Lecture 3

The Chemistry of Life (2)

(ORGANIC COMPOUNDS)

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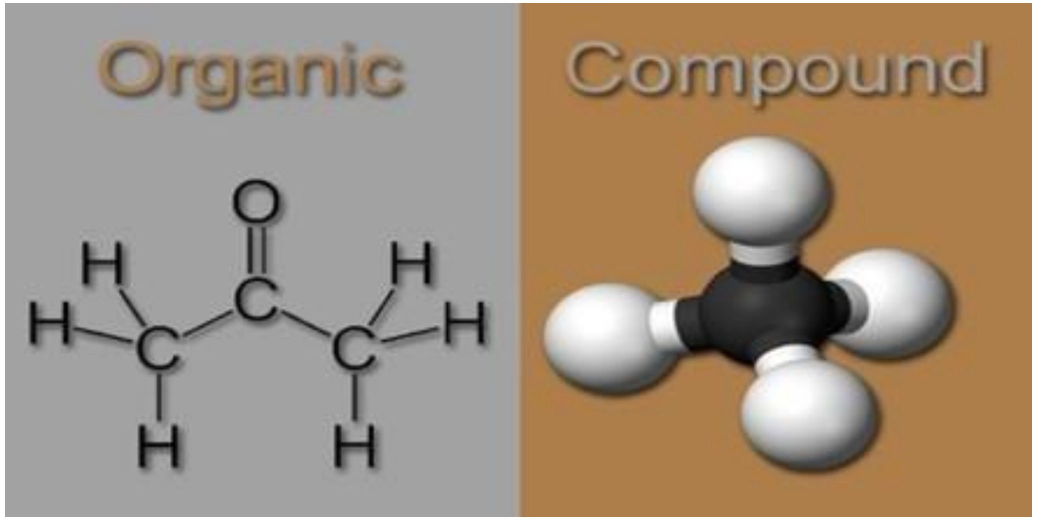
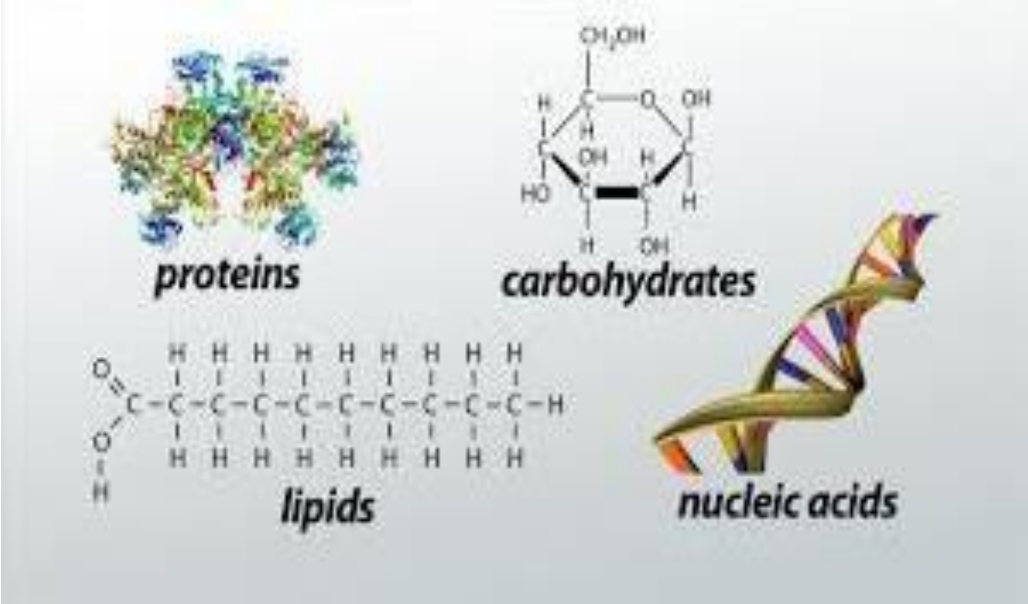
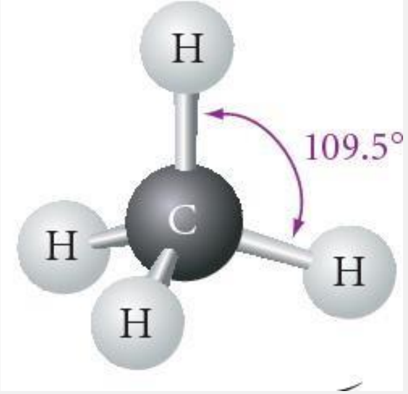
Carbon: The Backbone of Life



- Although cells are 70–95% water, the rest consists mostly of carbon-based compounds(organic compounds)
- Carbon is unparalleled in its ability to form large, complex, and diverse molecules
- Proteins, DNA, carbohydrates, and other molecules that distinguish living matter are all composed of carbon compounds



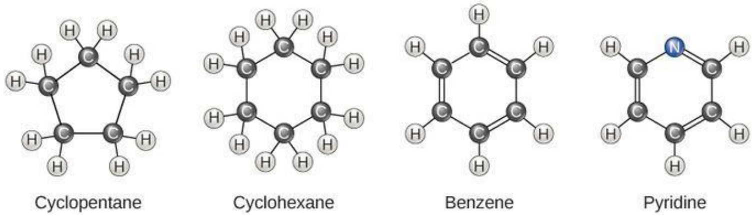


ORGANIC COMPOUNDS

Living organisms are made up of chemicals based mostly on the element carbon. For example, a cell is mostly water, and the rest of the cell consists mainly of carbon-based molecules (organic compounds). compounds containing carbon are said to be organic, and their study is called organic chemistry. Living matter is made mostly of carbon, oxygen, hydrogen, and nitrogen. Biological diversity results from carbon's ability to form a huge number of molecules with shapes and properties.

Carbon, with a valence of 4, can bond to various other atoms, including O, H, and N. Carbon can also bond to other carbon. atoms, forming the carbon skeletons of organic compounds. These skeletons vary in length and shape and have bonding sites for atoms of other elements.

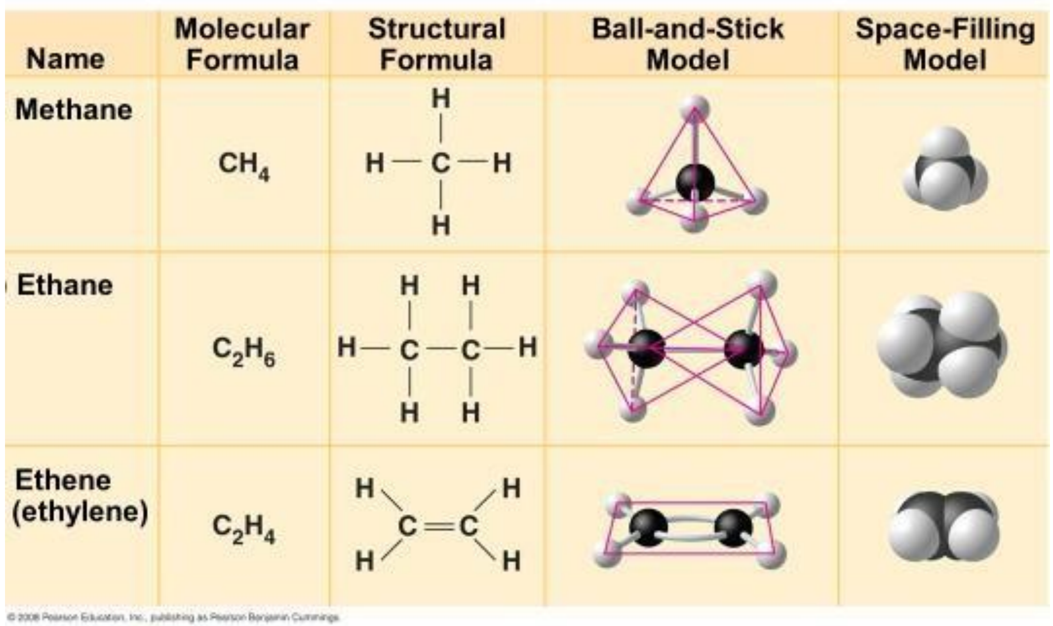
Organic Compounds

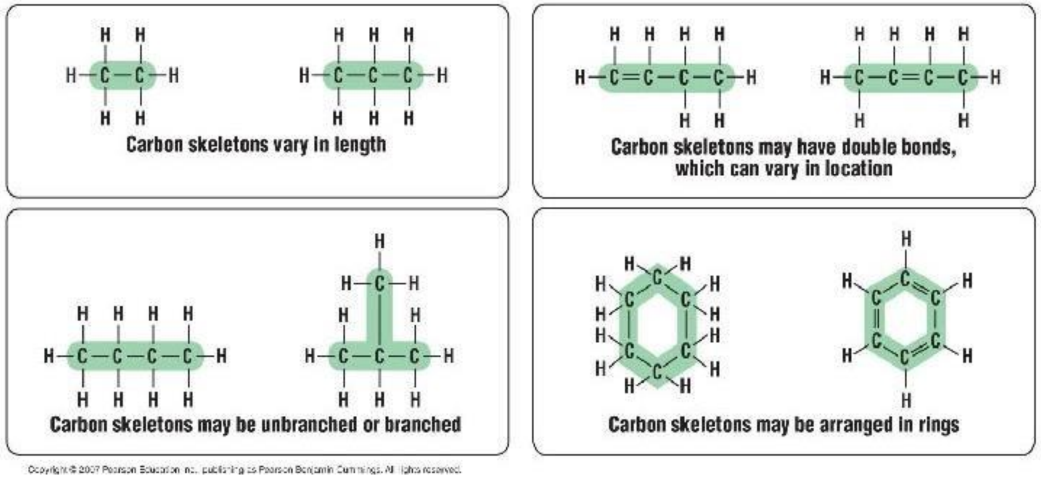


- Organic chemistry is the study of compounds that contain carbon
- Living matter is made mostly of carbon, oxygen, hydrogen, and nitrogen.
- Biological diversity results from carbon's ability to form a huge number of molecules with shapes and properties.

Carbon Atoms can Form Diverse Molecules By Bonding to Four Other Atoms

Carbon can **share electrons** with other atoms in **four covalent bonds** Because carbon can use one or more of its bonds to attach to other carbon atoms, it is possible to construct an endless diversity of carbon skeletons varying in size and branching pattern.





THE STRUCTURE AND FUNCTION OF BIOLOGICAL MOLECULES:

Given the rich complexity of life on Earth, it might surprise you that the most important large molecules found in all living things—from bacteria to elephants—can be sorted into just four main classes: carbohydrates, lipids, proteins, and nucleic acids. On the molecular scale, members of three of these classes—carbohydrates, proteins, and nucleic acids—are huge and are therefore called macromolecules.

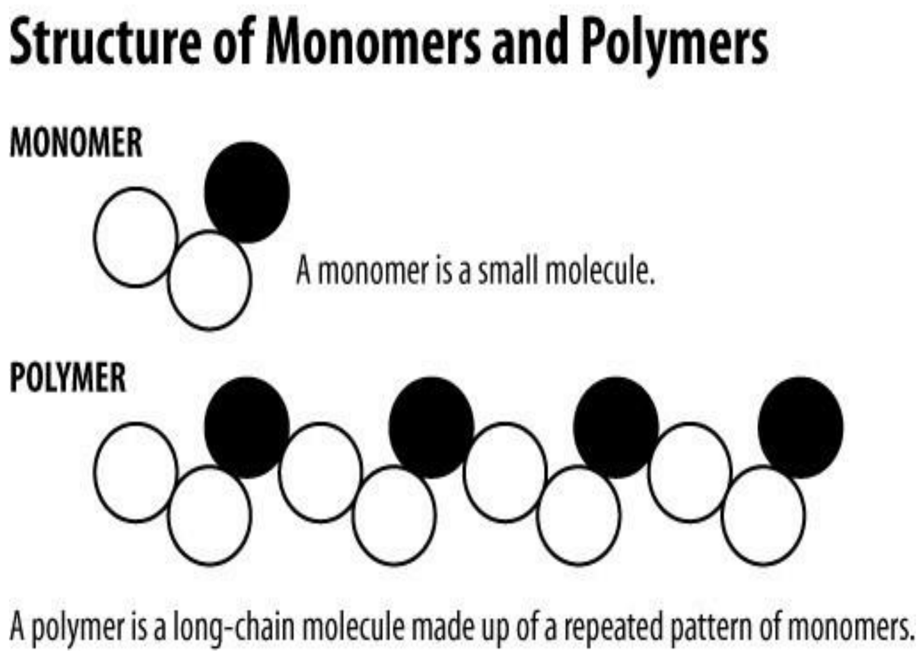
The macromolecules in three of the four classes of life's organic compounds—carbohydrates, proteins, and nucleic acids, all except lipids—are chain-like molecules called polymers (from the Greek polys, many, and meros, part). A polymer is a long molecule consisting of many similar or identical building blocks linked by covalent bonds, much as a train consists of a chain of cars. The repeating units that serve as the building blocks of a polymer are smaller molecules called monomers (from the Greek monos, single). Some monomers also have other functions of their own.

