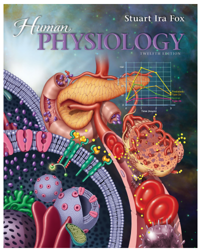


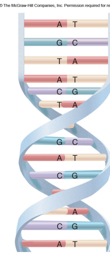

# Chapter 2

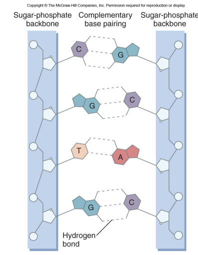
**Chemical Composition of the Body**

Lecture PowerPoint



# I. Atoms, Ions, and Chemical Bonds






# Body Chemistry

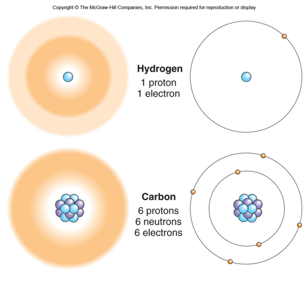
- A general understanding of chemistry is necessary for understanding human physiology.
  - Physiological processes are based on chemical interactions.

# Atoms

- An atom is the smallest unit of an element. It has:
  - A *nucleus* with positively charged protons and uncharged neutrons
  - Orbiting *electrons* with negative charges
  - An *atomic mass* equal to the number of protons plus the number of neutrons
  - An *atomic number* equal to the number of protons

# Atoms






# Electron Orbitals

- Orbitals (or shells) are energy levels that surround the nucleus of an atom.
- Electrons fill the shells, starting with the one closest to the nucleus.
  - The first shell holds 2 electrons.
  - Each shell thereafter holds 8 electrons. (Nonbiological elements fill distant shells that hold more than 8.)
  - Atoms are most stable when the outer shell is filled. Electrons in unfilled outer shells participate in bonding; they are called **valence electrons.**

## Common Biological Atoms



**Table 2.1 | Atoms Commonly Present in Organic Molecules**

| Atom | Symbol | Atomic Number | Atomic Mass | Electrons in Shell 1 | Electrons in Shell 2 | Electrons in Shell 3 | Number of Chemical Bonds |
|---|---|---|---|---|---|---|---|
| Hydrogen | H | 1 | 1 | 1 | 0 | 0 | 1 |
| Carbon | C | 6 | 12 | 2 | 4 | 0 | 4 |
| Nitrogen | N | 7 | 14 | 2 | 5 | 0 | 3 |
| Oxygen | O | 8 | 16 | 2 | 6 | 0 | 2 |
| Sulfur | S | 16 | 32 | 2 | 8 | 6 | 2 |

## Isotopes

- Sometimes atoms do not have the same number of neutrons as protons.
  - Their atomic number is the same, but the atomic mass is different.
  - Some isotopes are radioactive and used in medical testing and physiological research.

## Chemical Bonds

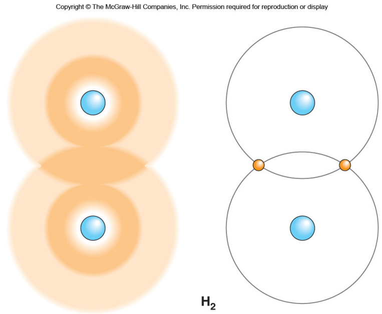
- A molecule forms when electrons of several atoms interact to form *chemical bonds.*
  - The number of bonds an atom can form is determined by the number of valence electrons.
    - Hydrogen has one electron; it needs one more to fill the inner shell so that it can form one bond.
    - Carbon has 6 electrons; 2 fill the inner shell and 4 are in the next shell. It needs 4 more electrons so that it can form 4 bonds.

## Covalent Bonds

- Valence electrons are shared.
  - Nonpolar electrons are shared equally.
    - Example: 2 hydrogen atoms
  - Polar electrons are not shared equally; they have positive and negative ends.
    - Example: water

## Covalent Bonds

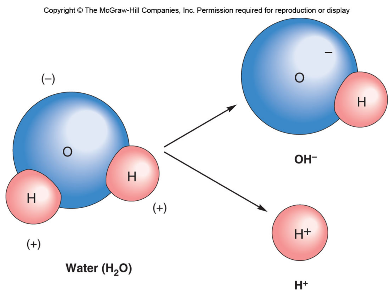





## Water

- Polar molecule
- Good solvent (substances dissolve in it)
- When split, it can contribute to the pH of a substance.

