

CHAPTER 2

LECTURE OUTLINE

I. INTRODUCTION

- A. Since chemicals compose your body and all body activities are chemical in nature, it is important to become familiar with the language and fundamental concepts of chemistry.
- B. Basic Principles
 - 1. *Chemistry* is the science of the structure and interactions of matter.
 - 2. *Matter* is anything that occupies space and has mass.
 - 3. *Mass* is the amount of matter a substance contains; *weight* is the force of gravity acting on a mass.

II. HOW MATTER IS ORGANIZED

- A. Chemical Elements
 - 1. Matter exists in three forms:
 - a. solid (bones and teeth)
 - b. liquid (blood plasma)
 - c. gas (oxygen and carbon dioxide)
 - 2. All forms of matter are composed of *chemical elements* which are substances that cannot be split into simpler substances by ordinary chemical means.
 - 3. Elements are given letter abbreviations called *chemical symbols*.
 - 4. Oxygen (O), carbon (C), hydrogen (H), and nitrogen (N) make up 96% of body weight.
 - 5. Table 2.1 lists the major and trace elements of the human body.
- B. Structure of Atoms
 - 1. Units of matter of all chemical elements are called *atoms*. An element is a quantity of matter composed of atoms of the same type.
 - 2. atoms: the smallest units of matter that retain the properties and characteristics of the element
 - a. subatomic particles: compose individual atoms.
 - 1. protons: positively charged protons (p^+) located within the nucleus
 - 2. neutrons: uncharged (neutral; n^0), located within the nucleus

3. electrons: tiny, negatively charged electrons (e^-)
2. Atoms consist of a *nucleus*, which contains positively charged *protons* and neutral (uncharged) *neutrons*, and negatively charged *electrons* that move about the nucleus in energy levels (Figure 2.1a).
3. Electrons revolve around the nucleus of an atom tending to spend most of the time in specific atomic regions, called *shells* (Figure 2.1b).
 - a. Each shell can hold a certain maximum number of electrons.
 - b. The first shell, the one nearest the nucleus, can hold a maximum of 2 electrons; the second shell, 8; the third shell, 18; the fourth shell, 18; and so on (Figure 2.1b).
4. The number of electrons in an atom of a neutral element always equals the number of protons.

C. Atomic Number and Mass Number

1. The number of protons in the nucleus of an atom
 - a. The number of protons in the nucleus makes the atoms of one element different from those of another as illustrated in Figure 2.2.
 - b. Since all atoms are electrically neutral, the atomic number also equals the number of electrons in each atom.
2. The mass number of an atom is the total number of protons and neutrons.
3. Different atoms of an element that have the same number of protons but different numbers of neutrons are called isotopes.
 - a. Stable isotopes do not change their nuclear structure over time.
 - b. Certain isotopes called *radioactive isotopes* are unstable because their nuclei decay to form a simpler and thus more stable configuration.
 - c. Radioactive isotopes can be used to study both the structure and function of particular tissues as described in the Clinical Connection on “Harmful and Beneficial Effects of Radiation.”

D. Atomic Mass

1. The standard unit for measuring the mass of atoms and their subatomic particles is a dalton, also known as an atomic mass unit (amu).
 - a. a neutron has a mass of 1.008 daltons
 - b. a proton has a mass of 1.007 daltons
 - c. an electron has a mass of 0.0005 daltons

2. is almost 2000 times smaller than the mass of a neutron or proton
3. The *atomic mass*, also called the atomic weight, of an element is the average mass of all its naturally occurring isotopes and reflects the relative abundance of isotopes with different mass numbers.
4. The mass of a single atom is slightly less than the sum of the masses of its neutrons, protons, and electrons because some mass (less than 1%) was lost when the atom's components came together to form an atom.

E. Ions, Molecules, and Compounds

1. If an atom either gives up or gains electrons, it becomes an *ion* - an atom that has a positive or negative charge due to having unequal numbers of protons and electrons.
2. When two or more atoms share electrons, the resulting combination is called a *molecule* (Figure 2.3a).
3. Clinical Connection: A *free radical* is an electrically charged atom or group of atoms with an unpaired electron in its outermost shell (Figure 2.3b).
 - a. Free radicals become stable by either giving up their unpaired electron or by taking on an electron from another molecule.
 - b. Antioxidants are substances that inactivate oxygen-derived free radicals.
4. A *compound* is a substance that can be broken down into two or more different elements by ordinary chemical means.
5. Free radicals are linked to numerous disorders and diseases as described in the Clinical Connection on "Free Radicals and Their Effects on Health."