" *Macromolecules are polymers, built from monomers* "

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

Macromolecules are polymers, built from monomers..



- A **polymer** is a long molecule consisting of many similar building blocks
- These small building-block molecules are called **monomers**
- Three of the four classes of life's organic molecules are polymers:
  - Polysaccharides a type of (Carbohydrates)
  - Proteins
  - Nucleic acids

MAKING POLYMERS & BREAKING POLYMERS:

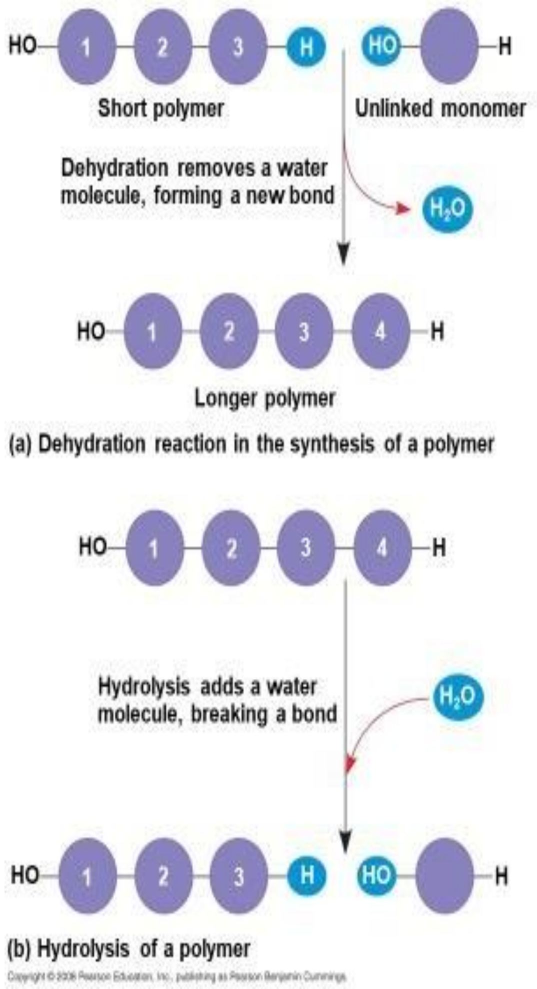
The Synthesis and Breakdown of Polymers Although each class of polymer is made up of a different type of monomer, the chemical mechanisms by which cells make and break down polymers are basically the same in all cases. In cells, these processes are facilitated by enzymes, specialized macromolecules that speed up chemical reactions. Monomers are connected by a reaction in which two molecules are covalently bonded to each other, with the loss of a water molecule; this is known as **a dehydration reaction**. 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). This reaction is repeated as monomers are added to the chain one by one, making a polymer. Polymers are disassembled to monomers by hydrolysis, a process that is essentially the reverse of the dehydration reaction (Fig 9). **Hydrolysis** means water breakage (from the Greek hydro, water, and lysis, break). The bond between monomers is broken by the addition of a water molecule, with a hydrogen from water (Fig. 10) attaching to one monomer and the hydroxyl group attaching to the other. An example of hydrolysis within our bodies is the process of digestion. The bulk of the organic material in our food is in the form of polymers that are much too large to enter our cells. Within the digestive tract, various enzymes attack the polymers, speeding up hydrolysis. Released monomers are then absorbed into the bloodstream for distribution to all body cells.

The Synthesis and Breakdown of Polymers

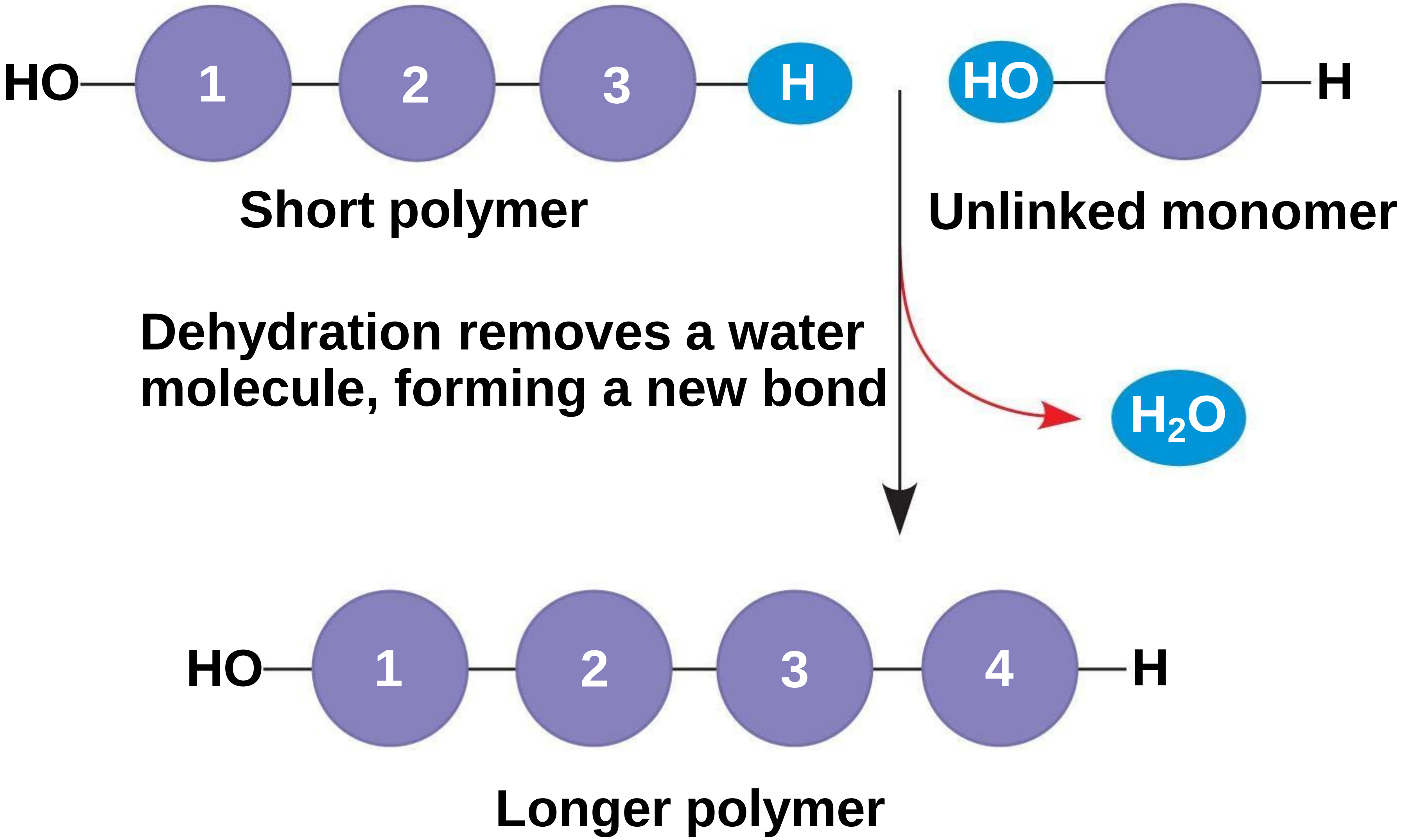
A **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule

Enzymes are macromolecules that speed up the dehydration process

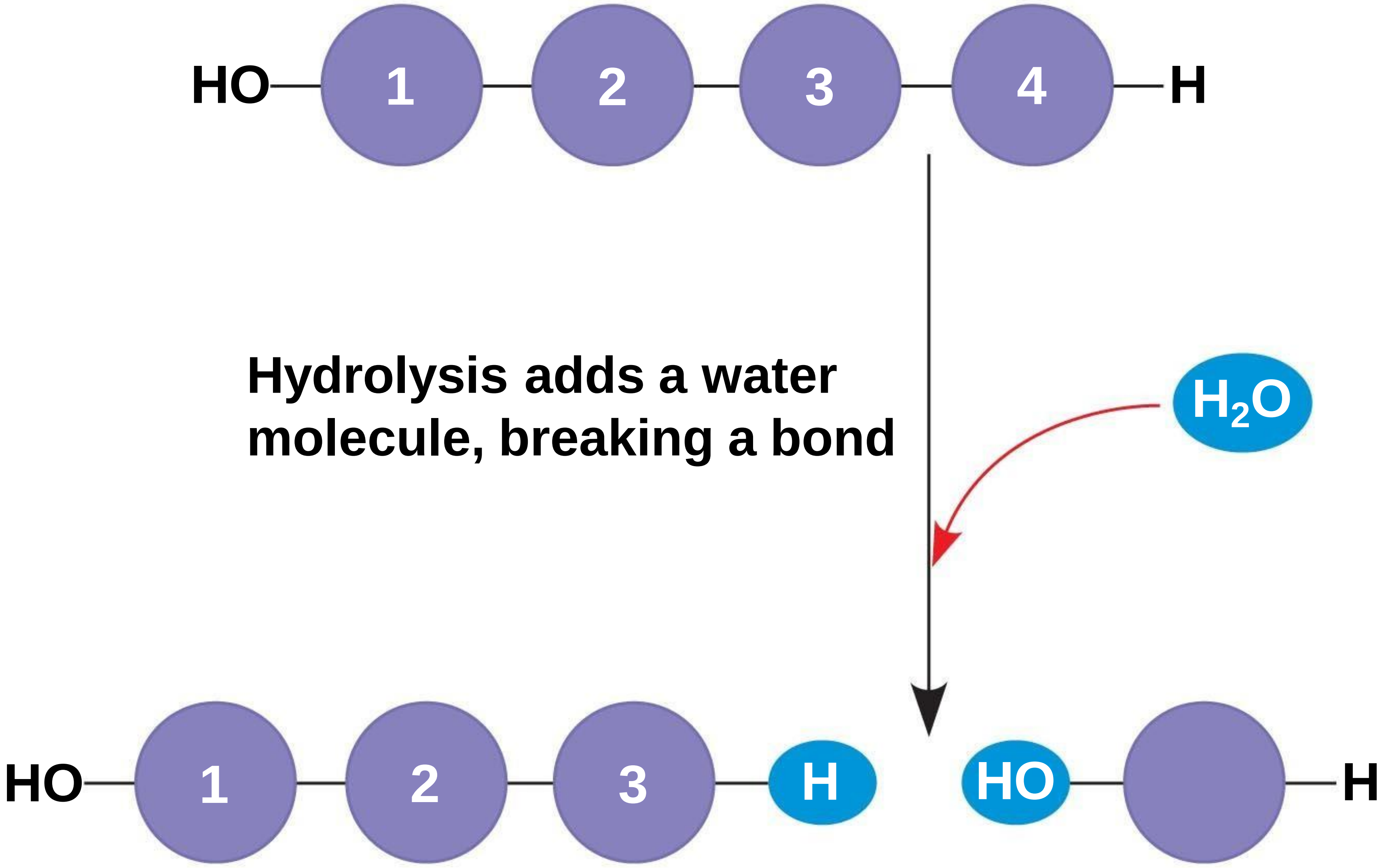
Polymers are disassembled to monomers by **hydrolysis**, a reaction that is essentially the reverse of the dehydration reaction



PLAY Animation: Polymers



(a) Dehydration reaction in the synthesis of a polymer



(b) Hydrolysis of a polymer

LARGE BIOLOGICAL MOLECULES

Carbohydrates

LARGE BIOLOGICAL MOLECULES :