## Water




## Ionic Bonds

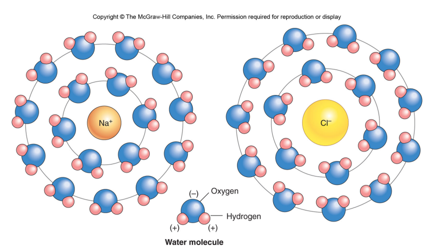
- In an ionic bond, one atom gives electrons to another so that both have filled valence shells.
  - The electron donor becomes positively charged.
    - Atom now called a cation.
  - The electron receiver becomes negatively charged.
    - Atom now called an anion.
  - Cations and anions form ionic compounds.

## Ionic Bonds

- Much weaker than covalent bonds
  - They easily dissociate when dissolved in water.
    - The negative side of water is attracted to the cation, and the positive side of water is attracted to the anion.
  - Molecules that dissolve in water are considered hydrophilic.
    - Fat is made up of nonpolar covalent bonds and will not dissolve in water. It is hydrophobic

## Dissolving Solvents in Water

- Sodium chloride dissociates in water.




## Ionic Bonds

Sodium + chlorine →

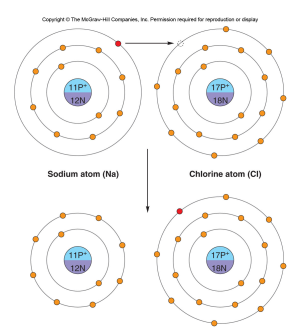
Sodium ions ($Na^+$)

+

Chloride ions ($Cl^-$)

- These free ions are critical to many physiological processes.

## Ionic Bonds



## Hydrogen bond

- Weak bond formed between two polar molecules based on opposite charges attracting (not based on electron sharing)
  - Forms between water molecules
  - Forms between amino acids on a protein to produce the 3D structure of the protein
  - Holds the two strands of the DNA molecule together.

## Acids, Bases, and pH

- Some water molecules break to form free hydrogen ions ($H^+$) and hydroxide ions ($OH^-$).
- When this happens, there are the same number of $H^+$ ions as $OH^-$ ions in solution, so the solution is neutral.
- A neutral solution is said to have a pH of 7 (which means $10^{-7}$ molar concentration $H^+$).

## Acids, Bases, and pH

- Sometimes a solution has more $H^+$ ions than $OH^-$ ions. This is called an acid, and its pH is below 7.
  - Often called a proton donor
- Sometimes a solution has more $OH^-$ ions than $H^+$ ions. This is called a base, and its pH is above 7. (Such solutions are also called alkaline.)
  - Often called a proton acceptor

## pH Scale

- Runs from 0 to 14, with 0 the strongest acid and 14 the strongest base.

$$\text{pH} = \log \frac{1}{H^+ \text{ concentration}}$$

- Pure water has a $H^+$ concentration of $10^{-7}$, so the pH is 7. A pH 6 solution actually has 10 times the number of $H^+$ ions.

## pH Scale



**Table 2.3 | The pH Scale**

| | $H^+$ Concentration (Molar)* | pH | $OH^-$ Concentration (Molar)* |
|---|---|---|---|
| *Acids* | 1.0 | 0 | $10^{-14}$ |
| | 0.1 | 1 | $10^{-13}$ |
| | 0.01 | 2 | $10^{-12}$ |
| | 0.001 | 3 | $10^{-11}$ |
| | 0.0001 | 4 | $10^{-10}$ |
| | $10^{-5}$ | 5 | $10^{-9}$ |
| | $10^{-6}$ | 6 | $10^{-8}$ |
| *Neutral* | $10^{-7}$ | 7 | $10^{-7}$ |
| *Bases* | $10^{-8}$ | 8 | $10^{-6}$ |
| | $10^{-9}$ | 9 | $10^{-5}$ |
| | $10^{-10}$ | 10 | 0.0001 |
| | $10^{-11}$ | 11 | 0.001 |
| | $10^{-12}$ | 12 | 0.01 |
| | $10^{-13}$ | 13 | 0.1 |
| | $10^{-14}$ | 14 | 1.0 |

*Molar concentration is the number of moles of a solute dissolved in one liter. One mole is the atomic or molecular weight of the solute in grams. Since hydrogen has an atomic weight of one, one molar hydrogen is one gram of hydrogen per liter of solution.

