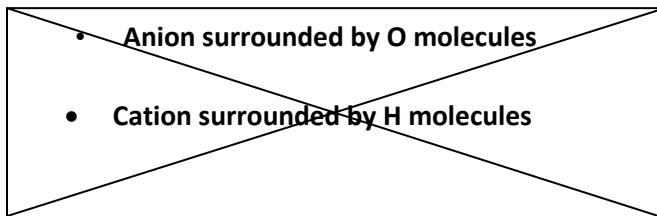


Before studying chapter 5 .. please back to chapter 3 and correct this information 😊

in chapter 3 > page 11 > The solvent of life > the 2 points before the last ..

we wrote :



The correct information is :

- Anion (negative ion) surrounded by H molecules
- Cation (positive ion) surrounded by O molecules

Chapter 5 : The Structure and Function of Large Biological Molecules

Overview: The Molecules of Life

- All living things are made up of four classes of large biological molecules: carbohydrates, lipids, proteins, and nucleic acids
- Within cells, small organic molecules are joined together to form larger molecules
- **Macromolecules** are large molecules composed of thousands of covalently connected atoms
- Molecular structure and function are inseparable
- carbohydrates, proteins and nucleic acids are called macromolecules

To know how these molecules work continue 😊

Concept 5.1: Macromolecules are polymers, built from monomers

- Macromolecules -are chains- called polymers
- A **polymer** is a long molecule consisting of many similar or identical building blocks linked by covalent bonds
- These small building-block molecules are called **monomers**
- Three of the four classes of life's organic molecules are polymers:
Carbohydrates _ Proteins _ Nucleic acids
- Polymers differ in nature of monomers but the chemical mechanisms by which cells make and break down polymers are same in all cases

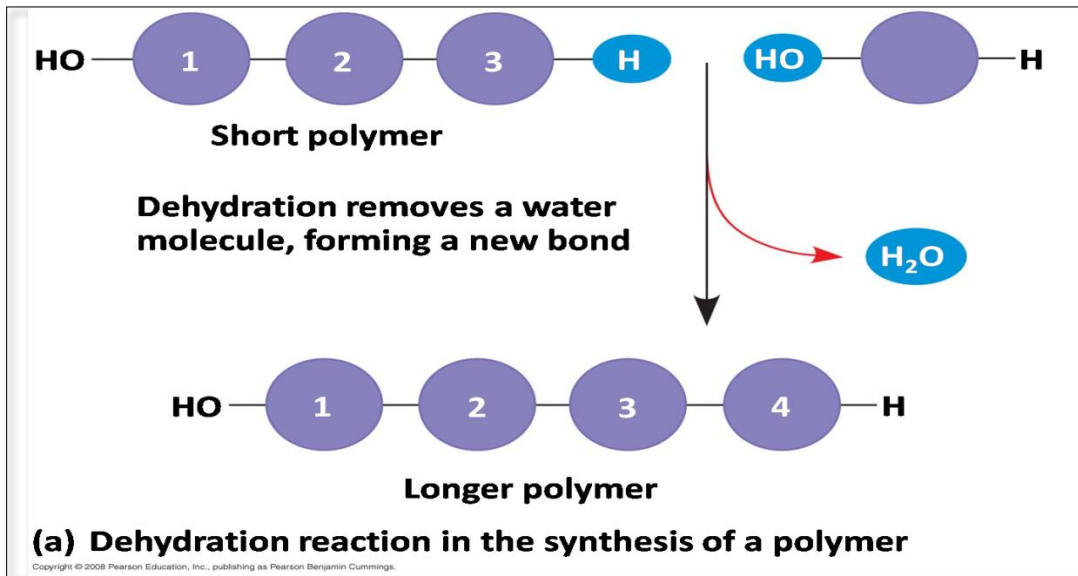
❖ The Synthesis and Breakdown of Polymers

- Polymers differ in nature of monomers but the chemical mechanisms by which cells make and break down polymers are same in all cases

➡ The Synthesis of Polymers

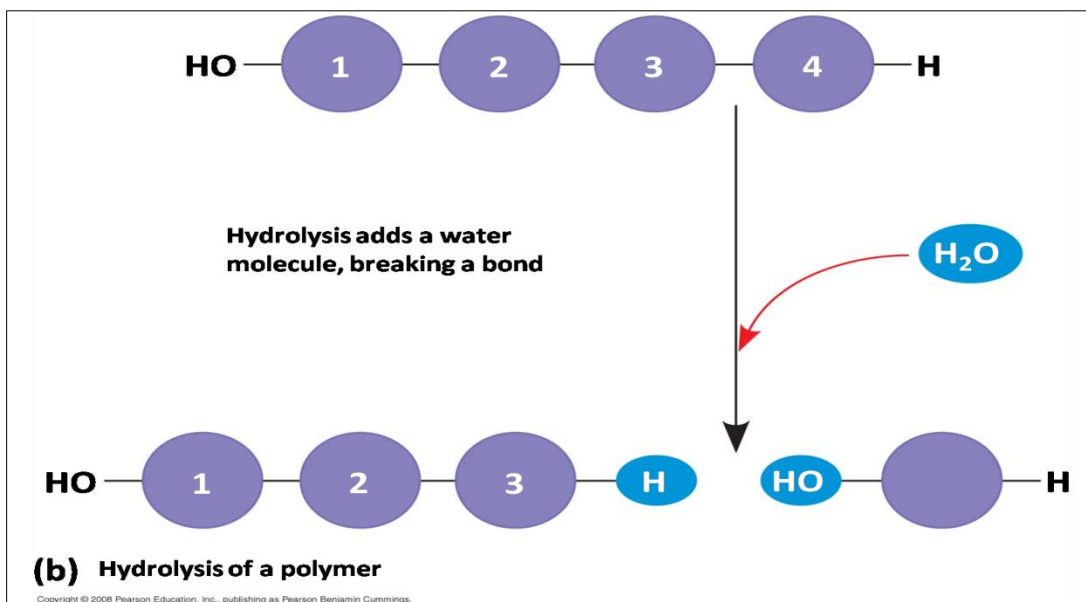
- Monomers are connected by a reaction in which two molecules are covalently bonded to each other ,with the loss of water molecule ,this is known as a **dehydration reaction**
- **Enzyme** is macromolecule that speeds up the dehydration process

- When a bond forms between two monomers each monomer contributes part of the water molecule that is released during the reaction: one monomer provides a hydroxyl group (-OH) ,while the other provides a hydrogen (-H) .



↻ The Breakdown of Polymers

- Polymers are disassembled (تفكك) to monomers by **hydrolysis**, a reaction that is essentially the reverse of the dehydration reaction
- Hydrolysis means **to break using water**
- An example of hydrolysis working within our bodies is the process of digestion .



❖ The Diversity of Polymers

- Each cell has thousands of different kinds of macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species. Because an immense variety of polymers can be built from a small set of monomers

Concept 5.2: Carbohydrates serve as fuel and building material

- **Carbohydrates** include sugars and polymers of sugars
- The simplest carbohydrates are monosaccharides, or simple sugars
- **Monosaccharides or simple sugars** are the monomers for more complex carbohydrates (disaccharides and polysaccharides) ..
- **Disaccharides** are double sugar consisting of two monosaccharides joined by a covalent bond
- **Polysaccharides** are polymers composed of many sugar building blocks .

❖ Sugars

- **Monosaccharides** have molecular formulas that are usually multiple of the unit CH_2O
- Glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) is the most common monosaccharide
- In monosaccharide structure you will find

_ carbonyl group ($>\text{C}=\text{O}$)

_ multiple of hydroxyl group (-OH)

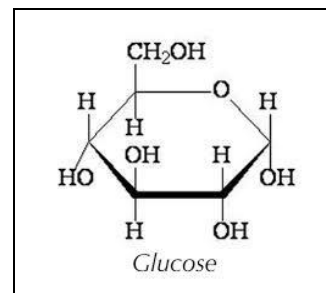
- Monosaccharides are classified by

1. The location of the carbonyl group (as aldose or ketose)
2. The size of the carbon skeleton (number of carbons in the molecule structure), which ranges from three to seven carbons

- Glucose, fructose and other sugars that have six carbons are called hexoses . Trioses (three carbon sugars) and pentoses (five carbon sugars) are also common .

3. Spatial arrangement of atoms around asymmetric carbon

- Asymmetric carbon is a carbon attached to four different atoms or groups of atoms

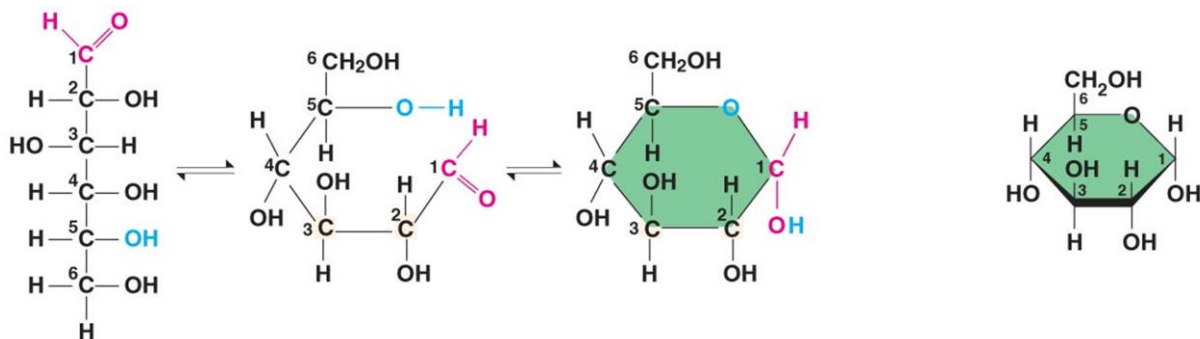


- Example : glucose and galactose , both of them are hexose and aldose but their's spatial arrangement are not the same so their shapes and behaviors are not the same .. look to next figure

| | Trioses (C ₃ H ₆ O ₃) | Pentoses (C ₅ H ₁₀ O ₅) | Hexoses (C ₆ H ₁₂ O ₆) | |
|--|---|---|--|-------------------------|
| Aldoses (Aldehyde sugars) carbonyl group at the end of carbon skeleton | <p>Glyceraldehyde</p> | <p>Ribose</p> | <p>Glucose</p> | <p>Galactose</p> |
| Ketoses (ketone sugars) carbonyl group Within carbon skeleton | <p>Dihydroxyacetone</p> | <p>Ribulose</p> | <p>Fructose</p> | |

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Although glucose often drawn as linear skeletons, in aqueous solutions , glucose molecules form rings ..



(a) Linear and ring forms

(b) Abbreviated ring structure

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- Functions of mono-saccharides :

1. major nutrients for cells
2. major fuel for cellular work

example : the process of cellular respiration start with glucose molecules

3. their carbon skeletons also serve as raw material for the synthesis of other types of small organic molecules, such as amino acids and fatty acids
4. incorporated as monomers into disaccharides or polysaccharides

- a **disaccharide** consists of two monosaccharides joined by a **glycosidic linkage**

>> Glycosidic linkage : is a covalent bond formed between two monosaccharides by a dehydration reaction .