There are four categories of large biological molecules found in all living creatures: 1. Carbohydrates 2. Lipids 3. Proteins 4. Nucleic acids

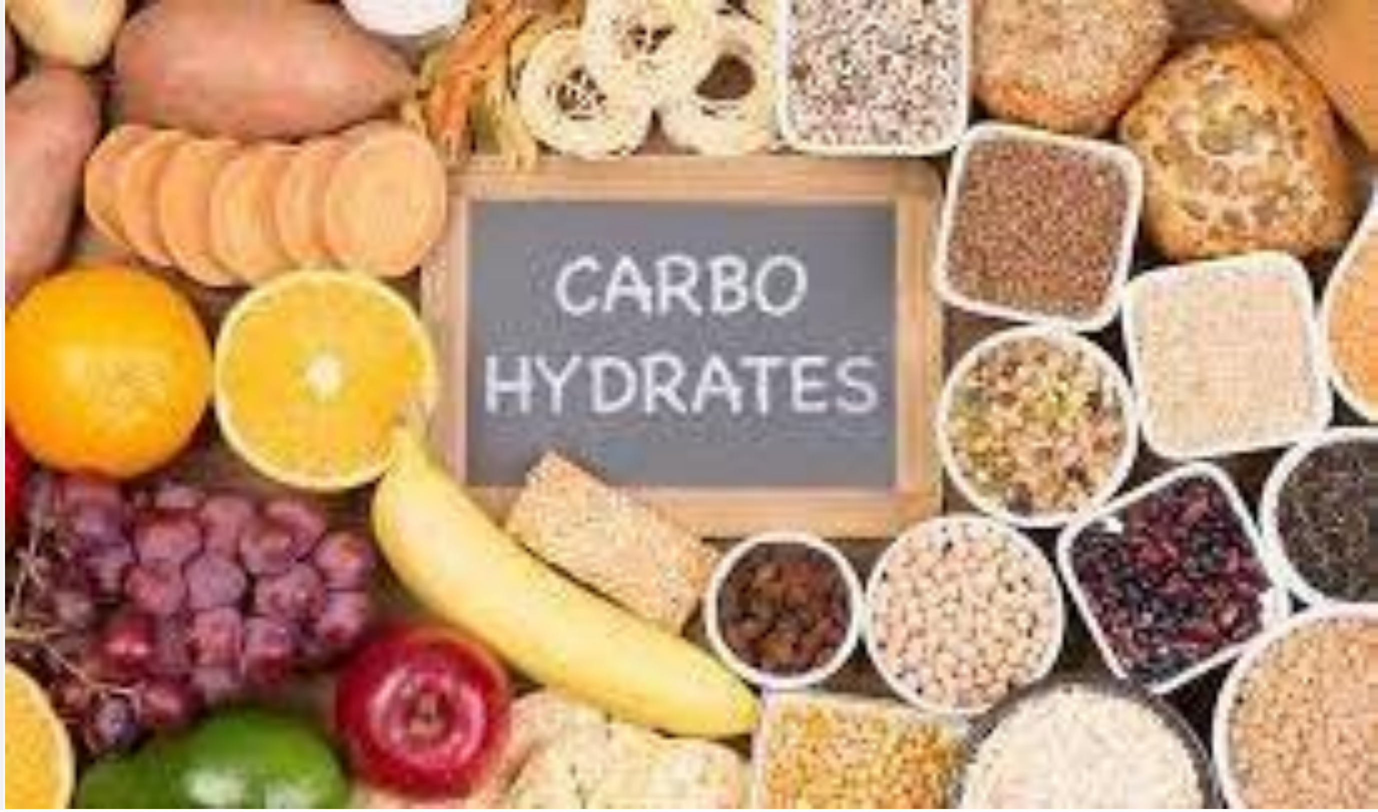
Carbohydrates

Carbohydrates include sugars and polymers of sugars. The simplest carbohydrates are the :

1-*monosaccharides*, or simple sugars; these are the monomers from which more complex carbohydrates are built. Glucose (C6H12O6), the most common monosaccharide, is of central importance in the chemistry of life. Monosaccharides serve as a major fuel for cells and as raw material for building molecules.

2-*Disaccharides* are double sugars, consisting of two monosaccharides joined by a covalent bond between two monosaccharides by a dehydration reaction .This covalent bond is called a glycosidic linkage. For example, maltose is a disaccharide formed by the linking of two molecules of glucose .

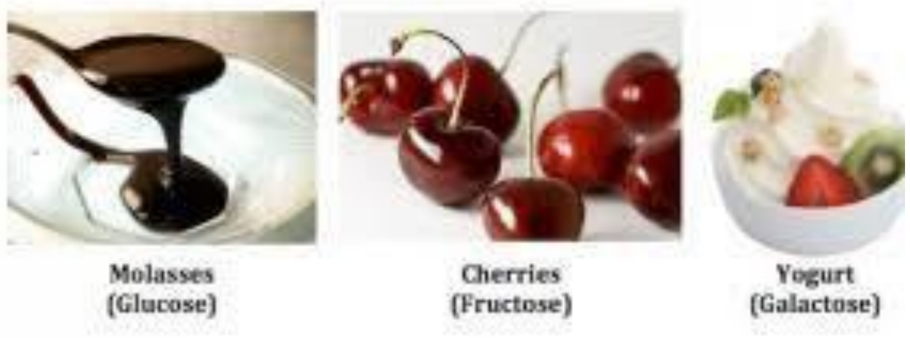
3-Carbohydrate macromolecules are polymers called *polysaccharides*, composed of many sugars building blocks. Both plants and animals store sugars for later use in the form of storage polysaccharides. Plants store starch, a polymer of glucose monomers. Glycogen is a storage polysaccharide in animals.

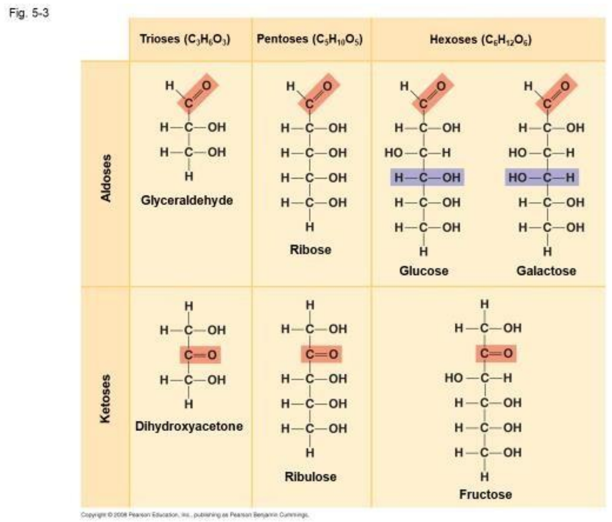


- **Carbohydrates** include sugars and the polymers of sugars
- Simple sugars (monosaccharides), double sugars (disaccharides) and polymers of sugar (polysaccharides).

Monosaccharides

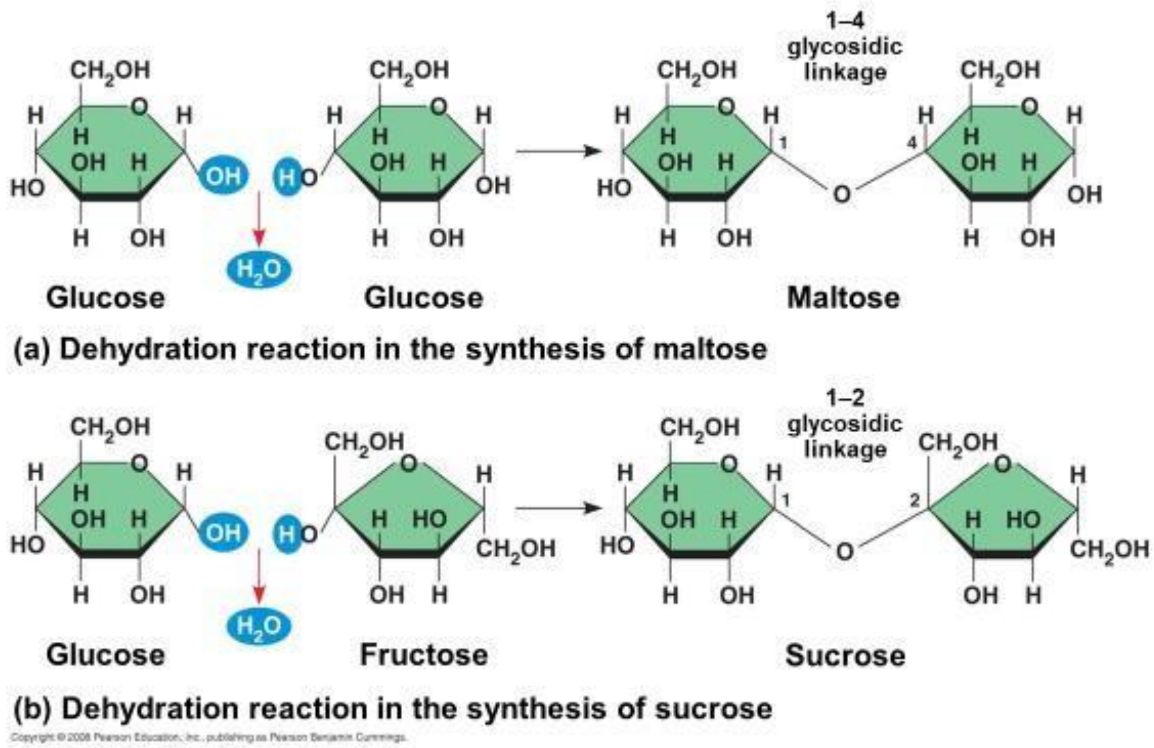
- **Monosaccharides** have molecular formulas that are usually multiples of CH_2O
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Monosaccharides serve as a major fuel for cells and as raw material for building molecules.





Disaccharide

- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**



Polysaccharides

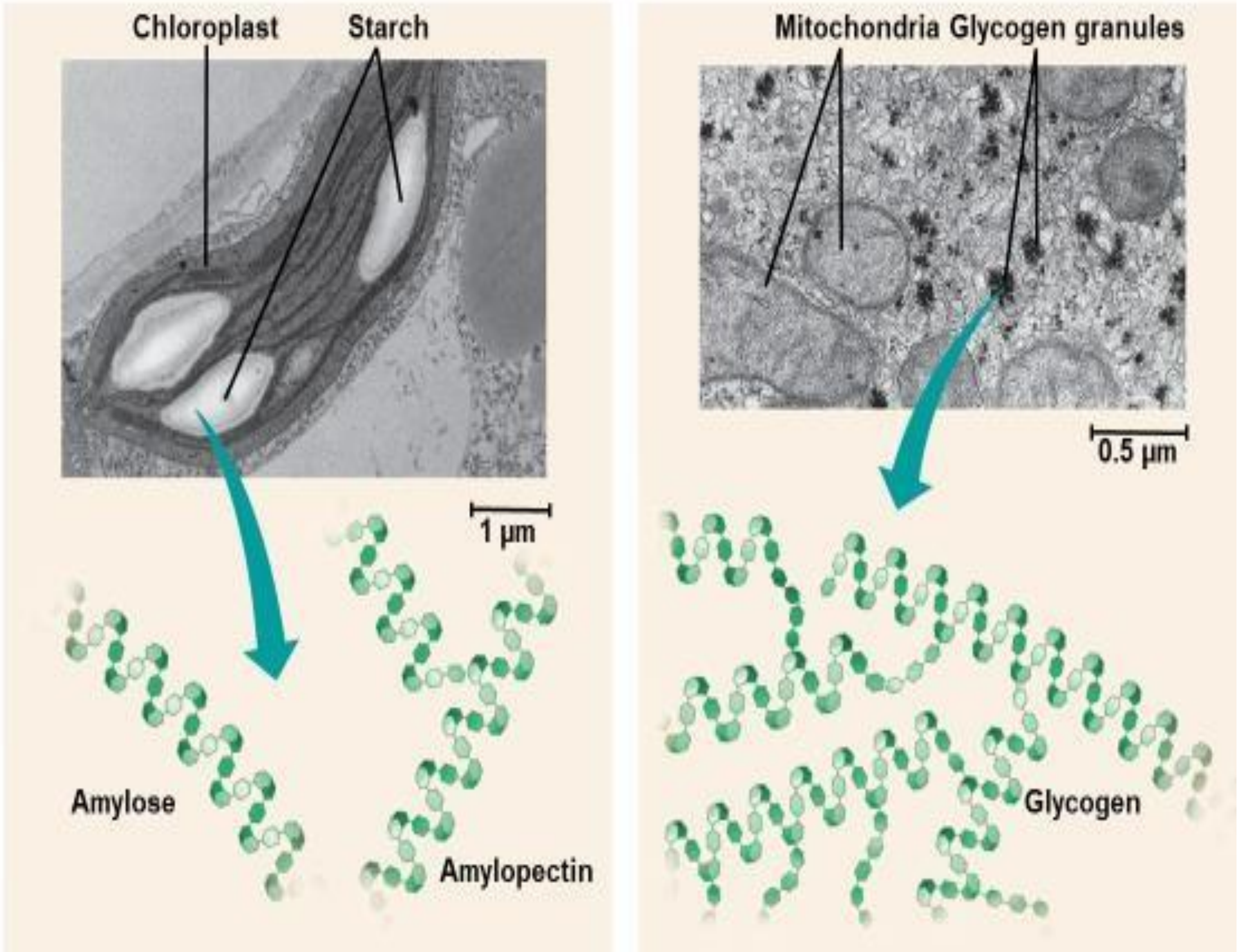
Polysaccharides, the polymers of sugars, have storage and structural roles.