## Buffers

- Buffers stabilize $H^+$ concentration in a solution.
  - In blood, two molecules stabilize pH: bicarbonate ion ($HCO_3^-$) and carbonic acid ($H_2O_3$).

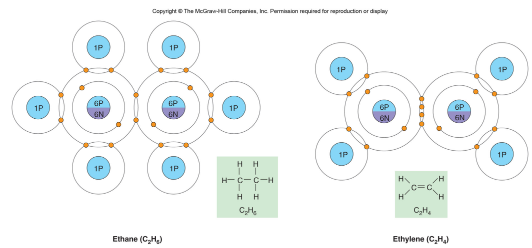
$$HCO_3^- + H^+ \leftrightarrow H_2O_3$$

- If blood falls below pH 7.35, the condition is called *acidosis.*
- If blood rises above pH 7.45, the condition is called *alkalosis.*

## Organic Molecules

- Contain carbon and hydrogen
  - Because carbon must form 4 bonds to satisfy the valence shell, it can form chains and rings of carbons while still bonding with other atoms.
  - Two carbons can share 1 or 2 electrons. If 2 are shared, it is a double bond and can bond with 2 additional atoms. If 1 electron is shared, it can bond with 3 additional atoms

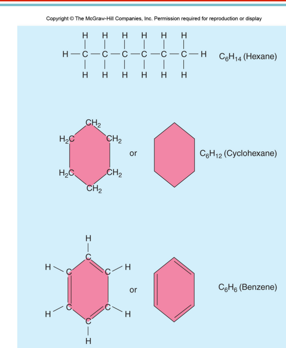
## Organic Molecules




## Carbon Rings

- Carbons are not shown but are understood to be at the corners of the molecule. Some show double bonds.
- Carbon rings form backbones for more reactive groups of atoms called functional groups.

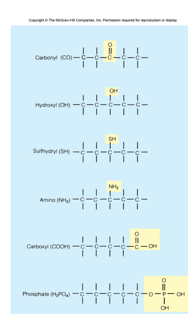
## Carbon Rings

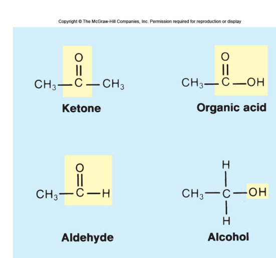



## Functional Groups

- Classes of molecules are named after their functional group.

## Functional Groups



## Stereoisomers

- Two molecules can have exactly the same atoms arranged in exactly the same sequence, but still differ in the spatial organization of their functional groups.
  - This characteristic is critical to function. A given enzyme may interact with one stereoisomer but not with another.
  - The sugars glucose, galactose, and fructose are stereoisomers.

## II. Carbohydrates

## Carbohydrates

- Organic molecules that contain carbon, hydrogen, and oxygen in a 1:2:1 ratio.
- Serve as a major source of energy in the body
- Include sugars and starches

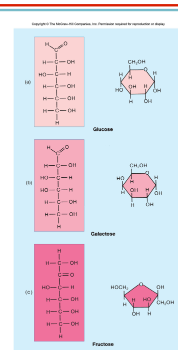
## Carbohydrates

- Monosaccharide: simple sugar, one carbon ring
  - Examples: glucose, fructose, galactose
- Disaccharide: two monosaccharides joined by a covalent bond
  - Examples: sucrose, maltose, lactose
- Polysaccharide: several monosaccharides joined together
  - Example: starch (composed of thousands of glucose molecules)

## Carbohydrates

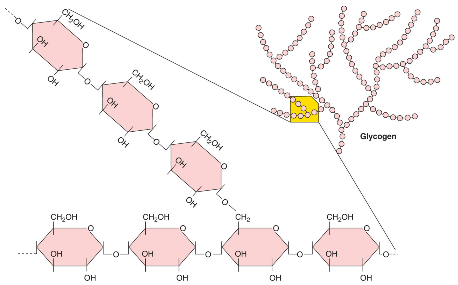
- Glycogen: another polysaccharide formed to store sugar in a cell
  - Glycogen does not pull in water via osmosis as simple sugars do.
- Cellulose: a polysaccharide made by plants
  - Cellulose is not digestible by humans.

