

**Human Anatomy & Physiology I – Dr. Sullivan**  
**Units II– Basic & Organic Chemistry**  
**Chapter 2**

**I. Chemical Elements**

- a. All matter (anything that occupies space and has mass) is made up of **chemical elements**.
- b. **Mass**: The amount of matter in any object
- c. **Chemical Elements** are the building blocks of matter and cannot be split into simpler substances by normal chemical means.
- d. Each element has a *chemical symbol* of 1 or 2 letters.
  - i. I.e.: O – oxygen, H – hydrogen, Na – sodium, etc.
- e. Each element is made of many of a single type **atom**, which is the smallest unit of an element still retaining the properties of that element.
- f. The atom has parts called **subatomic particles**.
  - i. **Protons**: positively charged particles within the nucleus of the atom
  - ii. **Neutrons**: uncharged particles within the nucleus of the atom
  - iii. **Electrons**: negatively charged particles surrounding the nucleus in a negatively charged “cloud”
    1. Electrons are arranged in “shells” surrounding the nucleus.
- g. Elements are distinguished from one another by the number of protons in their nucleus. This is called the **Atomic Number**. *All atoms of the same element have the same number of protons.*
  - i. Neutrons can vary among atoms of the same element creating **isotopes**.
- h. The number of electrons always equals the number of protons in an atom so that they balance each other out and an atom is always uncharged.
- i. **Atomic Mass**: the average mass of neutrons plus protons per atom in all naturally occurring isotopes of an element.
- j. Sometimes an atom can lose or gain electrons. This is called *ionization* and the resulting particle is called an **ion**.
  - i. **Ion**: formed when an atom loses or gains electrons giving it a positive or negative charge because of an unequal number of electrons and protons.
  - ii. An ion is symbolized by writing the number of its charge after the chemical symbol.
    1. i.e.: Cl is the symbol for Chlorine, whereas Cl<sup>-</sup> is the symbol for the ionized version of chlorine called *chloride*, which is chlorine after it has gained an electron
    2. Calcium (Ca) loses two electrons when ionized and is therefore written in this way: Ca<sup>++</sup>
- k. When two or more atoms share or exchange electrons with each other, they bond together to form a **molecule**.
  - i. A molecule may consist of two or more atoms of the same element, such as Oxygen (O<sub>2</sub>)
  - ii. A **molecular formula** indicates the elements and the number of atoms of each that make up a molecule.
    1. i.e. C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> is the molecular formula for Glucose and tells us that one glucose molecule is made of 6 Carbon atoms, 12 Hydrogen atoms, and 6 Oxygen atoms.
- l. Free radicals are atoms that have an unpaired electron in their outer shells. They become destructive to the body’s cells because they destroy body molecules to try to pair their outer shell electron.
  - i. Free radicals result from overexposure to ultraviolet light, exposure to CCL<sub>4</sub>, used in dry cleaning chemicals, X-rays, and some normal metabolic processes.

- ii. Free radicals are linked to cancer, atherosclerosis, Alzheimer's disease, emphysema, diabetes mellitus, cataracts, macular deterioration, rheumatoid arthritis, and degeneration associated with aging.
  - 1. Anti-oxidants such as Vitamin C & E, Beta-carotene, and selenium help inactivate free radicals and protect the body from damage.

## II. Chemical Bonds

- a. The forces that hold the atoms of a molecule together are called **chemical bonds**
- b. Most atoms have an outer electron shell (aka *valence shell*) that can hold a maximum of 8 electrons. When an atom has less than 8 electrons in its valence shell, it would like to share or exchange electrons with another atom to give them each 8. This is how molecules are formed.
  - i. This is called the **octet rule**: 2 or more atoms interact in such a way that they all can have a stable arrangement of 8 valence electrons.
- c. There are three ways this can happen:
  - i. An atom either empties its partially filled valence shell
  - ii. An atom receives donated electrons from another atom's valence shell
  - iii. Two or more atoms share electrons
- d. Which one of these occurs determines what type of bond we will have
- e. **Ionic Bonds**: When two ions of opposite charges come together to form a molecule based on their opposite charge attraction: it is called an **Ionic Bond**
  - i. Cation: positively charged ion
  - ii. Anion: negatively charged ion
    - 1. **i.e.** Sodium (Na) has one valence electron, chlorine (Cl) has seven valence electrons. Therefore, sodium would love to give up one, convert its next shell (8 electrons) to be its valence shell AND chlorine would love to take on one more electron to fill its valence shell to 8.
    - 2. When sodium donates an electron, it leaves it with one more proton than electron and hence, it becomes a positive ion (Na<sup>+</sup>).
    - 3. When Chlorine receives an electron, it has one more electron than protons and hence, it becomes a negative ion (Cl<sup>-</sup>).
    - 4. The positive and negative charges of these ions draw them together and form an Ionic Bond written as NaCl, or common table salt.
- f. **Covalent Bonds**: When two or more elements share pairs of electrons rather than exchange electrons
  - i. **Non-Polar covalent bonds**: when the electrons are shared equally by the atoms
  - ii. **Polar covalent bonds**: when one atom attracts the shared electrons more than the other, causing the atoms to have partial charges.
    - 1. The atom that attracts the electrons has a partial negative charge
    - 2. The atom that does not attract the electrons has a partial positive charge
  - iii. **Single bond**: one pair of electrons is shared
  - iv. **Double bond**: two pairs of electrons are shared
  - v. **Triple bond**: three pairs of electrons are shared
- g. **Hydrogen Bonds (figure 2.8)**: polar covalent bonds formed between hydrogen atoms bonded to a highly electronegative element and other atoms.
  - i. Hydrogen bonds are formed from the attraction of partially charged parts of molecules and not from sharing of electrons.
  - ii. Hydrogen bonds do not form molecules, rather they establish links between molecules or between separate parts of large molecules.
  - iii. A water molecule (H<sub>2</sub>O) is a polar covalent bond between hydrogen and oxygen atoms. Separate water molecules are held together by hydrogen bonds.