- Examples of disaccharide :

1. *Maltose* “ malt sugar “

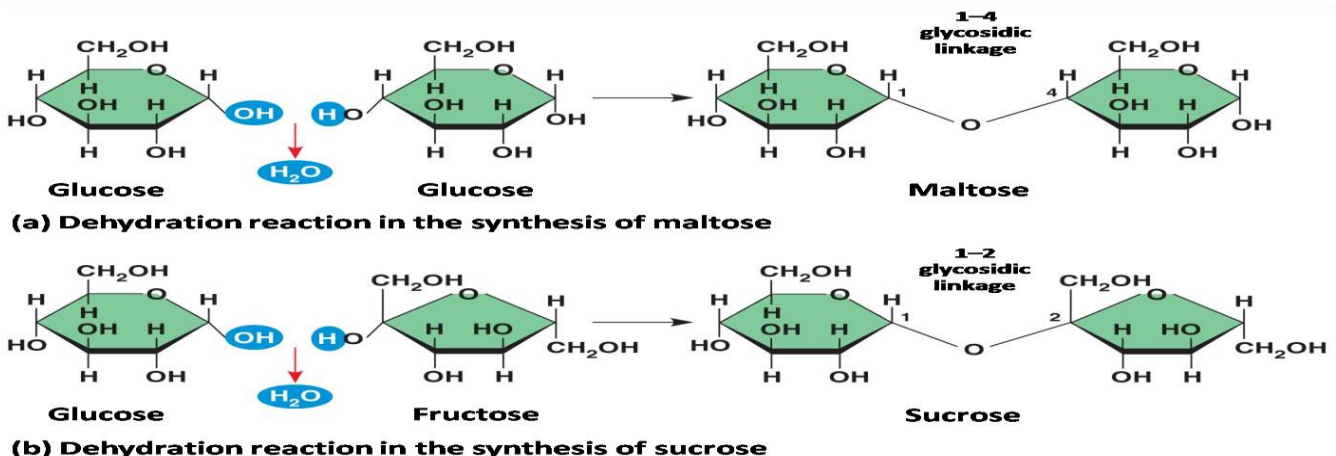
- _ consists of two molecules of glucose
- _ maltose is an ingredient used in brewing beer

2. *Sucrose* “ table sugar “

- _ consists of two mono-saccharides are glucose and fructose
- _ plants transport carbohydrates from leaves to roots and other nonphotosynthetic organs in the form of sucrose

3. *Lactose* “ milk sugar “

- _ sugar presents in milk and consists of glucose molecule joined to a galactose molecule



Polysaccharides

- **Polysaccharides** are macromolecules, polymers with a few hundred to a few thousands monosaccharides joined by glycosidic linkages
- **Polysaccharides**, the polymers of sugars, have storage and structural roles
- The structure and function of a polysaccharide are determined by its sugar monomers and by the positions of its glycosidic linkages

⇒ **Storage Polysaccharides**

- Hydrolyzed as needed to provide sugar for cells
- Examples :

1. Starch

2. Glycogen

- both plants and animals store sugar for later use in the form of storage polysaccharides

Starch

- **Starch**, a storage polysaccharide of plants, is a polymer consists entirely of glucose monomers only ..
- Plants store surplus starch as granules within cellular structure (chloroplasts and other plastids)
- Most animals, including humans, have enzymes that can hydrolyze plant starch, making glucose available as a nutrient for cells
- Starch has two forms :

1. **amylose** :

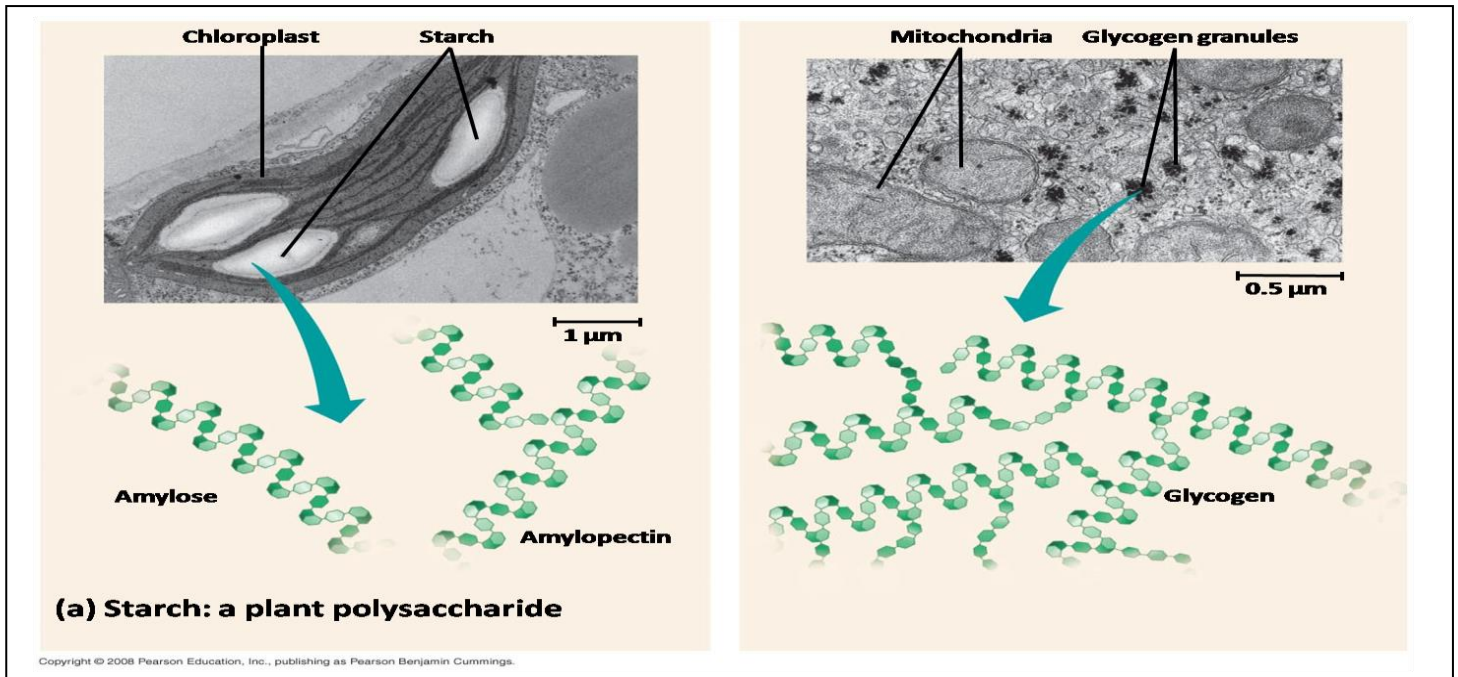
- The simplest form of starch
- un-branched
- glucose monomers in amylose are joined by **1-4 linkages** (number 1 carbon to number 4 carbon)

2. **amylopectin** :

- More complex starch
- branched
- Glucose monomers in amylopectin are joined by 1-4 linkages but at the branch points joined by 1-6 linkages.

Glycogen

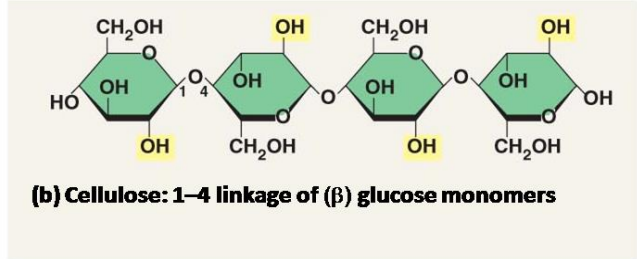
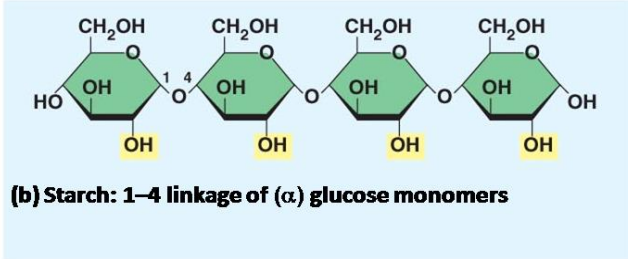
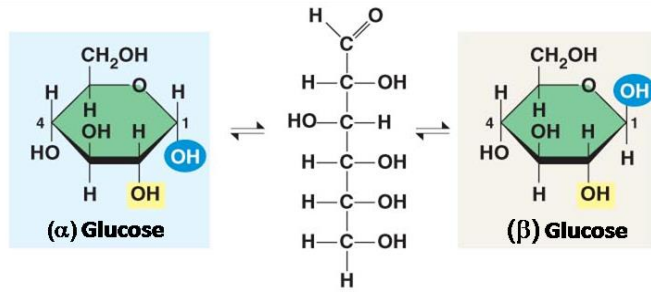
- **Glycogen** is a storage polysaccharide in animals
- Glycogen is a polymer of glucose monomers and it is like amylopectin but more extensively branched
- Humans and other vertebrates store glycogen as dense clusters (كتل) of granules mainly in liver and muscle cells
- Mitochondria are cellular organelles that help break down glucose released from glycogen



↻ Structural Polysaccharides

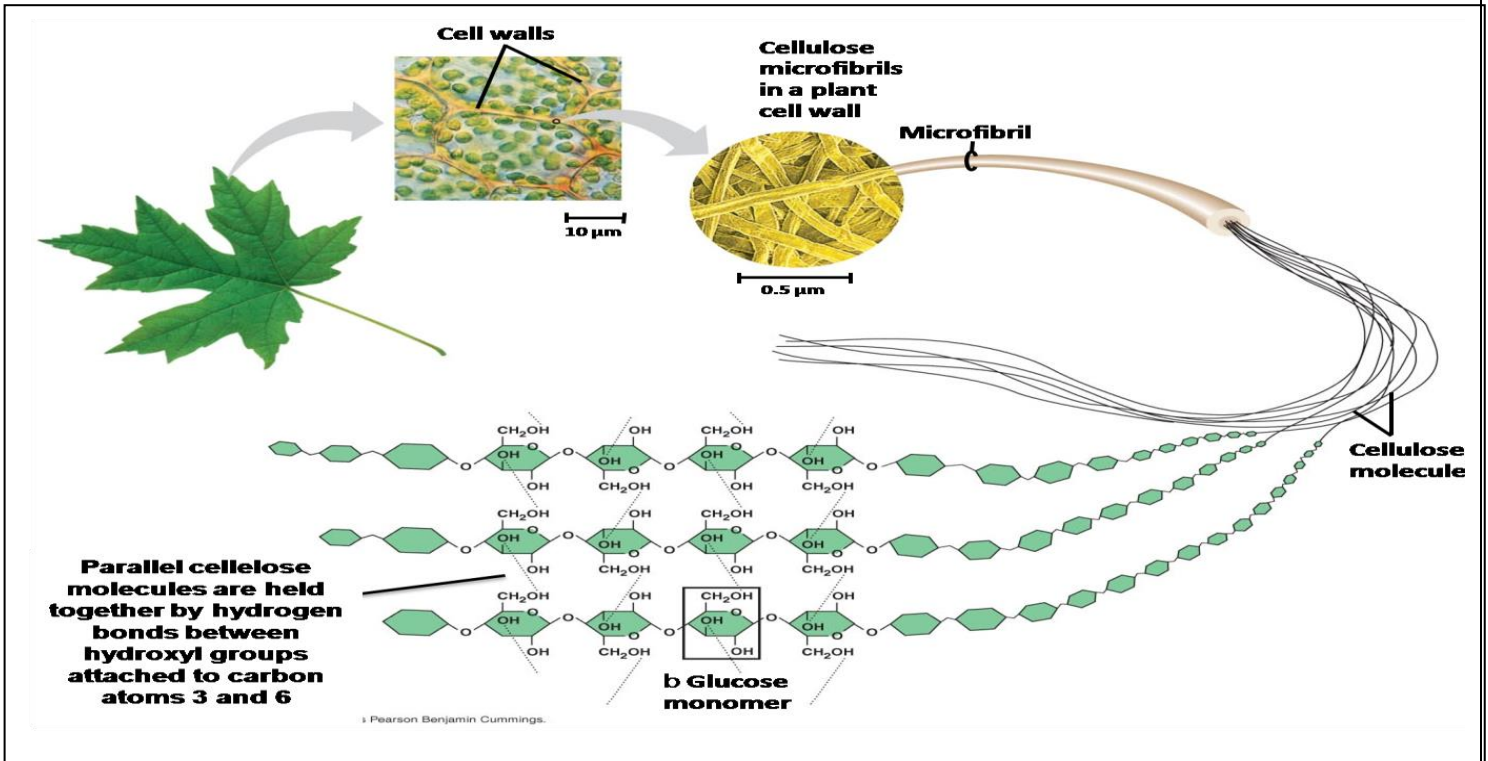
- The polysaccharide **cellulose** is a major component of the tough wall of plant cells
 - Like starch, cellulose is a polymer of glucose, but the glycosidic linkages differ
 - The difference is based on two ring forms for glucose: alpha (α) and beta (β)
- In cellulose, all the glucose monomers are in the (β) configuration, making every glucose monomer “upside down” with respect to its neighbors
- In starch, all the glucose monomers are in the (α) configuration (in the same orientation)
- The differing glycosidic linkages in starch and cellulose give the two molecules distinct three-dimensional shapes

(a) (α) and (β) glucose ring structures

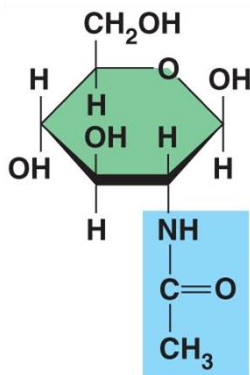


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- Polymers with α glucose (ex:starch) are helical
- Polymers with β glucose are straight , Cellulose is never branched
- ☒ In straight structures, H atoms on one strand can bond with OH groups on other strands
 - Parallel cellulose molecules held together in this way are grouped into units called microfibrils, which form strong building materials for plants .



