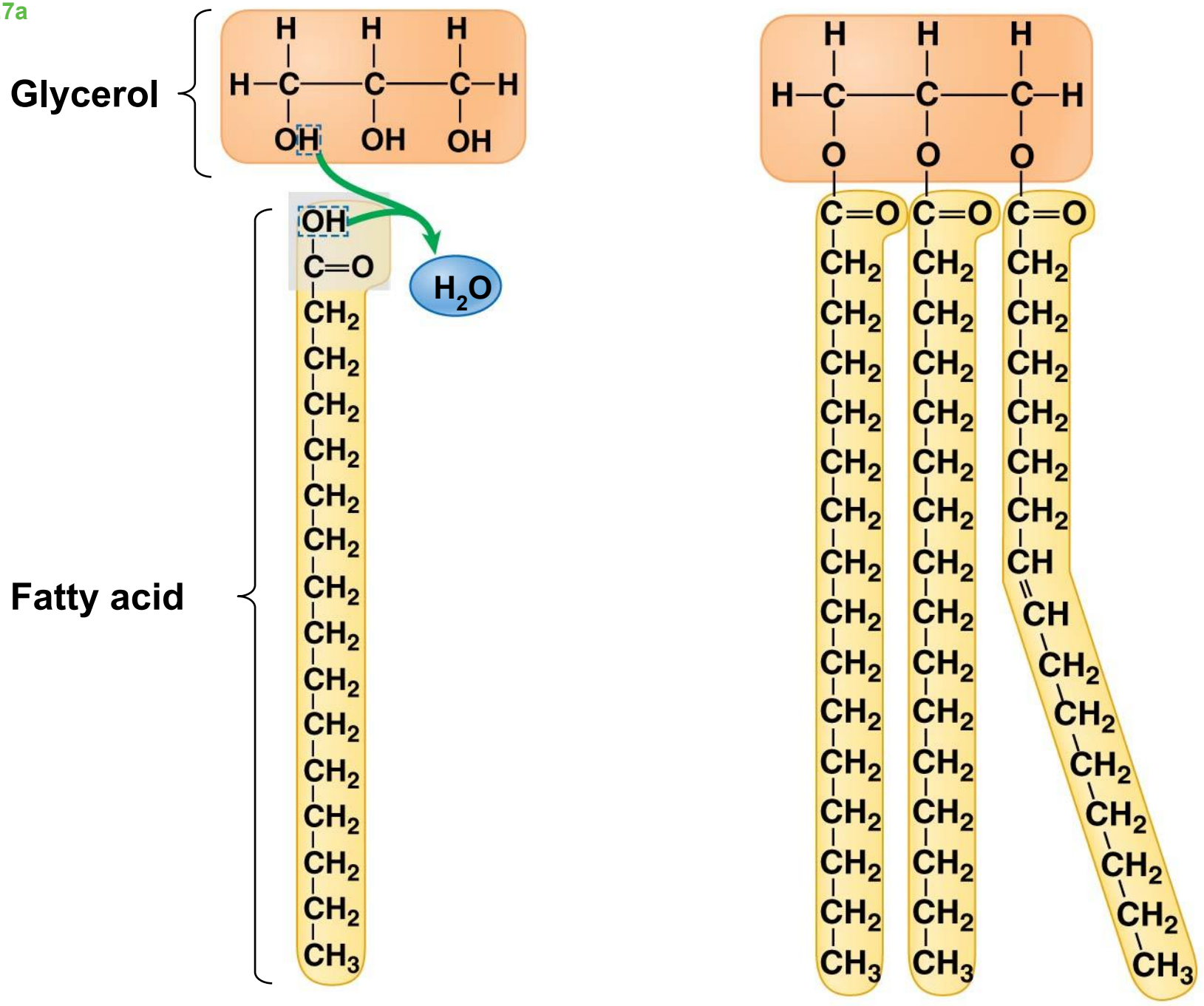
- Lipids vary a great deal in structure and function
- We will consider three types of lipids:
  1. fats
  2. phospholipids
  3. steroids