Example :

1Starch, a storage polysaccharide of plants, consists entirely of glucose monomers

2Glycogen is a storage polysaccharide in animals

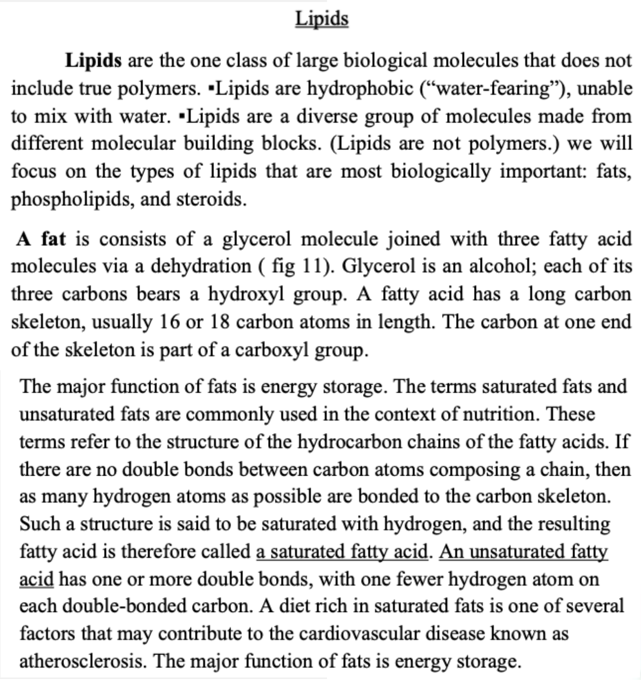
- ✓ Humans and other vertebrates store glycogen mainly in liver and muscle cells.



(a) Starch: a plant polysaccharide

(b) Glycogen: an animal polysaccharide

LIPIDS



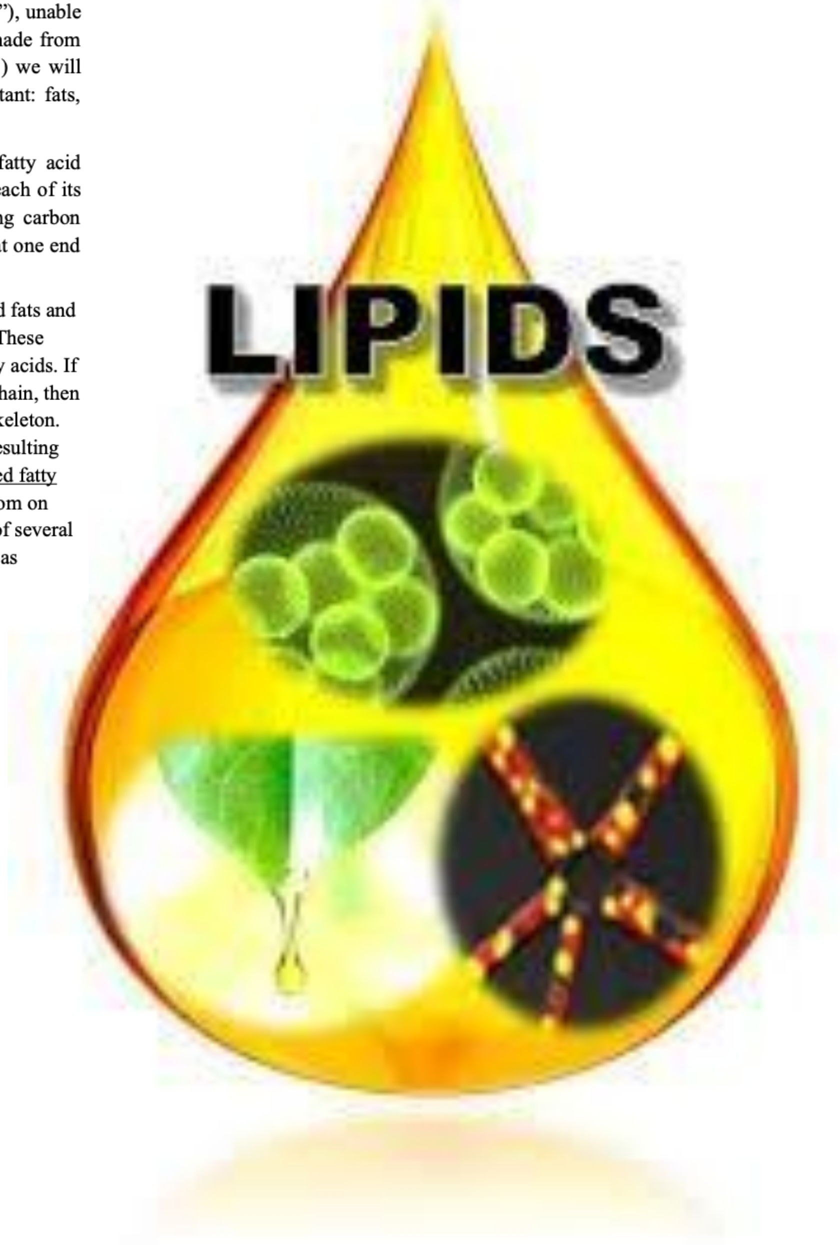
Lipids

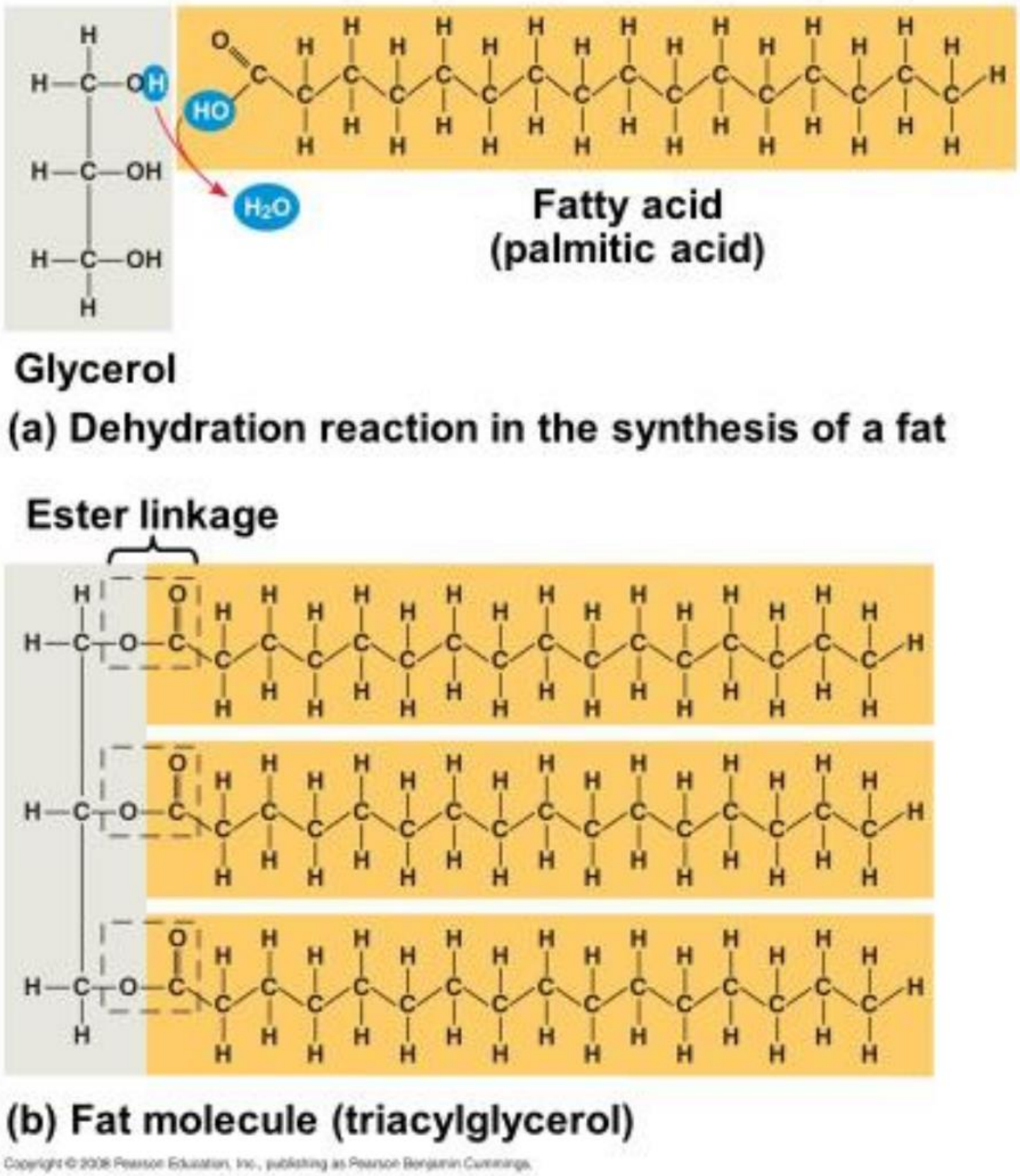
Lipids are the one class of large biological molecules that does not include true polymers. ▪Lipids are hydrophobic (“water-fearing”), unable to mix with water. ▪Lipids are a diverse group of molecules made from different molecular building blocks. (Lipids are not polymers.) we will focus on the types of lipids that are most biologically important: fats, phospholipids, and steroids.

A fat is consists of a glycerol molecule joined with three fatty acid molecules via a dehydration (fig 11). Glycerol is an alcohol; each of its three carbons bears a hydroxyl group. A fatty acid has a long carbon skeleton, usually 16 or 18 carbon atoms in length. The carbon at one end of the skeleton is part of a carboxyl group.

The major function of fats is energy storage. The terms saturated fats and unsaturated fats are commonly used in the context of nutrition. These terms refer to the structure of the hydrocarbon chains of the fatty acids. If there are no double bonds between carbon atoms composing a chain, then as many hydrogen atoms as possible are bonded to the carbon skeleton. Such a structure is said to be saturated with hydrogen, and the resulting fatty acid is therefore called a saturated fatty acid. An unsaturated fatty acid has one or more double bonds, with one fewer hydrogen atom on each double-bonded carbon. A diet rich in saturated fats is one of several factors that may contribute to the cardiovascular disease known as atherosclerosis. The major function of fats is energy storage.