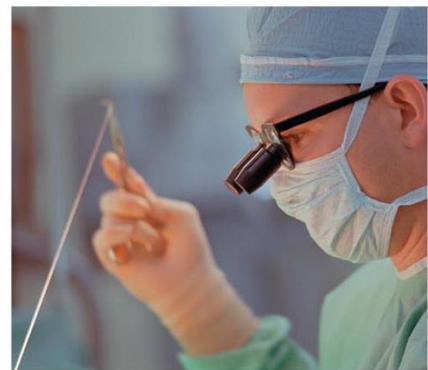
- Cellulose is very important for :
 - _ Plants, it is a strong building material for plants
 - _ Humans , because cellulose is the major constituent of paper and the only component of cotton
- Enzymes that digest starch by hydrolyzing α linkages can't hydrolyze β linkages in cellulose
- Few organisms possess (تملك) enzymes that can digest cellulose
 - Animals ,including humans do not posses enzymes that can digest cellulose
 - Cellulose in human food passes through the digestive tract as insoluble fiber
 - Some microbes use enzymes to digest cellulose
 - >Many herbivores, from cows to termites, have symbiotic relationships with these microbes
- Insoluble fiber refers mainly to cellulose
- **Chitin**, another structural polysaccharide, is found in the exoskeleton of arthropods
- Chitin also provides structural support for the cell walls of many fungi
- Chitin is similar to cellulose, with (β) linkages, except that the glucose monomer of chitin has a nitrogen –containing appendage



(a) The structure of the chitin monomer.



(b) Chitin forms the exoskeleton of arthropods.



(c) Chitin is used to make a strong and flexible surgical thread.

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Concept 5.3: Lipids are a diverse group of hydrophobic molecules

- **Lipids** are the one class of large biological molecules that does not include true polymers
- Lipids are not big enough to be one of macromolecules
- The unifying feature of lipids is having little or no affinity for water (they mix poorly ,if at all ,with water).
- Lipids are hydrophobic because they consist mostly of hydrocarbons, which form nonpolar covalent bonds.
- Although Lipids consist mostly of hydro carbonic regions , it may have some polar bonds associated with oxygen .
- Lipids are varied in form and function
- Lipids include waxes and certain pigments
- The most biologically important lipids are fats, phospholipids, and steroids

Fats

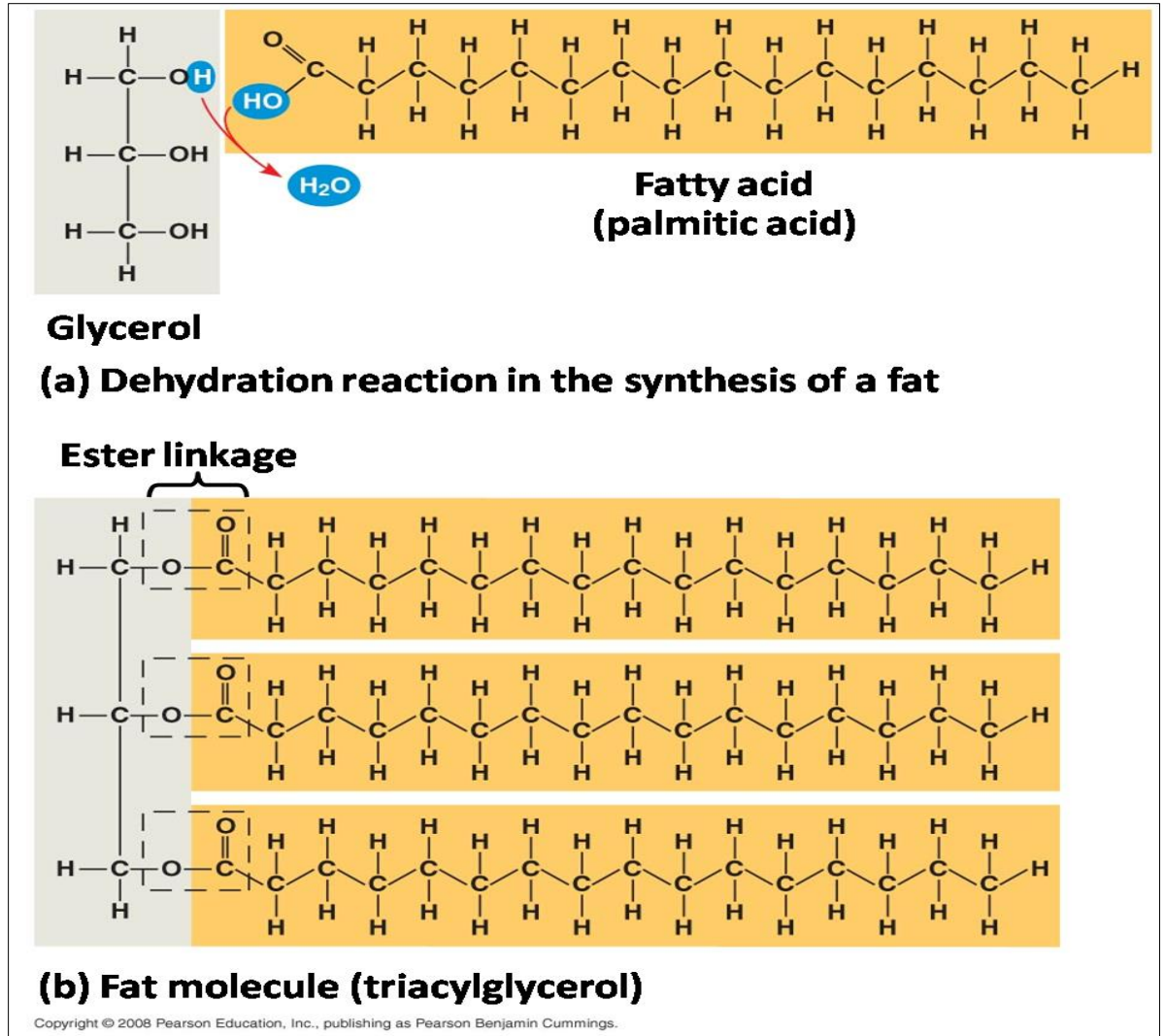
- **Fats** are assembled from two types of smaller molecules by dehydration reaction

These two types of smaller molecules are :

glycerol and **fatty acids**

- **Glycerol** is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton
 - The relatively nonpolar C-H bonds in the hydrocarbon chains of fatty acids are the reason of "fats are hydrophobic "
- Fats separate from water because water molecules form hydrogen bonds with each other and exclude the fats
- In a fat, three fatty acids are each joined to glycerol by an **ester linkage** .

Ester linkage : is a bond between a hydroxyl group and a carboxyl group
look to next figure >>

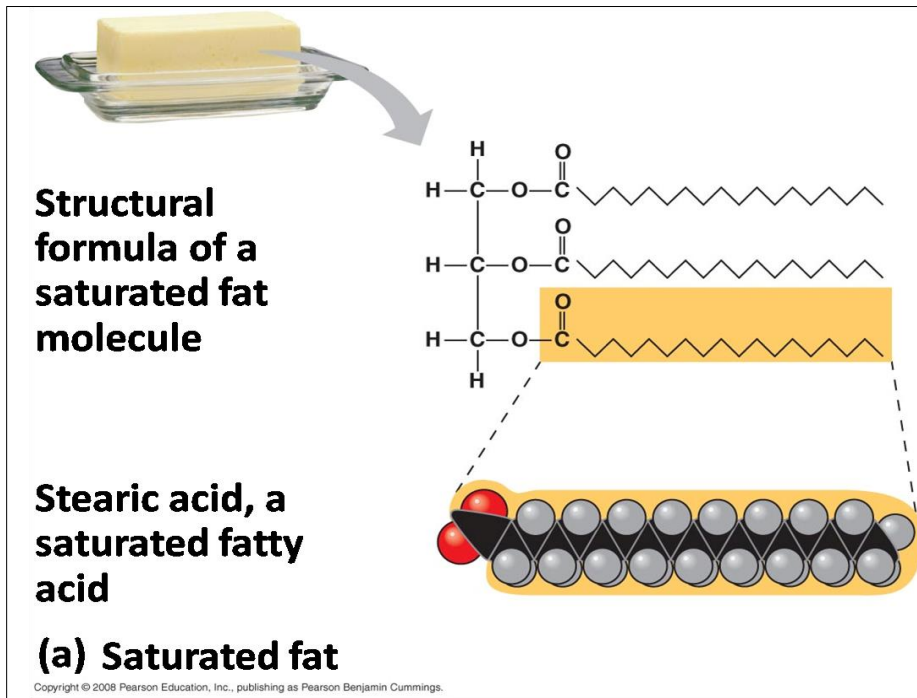


- Fat, also called a **triacylglycerol**, or triglyceride

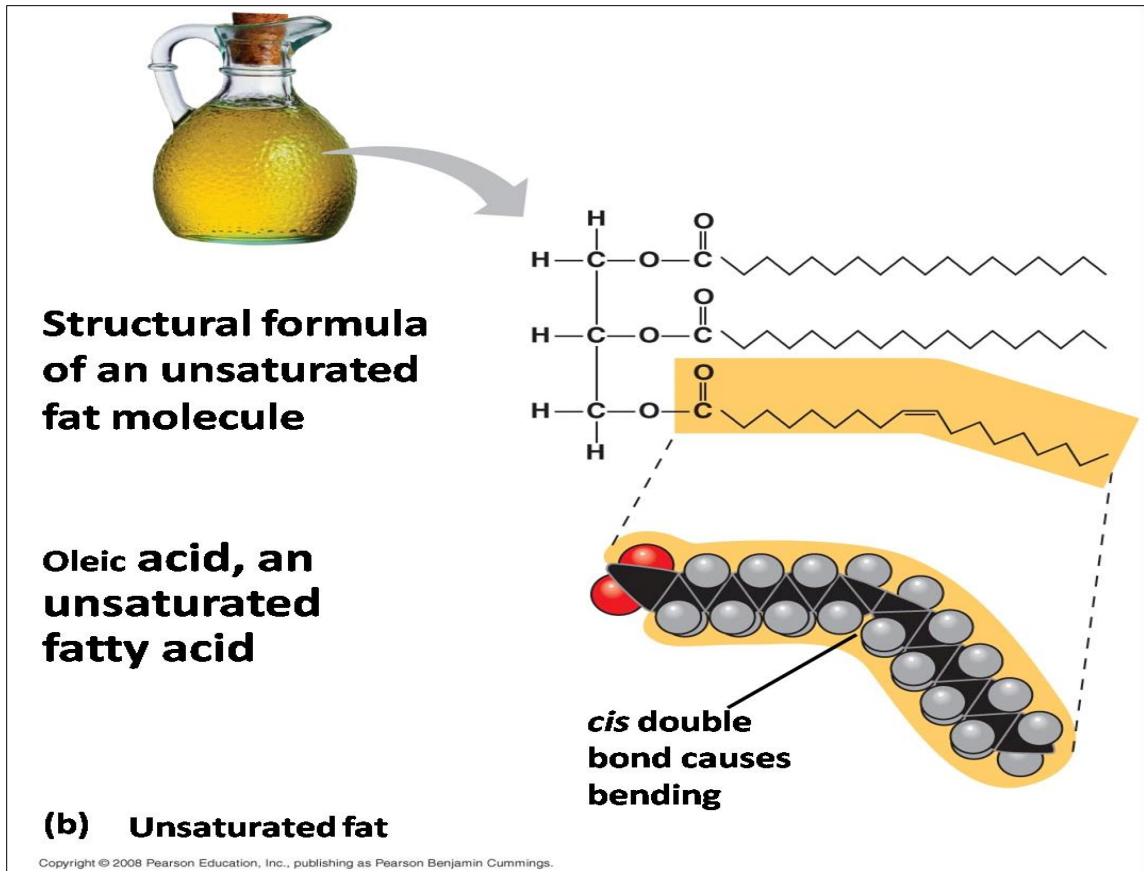
Fatty acids

- Fatty acids vary in length (number of carbons) and in the number and locations of double bonds
- **There is two types of fatty acids:**
 1. Saturated fatty acids
 2. Unsaturated fatty acids
- **Saturated fatty acids** have the maximum number of hydrogen atoms possible and no double bonds between carbon atoms composing a chain.

- Fats made from saturated fatty acids are called saturated fats
- Most animal fats are saturated (contain saturated fatty acids)
 - Saturated fats(such as lard and butter) are solid at room temperature
- A diet rich in saturated fats may contribute to cardiovascular disease through plaque deposits (ترسبات) within the walls of blood vessels .



- **Unsaturated fatty acids** have one or more double bonds, forms by the removal of one hydrogen atom in the carbon skeleton .
- Nearly all double bonds in naturally occurring fatty acids are" cis double bonds" , which cause a kink in the hydrocarbon chain wherever they occur , cis double bond prevent packing together .
- Fats made from unsaturated fatty acids are called unsaturated fats
 - Plant fats and fish fats are usually unsaturated and referred to as oils such as olive oil and cod liver oil
 - Unsaturated fats are liquid at room temperature
- **Hydrogenation** is the process of converting unsaturated fats to saturated fats by adding hydrogen
- Hydrogenating vegetable oils also creates unsaturated fats with "*trans* double bonds" .
 - These *trans* fats may contribute more than saturated fats to cardiovascular disease .