Fats

- A **fat** is a large lipid made from two kinds of smaller molecules:
  - glycerol
  - fatty acids
- A fatty acid can link to glycerol by a dehydration reaction
- A fat contains **one glycerol** linked to **three fatty acids** - are often called **triglycerides**

Saturated fats **Unsaturated fats**

Figure 2.7a



Fats are lipids that are mostly energy-storage molecules

- Some fatty acids contain one or more double bonds, forming **unsaturated fatty acids**
  - These have one fewer hydrogen atom on each carbon of the double bond
  - These double bonds cause kinks or bends in the carbon chain, preventing them from packing together tightly and solidifying at room temperature

- Fats with the maximum number of hydrogens (absence of double bond between carbon atom) are called **saturated fatty acids**

- Unsaturated fats are referred to as **oils**
- Most animal fats are saturated fats
- Hydrogenated vegetable oils are unsaturated fats that have been converted to saturated fats by adding hydrogen
- This hydrogenation creates **trans fats**, which are associated with health risks

Unsaturated fat is a healthier fat compared to saturated fat, while trans fats is the unhealthiest fat

Phospholipids

- **Phospholipids** are the major component of ALL cell membranes

- Phospholipids are structurally similar to fats
  - **Fats** contain three fatty acids attached to glycerol
  - **Phospholipids** contain two fatty acids attached to glycerol