## III. Chemical Reactions- When new bonds form or when old bonds break

- a. Chemical reactions are the foundations of all life processes.
- b. Each chemical reaction has **reactants** and **products**

- i. Reactants: the starting substances (i.e.  $2\text{H}_2$  &  $\text{O}_2$ )
  - ii. Products: the result of the reaction (i.e.  $2\text{H}_2\text{O}$ )
- c. Activation Energy: the amount of energy needed to start a chemical reaction between two atoms or molecules
  - i. Usually achieved by temperature or concentration of molecules (increasing their chances of colliding with each other)
- d. **Catalyst:** a chemical compound that speeds up chemical reactions by lowering the activation energy needed for a reaction to occur.

**IV. Water: the most abundant inorganic (without carbon) molecule in all living systems**

- a. Nearly all of the body's natural chemical reactions require a watery medium (aqueous)
- b. **Solution:** the result when a solute is dissolved within a solvent
  - i. Water is the solvent and salt is the solute in salt water (the solution)
- c. Hydrophilic: easily dissolved in water
- d. Hydrophobic: cannot be dissolved in water
- e. Concentration: a measure of how much solute is dissolved in a solution.
- f. Mixture: a physically blended combination of elements or compounds that have not chemically reacted with each other
  - i. Solutions usually look clear because the solute is evenly dispersed within the solvent
  - ii. In **colloids** the solute is in large particles that can scatter light (water droplets in the air during a fog), which causes it to be cloudy or opaque
  - iii. Suspension: a mixture in which the solute is mixed within the solvent, but will eventually settle out.
    - 1. i.e. blood

**V. Acids, Bases, and Salts**

- a. When acids, bases (alkaline), or salts dissolve in water they *dissociate*, which means they separate into ions and become surrounded by water.
  - i. Acids dissociate into Hydrogen ions with a positive charge ( $\text{H}^+$ )
  - ii. Bases dissociate into hydroxide ions with a negative charge ( $\text{OH}^-$ )
  - iii. When a salt dissolves in water, it dissociates into anions and cations, neither of which is  $\text{H}^+$  or  $\text{OH}^-$ 
    - 1. In the body, salts are *electrolytes*, which are important for carrying electrical currents in muscle and nerve tissue.
    - 2. Electrolytes are also important to provide essential chemical elements in body fluids such as blood, lymph, and interstitial fluid.
  - iv. When an acid and base of equal concentrations react with each other, a salt and water are produced, creating a neutral solution.
    - 1.  $\text{HCl} + \text{KOH} \rightarrow \text{H}^+ + \text{Cl}^- + \text{K}^+ + \text{OH}^- \rightarrow \text{KCl} + \text{H}_2\text{O}$ 
      - a. HCl: acid
      - b. KOH: base
      - c. KCl: salt
      - d.  $\text{H}_2\text{O}$ : water
- b. pH: a scale used to measure the acidity or alkalinity of a solution.
  - i. 7 = neutral
  - ii. <7 = acid
  - iii. >7 = base

**VI. Organic Compounds**

- a. Organic compounds are relatively large, contain carbon, and have specific characteristics that allow them to carry out important functions for living systems.
- b. Carbon bonds easily with other carbon atoms and with many other elements to form organic compounds needed by living organisms.
  - i. H, N, O, S, P are all important elements that covalently bond with carbon to make organic compounds
- c. Carbon also bonds together using covalent bonds that do not dissolve easily in water

- i. This makes it very good for building body structures
- d. A chain of carbon atoms in an organic molecule is called the **carbon skeleton** (see table 2.5)
  - i. The molecule also has **functional groups**, which are areas on the compound made up of other elements bonding with carbon and hydrogen.
  - ii. These functional groups have specific arrangements of atoms and act on other organic molecules in specific ways.