III. CHEMICAL BONDS

- A. The atoms of a molecule are held together by forces of attraction called *chemical bonds*.
 1. The likelihood that an atom will form a chemical bond with another atom depends on the number of electrons in its outermost shell, also called the *valence shell*.
 2. An atom with a valence shell holding eight electrons (2 electrons for hydrogen and neon) is chemically stable, which means it is unlikely to form chemical bonds with other atoms.

3. To achieve stability, atoms that do not have eight electrons in their valence shell (or 2 in the case of H and He) tend to empty their valence shell or fill it to the maximum extent (figure 2.2).
4. Atoms with incompletely filled outer shells tend to combine with each other in chemical reactions to produce a chemically stable arrangement of eight valence electrons for each atom. This chemical principle is called the *octet rule*.

B. Ionic Bonds

1. When an atom loses or gains a valence electron, ions are formed (Figure 2.4a).
 - a. Positively and negatively charged ions are attracted to one another.
 - b. When this force of attraction holds ions having opposite charges together, an *ionic bond* results.
2. *Cations* are positively charged ions that have given up one or more electrons (they are electron donors).
3. *Anions* are negatively charged ions that have picked up one or more electrons that another atom has lost (they are electron acceptors).
4. In general, ionic compounds exist as solids but some may dissociate into positive and negative ions in solution. Such a compound is called an *electrolyte*.
5. Table 2.2 lists the names and symbols of the most common ions and ionic compounds in the body.

C. Covalent Bonds

1. Covalent bonds are formed by the atoms of molecules sharing one, two, or three pairs of their valence electrons.
2. Covalent bonds are the most common chemical bonds in the body.
3. Single, double, or triple covalent bonds are formed by sharing one, two, or three pairs of electrons, respectively (Figure 2.5b,c).
4. Covalent bonds may be nonpolar or polar.
 - a. In a nonpolar covalent bond, atoms share the electrons equally; one atom does not attract the shared electrons more strongly than the other atom (Figure 2.5a-c).

- b. In a polar covalent bond, the sharing of electrons between atoms is unequal; one atom attracts the shared electrons more strongly than the other ([Figure 2.5e](#)).

D. Hydrogen Bonds

1. In a *hydrogen bond*, two other atoms (usually oxygen or nitrogen) associate with a hydrogen atom ([Figure 2.6](#)).
2. Hydrogen bonds are weak and cannot bind atoms into molecules. They serve as links between molecules.
3. They provide strength and stability and help determine the three-dimensional shape of large molecules.
4. Hydrogen bonds linking neighboring water molecules ([Figure 2.6](#)) give water considerable cohesion which creates a very high surface tension.

IV. CHEMICAL REACTIONS

A. A *chemical reaction* occurs when new bonds are formed or old bonds break between atoms ([Figure 2.7](#)).

1. The starting substances of a chemical reaction are known as *reactants*.
2. The ending substances of a chemical reaction are the *products*.
3. In a chemical reaction, the total mass of the reactants equals the total mass of the products (the law of conservation of mass).
4. *Metabolism* refers to all the chemical reactions occurring in an organism.

B. Forms of Energy and Chemical Reactions

1. *Energy* is the capacity to do work.
 - a. *Potential energy* is energy stored by matter due to its position.
 - b. *Kinetic energy* is the energy associated with matter in motion.
 - c. *Chemical energy* is a form of potential energy stored in the bonds of compounds or molecules.
2. The total amount of energy present at the beginning and end of a chemical reaction is the same; energy can neither be created nor destroyed although it may be converted from one form to another (law of conservation of energy).

C. Energy Transfer in Chemical Reactions

1. Breaking chemical bonds requires energy and forming new bonds releases energy.

- a. An *exergonic* reaction is one in which the bond being broken has more energy than the one formed so that extra energy is released, usually as heat (occurs during catabolism of food molecules).
 - b. An *endergonic* reaction is just the opposite and thus requires energy, usually from a molecule called ATP, to form a bond, as in bonding amino acid molecules together to form proteins
2. *Activation energy* is the collision energy needed to break chemical bonds in the reactants (Figure 2.8).
- a. Activation energy is the initial energy needed to start a reaction.
 - b. Factors that influence the chance that a collision will occur and cause a chemical reaction include
 - 1) Concentration: The more particles of matter present in a confined space, the greater the chance that they will collide
 - 2) Temperature: As temperature rises, particles of matter move about more rapidly.
3. *Catalysts* are chemical compounds that speed up chemical reactions by lowering the activation energy needed for a reaction to occur (Figure 2.9).
- a. A catalyst does not alter the difference in potential energy between the reactants and products. It only lowers the amount of energy needed to get the reaction started.
 - b. A catalyst helps to properly orient the colliding particles of matter so that a reaction can occur.
 - c. The catalyst itself is unchanged at the end of the reaction.