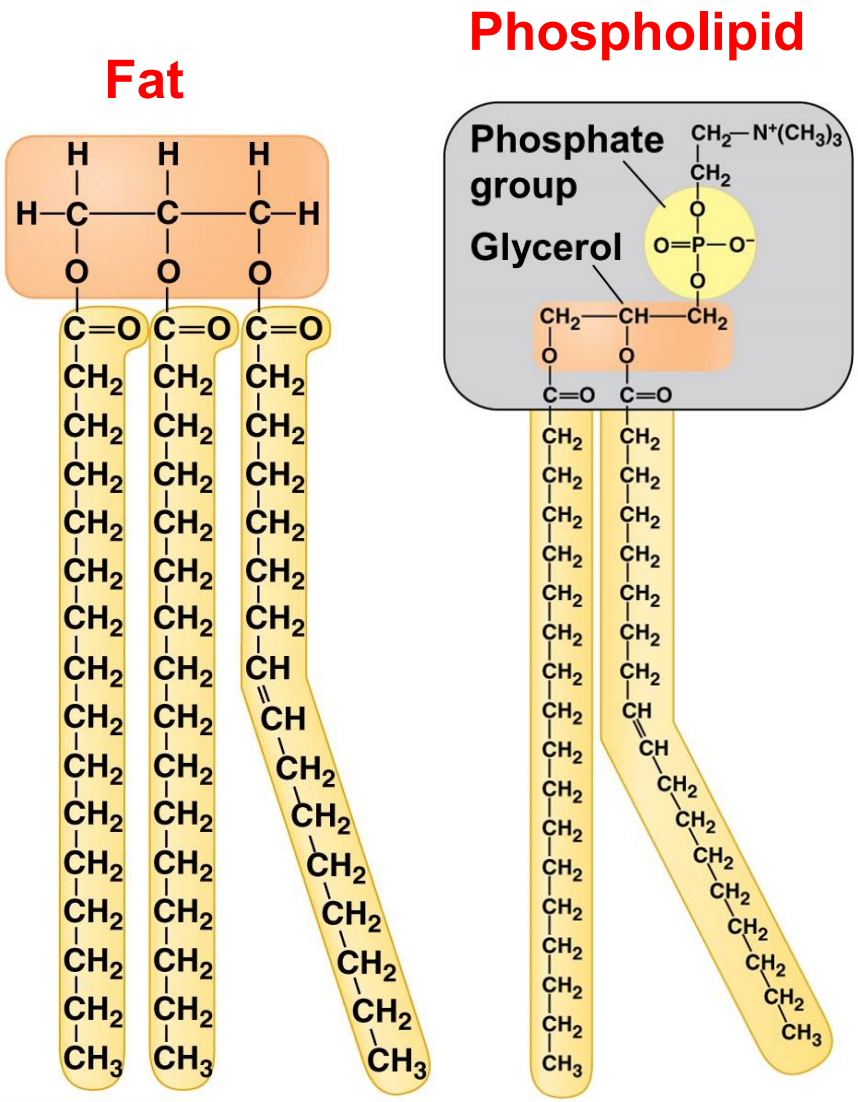
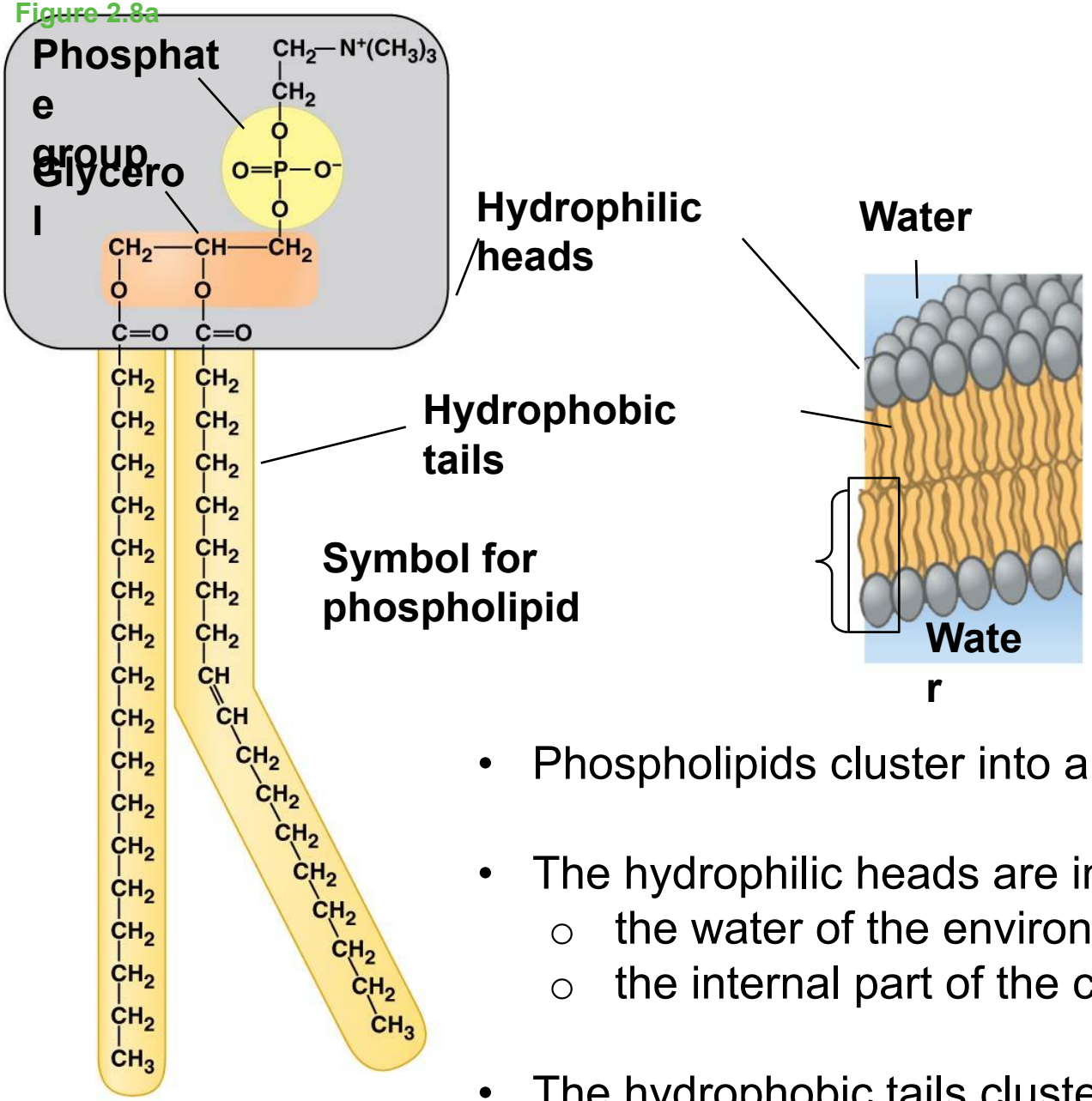


