AP Biology Review: The Chemistry of Life
Chapter 2: The Chemical Context of Life

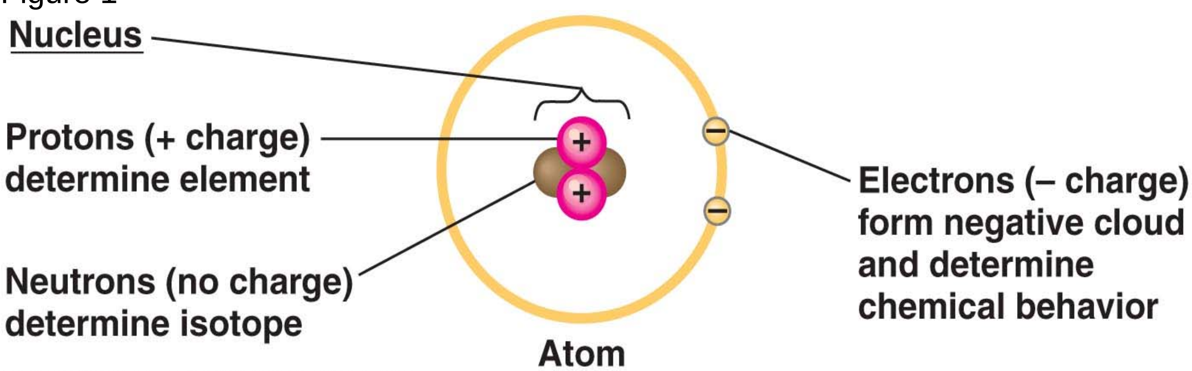
You Must Know
1. The three subatomic particles and their significance.
2. The types of bonds, how they form, and their relative strengths.

Concept: Matter Consists of Chemical Elements in pure form and in combinations called compounds

a. **Matter** is anything that takes up space and has mass.
b. An **element** is a substance that cannot be broken down to other substances by chemical reactions. Examples: Gold, copper, lead, carbon, oxygen.
c. A **compound** is a substance consisting of two or more elements combined in a fixed ratio. Examples: Water (H_2O), Salt (NaCl), Ammonia (NH_3).
d. **C,O, H, N** make up 96% of living matter. About 25 of the 92 natural elements are known to be essential to life.
e. **Trace elements** are those required in only minute quantities. (Iron, Iodine, Magnesium)

Concept: An element's properties depend on the structure of its atoms

a. **Atoms** are the smallest unit of an element that still retains the properties of the element. Atoms are made of up of protons, neutrons and electrons.
a. **Protons** are positively charged particles. They are found in the nucleus and determine the element.
b. **Neutrons** are particles with no charge. They are found in the nucleus. Their number can vary in number in the same element, resulting in *isotopes*. Examples: C^{12} and C^{14} are isotopes of carbon. Both have 6 protons and while C^{12} has 6 neutrons; C^{14} has 8 neutrons.
c. **Electrons** are negatively charged particles that are found in *electron shells* around the nucleus. They, (the electrons), determine the chemical properties of an element. The electrons also determine the reactivity of the element.
Figure 1



d. The **atomic number** is the number of protons an element possesses. This number is unique to *EVERY* element.
e. The **mass number** of an element is the number of protons *plus* neutrons.

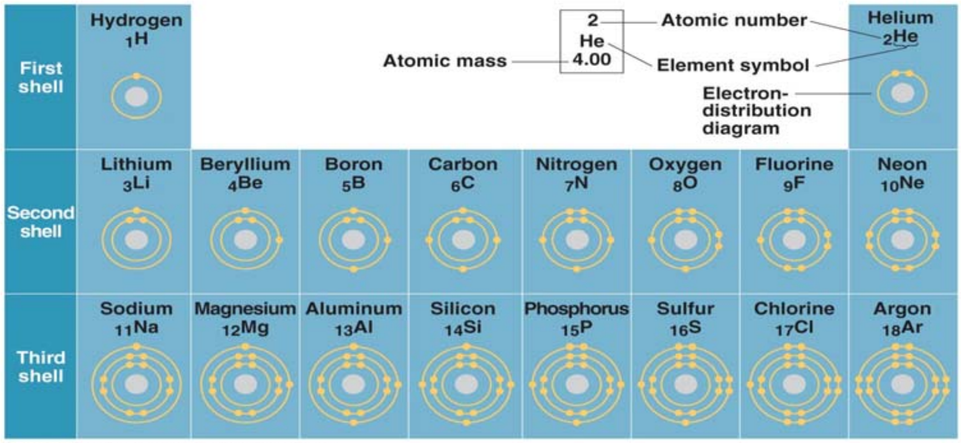


Figure 2

Concept: The formation of molecules depend on chemical bonding between atoms

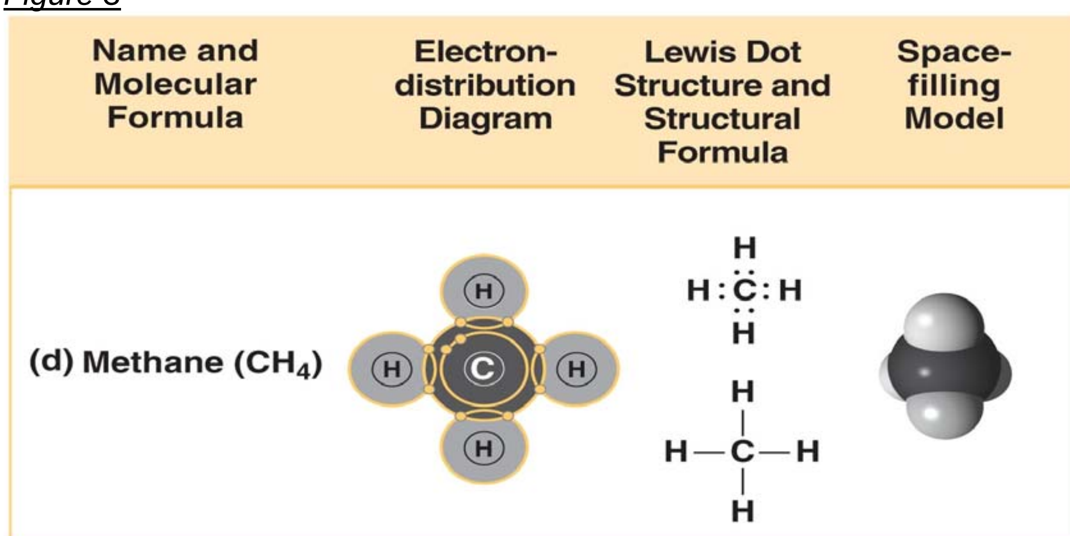
a. **Chemical bonds** are defined as interactions between valence electrons of different atoms. Atoms are held together by chemical bonds to form **molecules.**

b. **Covalent bond** occurs when valence *electrons are shared* by two atoms.

i. **Nonpolar covalent bonds** occur when the electrons being shared are shared equally between atoms. (O=O, H-H, C-H)

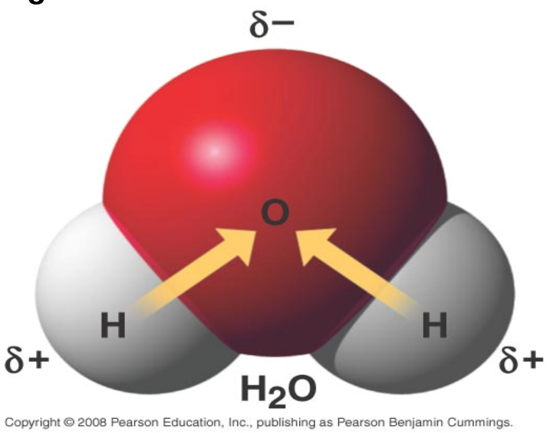
ii. Atoms vary in their tendency to attract electrons of a covalent bond. Elements like Nitrogen and Oxygen have a strong attraction of electrons. This concept is called ***electronegativity.***

Figure 3



iii. In **polar covalent bonds,** <u>one atoms has greater electronegativity than the other, resulting in an **unequal sharing** of electrons.</u> See the figure below. Note that in Figure 4 and note that within each molecule of H_2O the ***electrons are unequally shared*** resulting in a region on the oxygen atom being slightly negative, while the regions about the hydrogen atoms are slightly positive.