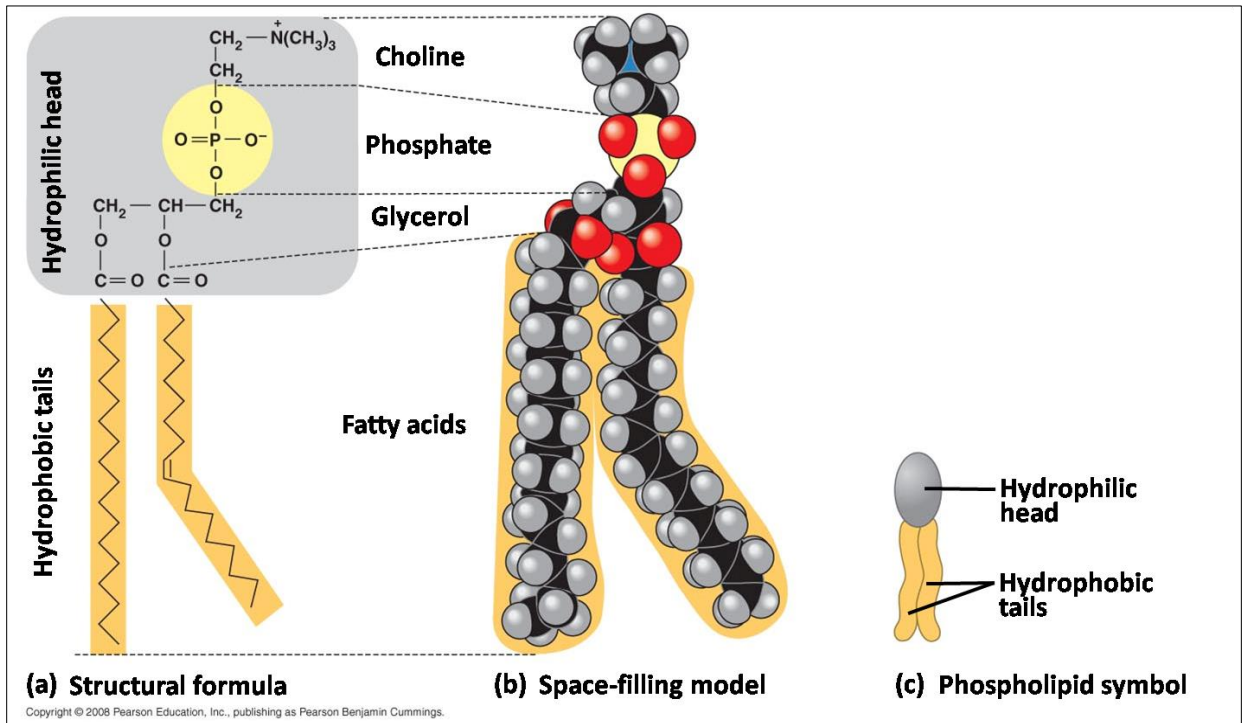


- The major function of fats is energy storage
- A gram of fat stores more than twice as much energy as a gram of a polysaccharide, such as starch
- Humans and other mammals store their fat in adipose cells
- Adipose tissue also cushions vital organs as the kidneys and insulates the body .

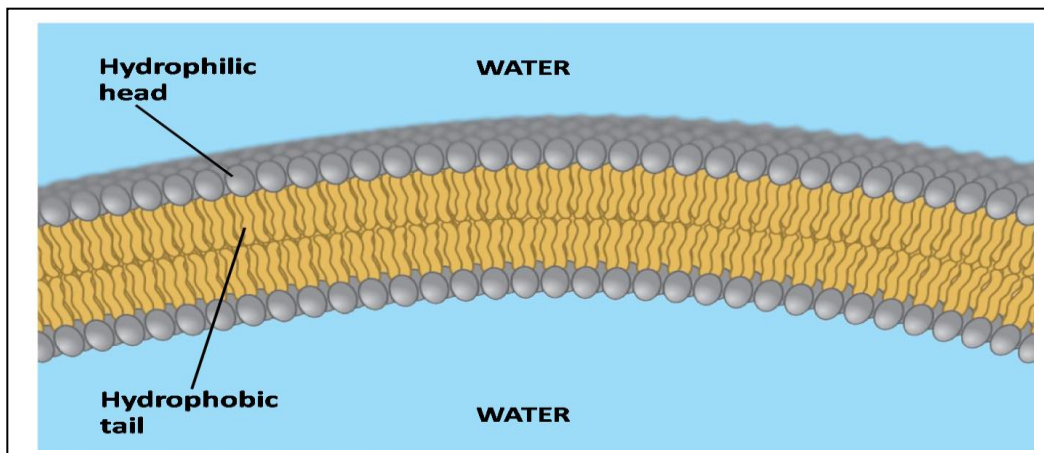
Phospholipids

- Phospholipids are essential for cells because they make up cell membranes (cells could not exist without phospholipids)
- In a **phospholipid**, two fatty acids and a phosphate group are attached to glycerol
- The hydrocarbon tails are **hydrophobic**, but the phosphate group and its attachments form a **hydrophilic head**
- Phospholipids diversity is based on differences *in the two fatty acids and *in the groups attached to the phosphate group

- The phospholipid in the figure 5.13 called a phosphatidylcholine ,which has an attached choline group



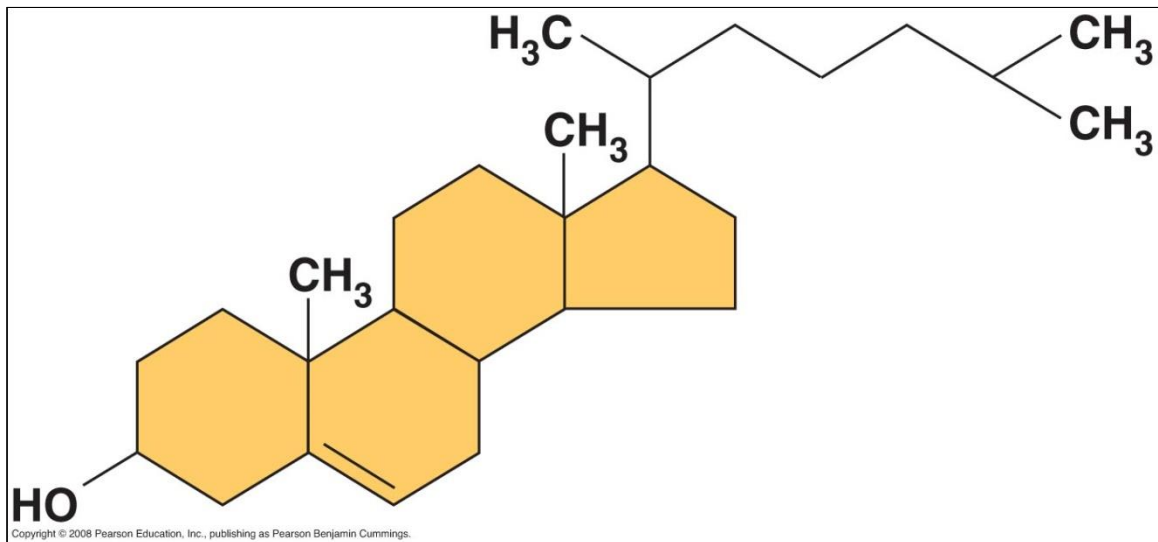
- When phospholipids are added to water, they self-assemble into a bilayer, shielding their hydrophobic portions from water
- The structure of phospholipids results in a bilayer arrangement found in cell membranes
 - The hydrophilic head are on the outside of bilayer, in contact with the aqueous solutions inside and outside of the cell
 - The hydrophobic tails point toward the interior of the bilayer , in contact with each other and away from water.
- The phospholipid bilayer forms a boundary between the cell and its external environment



Steroids

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings.
- Steroids vary in the chemical groups attached to their four interconnected rings.
- Cholesterol and vertebrate sex hormones are examples of steroids .
- ➔ **Cholesterol**, an important steroid, is a component in animal cell membranes
 - cholesterol is a common component of animal cell membranes and is also the precursor for which other steroids are synthesized
- Although cholesterol is essential in animals, high levels in the blood may contribute to cardiovascular disease such as arteriosclerosis
- In vertebrates, cholesterol is synthesized in the liver
- Saturated fat and trans exert their negative impact on health by affecting cholesterol levels

This figure shows a steroid ☺



Concept 5.4: Proteins have many structures, resulting in a wide range of functions

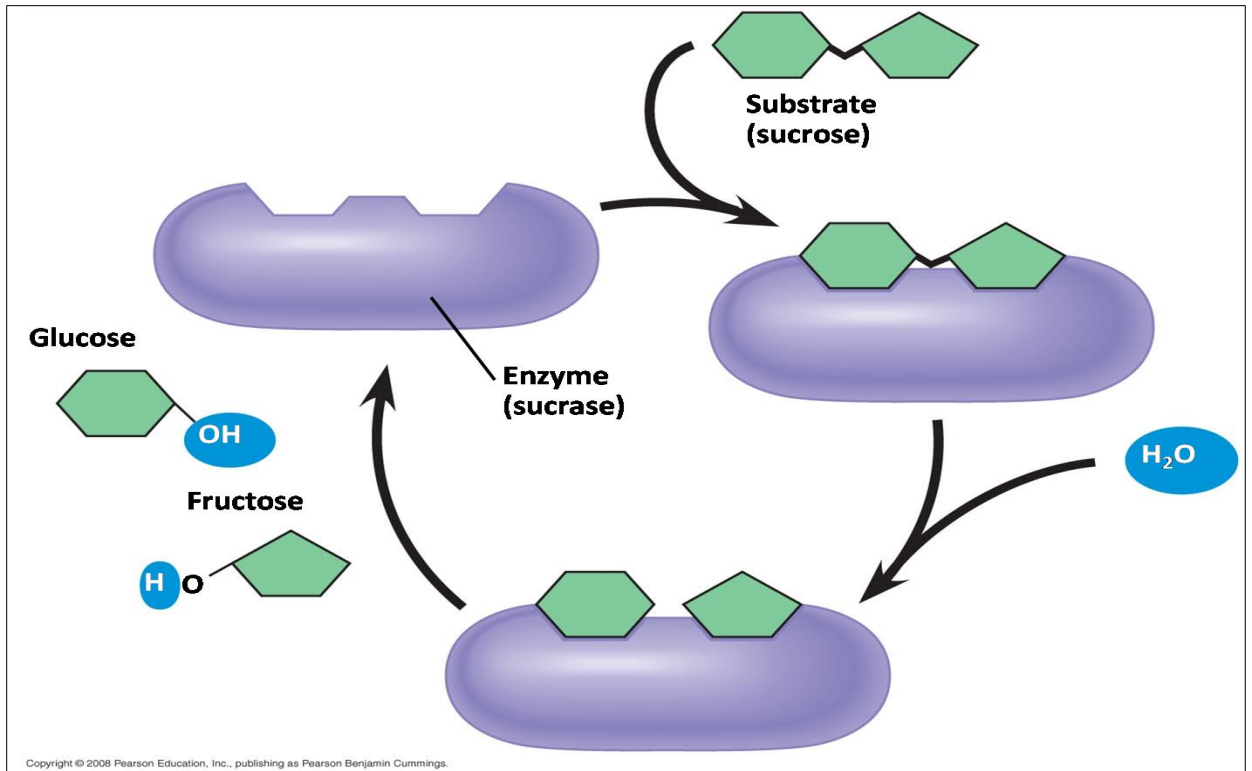
- Proteins account for more than 50% of the dry mass of most cells and they are instrumental in almost everything organisms do.
- Protein functions include structural support, storage, transport, cellular communications, movement, and defense against foreign substances.