Figure 2.8a



- Phospholipids cluster into a <u>bilayer of phospholipids</u>
- The hydrophilic heads are in contact with
  - the water of the environment
  - the internal part of the cell
- The hydrophobic tails cluster together in the center of the bilayer

Steroids are important lipids with a variety of functions

- **Steroids** are lipids in which the carbon skeleton contains four fused rings

- **Cholesterol** is
  - a common component in animal cell membranes
  - a starting material for making steroids, including sex hormones

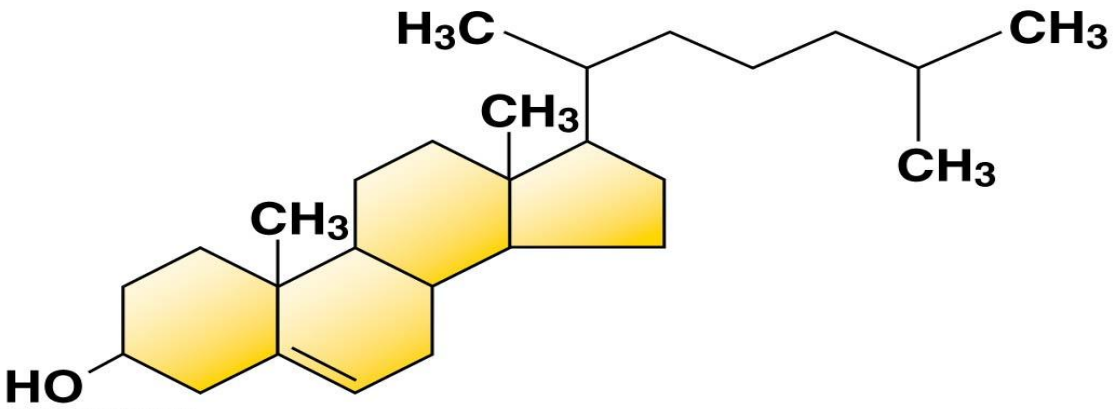


Figure 2.9

PROTEINS

Proteins

- **Proteins** are
  - involved in nearly every dynamic function in your body
  - very diverse, with tens of thousands of different proteins, each with a specific structure and function, in the human body
- Proteins are composed of differing arrangements of a common set of just 20 **amino acid** monomers
- Probably the most important role for proteins is as **enzymes**, proteins that
  - serve as catalysts
  - regulate virtually all chemical reactions within cells

Types of Proteins

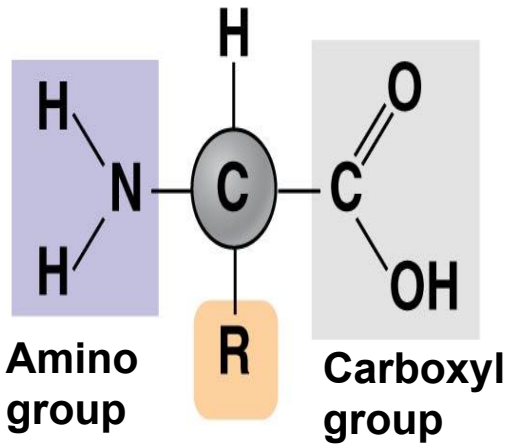
- Besides **enzymes**, other types of proteins include
  - **transport proteins** embedded in cell membranes, which move sugar molecules and other nutrients into your cells
  - **defensive proteins**, such as antibodies of the immune system
  - **signal proteins** such as many hormones and other chemical messengers that help coordinate body activities
  - **receptor proteins**, built into cell membranes, which receive and transmit signals into your cells
  - **contractile proteins** found within muscle cells
  - **structural proteins** such as collagen, which form the long, strong fibers of connective tissues
  - **storage proteins**, which serve as a source of amino acids for developing embryos in eggs and seeds