Figure 4

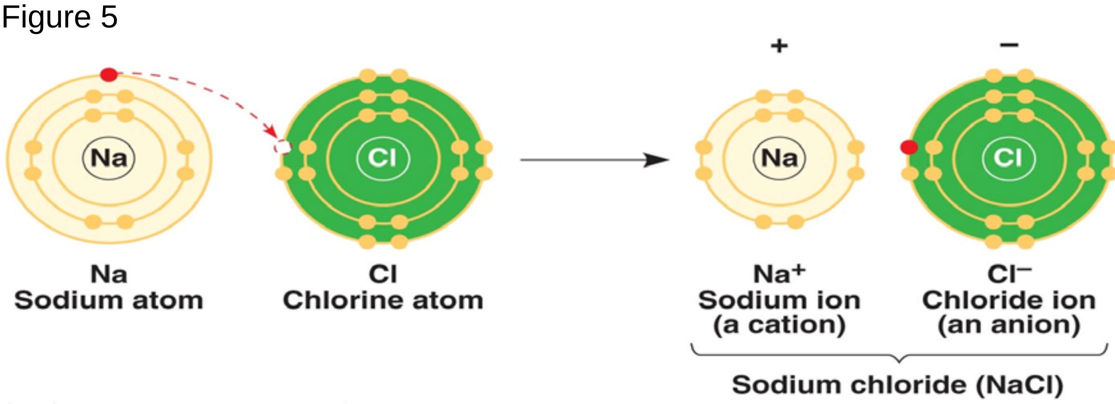


c. **Ionic bonds** are ones in which two atoms attract valence electrons so unequally that the *more electronegative atom steals the electron from the less electronegative atom.*

i. An **ion** is a the resulting charged atom or molecule (positive ions are **cations** and negative ions are **anions.**

ii. **Ionic bonds** occur because these ions will be either positively or negatively charged, and will attracted to each other by these opposite charges.

Figure 5



d. **Hydrogen bonds**: are relatively weak bonds that form between the positively charged hydrogen atom and the strongly electronegative oxygen or nitrogen of *another* molecule.

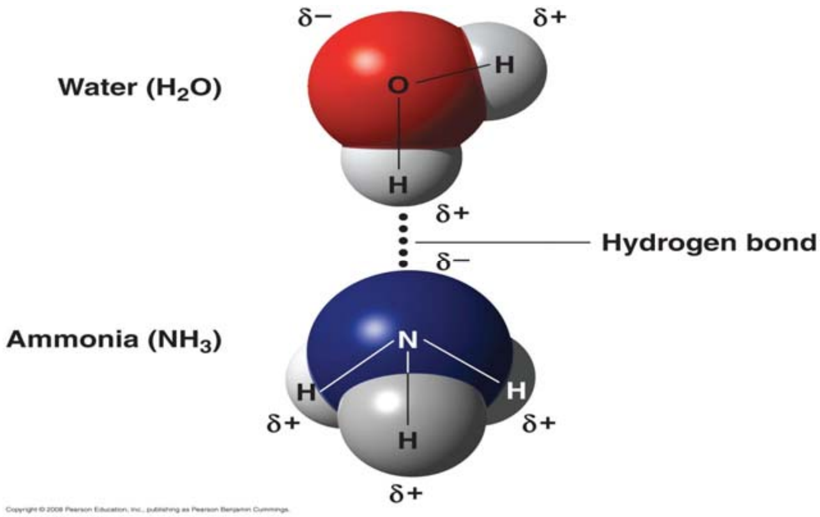


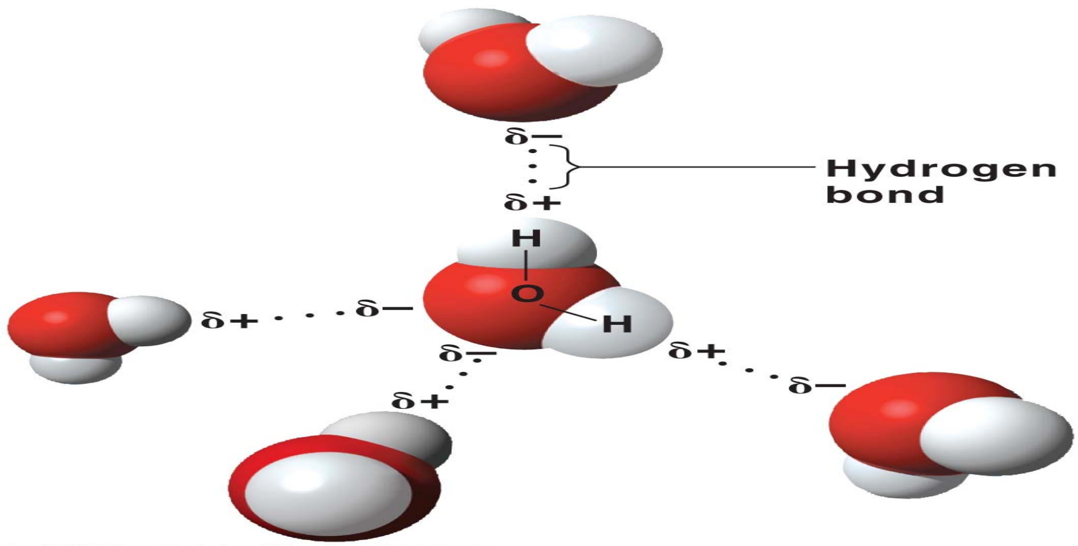
Figure 6

e. **Van der Waals interactions:** are very weak, transient connections that are the result of asymmetrical distribution of electrons within a molecule. These weak interactions contribute to the three-dimensional shape of large molecules.

Chapter 3: Water and the Fitness of the Environment

<u>You Must Know:</u>
1. The importance of hydrogen bonding to the properties of water.
2. Four unique properties of water, and how each contributes to life on Earth.
3. How to interpret the pH scale.
4. The importance of buffers in biological systems.

<u>Concept: The polarity of water molecules results in hydrogen bonding</u>
a. The **structure of water** is the key to its special properties. Water is made up of one atom of oxygen and two atoms of hydrogen, bonded to form a molecule.
b. Water molecules are **polar**. The end bearing the oxygen atom has a slightly negative charge, whereas the end bearing the hydrogen atoms has a slightly positive charge.
c. **Hydrogen bonds** form between water molecules. The slightly negative oxygen atom from one water molecule is attracted to the slightly positive hydrogen end of *<u>another</u>* water molecule.
d. Each water molecule can form a maximum of <u>FOUR</u> hydrogen bonds at a time.