D. Types of Chemical Reactions

1. *Synthesis* reactions occur when two or more atoms, ions, or molecules combine to form new and larger molecules. These are *anabolic* reactions, meaning that bonds are formed.
2. In a *decomposition* reaction, a molecule is broken down into smaller parts. These are *catabolic* reactions, meaning that chemical bonds are broken in the process.
3. *Exchange* reactions involve the replacement of one atom or atoms by another atom or atoms.
4. In *reversible* reactions, end products can revert to the original combining molecules.

5. Oxidation-reduction reactions: These reactions are concerned with the transfer of electrons between atoms and molecules.
 - a. Oxidation refers to the loss of electrons
 - b. Reduction refers to the gain of electrons

V. INORGANIC COMPOUNDS AND SOLUTIONS

A. Inorganic compounds usually lack carbon and are simple molecules; whereas organic compounds always contain carbon and hydrogen, usually contain oxygen, and always have covalent bonds.

B. Water

1. *Water* is the most important and abundant inorganic compound in all living systems.
 - a. The most important property of water is its polarity, the uneven sharing of valence electrons that confers a partial negative charge near the one oxygen atom and two partial positive charges near the two hydrogen atoms in the water molecule.(Figure 2.5e)
 - b. Water enables reactants to collide to form products.
2. Water as a solvent
 - a. In a solution the solvent dissolves the solute.
 - b. The polarity of water allows it to interact with several neighboring ions or molecules.(Figure 2.10)
 - c. Substances which contain polar covalent bonds and dissolve in water are *hydrophilic*, while substances which contain non polar covalent bonds are *hydrophobic*.
 - d. Water's role as a solvent makes it essential for health and survival.
3. Water in Chemical Reactions
 - a. Water is the ideal medium for most chemical reactions in the body and participates as a reactant or product in certain reactions.
 - b. *Hydrolysis* breaks large molecules down into simpler ones by adding a molecule of water.
 - c. *Dehydration synthesis* occurs when two simple molecules join together, eliminating a molecule of water in the process.
4. Thermal properties of Water
 - a. Water has a high heat capacity.

- 1) It can absorb or release a relatively large amount of heat with only a modest change in its own temperature.
- 2) This property is due to the large number of hydrogen ions in water.

b. Water has a high heat of vaporization. It requires a large amount of heat to change from a liquid to a gas.

5. Water as a Lubricant

- a. Water is a major part of mucus and other lubricating fluids.
- b. It is found wherever friction needs to be reduced or eliminated

C. Solutions, Colloids, and Suspensions

1. A *mixture* is a combination of elements or compounds that are physically blended together but are not bound by chemical bonds. Three common liquid mixtures are solutions, colloids, and suspensions.
 - a. In a *solution*, a substance called the solvent dissolves another substance called the solute. Usually there is more solvent than solute in a solution.
 - b. A colloid differs from a solution mainly on the basis of the size of its particles with the particles in the colloid being large enough to scatter light.
 - c. In a suspension, the suspended material may mix with the liquid or suspending medium for some time, but it will eventually settle out.
2. Percentage and molarity are ways of describing the concentration of a molecule or the amount of that molecule dissolved in solution (Table 2.3).
 - a. Percent gives the relative mass of a solute found in a given volume of solution.
 - b. A mole is the name for the number of atoms in an atomic weight of that element, or the number of molecules in a molecular weight of that type of molecule, with the molecular weight being the sum of all the atomic weights of the atoms that make up the molecule.

D. Inorganic Acids, Bases, and Salts

1. When molecules of inorganic acids, bases, or salts dissolve in water, they undergo *ionization* or dissociation; that is, they separate into ions.
2. *Acids* ionize into one or more hydrogen ions (H^+) and one or more *anions* (negative ions) (Figure 2.11a).