- The **functions** of different types of proteins depend on their individual **shapes**
- The shape of a protein is the result from 4 level of structures
- Protein is a **polypeptide chain** contains hundreds or thousands of **amino acids linked by "peptide bonds"**

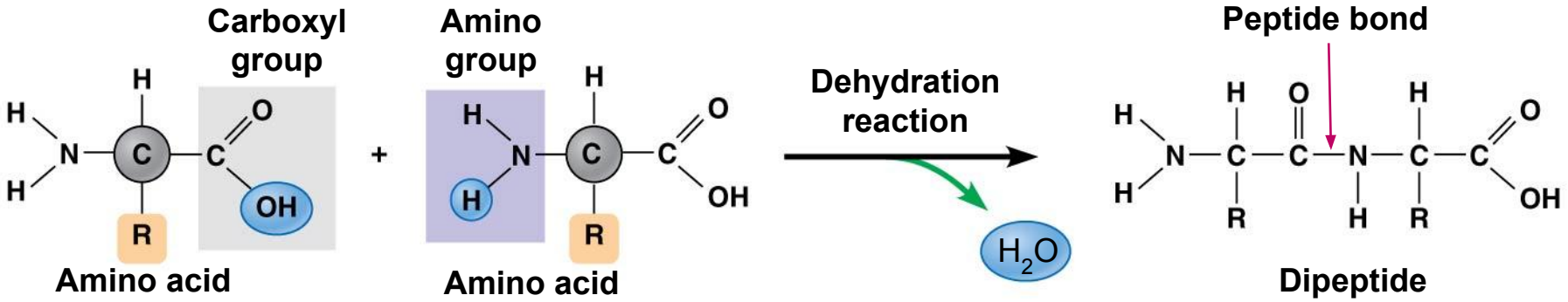
- Changes in protein shapes (damage of the secondary, tertiary and quaternary structures), referred as the "**denaturation**" process results in protein malfunction
- Proteins can be denatured by changes in salt concentration, changes in pH, or high heat

Proteins are made from amino acids linked by peptide bonds

- **Amino acids** all have
  - an amino group
  - a carboxyl group (which makes it an acid)
- Also bonded to the central carbon is
  - a hydrogen atom
  - a chemical group symbolized by R, which determines the specific properties of each of the 20 amino acids used to make proteins