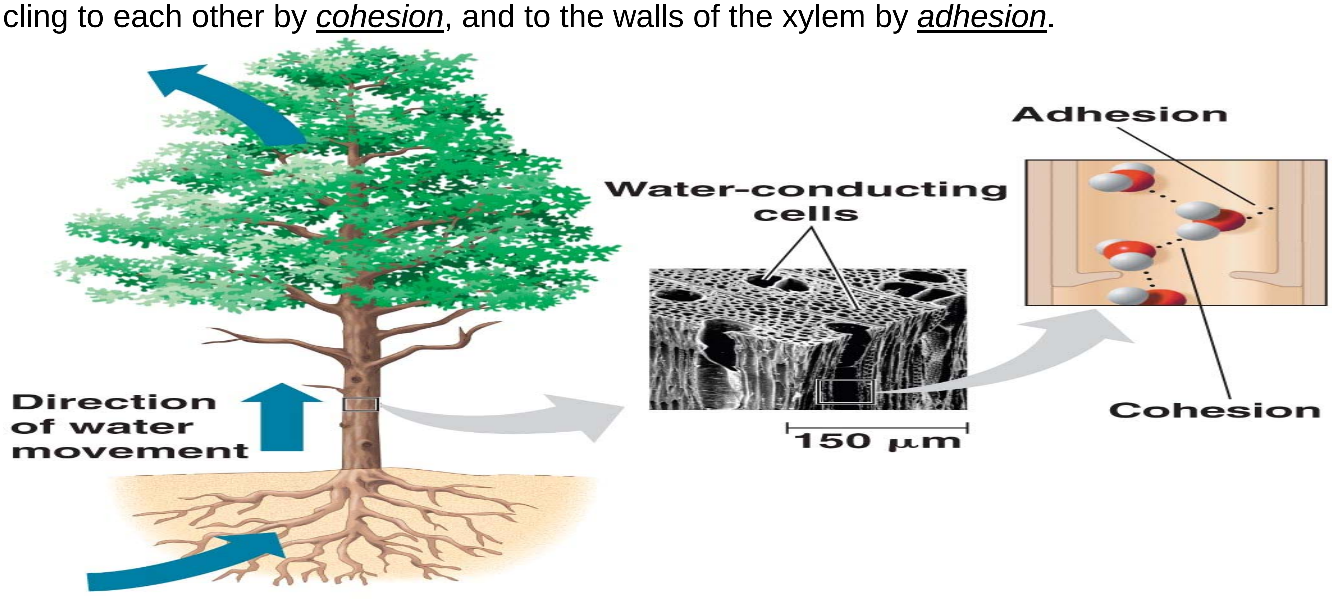
<u>Concept: Four emergent properties of water contribute to Earth's fitness for life</u>

-The key to each of these properties is *<u>hydrogen bonds</u>*. This is what makes water so unique.

1. **Cohesion**. Cohesion is the linking of like molecules. Think "water molecule joined to water molecule" and visualize a water strider walking on top of a pond due to the surface tension that is the result of this properties.

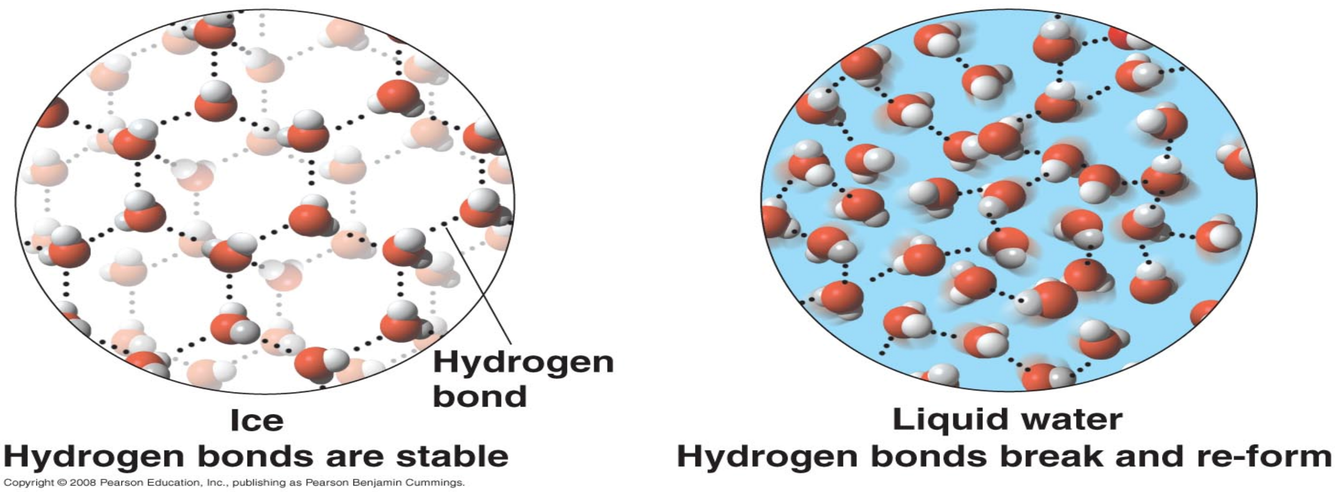
a. **Adhesion** is the clinging of one substance to another. Think "water molecule attached to some other molecule" such as water droplets adhering to a glass windshield.

b. **Transpiration** is the movement of water molecules up the very thin xylem tubes and their evaporation from the stomates in plants. The water molecules cling to each other by *<u>cohesion</u>*, and to the walls of the xylem by *<u>adhesion</u>*.



2. Moderation of temperature is possible because of water's high specific heat.
a. **Specific heat** is the amount of heat required to raise or lower the temperature of a substance by 1 degree Celsius. Relative to most other materials, the temperature of water changes less when a given amount of heat is lost or absorbed. This high specific heat makes the temperature of Earth's oceans relatively stable and able to support vast quantities of both plant and animal life.

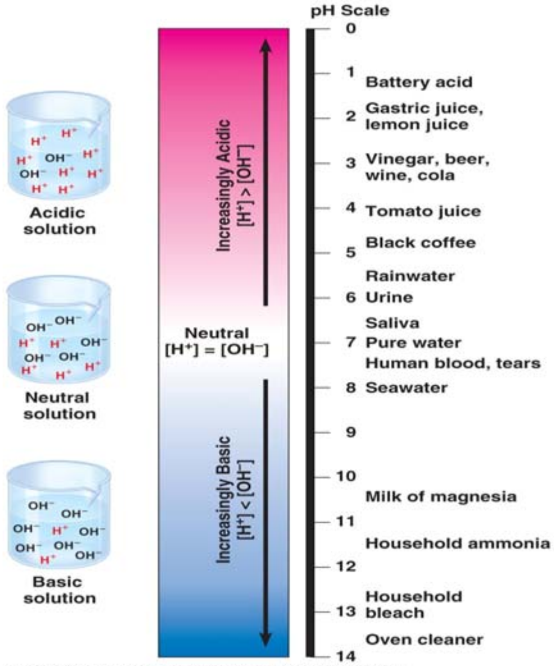
3. Insulation of bodies of water by floating ice.
a. Water is less dense as a solid than in its liquid state, whereas the opposite is true of most other substances. Because ice is less dense than liquid water, ice floats. This keeps large bodies of water from freezing solid and therefore moderates temperature.