- **Lipids** are the one class of large biological molecules that do not form polymers.
- Lipids are hydrophobic (“water-fearing”), unable to mix with water
- The most biologically important lipids are fats, phospholipids, and steroids





(a) Dehydration reaction in the synthesis of a fat

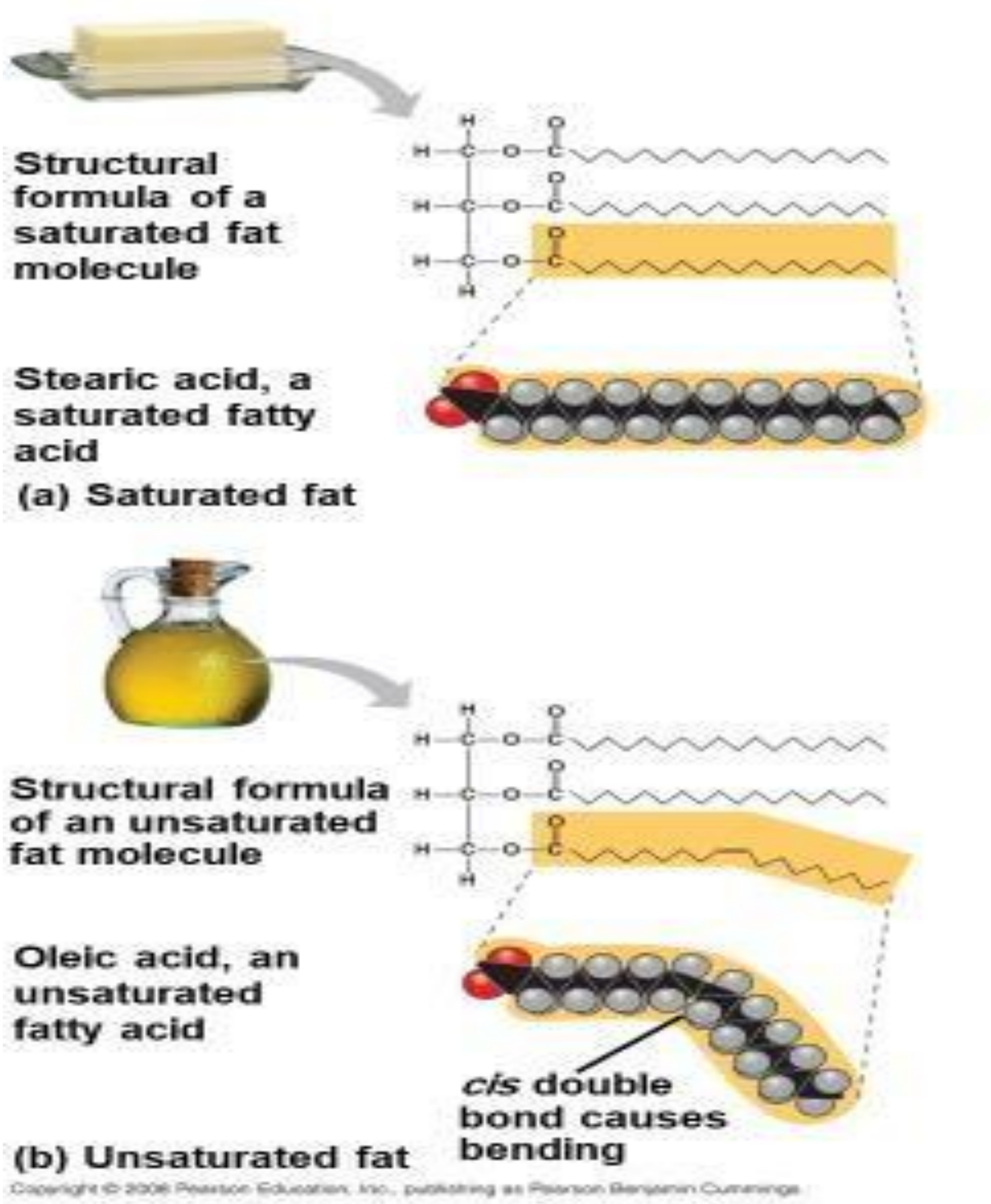
(b) Fat molecule (triacylglycerol)

Fats(Triglycerides)

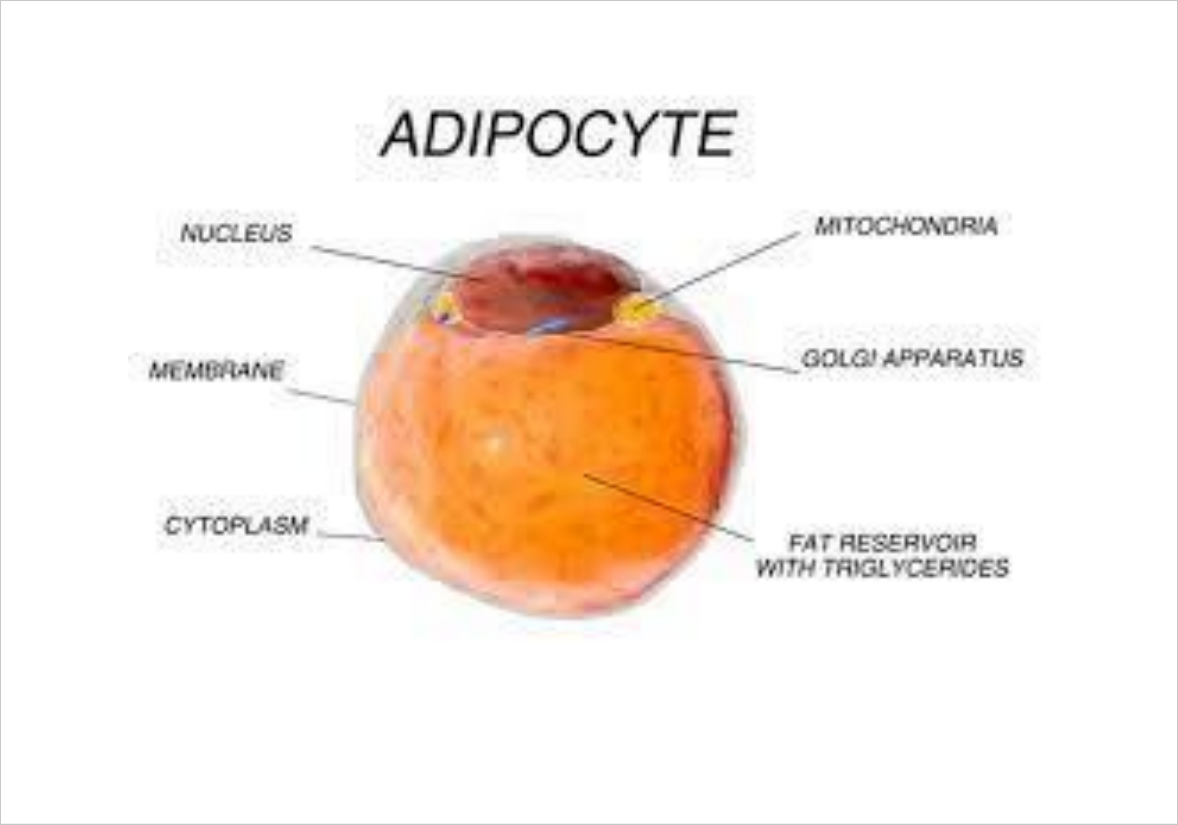
- **Triglyceride** consists of a glycerol molecule joined with three fatty acid molecules via a dehydration
- **Glycerol** is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton
- Fats perform essential functions in the human body.
- Long-term energy storage

- Fatty acids vary in length (number of carbons) and in the number and locations of double bonds
- **Saturated fatty acids** have the maximum number of hydrogen atoms possible and no double bonds
- **Unsaturated fatty acids** have one or more double bonds

PLAY Animation: Fats



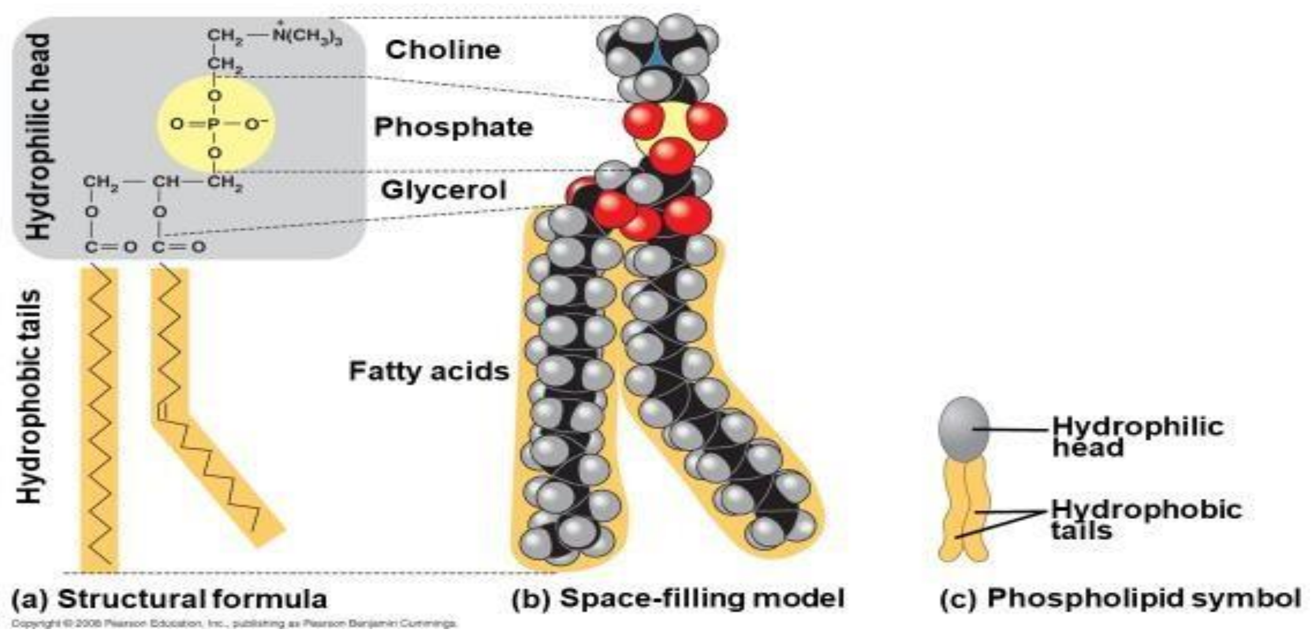
- Fats made from saturated fatty acids are called **saturated fats**, and are **solid** at room temperature
- Most animal fats are saturated
- Fats made from unsaturated fatty acids are called **unsaturated fats** or oils, and are **liquid** at room temperature
- Plant fats and fish fats are usually unsaturated



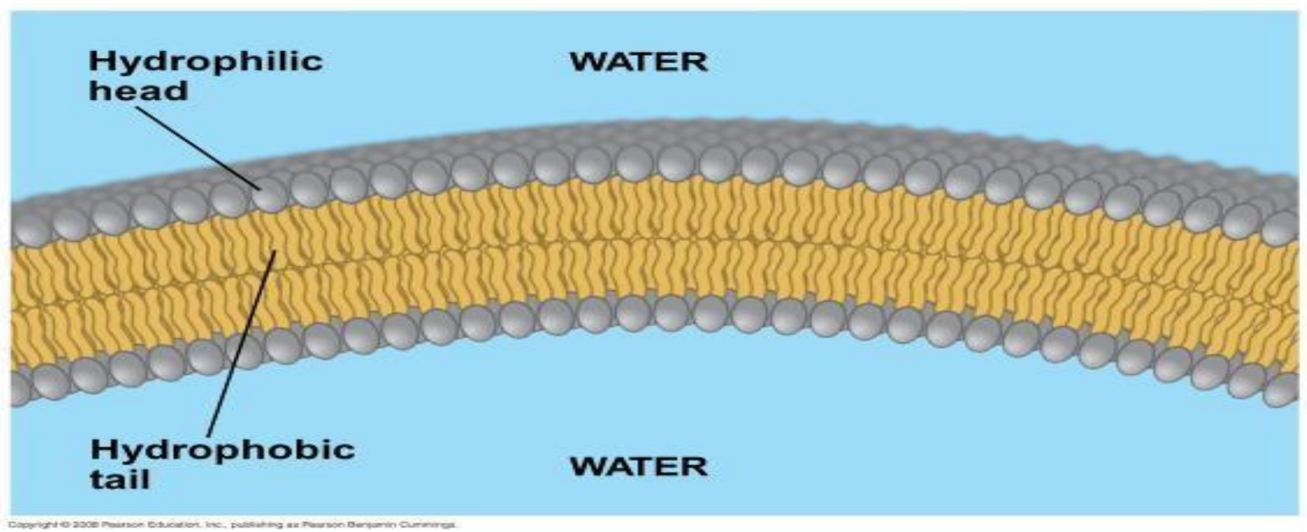
- The major function of fats is energy storage.
- Humans and other mammals store their fat in adipose cells.
- Adipose tissue also cushions vital organs and insulates the body.