3. *Bases* dissociate into one or more hydroxide ions (OH^-) and one or more *cations* (positive ions) and are proton acceptors (Figure 2.11b).
 4. A *salt*, when dissolved in water, dissociates into cations and anions, neither of which is H^+ or OH^- (Figure 2.11c). Many salts are present in the body and are formed when acids and bases react with each other.
- E. Acid-Base Balance: The Concept of pH
1. Body fluids must constantly contain balanced quantities of acids and bases.
 2. Biochemical reactions are very sensitive to even small changes in acidity or alkalinity.
 3. A solution's acidity or alkalinity is based on the pH scale, which runs from 0 ($=10^0 = 1.0$ moles H^+/L) to 14 ($=10^{-14} = 0.00000000000001$ moles H^+/L) (Figure 2.12)
 - a. $\text{pH } 7.0 = 10^{-7} = 0.0000001$ moles H^+/L = neutrality or equal numbers of $[\text{H}^+]$ and $[\text{OH}^-]$.
 - b. Values below 7 indicate acid solutions ($[\text{H}^+] > [\text{OH}^-]$).
 - c. Values above 7 indicate alkaline solutions ($[\text{H}^+] < [\text{OH}^-]$).
- F. Maintaining pH: Buffer Systems
1. The pH values of different parts of the body are maintained fairly constant by buffer systems, which usually consist of a weak acid and a weak base.
 2. The function of a buffer system is to convert strong acids or bases into weak acids or bases.
 3. One important buffer system in the body is the carbonic acid-bicarbonate buffer system.
 - a. Bicarbonate ions (HCO_3^-) act as weak bases and carbonic acid (H_2CO_3) acts as a weak acid.
 - b. $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$
 4. Table 2.4 shows pH values for certain body fluids compared to common substances.

VI. ORGANIC COMPOUNDS

A. Carbon and Its Functional Groups

1. The carbon that organic compounds always contain has several properties that make it particularly useful to living organisms.

- a. It can react with one to several hundred other carbon atoms to form large molecules of many different shapes.
 - b. Many carbon compounds do not dissolve easily in water, making them useful materials for building body structures.
 - c. Carbon compounds are mostly or entirely held together by covalent bonds and tend to decompose easily; this means that organic compounds are a good source of energy.
 - d. The chain of carbon atoms in an organic molecule is the carbon skeleton. Attached to the carbon skeleton are distinctive functional groups, in which other elements form bonds with carbon and hydrogen atoms.
 - 1) Each types of functional group has a specific arrangement of atoms that confers characteristic chemical properties upon organic molecules.
 - 2) Table 2.5 lists the most common functional groups.
 - 3) Fig 2.13 shows two ways to indicate the structure of the sugar glucose.
2. Small organic molecules can combine to form very large molecules (macromolecules, or polymers, when composed of repeating units called monomers).
 - a. When two monomers joint together, the reaction is usually dehydration synthesis.
 - b. Macromolecules break down into monomers usually by hydrolysis.
 3. Molecules that have the same molecular formula but different structures are called *isomers*.

B. Carbohydrates

1. *Carbohydrates* provide most of the energy needed for life and include sugars, starches, glycogen, and cellulose.
 - a. Some carbohydrates are converted to other substances which are used to build structures and to generate ATP.
 - b. Other carbohydrates function as food reserves.
 - c. The general structural rule for carbohydrates is one carbon atom for each water molecule (CH₂O).

- d. Carbohydrates are divided into three major groups based on their size: monosaccharides, disaccharides, and polysaccharides (Table 2.6).
 2. Monosaccharides and Disaccharides: The Simple Sugars
 - a. Monosaccharides contain from three to seven carbon atoms and include glucose, a hexose that is the main energy-supplying compound of the body (Figure 2.14)
 - b. Disaccharides are formed from two monosaccharides by dehydration synthesis; they can be split back into simple sugars by hydrolysis (Figure 2.15). Glucose and fructose combine, for example, to produce sucrose.
 3. Polysaccharides
 - a. Polysaccharides are the largest carbohydrates and may contain hundreds of monosaccharides.
 - b. The principal polysaccharide in the human body is *glycogen*, which is stored in the liver or skeletal muscles. *Starches* are polysaccharides formed from glucose in plants. Cellulose is a polysaccharide formed from glucose but cannot be digested in humans (Figure 2.16)
 4. Artificial Sweeteners (Clinical connection)
- C. Lipids
 1. *Lipids*, like carbohydrates, contain carbon, hydrogen, and oxygen; but unlike carbohydrates, they do not have a 2:1 ratio of hydrogen to oxygen.
 - a. They have fewer polar covalent bonds and thus are mostly insoluble in polar solvents such as water (they are hydrophobic). To become soluble they join with proteins to become lipoproteins.
 - b. Table 2.7 summarizes the various types of lipids and highlights their roles in the human body.
 2. Fatty acids
 - a. Fatty acids are used to form triglycerides and provide cellular energy.
 - b. Fatty acids can be saturated, with only single covalent bonds, and unsaturated, with one or more double covalent bonds.
 3. Triglycerides