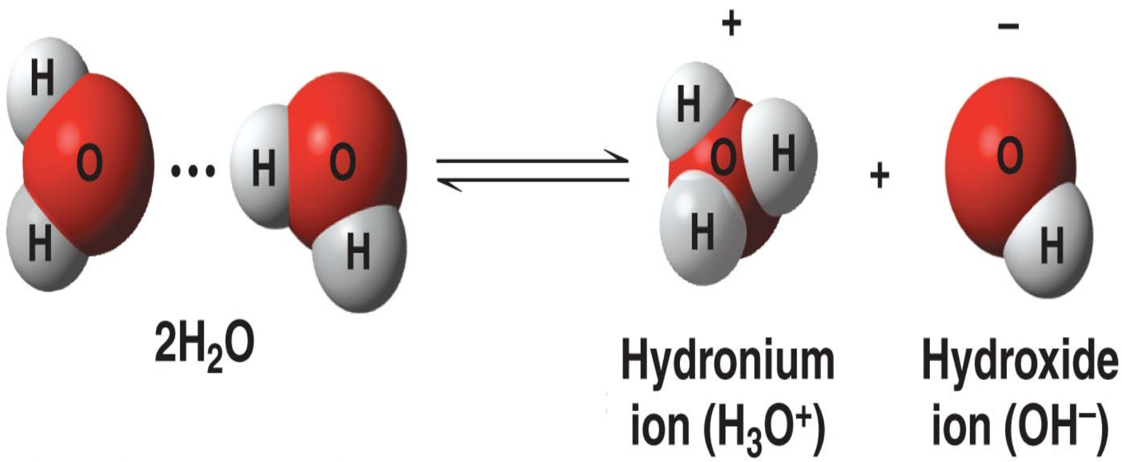


4. Water is an important solvent. (The substance that something is dissolved in is called the solvent, while the substance being dissolved is called the solute. Together, they are called the solution.)
a. **Hydrophilic**, substances are water-soluble. These include ionic compounds, polar molecules (for example sugar), and some proteins.
b. **Hydrophobic** substances such as oils are nonpolar and do not dissolve in water.

<u>Concept: Acidic and basic conditions affect living organisms</u>
1. The **pH** scale runs between 0 and 14 and measures the relative acidity and alkalinity of aqueous solutions.

2. **Acids** have an excess of H+ ions and a pH below 7.0 $[H^+] > [OH^-]$
3. **Bases** have an excess of OH^- ions, and pH above 7.0 $[H^+] < [OH^-]$
4. Pure water is neutral, which means it has a pH of 7.0 $[H^+] = [OH^-]$
5. **Buffers** are substances that minimize changes in pH. They accept H^+ when they are depleted.
6. **Carbonic acid (H_2CO_3)** is an important buffer of living systems. It moderates pH changes in blood plasma and the ocean.





Chapter 4: Carbon and the Molecular Diversity of Life

<u>You Must Know</u>

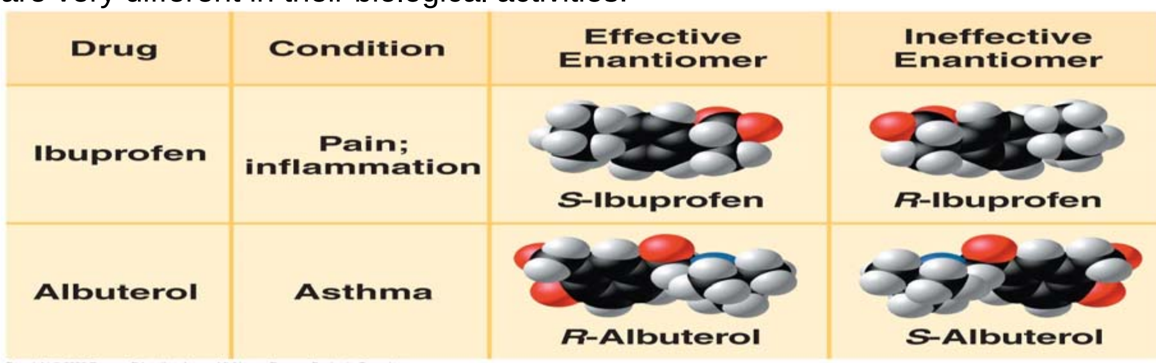
1. The properties of carbon that make it so important.

<u>Concept: Carbon atoms can form diverse molecules by bonding to four other atoms</u>

1. Carbon is unparalleled in its ability to form molecules that are large, complex and diverse. Why?

a. It has four valence electrons.
b. It can form up to 4 covalent bonds.
c. These can be single, double, or triple covalent bonds.
d. It can form large molecules.
e. These molecules can be chains, ring-shaped, or branched.

2. **Isomers** are molecules that have the same molecular formula but differ in their arrangement of these atoms. These differences can result in molecules that are very different in their biological activities.

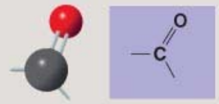
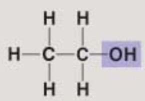
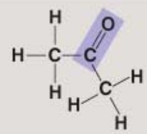
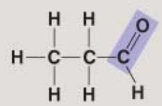
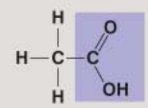
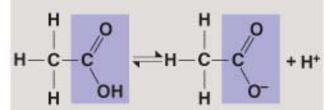


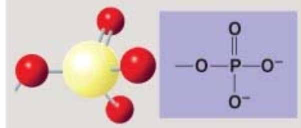
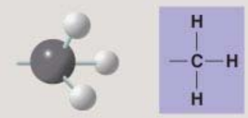
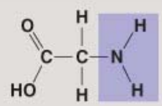
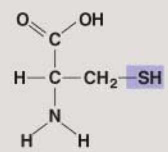
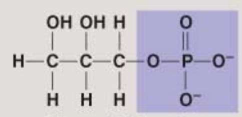
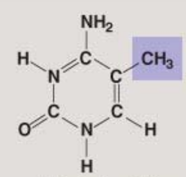
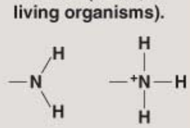
Characteristic chemical groups help control how biological molecules function

1. Functional groups attach to the carbon skeleton have diverse properties. The behavior of organic molecules is dependent on the identity of their functional groups.

2. Some common functional groups are listed below:

Functional Group Name/ Structure	**Organic Molecule with Functional Group and Items of Note about Functional Group**
-*Hydroxyl* -OH	Alcohols, such as ethanol, methanol, helps dissolve molecules such as sugars
-Carboxyl -COOH	Carboxylic acids such as fatty acids and sugars; acidic properties because it tends to ionize; source of H+ ions
-Carbonyl –C=O	Ketones and aldehydes such as sugars
-Amino, $-NH_2$	Amines such as amino acids
-Phosphate, PO_3/ PO_4	Organic Phosphates, including ATP, DNA, and phospholipids.
-Sulfhydryl, -SH	This group is found in some amino acids, forms disulfide bridges in proteins

CHEMICAL GROUP	Hydroxyl	Carbonyl	Carboxyl
STRUCTURE	 (may be written HO—) In a hydroxyl group (—OH), a hydrogen atom is bonded to an oxygen atom, which in turn is bonded to the carbon skeleton of the organic molecule. (Do not confuse this functional group with the hydroxide ion, OH^-.)	 The carbonyl group (>CO) consists of a carbon atom joined to an oxygen atom by a double bond.	 When an oxygen atom is double-bonded to a carbon atom that is also bonded to an —OH group, the entire assembly of atoms is called a carboxyl group (—COOH).
NAME OF COMPOUND	Alcohols (their specific names usually end in *-ol*)	Ketones if the carbonyl group is within a carbon skeleton Aldehydes if the carbonyl group is at the end of the carbon skeleton	Carboxylic acids, or organic acids
EXAMPLE	 Ethanol, the alcohol present in alcoholic beverages	 Acetone, the simplest ketone  Propanal, an aldehyde	 Acetic acid, which gives vinegar its sour taste
FUNCTIONAL PROPERTIES	• Is polar as a result of the electrons spending more time near the electronegative oxygen atom. • Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.	• A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal. • These two groups are also found in sugars, giving rise to two major groups of sugars: aldoses (containing an aldehyde) and ketoses (containing a ketone).	• Has acidic properties because the covalent bond between oxygen and hydrogen is so polar; for example,  Acetic acid Acetate ion • Found in cells in the ionized form with a charge of 1– and called a carboxylate ion (here, specifically, the acetate ion).