Phospholipids Cells as we know them could not exist without another type of lipid—phospholipids. Phospholipids are essential for cells because they are major constituents of cell membranes. Their structure provides a classic example of how form fits function at the molecular level. A phospholipid is similar to a fat molecule but has only two fatty acids attached to glycerol rather than three. A phospholipid has a hydrophilic (polar) head and two hydrophobic (nonpolar) tails (fig.12)

Phospholipids



- In a **phospholipid**, two fatty acids and a phosphate group are attached to glycerol.
- The two fatty acid tails are hydrophobic, but the phosphate group and its attachments form a hydrophilic head.



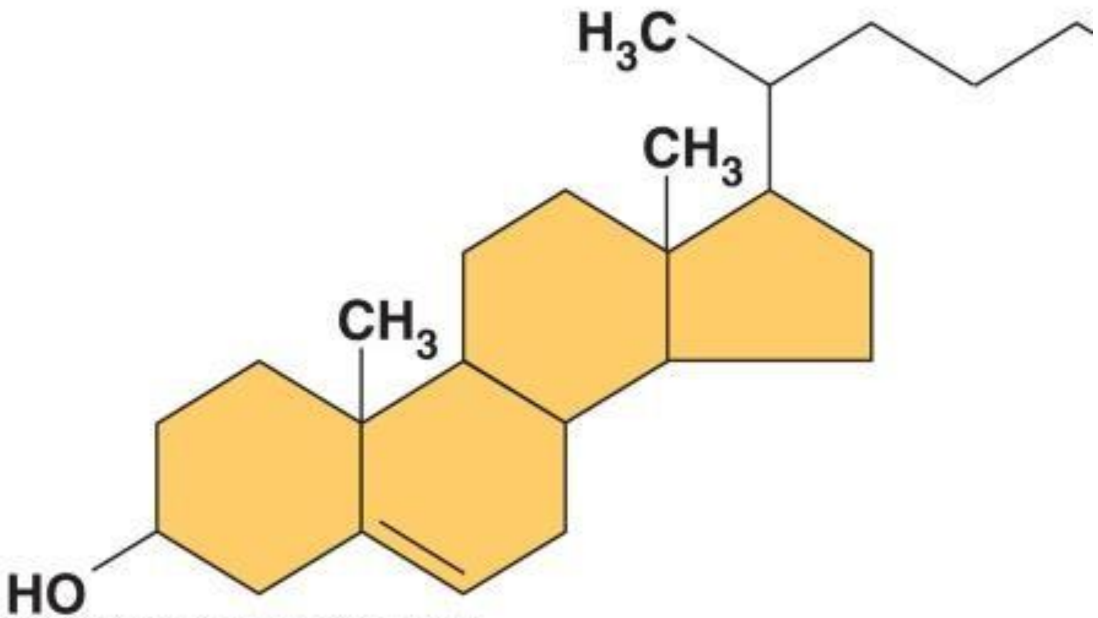
Phospholipids are the major component of all cell membranes

Steroids

Steroids are lipids characterized by a carbon skeleton consisting of four fused rings. Different steroids are distinguished by the particular chemical groups attached to this ensemble of rings. Cholesterol, a type of steroid, is a crucial molecule in animals . It is a common component of animal cell membranes and is also the precursor from which other steroids, such as the vertebrate sex hormones, are synthesized. In vertebrates, cholesterol is synthesized in the liver and is also obtained from the diet. A high level of cholesterol in the blood may contribute to atherosclerosis.

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings.
- **Cholesterol**, an important steroid, is a component in animal cell membranes.

➢ Although cholesterol is essential in animals, high levels in the blood may contribute to cardiovascular disease



PROTEINS

- Proteins account for more than 50% of the dry mass of most cells.
- Protein functions include structural support, storage, transport, cellular communications, movement, and defense against foreign substances.

Proteins:

Proteins account for more than 50% of the dry mass of most cells, and they are instrumental in almost everything organisms do. Some proteins speed up chemical reactions, while others play a role in defense, storage, transport, cellular communication, movement, or structural support. Fig.14 shows examples of proteins with these functions. Life would not be possible without enzymes, most of which are proteins. Enzymatic proteins regulate metabolism by acting as catalysts.

Diverse as proteins are, they are all constructed from the same set of 20 amino acids, linked in unbranched polymers. The bond between amino acids is called a **peptide bond**, so a polymer of amino acids is called a **polypeptide**. A protein is a biologically functional molecule made up of one or more polypeptides, each folded and coiled into a specific three dimensional structure. All amino acids share a common structure. An amino acid is an organic molecule with both an amino group and a carboxyl group (fig13) .

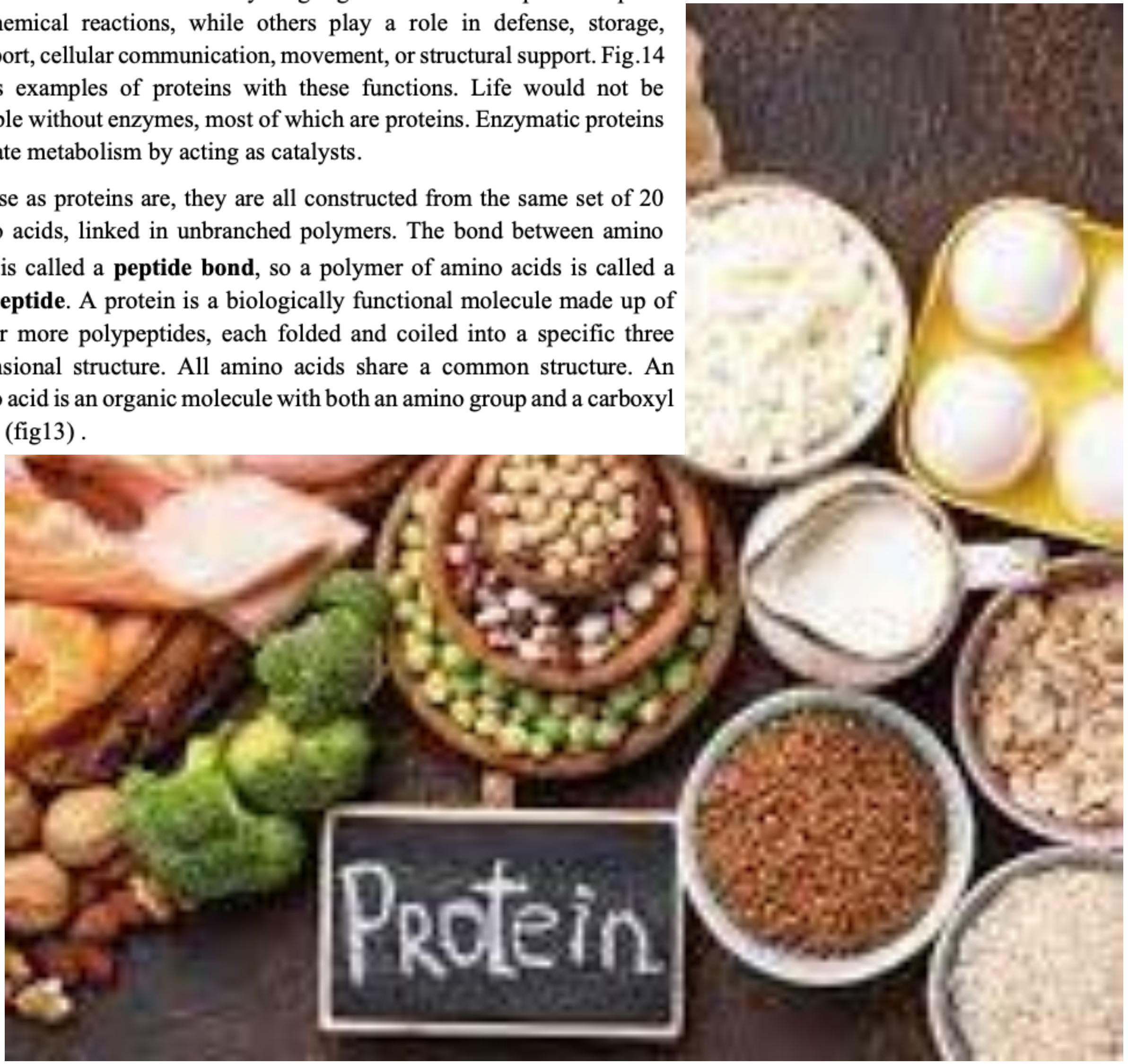
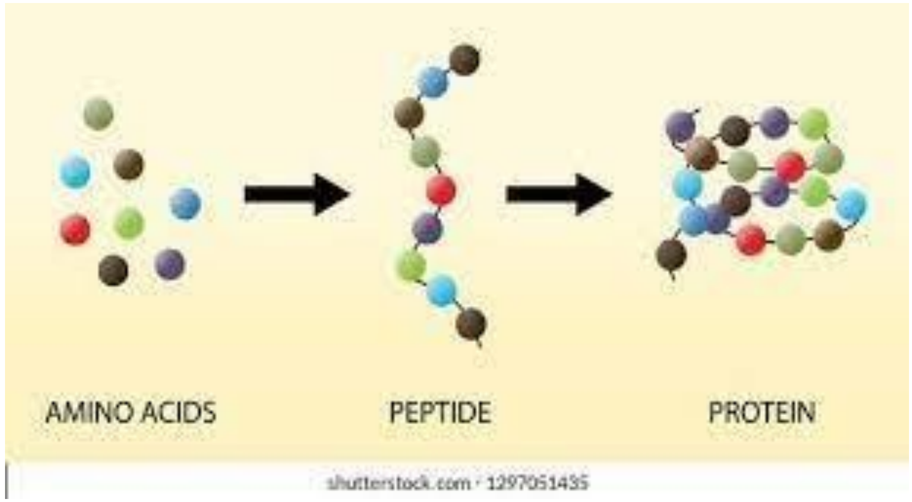


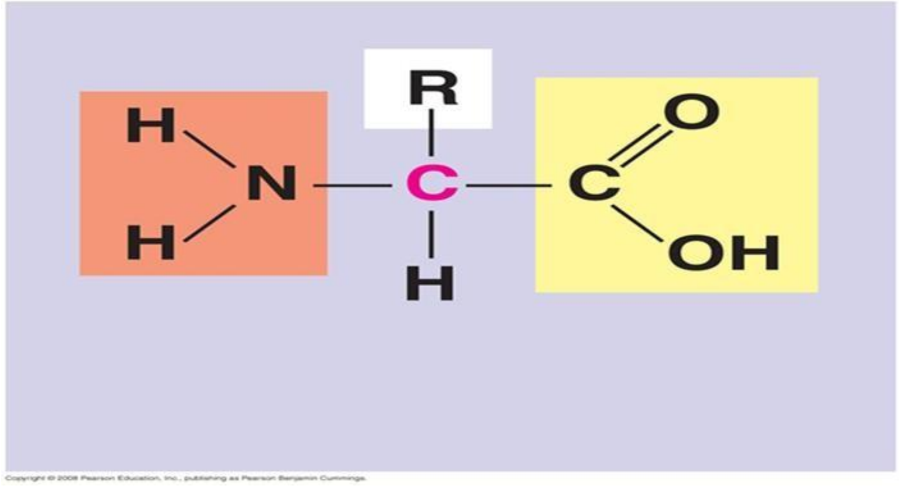
Table 5.1 An Overview of Protein Functions

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	Movement	Actin and myosin in muscles, proteins in cilia and flagella