## Carbohydrates



## Glycogen



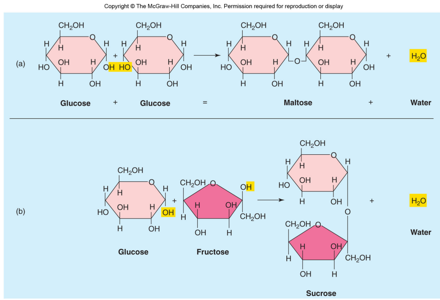



## Dehydration Synthesis and Hydrolysis

- Covalent bonds that hold monosaccharides together are formed via dehydration synthesis.
  - A hydrogen atom is removed from one molecule, and a hydroxyl group is removed from another to form water.
- Hydrolysis breaks bonds between monosaccharides.
  - Water is split and used to complete the individual molecules.
  - These processes are also used to build/break fats, proteins, and nucleic acids.

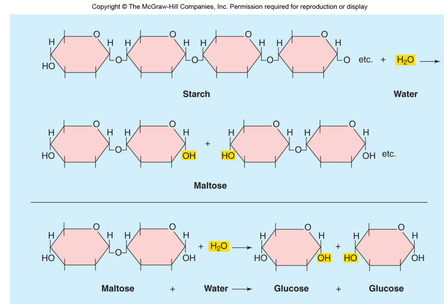
## Dehydration Synthesis






## Hydrolysis






## III. Lipids

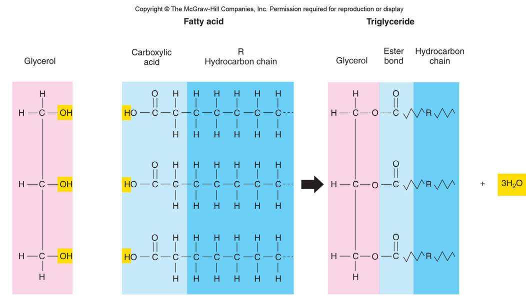
## Lipids

- Lipids consist of nonpolar hydrocarbon chains and rings.
  - This makes them hydrophobic (insoluble in water).
- There are several categories of lipids.

## Triglycerides (Triglycerols)

- Include fats and oils
- Composed of one molecule of glycerol and three molecules of fatty acids

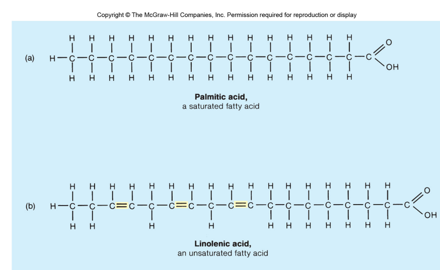
## Triglycerides (Triglycerols)




## Saturated and Unsaturated Fats

- If every carbon on the fatty acid chain shares a single electron, the fatty acid is saturated.
- If there are double bonds between carbons, the fatty acid is unsaturated.

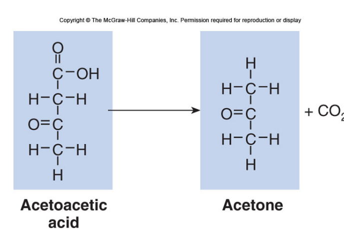
## Saturated and Unsaturated Fats




## Ketone Bodies

- Hydrolysis of triglycerides forms free fatty acids in the blood. These can be used for energy or converted into ketone bodies by the liver.
  - Strict low-carbohydrate diets and uncontrolled diabetes can result in elevated ketone levels, called *ketosis.*
  - Ketone levels low enough to lower pH can cause *ketoacidosis,* which can lead to coma and death.

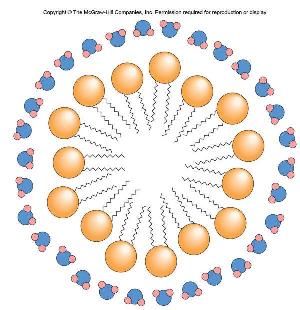
## Ketone Bodies



## Phospholipids

- Lipids with a phosphate group, which makes them polar.
  - Major component of cell membranes as a double layer, with hydrophilic phosphates pointing outward on each side and hydrophobic fatty acids and glycerol pointing inward.
  - As micelles, phospholipids can act as surfactants. The polar nature of the molecule decreases the surface tension of water.
    - Surfactant keeps lungs from collapsing.