CHEMICAL GROUP	Amino	Sulfhydryl	Phosphate	Methyl
STRUCTURE		 (may be written HS—)		
	The amino group (—NH_2) consists of a nitrogen atom bonded to two hydrogen atoms and to the carbon skeleton.	The sulfhydryl group consists of a sulfur atom bonded to an atom of hydrogen; resembles a hydroxyl group in shape.	In a phosphate group, a phosphorus atom is bonded to four oxygen atoms; one oxygen is bonded to the carbon skeleton; two oxygens carry negative charges. The phosphate group (—OPO_3^{2-}, abbreviated Ⓟ) is an ionized form of a phosphoric acid group (—OPO_3H^2; note the two hydrogens).	A methyl group consists of a carbon bonded to three hydrogen atoms. The methyl group may be attached to a carbon or to a different atom.
NAME OF COMPOUND	Amines	Thiols	Organic phosphates	Methylated compounds
EXAMPLE	 Glycine	 Cysteine	 Glycerol phosphate	 5-Methyl cytidine
	Because it also has a carboxyl group, glycine is both an amine and a carboxylic acid; compounds with both groups are called amino acids.	Cysteine is an important sulfur-containing amino acid.	In addition to taking part in many important chemical reactions in cells, glycerol phosphate provides the backbone for phospholipids, the most prevalent molecules in cell membranes.	5-Methyl cytidine is a component of DNA that has been modified by addition of the methyl group.
FUNCTIONAL PROPERTIES	• Acts as a base; can pick up an H^+ from the surrounding solution (water, in living organisms).  (nonionized) (ionized) • Ionized, with a charge of 1+, under cellular conditions.	• Two sulfhydryl groups can react, forming a covalent bond. This "cross-linking" helps stabilize protein structure. • Cross-linking of cysteines in hair proteins maintains the curliness or straightness of hair. Straight hair can be "permanently" curled by shaping it around curlers, then breaking and re-forming the cross-linking bonds.	• Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule; 1– when located internally in a chain of phosphates). • Has the potential to react with water, releasing energy.	• Addition of a methyl group to DNA, or to molecules bound to DNA, affects expression of genes. • Arrangement of methyl groups in male and female sex hormones affects their shape and function.

Chapter 5: The Structure and Function of Macromolecules

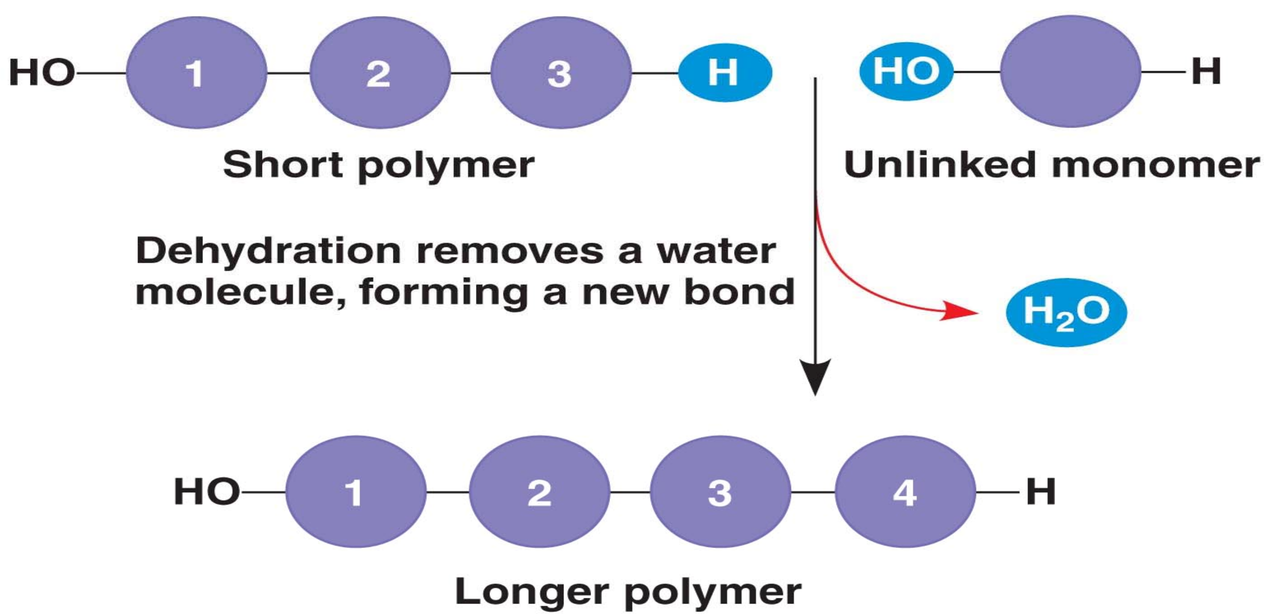
You Must Know:
1. The role of <u>dehydration synthesis</u> in the formation of organic compounds and <u>hydrolysis</u> in the digestion of organic compounds
2. How to recognize the four biologically important organic compounds (carbohydrates, lipids, proteins, and nucleic acids) by their structural formulas.
3. The cellular functions of all four organic compounds.
4. The four structural levels that proteins can go through to reach their final shape (<u>conformation</u>) and the <u>denaturing</u> impact that heat and pH can have on protein structure.

<u>Concept: Most macromolecules are polymers, built from monomers</u>
1. Polymers are longs chain molecules made of repeating subunits called **monomers**. Examples: *<u>Starch</u>* is a polymer composed of glucose monomers. Proteins are polymers composed of amino acid monomers.