Structure of Protein

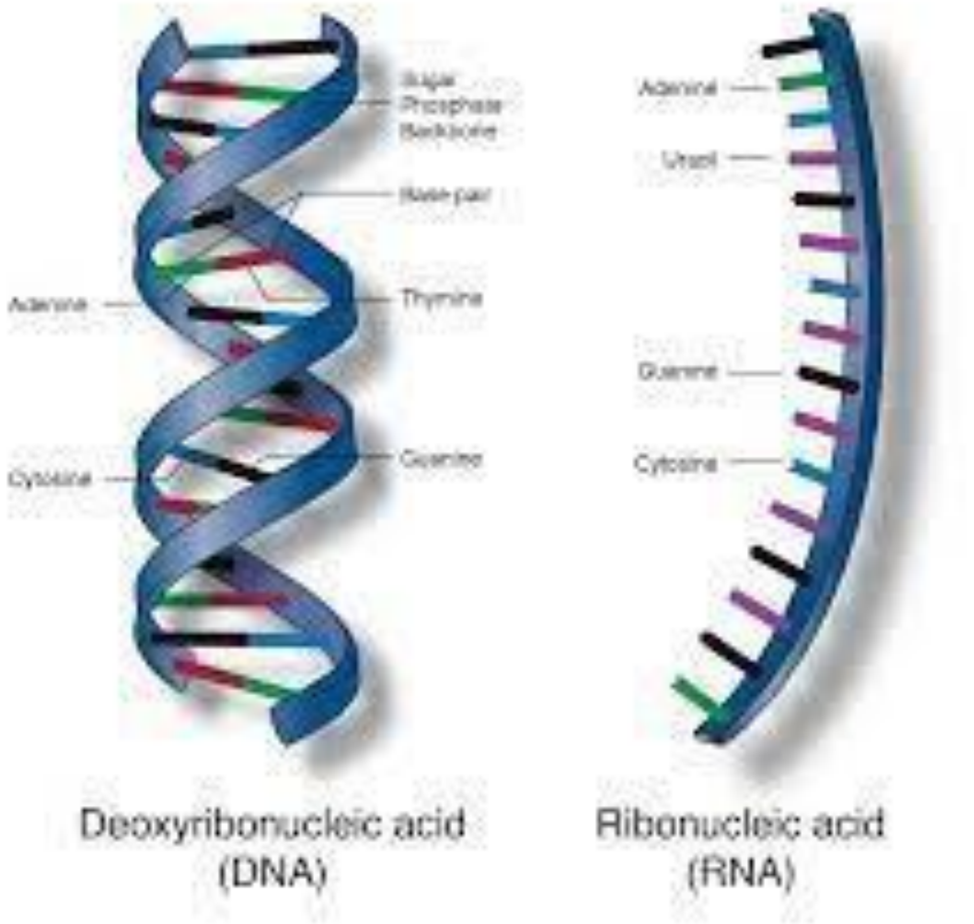
- **Polypeptides** are polymers built from the same set of 20 amino acids
- Amino acids are organic molecules with carboxyl and amino groups
- Amino acids are linked by peptide bonds
- A **protein** consists of one or more polypeptides





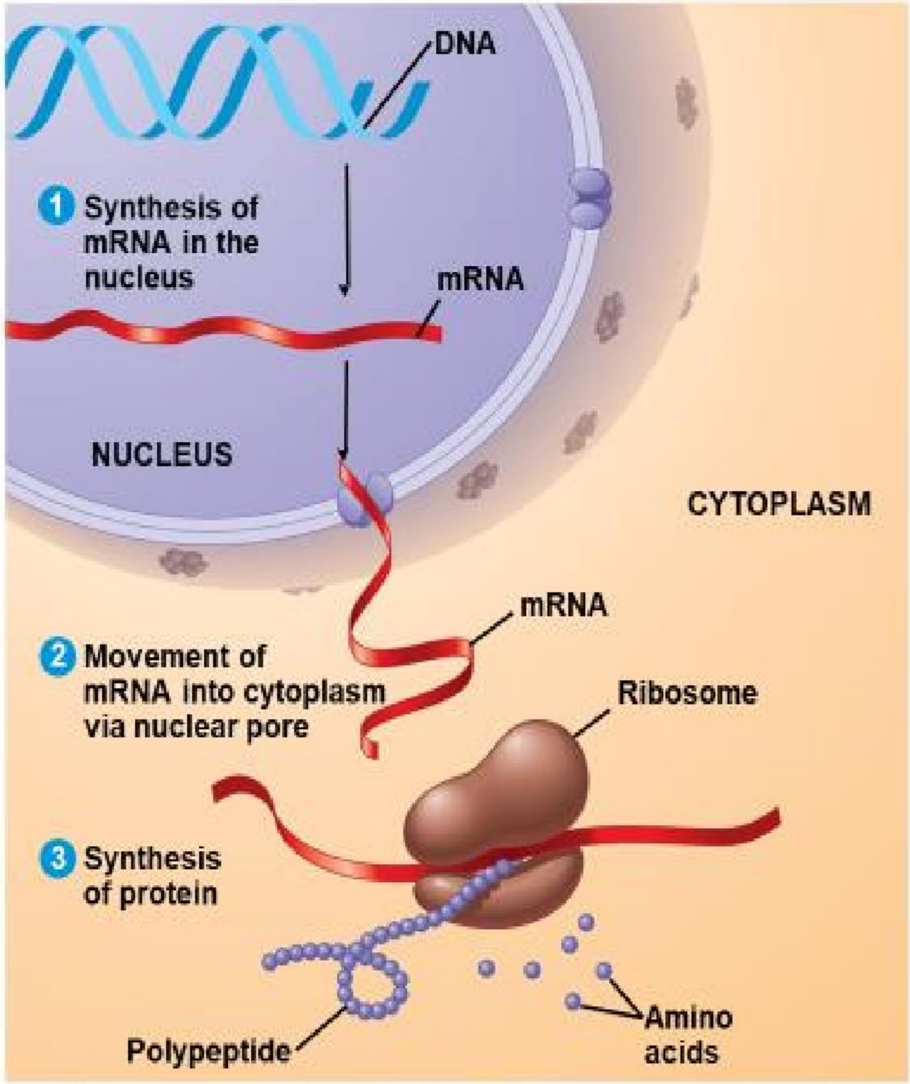
Nucleic acids store and transmit hereditary information

- The amino acid sequence of a polypeptide is programmed by a unit of inheritance called a **gene**
- Genes are made of DNA, (a **nucleic acid)**



The Nucleic Acids

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

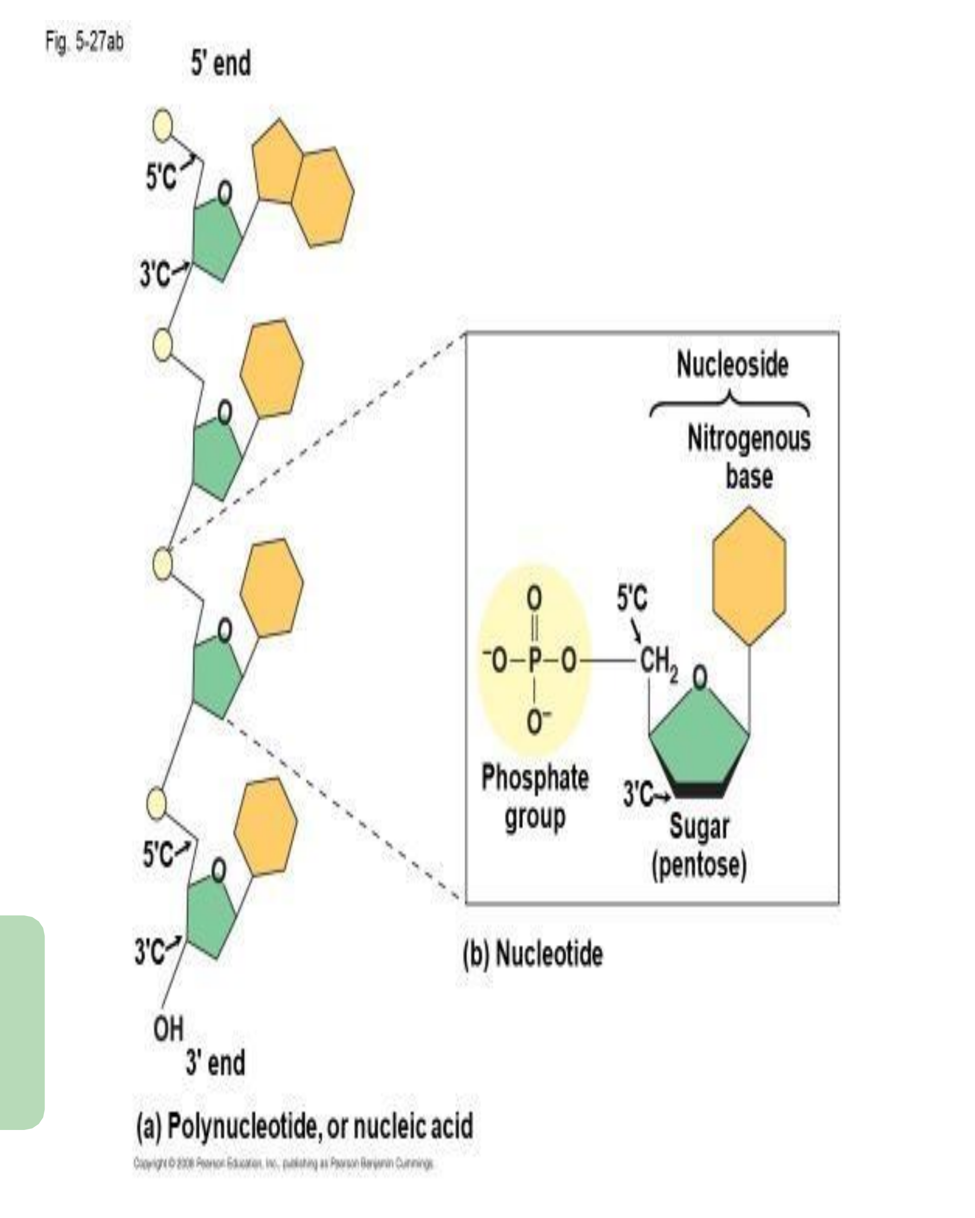


The Structure of Nucleic Acids

Nucleic acids are polymers called **polynucleotides**

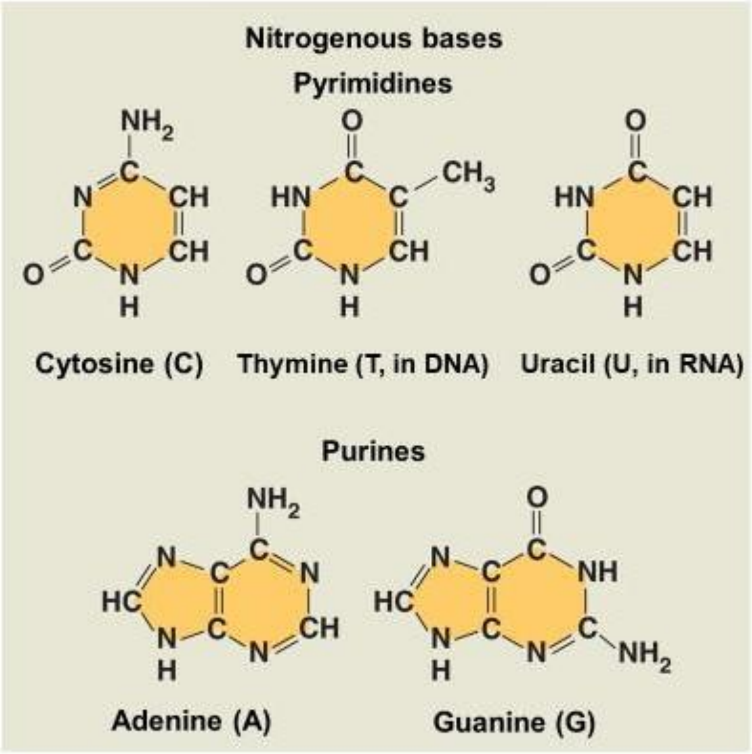
Each polynucleotide is made of monomers called **nucleotides**

Each nucleotide consists of a **nitrogenous base**, a **sugar**, and a **phosphate group**