- a. Triglycerides are the most plentiful lipids in the body and provide protection, insulation, and energy (both immediate and stored).
 - 1) At room temperature, triglycerides may be either solid (fats) or liquid (oils).
 - 2) Triglycerides provide more than twice as much energy per gram as either carbohydrates or proteins.
 - 3) Triglyceride storage is virtually unlimited.
 - 4) Excess dietary carbohydrates, proteins, fats, and oils will be deposited in adipose tissue as triglycerides.
 - b. Triglycerides are composed of glycerol and fatty acids ([Figure 2.17](#)).
 - c. The type of covalent bonds (and by inference, number of hydrogen atoms) found in the fatty acids determines whether a triglyceride is saturated, monounsaturated, or polyunsaturated.
 - d. Clinical connection (Fatty acids in Health and Disease)
4. Phospholipids
- a. *Phospholipids* are important membrane components.
 - b. They are amphipathic, with both polar and nonpolar regions ([Figure 2.18](#)).
5. Steroids
- a. *Steroids* have four rings of carbon atoms ([Figure 2.19](#)).
 - b. Steroids include sex hormones and cholesterol, with cholesterol serving as an important component of cell membranes and as starting material for synthesizing other steroids.
6. Other Lipids
- a. Eicosanoids include prostaglandins and leukotrienes.
 - 1) Prostaglandins modify responses to hormones, contribute to inflammatory responses, prevent stomach ulcers, dilate airways to the lungs, regulate body temperature, and influence blood clots, among other things.
 - 2) Leukotrienes participate in allergic and inflammatory responses.
 - b. Body lipids also include fatty acids; fat-soluble vitamins such as beta-carotenes, vitamins D, E, and K; and lipoproteins.

D. Proteins

1. *Proteins* give structure to the body, regulate processes, provide protection, help muscles to contract, transport substances, and serve as enzymes (Table 2.8).
2. Amino Acids and Polypeptides
 - a. Proteins are constructed from combinations of amino acids.
 - b. Amino acids contain carbon, hydrogen, oxygen and nitrogen in amine and carboxyl (acid) groups (Figure 2.20).
 - c. Amino acids are joined together in a stepwise fashion with each covalent bond joining one amino acid to the next forming a bond called a *peptide bond* (Figure 2.21).
 - d. Resulting polypeptide chains may contain 10 to more than 2,000 amino acids.
3. Levels of Structural Organization
 - a. Levels of structural organization include primary, secondary, tertiary, and quaternary structures (Figure 2.22).
 - b. The resulting shape of the protein greatly influences its ability to recognize and bind to other molecules.
 - c. *Denaturation* of a protein by a hostile environment causes loss of its characteristic shape and function.
4. Enzymes
 - a. Catalysts in living cells are called *enzymes*.
 - b. The names of enzymes usually end in the suffix *-ase*; oxidase, kinase, and lipase, are examples.
 - c. Although enzymes catalyze select reactions, they do so with great efficiency and with many built-in controls.
 - 1) Enzymes are highly *specific* in terms of the substrate with which they react.
 - 2) Enzymes are extremely *efficient* in terms of the number of substrate molecules with which they react.
 - 3) Enzymes are subject to a great deal of cellular *controls*.
 - d. Enzymes speed up chemical reactions by increasing frequency of collisions, lowering the activation energy and properly orienting the colliding molecules (Figure 2.23a).

E. Nucleic Acids: Deoxyribonucleic Acid (DNA) and Ribonucleic Acid (RNA)

1. *Nucleic acids* are huge organic molecules that contain carbon, hydrogen, oxygen, nitrogen, and phosphorus.
 - a. *Deoxyribonucleic acid* (DNA) forms the genetic code inside each cell and thereby regulates most of the activities that take place in our cells throughout a lifetime.
 - b. *Ribonucleic acid* (RNA) relays instructions from the genes in the cell's nucleus to guide each cell's assembly of amino acids into proteins by the ribosomes.
2. The basic units of nucleic acids are nucleotides, composed of a nitrogenous base, a pentose, sugar, and a phosphate group ([Figure 2.24a](#)).
3. DNA fingerprinting is used in research and in legal situations to determine the genetic identify of an individual. This technique is discussed in a Clinical Connections box.

F. Adenosine Triphosphate

1. Adenosine triphosphate (ATP) is the principal energy-storing molecule in the body.
2. Among the cellular activities for which ATP provides energy are muscular contractions, chromosome movement during cell division, cytoplasmic movement within cells, membrane transport processes, and synthesis reactions.
3. ATP consists of three phosphate groups attached to an adenosine unit composed of adenine and the five-carbon sugar ribose ([Figure 2.25](#)).
 - a. When energy is liberated from ATP, it is decomposed to adenosine diphosphate (ADP) and phosphorus (P).
 - b. ATP is manufactured from ADP and P using the energy supplied by various decomposition reactions, particularly that of glucose.