## VII. Categories of Organic Compounds

- a. **Carbohydrates:** include sugars, starches, glycogen, and cellulose.
  - i. Carbohydrates make up about 2-3% of a lean adult's body mass
  - ii. Plants store carbohydrates as starch and use cellulose to build the plant's cell wall.
  - iii. Humans eat cellulose, but do not digest it. It does, however create bulk and help move food and waste through the digestive tract.
  - iv. Carbohydrates are made of Carbon, Hydrogen, and Oxygen and are soluble in water (hydrophilic)
  - v. In animals, carbohydrates function mainly as a source of energy to drive metabolic reactions (carbohydrates provide about 4.1 kcal/gram of energy).
  - vi. There three types of carbohydrates: monosaccharides, disaccharides, and polysaccharides
    - 1. Monosaccharides and disaccharides are known as the *simple sugars*.
    - 2. Common Monosaccharides are glucose, fructose, and galactose.
    - 3. Two monosaccharides come together to form a *disaccharide*
      - a. Glucose + fructose = sucrose (table sugar)
      - b. Glucose + galactose = lactose (milk sugar)
      - c. Glucose + glucose = maltose
    - 4. Polysaccharides: tens to hundreds of monosaccharides joined together to be used for storage
      - a. Glycogen, starch, cellulose
- b. **Lipids:** fats
  - i. Lipids make up about 18-25% of a lean adults body mass
  - ii. Lipids are also made of Carbon, Hydrogen, and Oxygen, but have fewer polar covalent bonds, therefore, they are insoluble in water (hydrophobic)
  - iii. Only very small lipids (i.e. fatty acids) can dissolve in blood plasma (mostly water), therefore some larger lipids must bind with protein molecules so they can dissolve in plasma
    - 1. These complexes are called **Lipoproteins** (i.e. cholesterol)
  - iv. Examples of Lipids:
    - 1. triglycerides: fats and oils
    - 2. phospholipids: lipids that contain phosphorous
    - 3. steroids: contain rings of carbon atoms
    - 4. fatty acids, fat-soluble vitamins (A,D,E,K), and lipoproteins
  - v. Triglycerides are the most abundant lipid in your body and your diet and are stored in adipose (fat) tissue.
    - 1. Our capacity to store fat is unlimited and all excess dietary energy sources (carbohydrate, lipid, protein) are stored as triglyceride in adipose tissue if not used for tissue building or energy.
    - 2. Triglycerides contain approximately 9 kcal/gram of energy.
  - vi. Saturated Fats: lipids that have a hydrogen atom bonded to every available space on a carbon atom ("saturated with hydrogen")
    - 1. Occur mostly in animal fat, but sometimes in plant products such as: cocoa butter, palm oil, and coconut oil
    - 2. Saturated fats are usually solid at room temperature
      - a. Hydrogenated fat: hydrogen atoms are added to the lipid molecule to make the fat solid (margarine)

3. Saturated fats pose a higher risk for coronary artery disease (atherosclerosis)
- vii. Monounsaturated fats: one carbon atom is not saturated with hydrogen (olive oil, peanut oil)
  1. Not as likely to cause atherosclerosis as saturated fat
- viii. Polyunsaturated fat: More than one carbon atoms that are not saturated with hydrogen (canola oil, corn oil, safflower oil, sunflower oil, soybean oil).
  1. Even more unlikely to cause atherosclerosis

### VIII. Proteins

- a. Large molecules that contain carbon, hydrogen, oxygen and nitrogen.
- b. Proteins have much more complex structures than carbohydrates or lipids and are largely responsible for the structure of body tissues.
- c. Proteins can be:
  - i. Enzymes: help drive chemical reactions in the body (catalysts)
  - ii. Can be used as motors to drive muscle contractions
  - iii. Antibodies to defend against invading microorganisms
  - iv. Hormones that regulate homeostasis
- d. The building blocks of proteins are called amino acids and are held together by *peptide bonds* to form proteins.
  - i. An Amino acid's structure contains an *amino group*, which is a molecule consisting of a nitrogen and 2 hydrogen atoms (NH<sub>2</sub>)
  - ii. Peptide bonds are covalent bonds between a carbon and a nitrogen atom

### IX. Nucleic Acids

- a. DNA: deoxyribonucleic acid
  - i. Forms the inherited genetic material found inside of each cell.
  - ii. Each *gene* is a segment of a DNA molecule and determines our inherited traits, such as hair color, eye color, height, etc.
  - iii. By controlling protein synthesis, DNA regulates most of the activities that take place in a body's cells throughout its lifetime.
- b. RNA: ribonucleic acid
  - i. Relays instructions from genes to guide the production of proteins from amino acids
- c. Summary: DNA determines the traits you inherit from your family and RNA carries out the DNA's instructions when synthesizing new proteins to make sure those traits are there.

### X. Adenosine Triphosphate (ATP)

- a. ATP is the "energy currency" used in the body.
- b. ATP transfers the energy liberated in catabolic reactions (when the body breaks down molecules to produce energy) to the cells so they can use it to carry out the activities that require energy. Glucose is the most common molecule broken down for energy production.
  - i. I.e.: muscular contraction, chromosome movement during cell division, transport of substances across cell membranes, etc.
- c. **Anaerobic phase of ATP production:** in the absence of oxygen, glucose is partially broken down (catabolized) into a pyruvic acid molecule that yields two molecules of ATP for energy.
- d. **Aerobic phase of ATP production:** in the presence of oxygen, glucose is completely broken down into water and carbon dioxide (CO<sub>2</sub>) and generates from 36-38 ATP molecules.