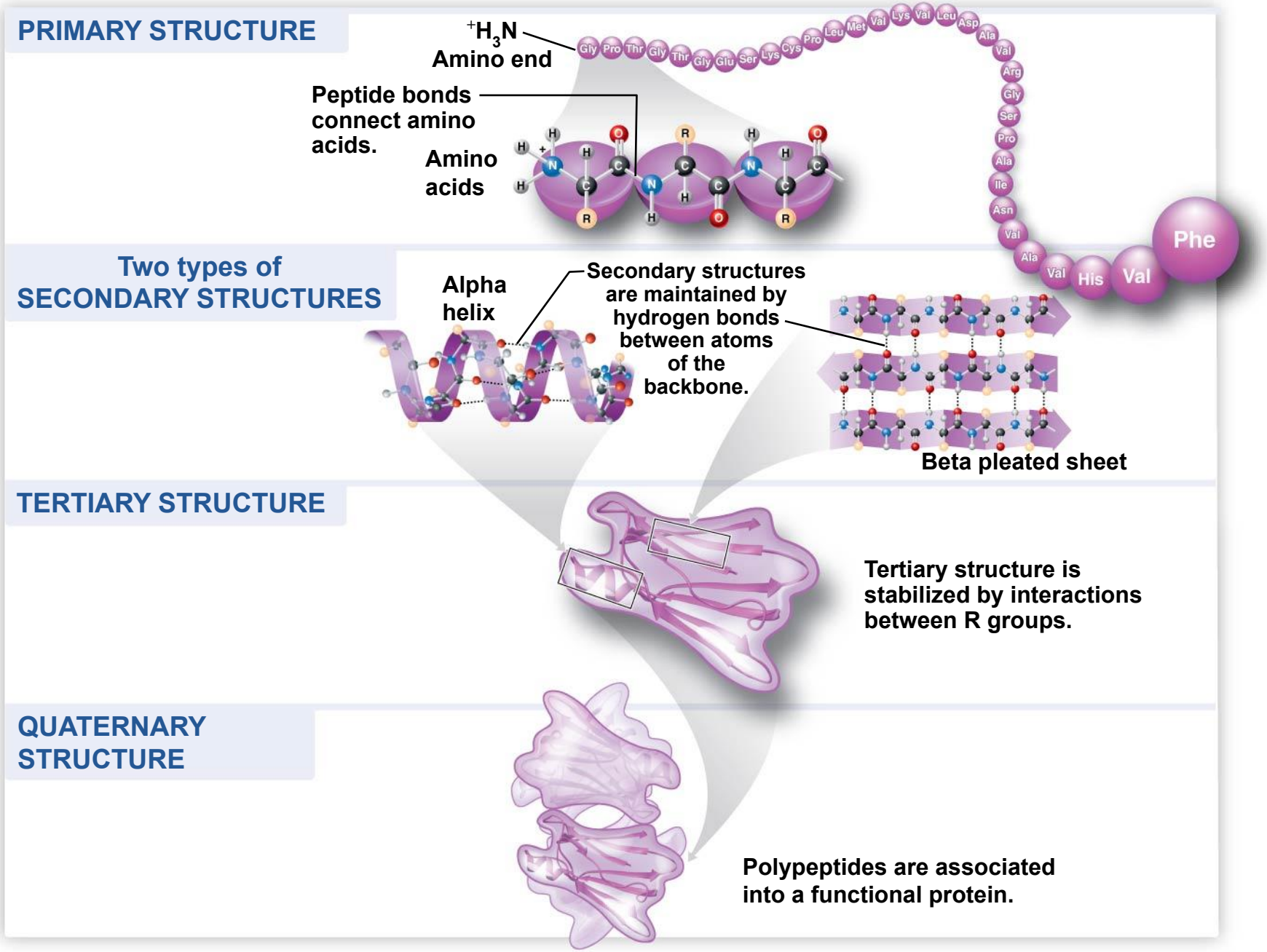
- Amino acid monomers are linked together in a dehydration reaction
- the carboxyl group of one amino acid is joined to the amino group of the next amino acid, and creating a **peptide bond**
- Additional amino acids can be added by the same process to create a chain of amino acids called a **polypeptide**



A protein's functional shape results from four levels of structure

- A protein can have **four levels of structure**:
  1. primary structure
  2. secondary structure
  3. tertiary structure
  4. quaternary structure