2. Condensation or dehydration reactions create polymers from monomers. Two monomers are joined by removing one molecule of water. Example:

$C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$

3. Hydrolysis occurs when water is added to split large molecules. This occurs in the reverse of the above reaction.

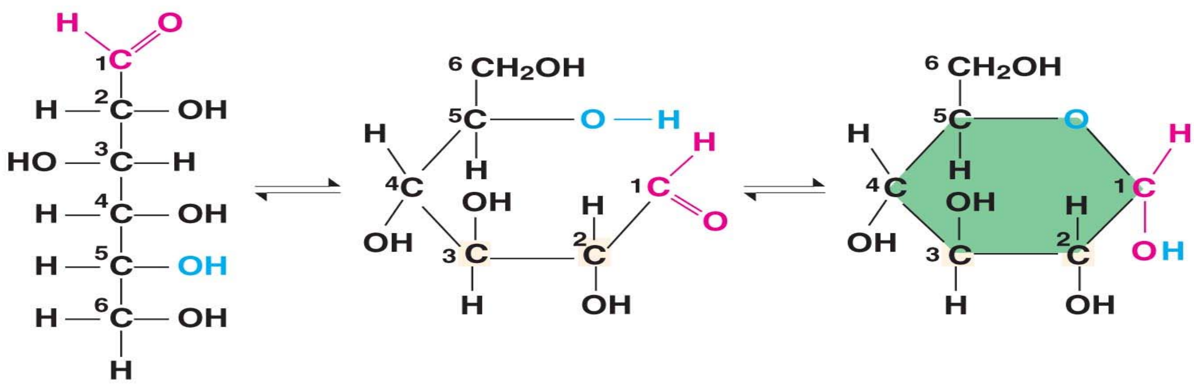


(a) Dehydration reaction in the synthesis of a polymer

Concept: Carbohydrates Serve as fuel and building material

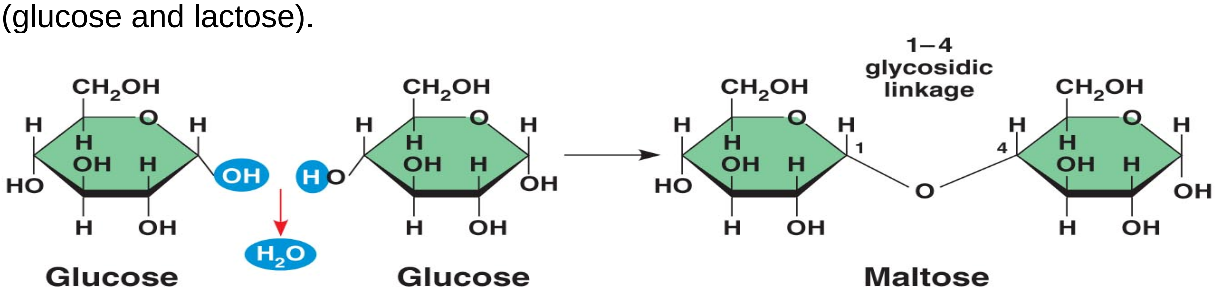
1. **Carbohydrates** include both simple sugars (glucose, fructose, galactose, ribose, deoxyribose, etc) and polymers such as starch made from these and other subunits. All carbohydrates exist in a ratio of 1 carbon: 2 hydrogen: 1 oxygen or CH_2O.

2. **Monosaccharides** are the monomers of carbohydrates. Examples include glucose $C_6H_{12}O_6$ and ribose $C_5H_{10}O_5$. Notice the 1:2:1 ratio discussed above.

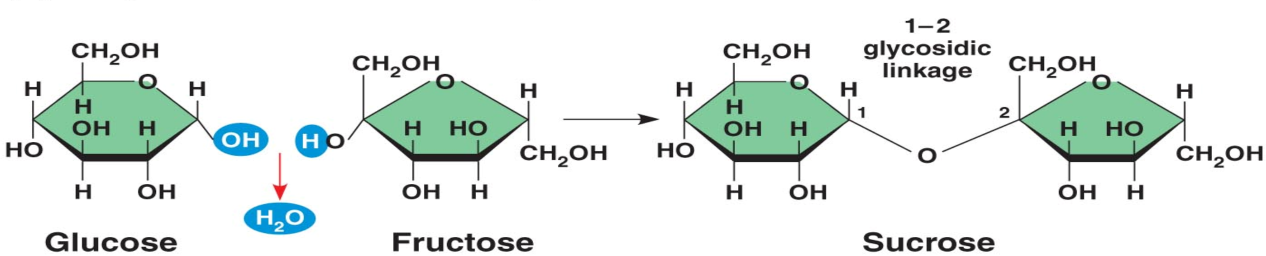


(a) Linear and ring forms

3. **Disaccharides** are polymers made of two monomers put together. Examples include sucrose (glucose and fructose); maltose (glucose and glucose); lactose (glucose and lactose).



(a) Dehydration reaction in the synthesis of maltose



(b) Dehydration reaction in the synthesis of sucrose

4. **Polysaccharides** are polymers of monosaccharides. Examples are starch, cellulose, and glycogen.

5. The two functions of polysaccharides are **energy storage** and **structural support.**

a. Energy Storage Polysaccharides

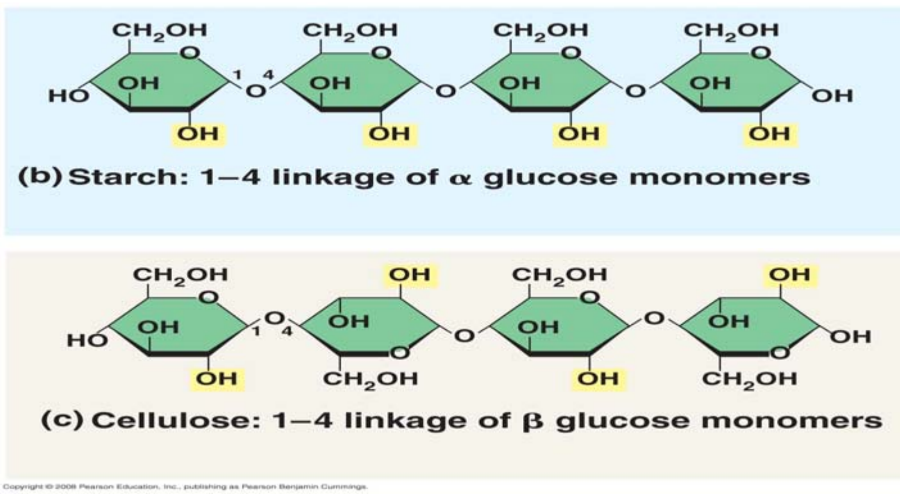
i. Starch is a storage polysaccharide found in plants (e.g., potatoes).

ii. **Glycogen** is a storage polysaccharide found in animals, vertebrate muscle and liver cells.

b. Structural Support Polysaccharides

i. Cellulose is a major component of plant cell wall (Fiber in diet)

ii. Chitin is found in the exoskeleton of arthropods, such as lobsters and insects and the cell walls of fungi. It gives cockroaches their “ crunch”.



(b) Starch: 1–4 linkage of α glucose monomers

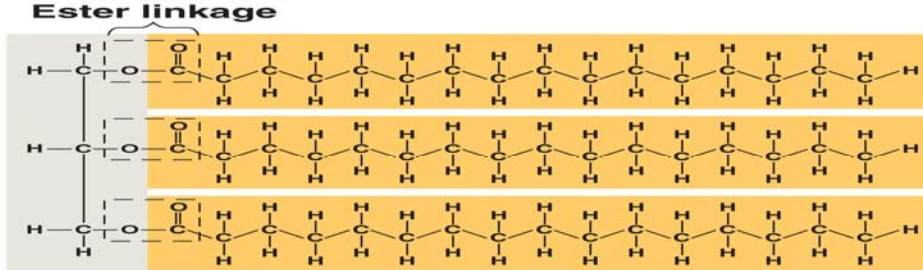
(c) Cellulose: 1–4 linkage of β glucose monomers

<u>**Concept: Lipids are a diverse group of hydrophobic molecules**</u>

1. Lipids are all **hydrophobic.** They aren’t polymers, as they are assembled from a variety of components. Examples include **waxes, oils, fats,** and **steroids.**

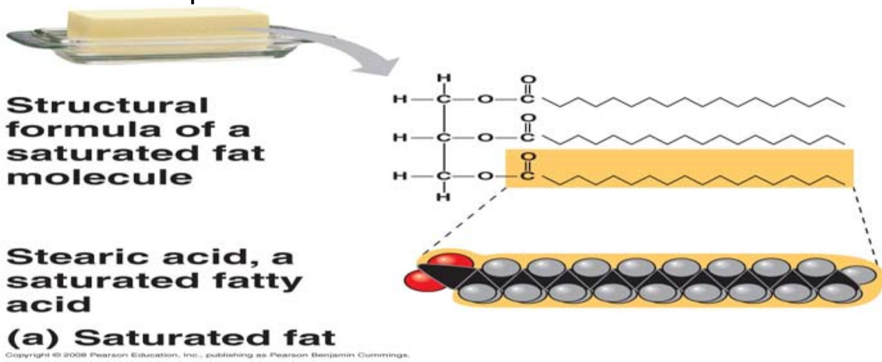
2. Fats (also called triglycerides) are made up of a **glycerol** molecule and three **fatty acid** molecules.