Table 5.1 An Overview of Protein Functions

| Type of Protein | Function | Examples |
|--------------------------------|--|---|
| Enzymatic proteins | Selective acceleration of chemical reactions | Digestive enzymes |
| Structural proteins | Support | Silk fibers; collagen and elastin in animal connective tissues; keratin in hair, horns, feathers, and other skin appendages |
| Storage proteins | Storage of amino acids | Ovalbumin in egg white; casein, the protein of milk; storage proteins in plant seeds |
| Transport proteins | Transport of other substances | Hemoglobin, transport proteins |
| Hormonal proteins | Coordination of an organism's activities | Insulin, a hormone secreted by the pancreas |
| Receptor proteins | Response of cell to chemical stimuli | Receptors in nerve cell membranes |
| Contractile and motor proteins | Movement | Actin and myosin in muscles, proteins in cilia and flagella |
| Defensive proteins | Protection against disease | Antibodies combat bacteria and viruses. |

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- Enzymes are a type of protein that acts as a catalyst to speed up chemical reactions
- Enzymes can perform their functions repeatedly, functioning as workhorses that carry out the processes of life (look to the figure in next page)
- A human has tens of thousands of different proteins each with a specific structure and function
- Each type of proteins having a unique three-dimensional shape

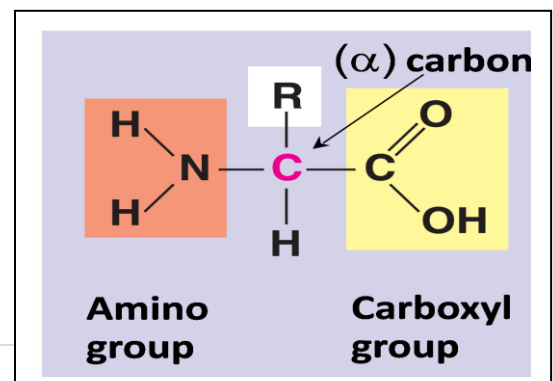


❖ Polypeptides

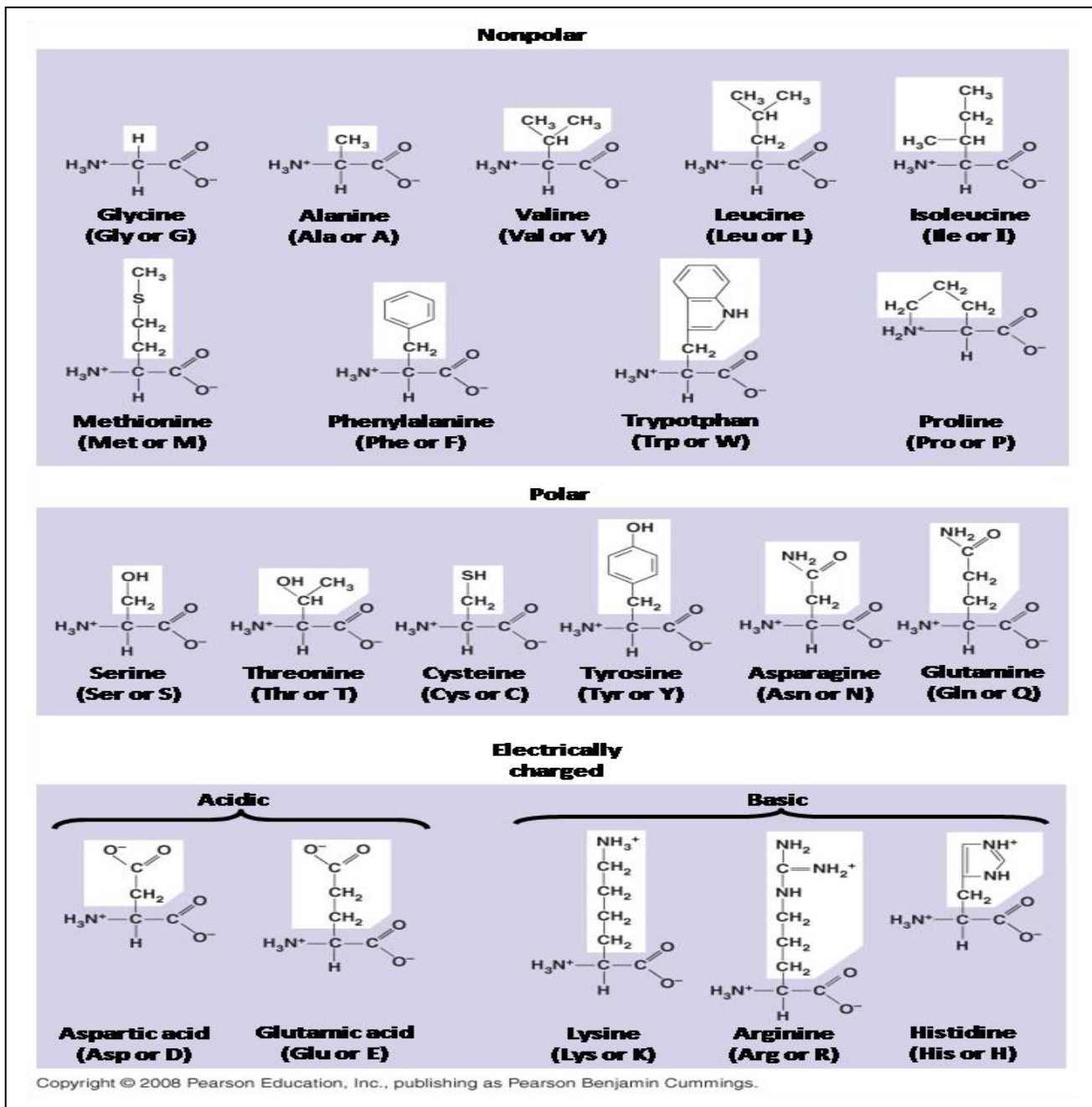
- **Polypeptides** are unbranched polymers built from the same set of 20 amino acids
- A **protein** consists of one or more polypeptides, each folded and coiled into a specific three dimensional shape

➤ **Amino Acid Monomers**

- **Amino acids** are organic molecules with carboxyl and amino groups
- At the center of the amino acid is an asymmetric carbon atom called the alpha (α) carbon
 - Its four different partners are an amino group, a carboxyl group, a hydrogen atom, and a variable group symbolized by R
- Amino acids differ in their properties due to differing side chains, called R groups

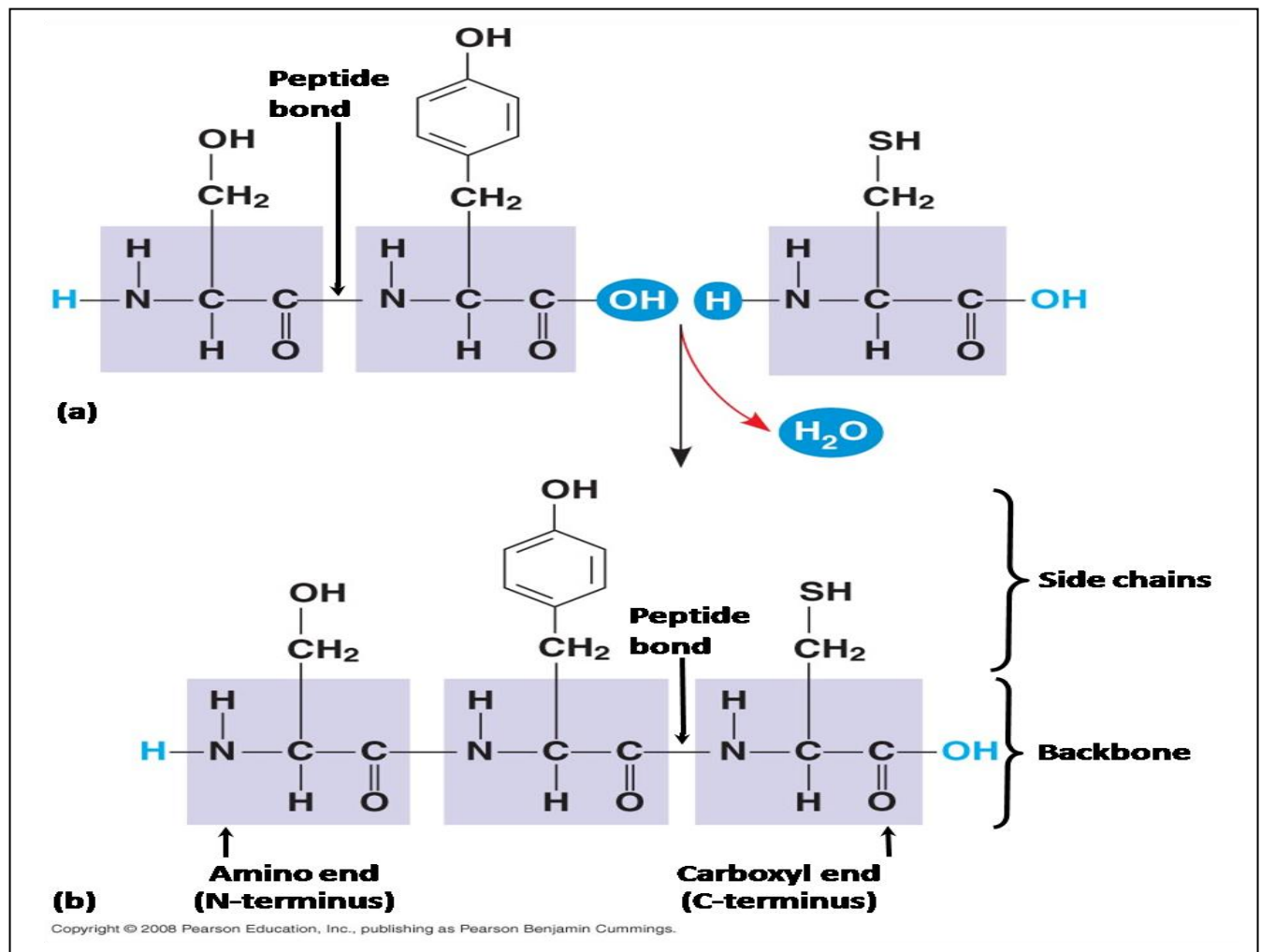


- The 20 types of amino acids are classified into three groups according to the properties of their side chain
- These three groups are :
 1. Nonpolar “ hydrophobic “
 2. Polar “ hydrophilic “
 3. Electrically charged “ hydrophilic “
- Physical and chemical properties of side chain determine the unique characteristics of a particular amino acid, thus affecting its functional role in a polypeptide.



➤ Amino Acid Polymers

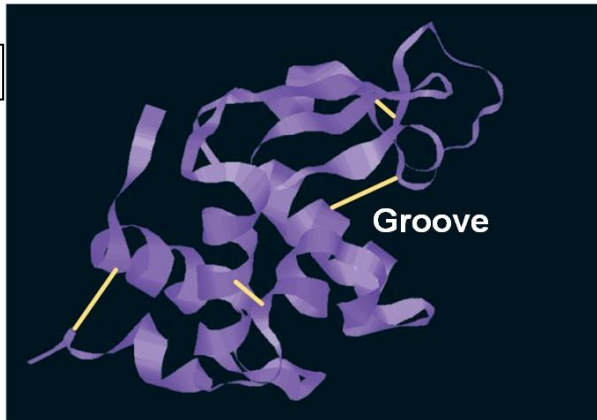
- Amino acids (the monomers) are linked by **peptide bonds**
- Peptide bonds are formed by dehydration reactions, which link the carboxyl group of one amino acid to the amino group of the next
- A polypeptide is a polymer of amino acids linked by peptide bonds
- Polypeptides range in length from a few to more than a thousand monomers
- Each polypeptide has a unique linear sequence of amino acids
- The first end of the polypeptide chain has a free amino group, while the opposite end has a free carboxyl group
 - Thus, a polypeptide of any length has a single amino end (N-terminus) and a single carboxyl end (C-terminus)
- The immense variety of polypeptides in nature illustrates an important concept – that cells can make many different polymers by linking a limited set of monomers into diverse sequences .



❖ Protein Structure and Function

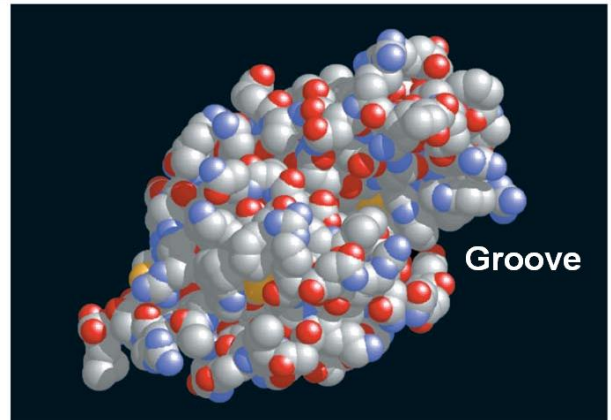
- The pioneer in determining the amino acid sequence of protein was “ Frederick Sanger “, who worked on the hormone insulin
- A functional protein consists of one or more polypeptides twisted, folded, and coiled into a unique shape

Enzyme



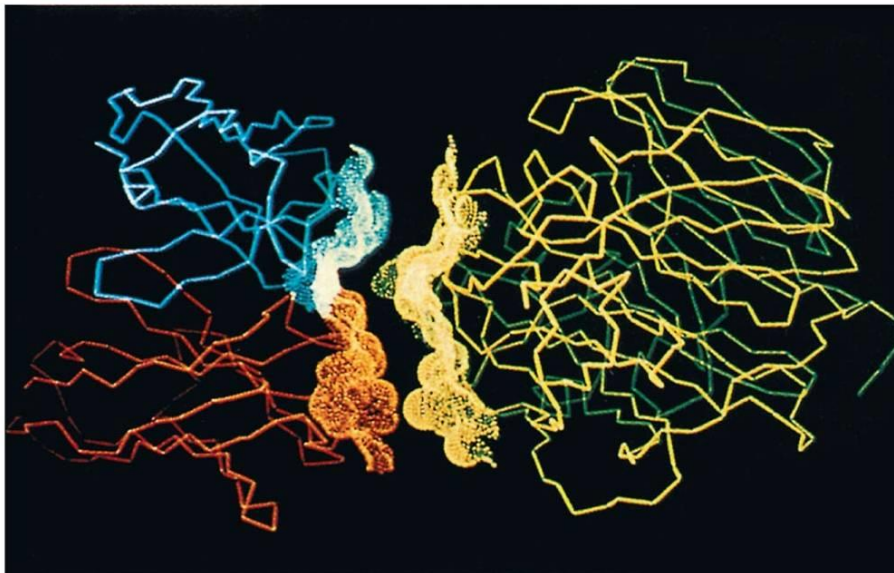
(a) A ribbon model of lysozyme

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(b) A space-filling model of lysozyme

- The sequence of amino acids determines a protein’s three-dimensional structure
- A protein’s structure determines its function .