Figure 2.10

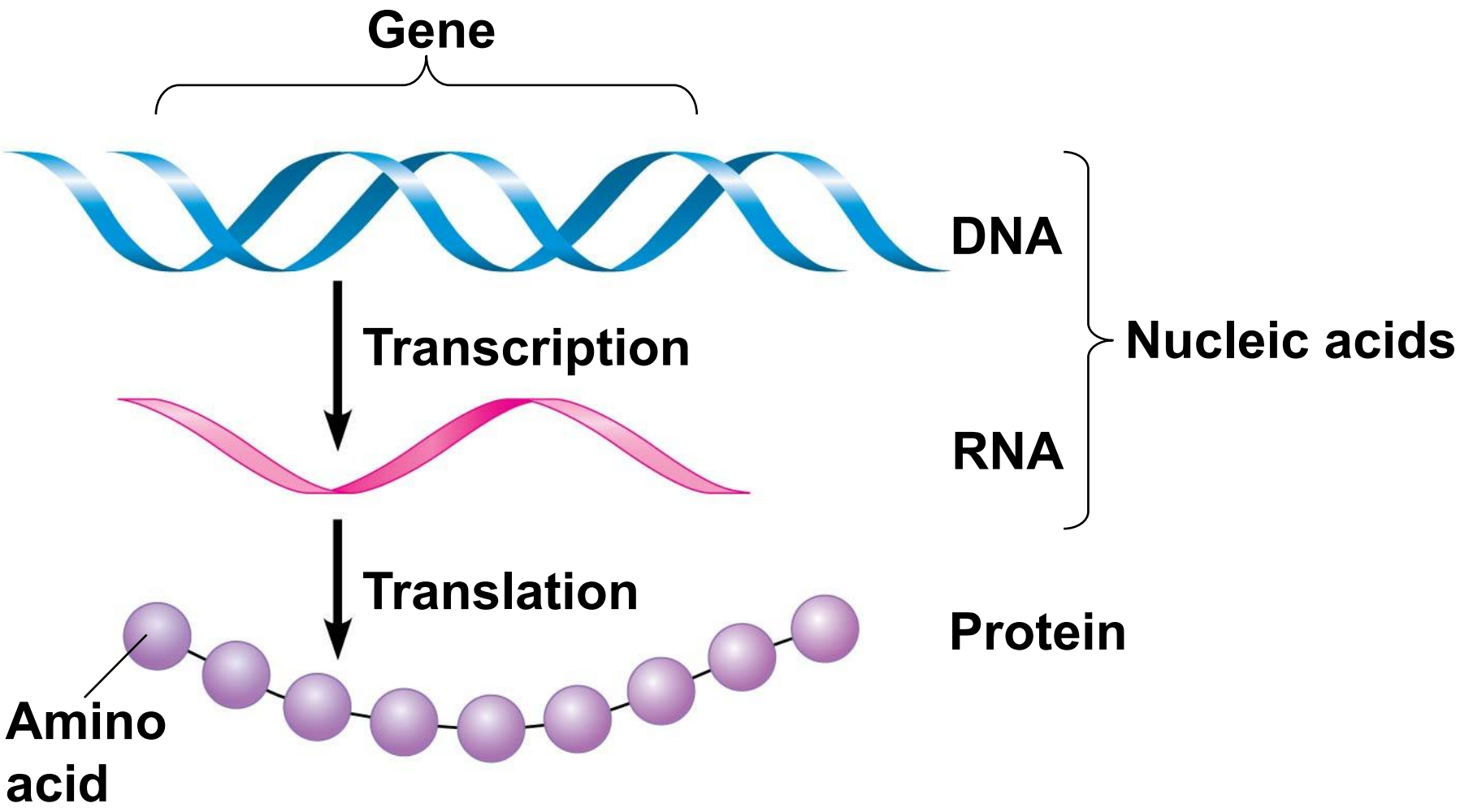


Nucleic Acids

DNA and RNA are the two types of nucleic acids

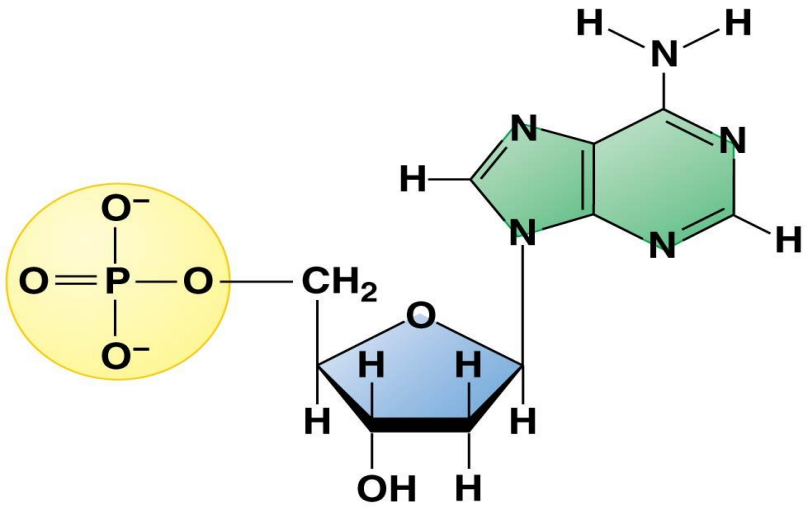
- The amino acid sequence of a polypeptide is programmed by a discrete unit of inheritance known as a **gene**
- Genes consist of **DNA** (**deoxyribonucleic acid**), a type of **nucleic acid**
- DNA is inherited from an organism's parents
- DNA provides directions for its own replication
- DNA programs a cell's activities by directing the synthesis of proteins
- DNA does not build proteins directly
- DNA works through an intermediary, **RNA** (**ribonucleic acid**).
  - DNA is **transcribed** into RNA in a cell's nucleus
  - RNA is **translated** into proteins in the cytoplasm