3. **Fatty acids** include hydrocarbon chains of variable lengths. These chains are nonpolar and therefore hydrophobic.

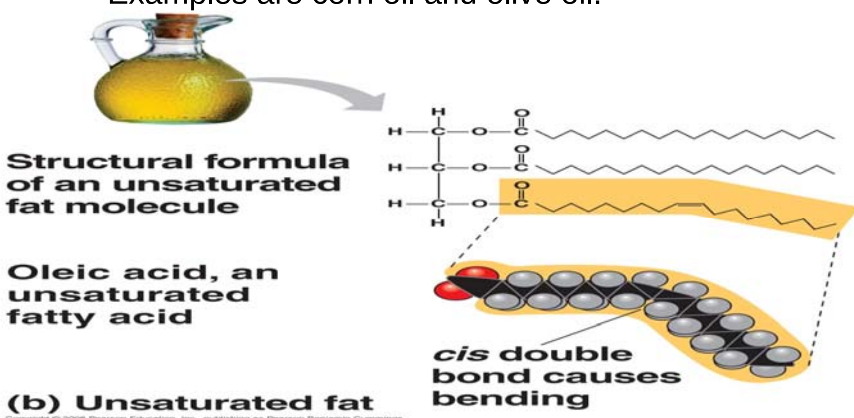


(b) Fat molecule (triacylglycerol)

a. Saturated Fatty Acids
-Have no double bonds between carbons
-Tend to pack solidly at room temperature
-Are linked to cardiovascular disease
-Are commonly produced by animals
-Examples are butter and lard

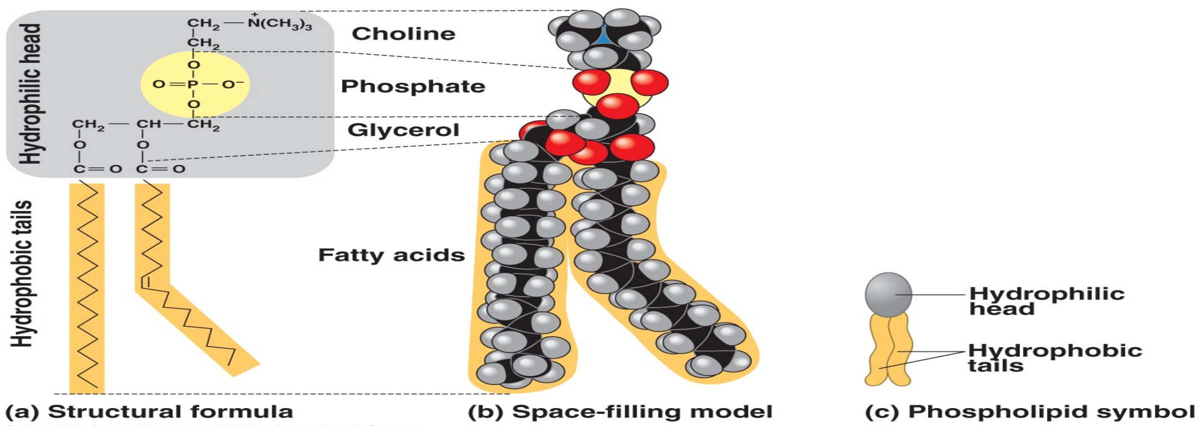


b. Unsaturated Fatty Acids
-Have some C=C (Carbon double bonds); this results in kinks or bending
-Tend to be a liquid at room temperature
-Are commonly produced by plants
-Examples are corn oil and olive oil.



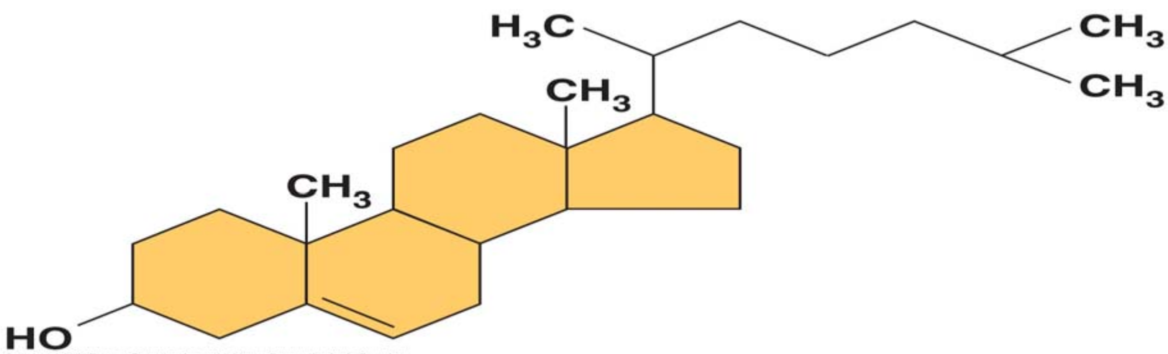
-Functions
1. **<u>Energy Storage</u>**: Fats store twice as many calories/gram as carbohydrates.
2. **<u>Protection</u>**: of vital organs and *<u>insulation</u>*. In humans and other mammals fat is stored in **adipose tissue.**

-Phospholipids make up the cell membranes. They
1. have a glycerol backbone (head), which is **hydrophilic**
2. have two fatty acid tails, which are **hydrophobic**
3. are arranged in bilayer in forming the cell membrane, with the hydrophilic heads pointing toward the watery cytosol or extra-cellular environment, and they hydrophobic tails sandwiched in between.



-Steroids are made up of four rings that are fused together.

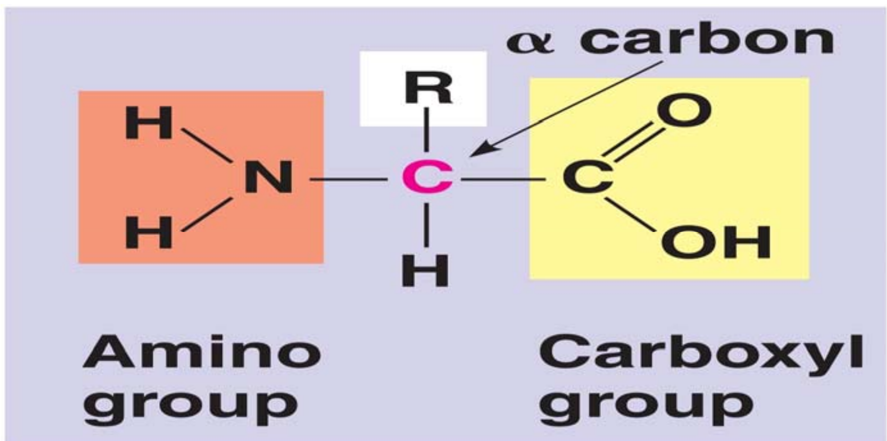
1. **Cholesterol** is a steroid. It is a common component of the cell membranes.
2. **Estrogen and testosterone** are steroid hormones.