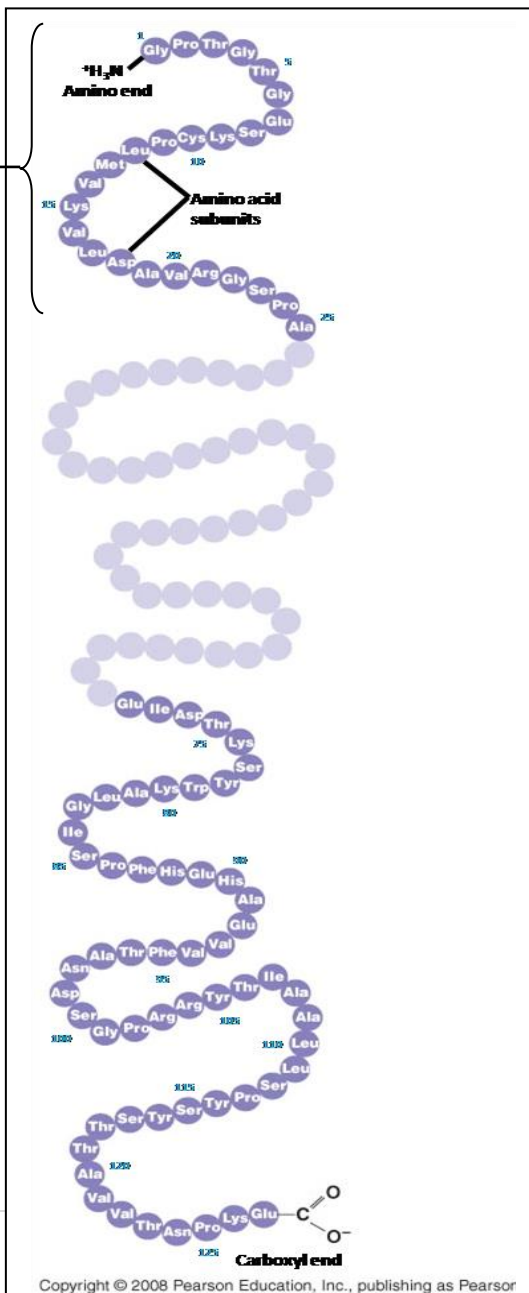
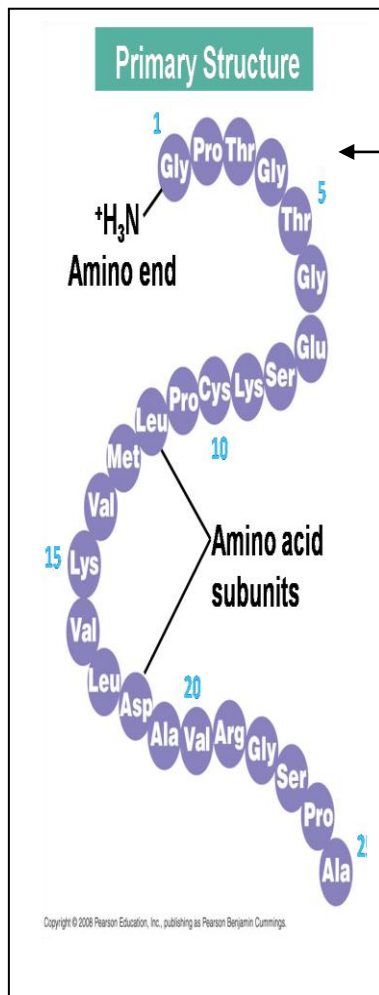
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Four Levels of Protein Structure

- All proteins share the first three level
 - The primary structure of a protein is its unique sequence of amino acids
 - Secondary structure, found in most proteins, consists of coils and folds in the polypeptide chain
 - Tertiary structure is determined by interactions among various side chains (R groups)
 - Quaternary structure results when a protein consists of multiple polypeptide chains.

➔ Primary structure:

- Primary structure : the sequence of amino acids in a protein, is like the order of letters in a long word.
- Primary structure is determined by inherited genetic information
- Proteins in this level are not functional
- In the primary structure there is only peptide bonds
- Example : **transthyretin**
- Transthyretin :
 - made up of four identical polypeptide chains each composed of 127 amino acids
 - Is a globular blood protein that transports vitamin A and one of the thyroid hormones throughout the body

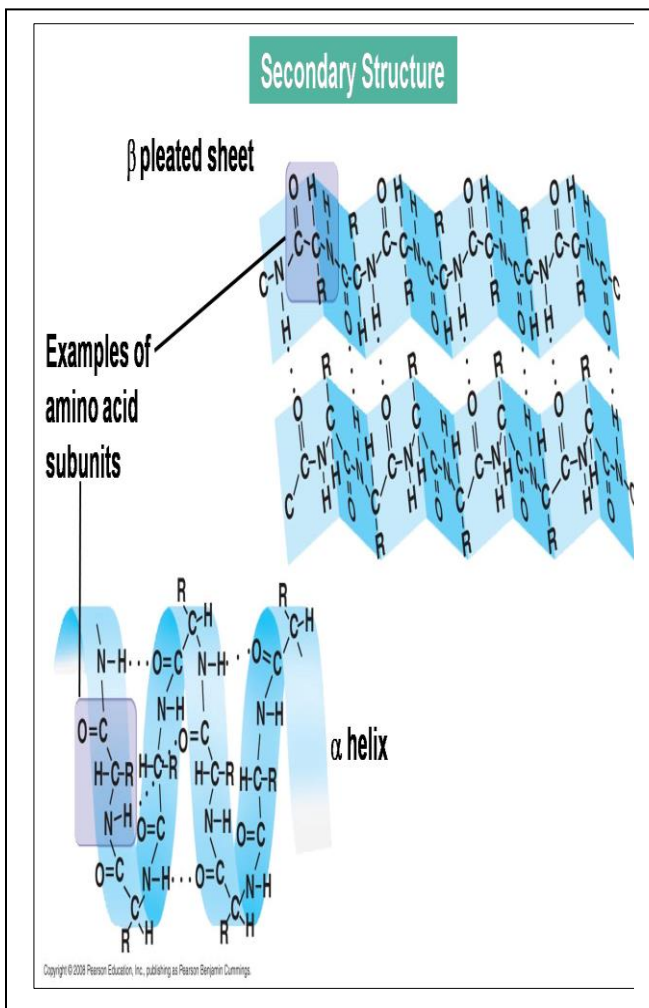


➔ Secondary structure :

- The coils and folds of **secondary structure** result from hydrogen bonds between repeating constituents of the polypeptide backbone.
- The hydrogen bonds are weak, but because they are repeated many times, they can support a particular shape for that part of the protein
- Proteins in this level are not functional
- In the secondary structure there is peptide bonds and hydrogen bonds
- There are two main types of secondary structure :

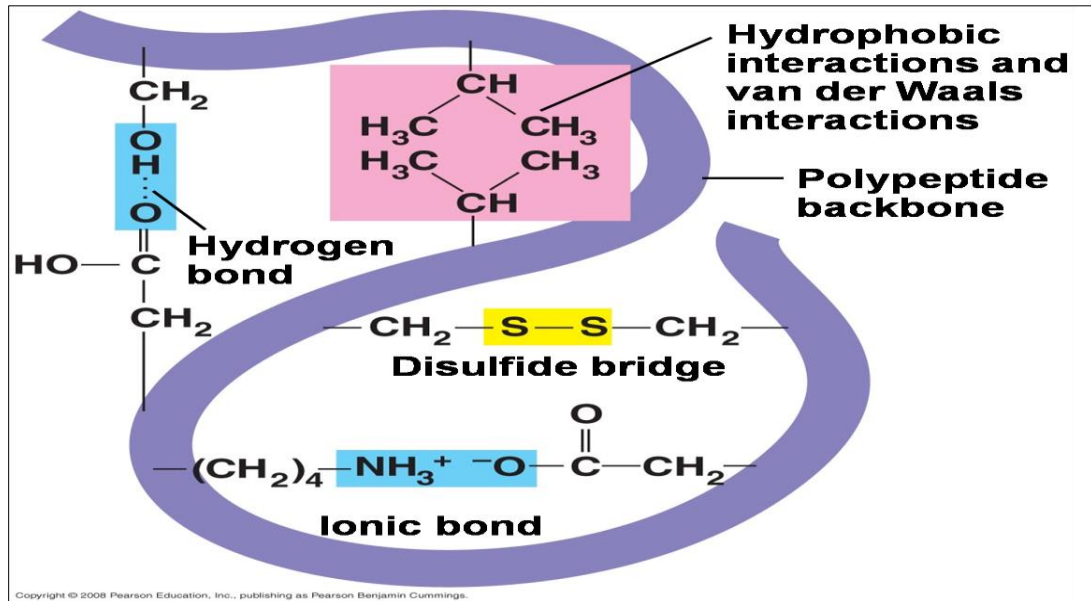
1. **α helix** , a delicate coil held together by hydrogen bonding between every fourth amino acid

2. **β pleated sheet** , in this structure two or more strands of the polypeptide chain lying side by side are connected by hydrogen bonds between parts of the two parallel polypeptide backbones



↻ Tertiary structure

- **Tertiary structure** is determined by interactions between R groups, rather than interactions between backbone constituents
- These interactions between R groups include hydrogen bonds, ionic bonds, **hydrophobic interactions**, and van der Waals interactions
- Strong covalent bonds called **disulfide bridges** may reinforce the protein's structure
- Proteins in this level are functional

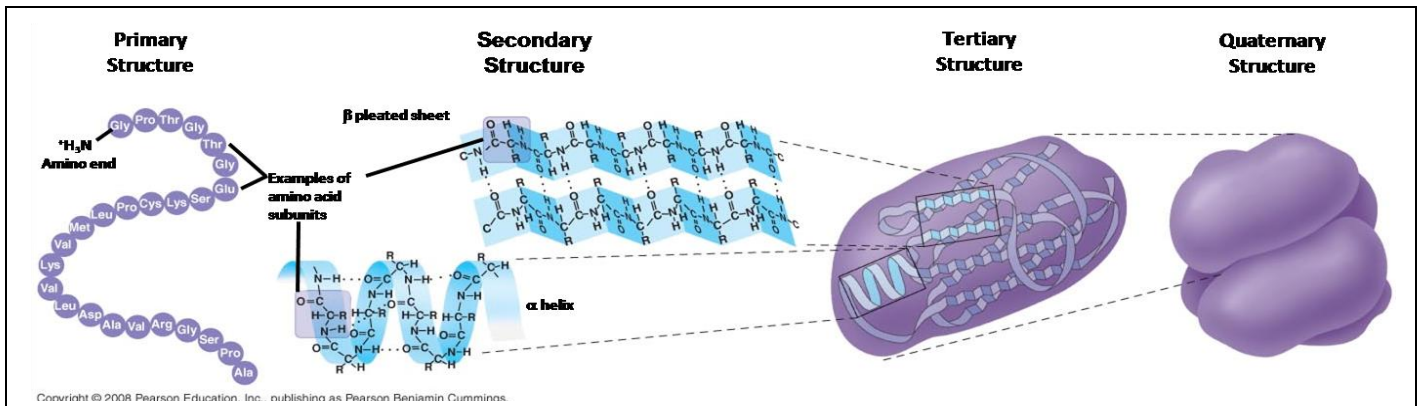
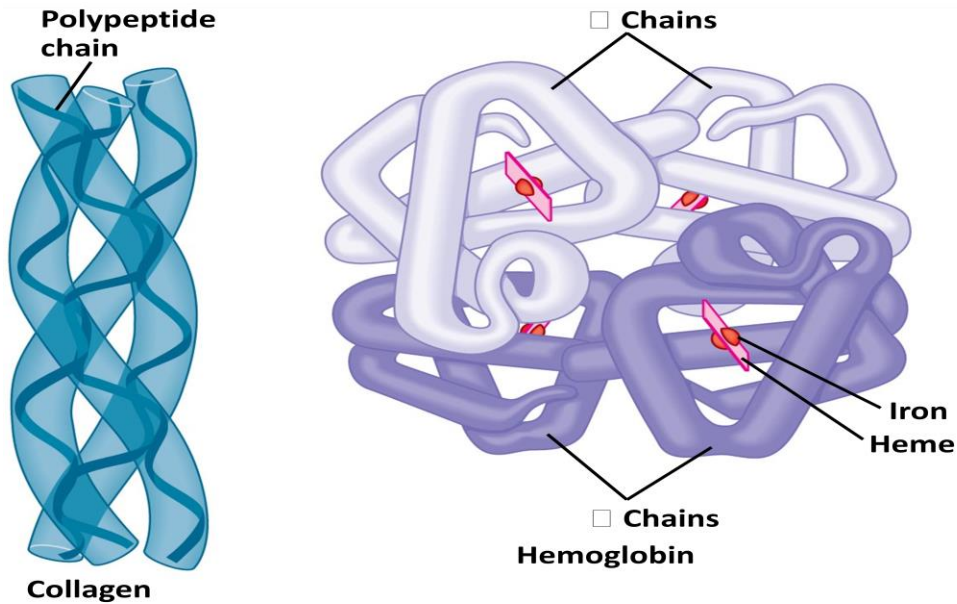