Figure 2.11-1



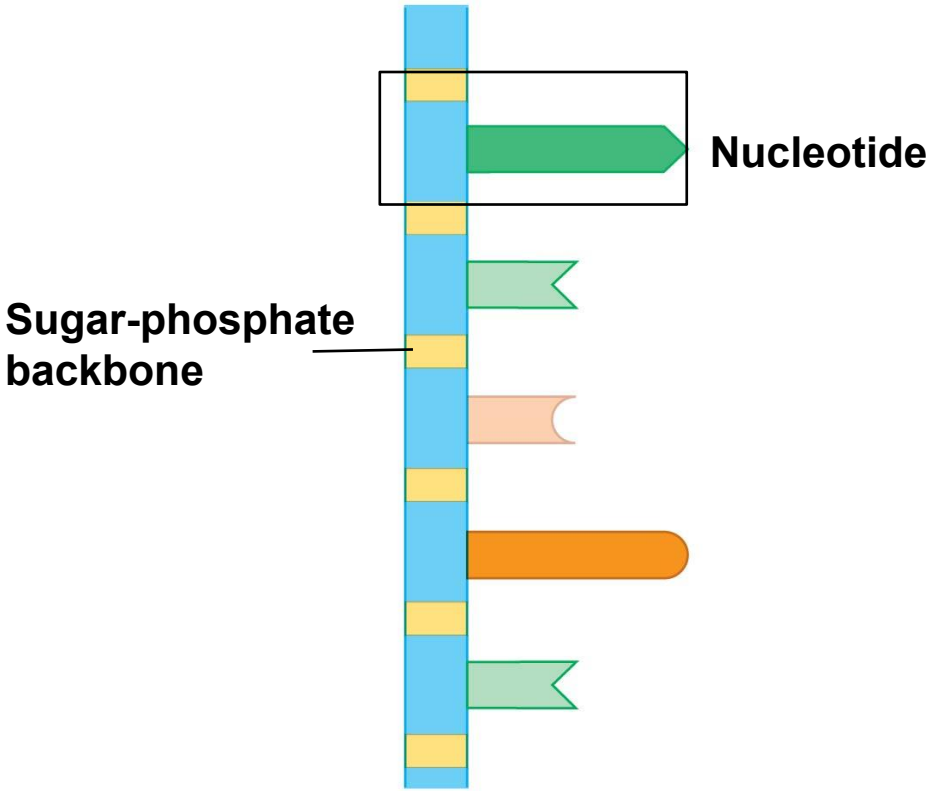
Nucleic acids are polymers of nucleotides

- 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



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

- A nucleic acid polymer, a polynucleotide, forms from the nucleotide monomers when the phosphate of one nucleotide bonds to the sugar of the next nucleotide by dehydration reactions.
- This produces a repeating **sugar-phosphate backbone** with protruding nitrogenous bases.



- RNA is usually a single polynucleotide strand

- DNA is a **double helix**, in which two polynucleotide strands wrap around each other
  - The two strands are associated because particular bases always **hydrogen-bond** to one another
  - A pairs with T, and C pairs with G, producing **base pairs**