## Micelles and Water



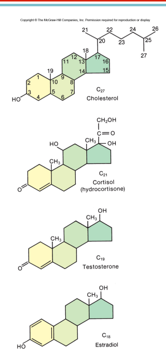

## Steroids

- A steroid is structurally very different from a triglyceride but nonpolar, so considered a lipid.
  - 3 six-carbon rings + 1 five-carbon ring + functional groups

## Steroids

- Cholesterol is a steroid used (1) as a precursor to steroid hormones, such as testosterone, estrogen, and aldosterone, and (2) to make molecules such as vitamin D and bile salts.

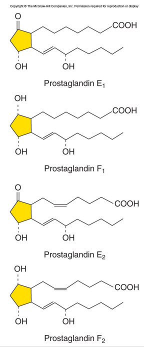
## Steroids




## Prostaglandins

- Type of fatty acid with a cyclic hydrocarbon group
  - Serve as communication molecules between cells in the same organ
  - Help regulate blood vessel diameter, ovulation, uterine contractions, inflammatory reactions, blood clotting, etc.

## Prostaglandins




## IV. Proteins

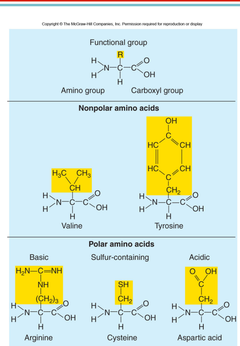
## Proteins

- Composed of an amino acid chain
  - There are 20 different amino acids that can be combined in an endless number of ways.
  - Amino acids are charged, so they attract each other to form kinks and folds in the protein.
  - The sequence of amino acids in a chain is determined by DNA.

## Amino Acids

- An amino acid has an amino group, a carboxyl group, and a functional group.
  - The functional group is what differentiates the 20 amino acids.

## Amino Acids

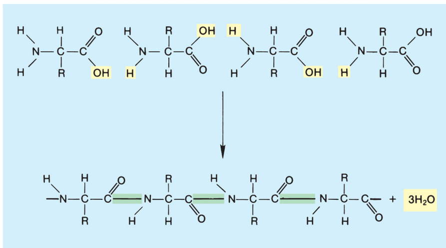



## Making a Protein

- When amino acids are joined, a H is stripped from the amino end and a OH is stripped from the carboxyl end in dehydration synthesis. This is called a peptide bond.

## Making a Protein






## Protein Structure

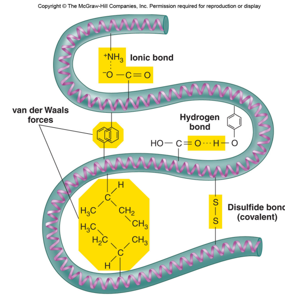
- A chain of amino acids is called a *polypeptide chain*.
  - The chain varies in length from 3 to 4,500 amino acids.
  - The chain is called the primary structure of the protein.
- Weak hydrogen bonds may form between neighboring amino acids.
  - This may form an alpha helix or a beta fold.
  - This is called the secondary structure of the protein.

## Protein Structure

- Attraction to amino acids further away produces bends and folds, creating a specific 3D shape.
  - This is the tertiary structure of the protein.
  - This structure dictates function.
  - Since weak bonds hold tertiary structure together, a protein is easily denatured (unfolded) by changes in pH or temperature.

## Protein Structure



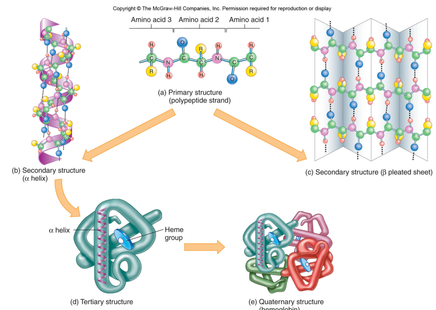



## Protein Structure

- Some functional proteins are composed of multiple polypeptide chains covalently bonded together.
  - This is called the quaternary structure of the protein.
  - Examples are the hemoglobin in blood and the hormone insulin.