Nucleotide: Nitrogen bases

- There are two families of **nitrogenous bases**:
  - **Pyrimidines** (cytosine, thymine, and uracil)
  - **Purines** (adenine and guanine)
- In DNA, the sugar is **deoxyribose**; in RNA, the sugar is **ribose**
- Nucleotide = nucleoside + phosphate group



(c) Nucleoside components: nitrogenous bases

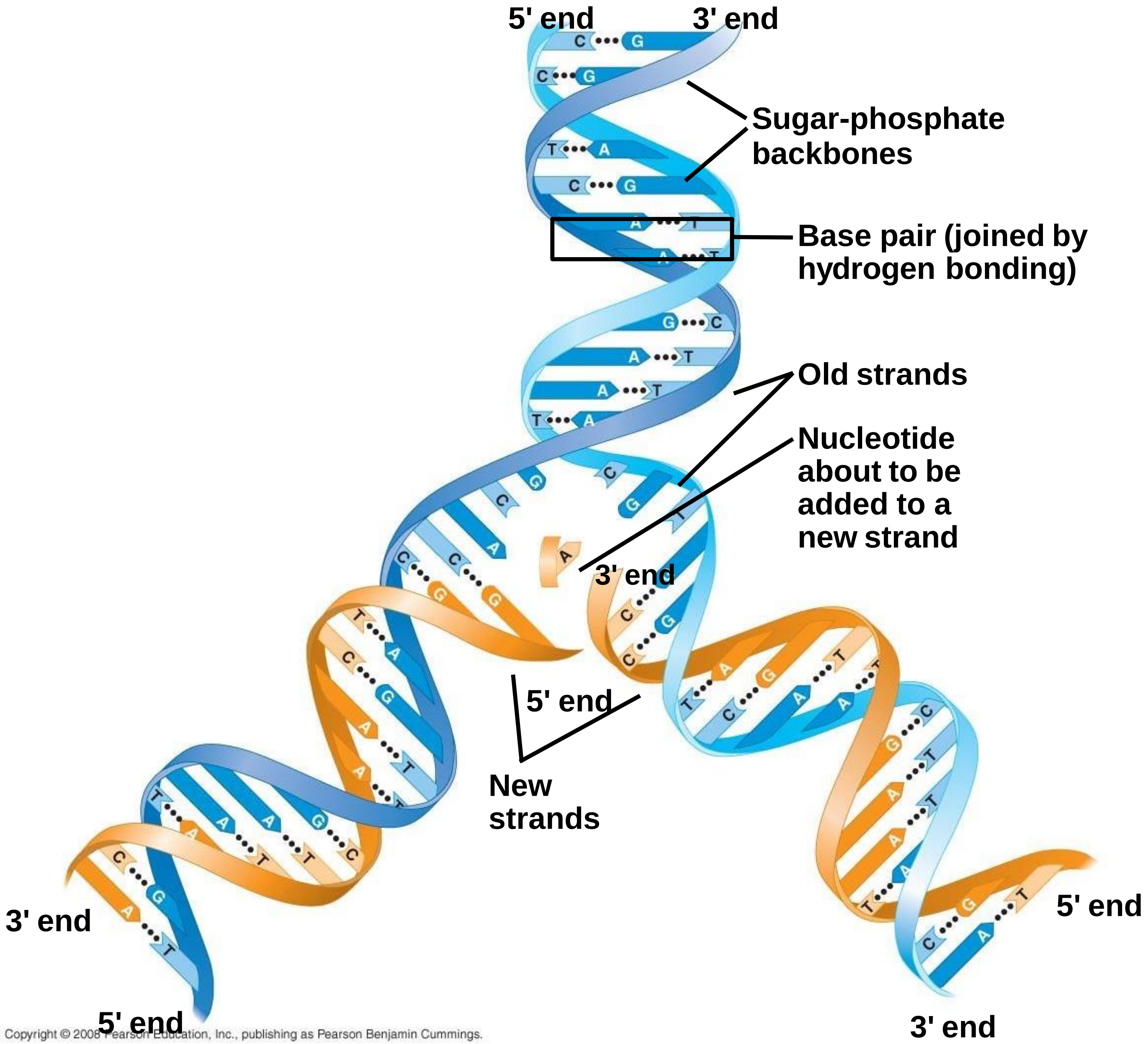
Nucleotide: Sugar

Sugars

Ribose (in RNA)

Deoxyribose (in DNA)

Figure: demonstrates difference between DNA and RNA in Nucleoside components: sugars



DNA Diagram representing the DNA Structure

Nucleic Acids

Genes consist of DNA, which belongs to the class of compounds called nucleic acids. Nucleic acids are polymers made of monomers called **nucleotides**.

The two types of nucleic acids: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), enable living organisms to reproduce their complex components from one generation to the next. Unique among molecules, DNA provides directions for its own replication. DNA also directs RNA synthesis and, through RNA, controls protein synthesis; this entire process is called gene expression.

A nucleotide, in general, is composed of three parts: a five-carbon sugar (a pentose), a nitrogen-containing (nitrogenous) base, and one or more phosphate groups (Fig 16)

There are two families of nitrogenous bases: pyrimidines and purines. A pyrimidine has one six-membered ring of carbon and nitrogen atoms. The members of the pyrimidine family are cytosine (C), thymine (T), and uracil (U). Purines are larger, with a six-membered ring fused to a five-membered ring. The purines are adenine (A) and guanine (G). The specific pyrimidines and purines differ in the chemical groups attached to the rings. Adenine, guanine, and cytosine are found in both DNA and RNA; thymine is found only in DNA and uracil only in RNA. Now let’s add the sugar to which the nitrogenous base is attached. In DNA the sugar is deoxyribose; in RNA it is ribose .

Question 1: Directions:

Match the organic compounds to the descriptions below.

Lipids (L) Carbohydrates (C) Proteins (P) Nucleic Acids (N)

1) ------------------ Stores genetic information essential for the production of proteins.

2) --------------- Long-term energy storage for organisms.

3) ---------------- Do not dissolve in water..

4) -----------------Examples include DNA and RNA

5) ---------------- Examples include-Fatty Acids, Steroids, Triglycerides and Phospholipids.

6) ----------------- Made of amino acids.

7) ----------------- Examples include enzymes.

8)-------------------- Store glucose in the form of glycogen (animal) and starch (plants).

9) ---------------------The major component of cell membrane

Question 1: Directions:

Match the organic compounds to the descriptions below.

Lipids (L) Carbohydrates (C) Proteins (P) Nucleic Acids (N)

1) _ _N_ Stores genetic information essential for the production of proteins.

2) __ L_ Long-term energy storage for organisms.

3) _ _L_ Do not dissolve in water..

4) _ _N_ Examples include DNA and RNA

5) __L _ Examples include-Fatty Acids, Steroids, Triglycerides and Phospholipids.

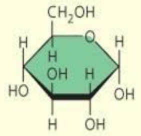
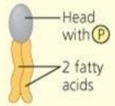
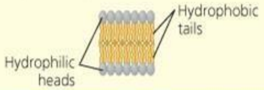
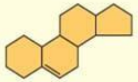
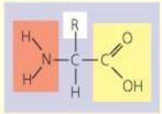
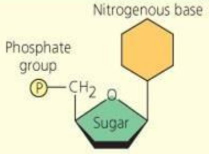
6) _ P__ Made of amino acids.

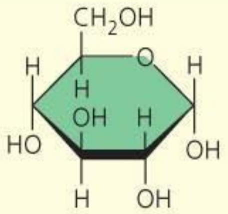
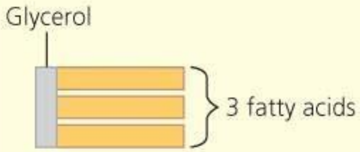
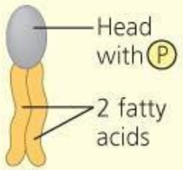
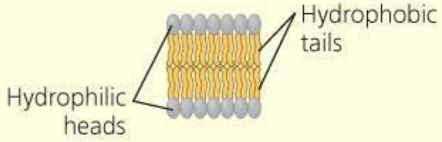
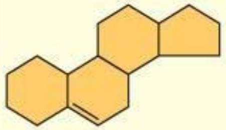
7) _ P__ Examples include enzymes.

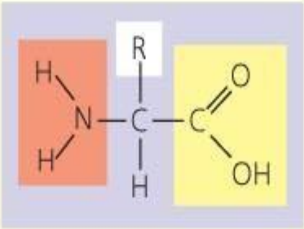
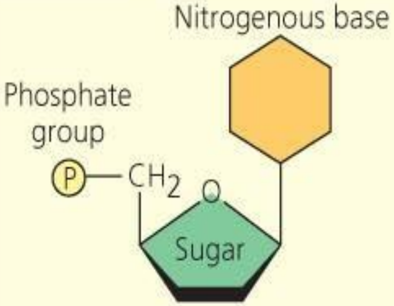
8) __ C_ Store glucose in the form of glycogen (animal) and starch (plants).

9) _ _L_ The major component of cell membrane

The Chemistry Of Life: A Review

Large Biological Molecules	Components	Examples	Functions
Concept 5.2 **Carbohydrates** serve as fuel and building material	 Monosaccharide monomer	Monosaccharides: glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Disaccharides: lactose, sucrose	
		Polysaccharides: • Cellulose (plants) • Starch (plants) • Glycogen (animals) • Chitin (animals and fungi)	• Strengthens plant cell walls • Stores glucose for energy • Stores glucose for energy • Strengthens exoskeletons and fungal cell walls
Concept 5.3 **Lipids** are a diverse group of hydrophobic molecules and are not macromolecules		Triacylglycerols (fats or oils): glycerol + 3 fatty acids	Important energy source 
		Phospholipids: phosphate group + 2 fatty acids	Lipid bilayers of membranes 
	 Steroid backbone	Steroids: four fused rings with attached chemical groups	• Component of cell membranes (cholesterol) • Signals that travel through the body (hormones)
Concept 5.4 **Proteins** have many structures, resulting in a wide range of functions	 Amino acid monomer (20 types)	• Enzymes • Structural proteins • Storage proteins • Transport proteins • Hormones • Receptor proteins • Motor proteins • Defensive proteins	• Catalyze chemical reactions • Provide structural support • Store amino acids • Transport substances • Coordinate organismal responses • Receive signals from outside cell • Function in cell movement • Protect against disease
Concept 5.5 Nucleic acids store and transmit hereditary information	 Nucleotide monomer	DNA:  • Sugar = deoxyribose • Nitrogenous bases = C, G, A, T • Usually double-stranded	Stores all hereditary information
		RNA:  • Sugar = ribose • Nitrogenous bases = C, G, A, U • Usually single-stranded	Carries protein-coding instructions from DNA to protein-synthesizing machinery

Large Biological Molecules	Components	Examples	Functions
Concept 5.2 **Carbohydrates** serve as fuel and building material	 Monosaccharide monomer	Monosaccharides: glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		Disaccharides: lactose, sucrose	
		Polysaccharides: • Cellulose (plants) • Starch (plants) • Glycogen (animals) • Chitin (animals and fungi)	• Strengthens plant cell walls • Stores glucose for energy • Stores glucose for energy • Strengthens exoskeletons and fungal cell walls
Concept 5.3 **Lipids** are a diverse group of hydrophobic molecules and are not macromolecules		Triacylglycerols (fats or oils): glycerol + 3 fatty acids	Important energy source 
		Phospholipids: phosphate group + 2 fatty acids	Lipid bilayers of membranes 
	 Steroid backbone	Steroids: four fused rings with attached chemical groups	• Component of cell membranes (cholesterol) • Signals that travel through the body (hormones)

Large Biological Molecules	Components	Examples	Functions
Concept 5.4 **Proteins** have many structures, resulting in a wide range of functions	 Amino acid monomer (20 types)	• Enzymes • Structural proteins • Storage proteins • Transport proteins • Hormones • Receptor proteins • Motor proteins • Defensive proteins	• Catalyze chemical reactions • Provide structural support • Store amino acids • Transport substances • Coordinate organismal responses • Receive signals from outside cell • Function in cell movement • Protect against disease
Concept 5.5 Nucleic acids store and transmit hereditary information	 Nucleotide monomer	DNA:  • Sugar = deoxyribose • Nitrogenous bases = C, G, A, T • Usually double-stranded	Stores all hereditary information
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