↻ Quaternary structure

- **Quaternary structure** results when two or more polypeptide chains form one macromolecule
- Some proteins are in this level
- Proteins in this level are functional
- Examples :
 1. Globular transthyretin protein
 - made up of four polypeptides
 2. Collagen
 - a fibrous protein that has three identical helical polypeptides intertwined into a large triple helix , Its three identical helical polypeptides coiled like a rope
 - Collagen accounts for 40% of the protein in a human body

3. Hemoglobin

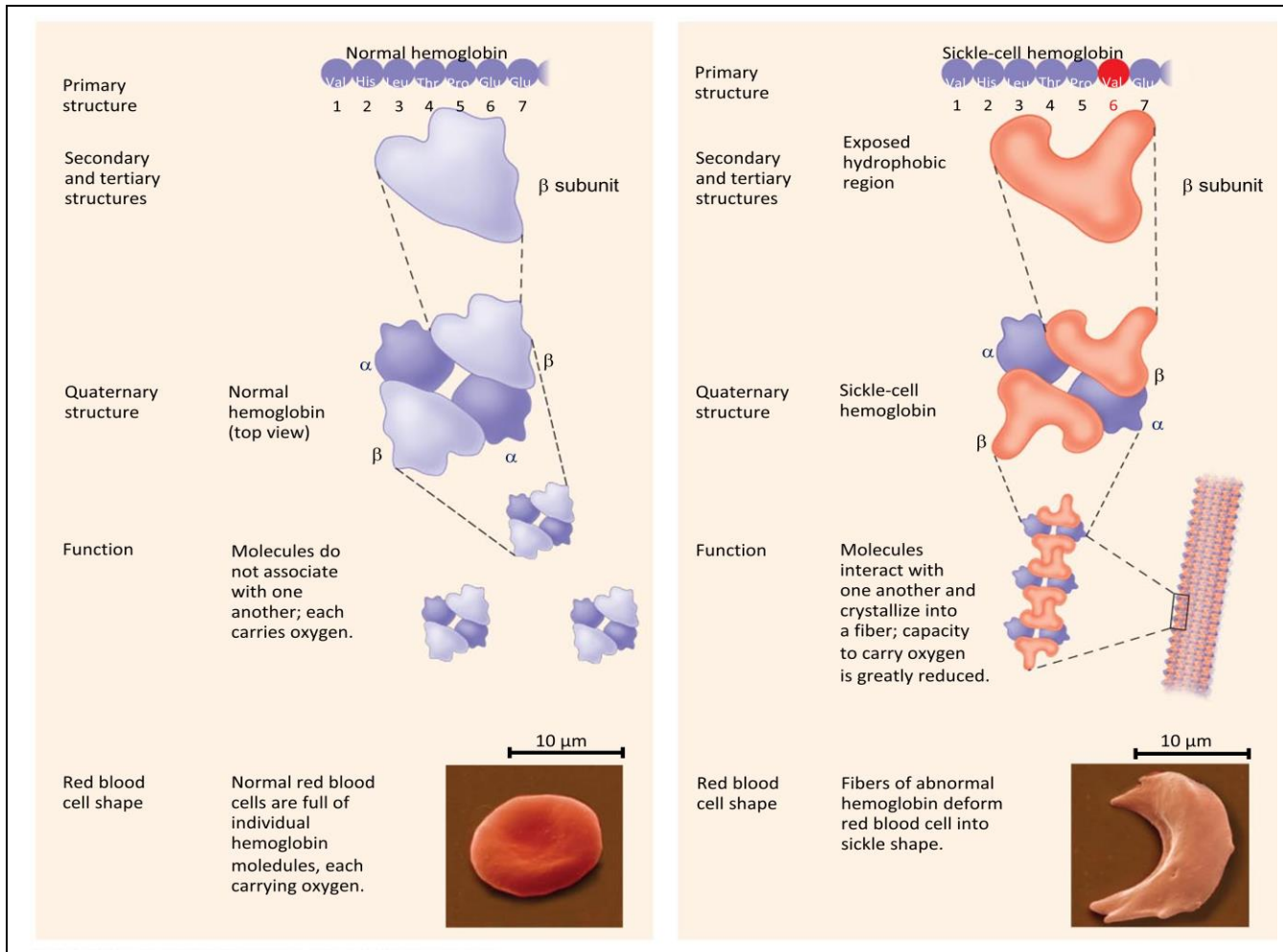
- a globular protein consisting of four polypeptides: two alpha and two beta chains
- Both alpha and beta subunits consist primarily of α -helical secondary structure
- Each subunits has a non-polypeptide component called "heme", with an iron atom that binds oxygen



Sickle-Cell Disease: A Change in Primary Structure

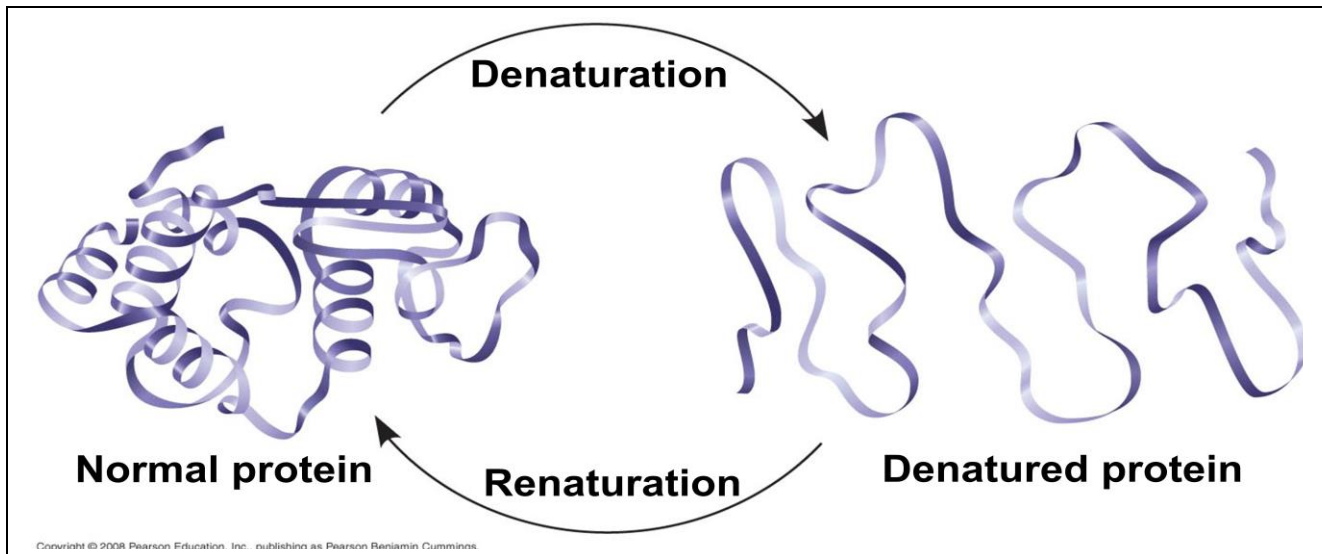
- A slight change in primary structure can affect a protein's structure and ability to function
- Sickle-cell disease, an inherited blood disorder, caused by substitution of one amino acid (valine) for the normal one (glutamic acid) at a particular position in the primary structure of hemoglobin

- A person with the sickle-cell disease has periodic “sickle-cell crises” when the angular cells clog tiny blood vessels , impeding blood flow .



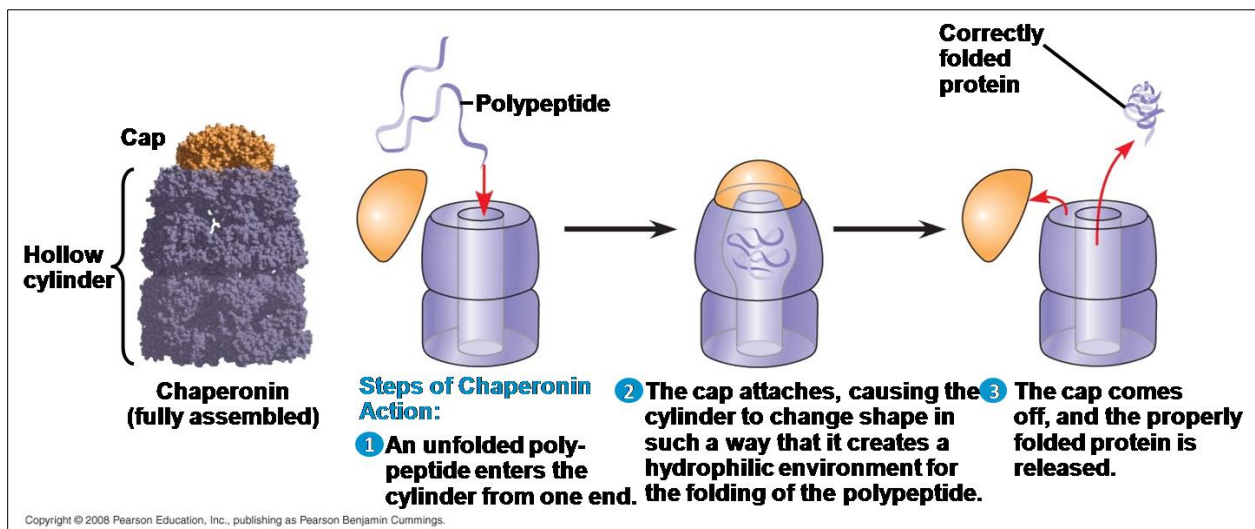
What Determines Protein Structure?