## Protein Structure





## Conjugated Proteins

- Sometimes proteins are combined with other molecules:
  - Glycoprotein = Protein + Carbohydrate
    - Examples: some hormones
  - Lipoprotein = Protein + Lipid
    - Example: in cell membranes, carrier molecules in blood

## Conjugated Proteins



Table 2.4 | Composition of Selected Proteins Found in the Body

| Protein | Number of Polypeptide Chains | Nonprotein Component | Function |
|---|---|---|---|
| Hemoglobin | 4 | Heme pigment | Carries oxygen in the blood |
| Myoglobin | 1 | Heme pigment | Stores oxygen in muscle |
| Insulin | 2 | None | Hormonal regulation of metabolism |
| Blood group proteins | 1 | Carbohydrate | Produces blood types |
| Lipoproteins | 1 | Lipids | Transports lipids in blood |

## Protein Functions

- Structural: collagen fibers in connective tissues; keratin in skin
- Enzymes: assist every chemical process in the body
- Antibodies: part of the immune system
- Receptors: receive communication from other cells for regulation of cell activity
- Carriers: across cell membranes or in blood

## V. Nucleic Acids

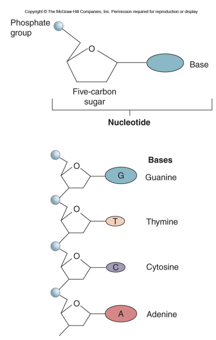
## Nucleotides

- Building blocks for nucleic acids
  - Composed of a five-carbon sugar, a phosphate group, and a nitrogenous base
  - Nitrogenous bases fall into two categories:
    - Pyrimidine: a single carbon ring + nitrogen
    - Purine: 2 carbon rings + nitrogen

## Deoxyribonucleic Acid (DNA)

- The sugar in this molecule is called deoxyribose and can bind to one of four nitrogenous bases:
  - Guanine
  - Thymine
  - Cytosine
  - Adenine

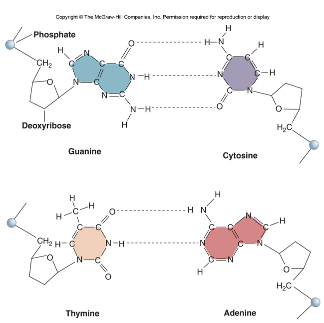
## Deoxyribonucleic Acid (DNA)



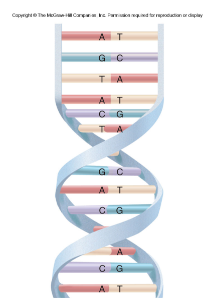

## DNA Structure

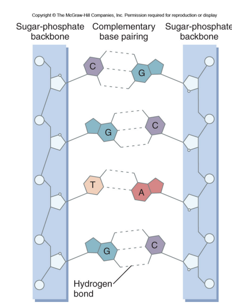
- Deoxyribose bonds with a phosphate group (via dehydration synthesis) to form a long chain, which serves as the backbone of the molecule.
- Each nitrogenous base can form a hydrogen bond with another to result in a double-stranded molecule.
  - Cytosine can only bind with guanine.
  - Tyrosine can only bind with adenine.
- The two chains of DNA are twisted, forming a double helix.

## DNA Structure




## DNA Structure

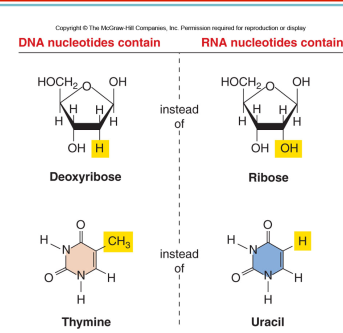





## Ribonucleic Acid (RNA)

- Similar to DNA except:
  - Has ribose sugar instead of deoxyribose
  - Is single-stranded instead of double-stranded
  - Has uracil instead of thymine

## Ribonucleic Acid (RNA)



## Types of RNA

- Three types of RNA are used to take information for assembling a protein out of the nucleus and to actually assemble it:
  - Messenger RNA
  - Transfer RNA
  - Ribosomal RNA

- Other RNA-related molecules serve important functions in the body: ATP, cAMP, NAD, FAD.