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

1. **Proteins** are polymers made up of amino acid monomers

2. **Amino Acids** contain a central carbon bonded to a carboxyl group, an amino group, a hydrogen atom, and an R group (variable group or side chain)



3. **Peptide bonds** link amino acids. They are formed by dehydration synthesis. The function of a protein depends on the order and number of amino acids. The R group determines the characteristic of each amino acid.

4. **There are four levels of protein structure.**

a. Primary structure is the unique sequence in which amino acids are j oined.

b. Secondary structure refers to one of the two three-dimensional shapes that are the result of **hydrogen bonding.**

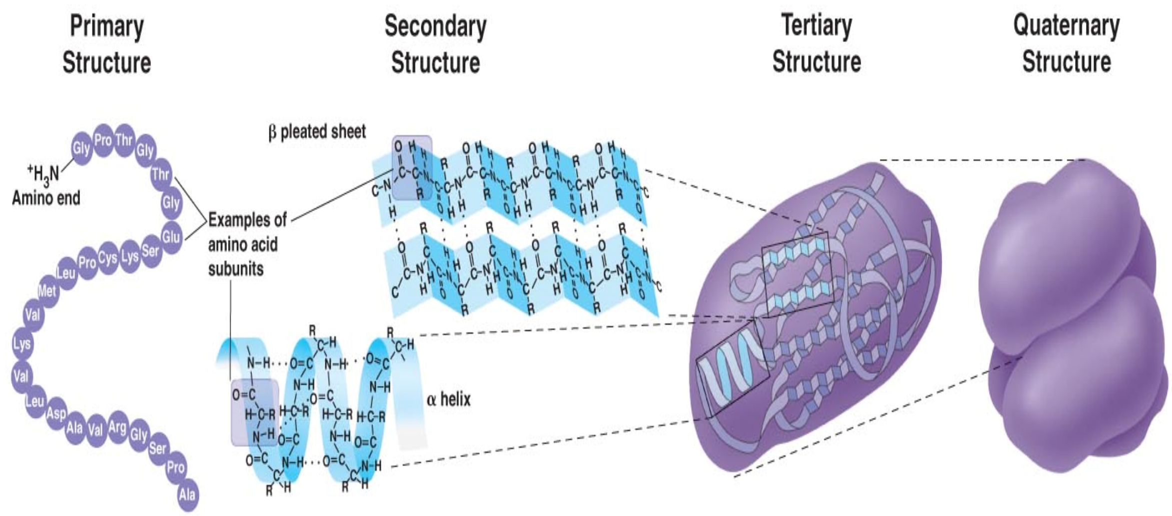
i. **Alpha helix** is a coiled shape (spring, DNA-like—single helix)

ii. **Beta pleated sheet** is an accordion shape.

c. Tertiary structure results in a complex globular shape, due to the interaction between R-groups, such as hydrophobic interactions, van der Waals interactions, hydrogen bonds, and disulfide bridges.

i. Globular proteins such as enzymes are held in position by these R-group interactions.

d. Quaternary structure refers to the association of two or more polypeptide chains into one protein. Hemoglobin is a globular protein with quaternary structure, as it is composed of four chains.



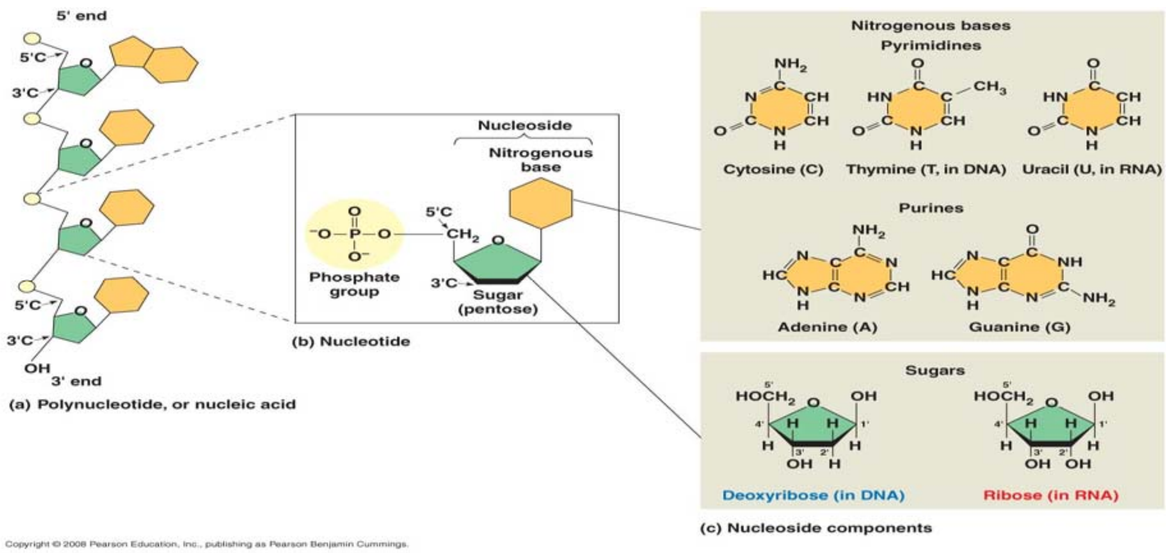
d. Protein shape is crucial to protein function. When a protein does not fold properly, its function is changed. This can be the result of single amino acid substitution, such as that seen in the abnormal hemoglobin typical of sickle cell disease.

e. Chaperonins are protein molecules that assist in the proper folding of proteins within cells. They provide an isolating environment in which a polypeptide chain may attain final conformation.

f. Denaturation occurs when a protein **A protein** is **denatured** when it loses its shape and ability to function due to **heat,** a **change in pH,** or some other disturbance.

Concept: Nucleic acids store and transmit hereditary information

1. **DNA** (deoxyribonucleic acid) and **RNA** (ribonucleic acid) are the two nucleic acids. Their monomers are nucleotides.
2. **Nucleotides** are made up of three parts
   - **a. Nitrogenous base** (adenine, thymine, cytosine, guanine, and uracil)
   - **b. Pentose** (5 carbon) sugar (deoxyribose in DNA or ribose RNA)
   - **c. Phosphate group**



3. **DNA** is the molecule of heredity.
   - a. It is a double-stranded helix.
   - b. Its nucleotides are adenine, thymine, cytosine and guanine.
   - c. Adenine will hydrogen bond to thymine and cytosine will hydrogen bond to guanine.

4. **RNA** is single-stranded. (for the most part) Its nucleotides are adenine, uracil, cytosine, and guanine. Note that uracil replaces thymine in RNA.

Macromolecule or Polymers	**Monomer/Components**	**Examples**	**Functions**
Carbonhydrates	Monosaccharides	Sugars, starch, glycogen, cellulose	Energy, energy storage, and structural
Lipids	Fatty Acids and Glycerol	Fats and Oils	Important Energy source, Insulation
Proteins	Amino Acids	Hemoglobin, Pepsin, Collagen	Enzymes, movement
Nucleic Acids	Nucleotides (sugar, phosphate group, nitrogenous base)	DNA and RNA	Heredity, code for amino acid sequence