- In addition to primary structure, physical and chemical conditions can affect structure
- Alterations in pH, salt concentration, temperature, or other environmental factors can cause a protein to unravel
- This loss of a protein’s native structure is called **denaturation**
- A denatured protein is biologically **inactive**
- Most proteins become denatured if they are transferred from an aqueous environment to a nonpolar solvent, such as ether or chloroform
- Some chemicals can disrupt the hydrogen bonds, ionic bonds, and disulfide bridges that maintain a protein’s shape ,so the protein become inactive
- **Renaturation** : when protein get back to its normal shape when the chemical and physical aspects of its environment are restored to normal



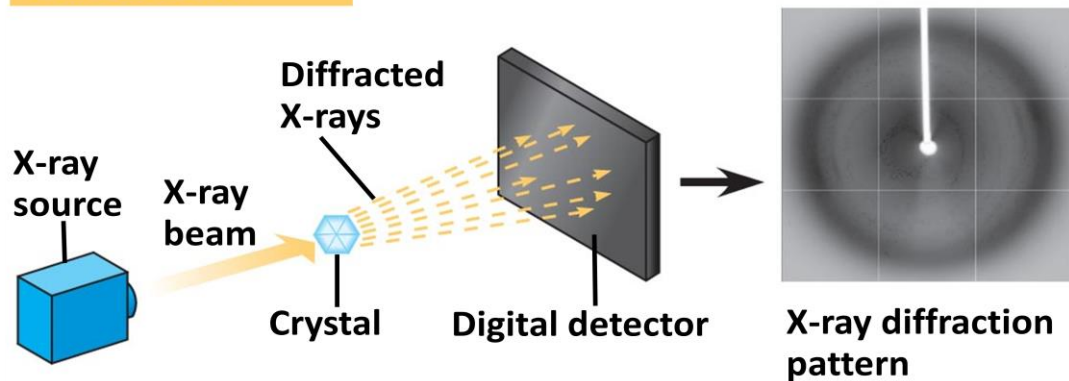
Protein Folding in the Cell

- It is hard to predict a protein’s structure from its primary structure
- Most proteins probably go through several states on their way to a stable structure
- Folding process occur by **chaperonins** (also called chaperone proteins)
- **Chaperonins** (chaperone proteins) are protein molecules that assist the proper folding of other proteins
- Chaperonins do not specify the final structure of a polypeptide but they keep the new polypeptide segregated from “bad influences” in the cytoplasmic environment while it folds spontaneously
- The chaperonin shown in next figure is a giant multiprotein complex shaped like a hollow cylinder
 - The cavity provides a shelter for the proper folding of newly made polypeptides

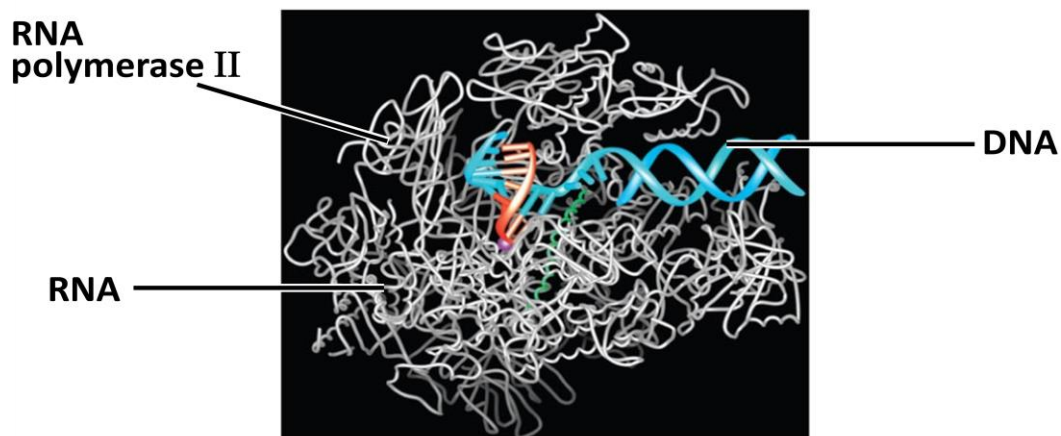


- Misfolding of polypeptides lead to many disease such as Alzheimer's, Pankinson's and mad cow disease
- In fact, misfolded versions of the transthyretin protein have been implicated in several disease, including one form of senile dementia
- Scientists use **X-ray crystallography** to determine a protein's structure.
- Another method is nuclear magnetic resonance (NMR) spectroscopy, which does not require protein crystallization.
- Bioinformatics uses computer programs to predict protein structure from amino acid sequences.

EXPERIMENT



RESULTS



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Concept 5.5: Nucleic acids store and transmit hereditary information

- The amino acid sequence of a polypeptide is programmed by a unit of inheritance called a **gene**
- Genes are made of DNA (belongs to class of compounds called nucleic acids)

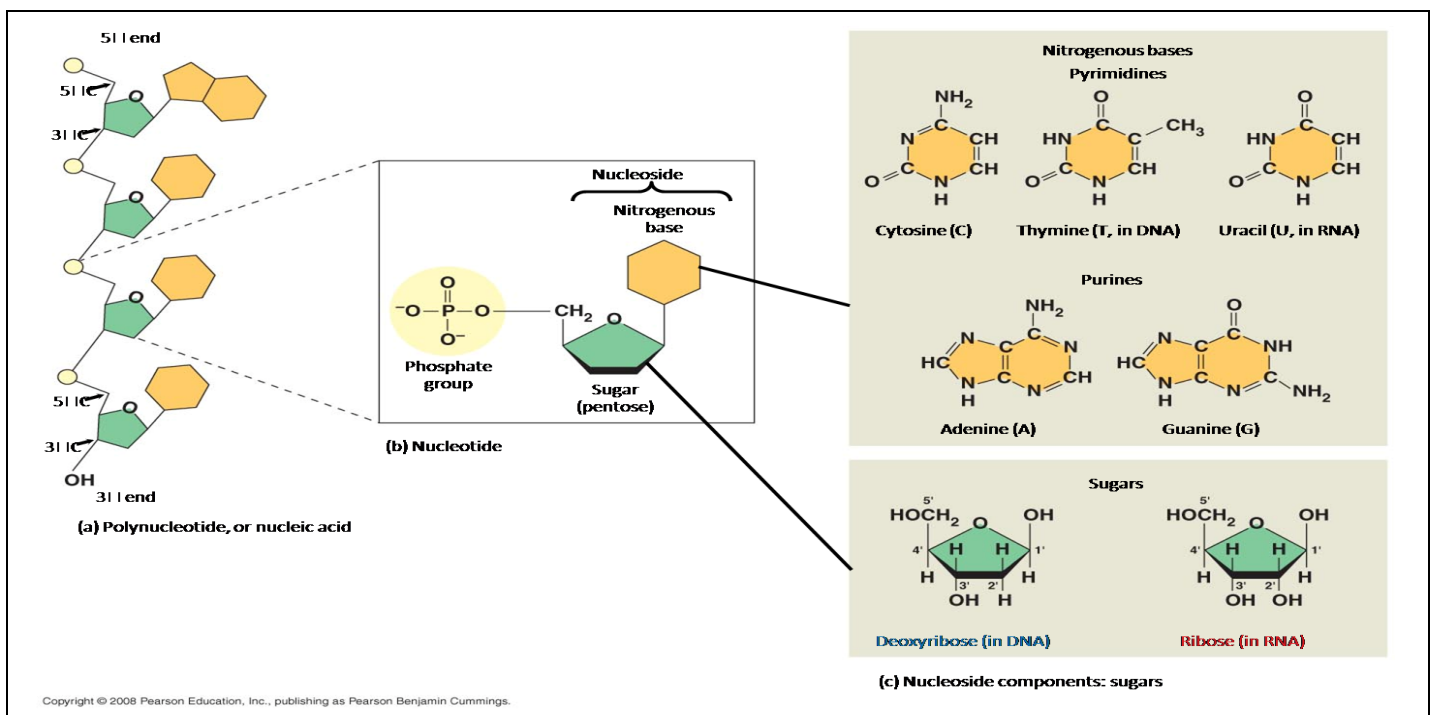
The Roles of Nucleic Acids

- There are two types of nucleic acids:
 - **Deoxyribonucleic acid (DNA)**
 - **Ribonucleic acid (RNA)**
- DNA provides directions for its own replication, directs synthesis of messenger RNA (mRNA) and (through mRNA) DNA controls protein synthesis
 - Protein synthesis occurs in ribosomes

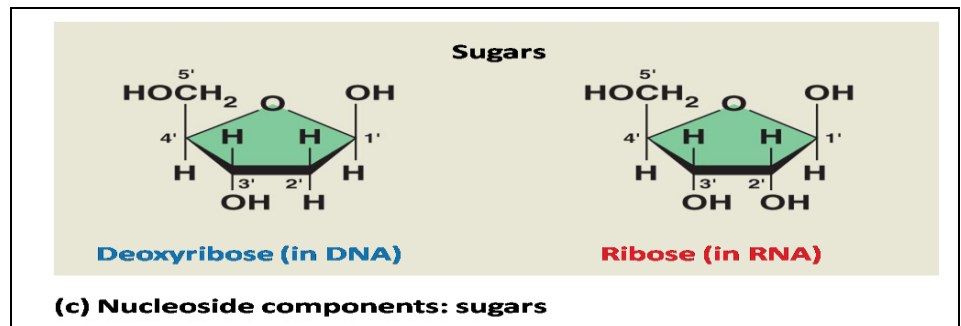
The Structure of Nucleic Acids

- Nucleic acids are macromolecules that exist as polymers called **polynucleotides**
- Each polynucleotide is made of monomers called **nucleotides**
- Each nucleotide consists of a nitrogenous base, a pentose sugar, and a phosphate group
- The portion of a nucleotide without the phosphate group is called a *nucleoside*

Nucleoside = nitrogenous base + sugar



- There are two families of nitrogenous bases:
 - **Pyrimidines** (cytosine, thymine, and uracil) have a single six-membered ring
 - **Purines** (adenine and guanine) are larger, with a six-membered ring fused to a five-membered ring
 - Adenine, guanine, and cytosine are found in both DNA and RNA, thymine, is found only in DNA and uracil found only in RNA
- In DNA, the sugar is **deoxyribose**; in RNA, the sugar is **ribose**
- **Nucleotide** = nucleoside + phosphate group



Nucleotide Polymers

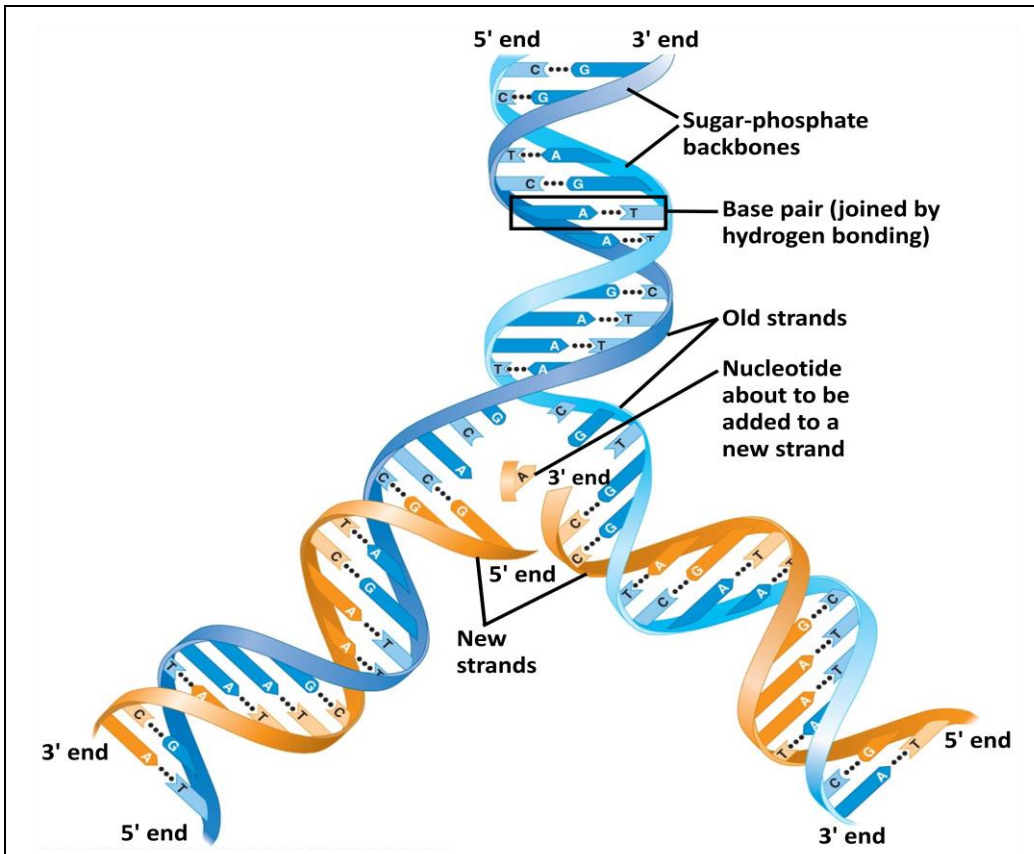
- Nucleotide polymers are linked together to build a polynucleotide
- Adjacent nucleotides are joined by covalent bonds that form between the (–OH group on the 3' carbon of one nucleotide) and the (phosphate on the 5' carbon on the next nucleotide).
- This covalent bonds that joined the adjacent nucleotides called **phosphodiester linkage**
- These links create a backbone of sugar-phosphate units with nitrogenous bases as appendages
- The sequence of bases along a DNA or mRNA polymer is unique for each gene

The DNA Double Helix

- **RNA** molecules usually exist as single polynucleotides but **DNA** molecule has two polynucleotides spiraling around an imaginary axis, forming a **double helix**.
- In the DNA double helix, the two backbones run in opposite 5' → 3' directions from each other, an arrangement referred to as **antiparallel**
- The sugar-phosphate backbones are on the outside of the helix, and the nitrogenous bases are paired in the interior of the helix

- The nitrogenous bases in DNA pair up and form hydrogen bonds: adenine (A) always with thymine (T), and guanine (G) always with cytosine (C)
- Strands of the double helix are complementary

Note : In RNA adenine (A) pairs with uracil (U)



DNA and Proteins as Tape Measures of Evolution

- The linear sequences of nucleotides in DNA molecules are passed from parents to offspring
- Two closely related species are more similar in DNA than those distantly related species ..
- Molecular biology can be used to assess evolutionary kinship

The end of chapter 5 😊