ATOMS AND MOLECULES

ABSTRACT: This unit is an introduction to the structure of atoms and molecules. The formation of ionic and covalent bonds is described and the composition and importance of the 4 major types of organic molecules are introduced.

REQUIRED READINGS: Martini & Nath (8th ed) pp. 29-34, 40, 61
Tortora & Derrickson (12th ed) pp. 29-36, 39, 43-44

OBJECTIVES: To be able to:

1. Define the term “chemical element”, specify the name and symbol for the four most common chemical elements in the human body, and describe the importance of each.

2. Define the term “atom” and describe the structure of an atom.

3. Define the terms “molecule” and “compound.”

4. Describe the formation of ions and of an ionic bond.

5. Describe the formation of a covalent bond.

6. Distinguish between organic and inorganic molecules, name the four major classes of organic molecules and specify their composition & main functions.

7. Describe how the bonding properties of carbon allow for a large amount of variation in the shape and size of organic molecules, explain the significance of this variation to living organisms, and specify two additional characteristics of organic molecules that make them useful to living organisms.

Table 1: The Four Most Common Chemical Elements in the Human Body

1. Name of Element	Oxygen			
2. Chemical Symbol		C		
3. % of Total Body Weight	65	18.6	9.7	3.2
4. Atomic Number				7
5. Electron Shell Model				
6. Number of Covalent Bonds Atom Forms *[1]			1	
7. Importance	Part of water and all organic molecules (though little in lipids)	Major structural part of all organic molecules.	Component of all organic molecules and water.	Component of proteins and nucleic acids.

*[1]Page 34 of Martini and Nath (8th ed.) has a mnemonic for remembering how many covalent bonds are made by atoms of these four elements. The mnemonic is: **HONC 1234** ⇒ H makes 1, O makes 2, and so on…..

ATOMS AND MOLECULES

1. ***Define the term "chemical element" and specify the name and symbol of the four most common chemical elements in the human body*, and describe the importance of each.**

   Read the section on chemical elements on p. 30 of Martini & Nath (8th ed) OR on p. 29 of Tortora & Derickson (12th ed).

   A **chemical element** is a pure substance that cannot be broken down any further by chemical means. The chemical elements that make up the human body, listed from most to least percentage of total body weight, are shown in Table 2-1 of Martini & Nath (8th ed) OR Table 2.1 of Tortora & Derickson (12th ed). The first four elements make up approximately 96% total human body weight. The next 9 elements together only make up about 4% of human body weight. Finally, the 14 elements listed at the bottom of each table, together make up less than 0.1% of the body weight. Since they are required in such small amounts, these 14 elements are referred to as **trace elements**.

   Chemical elements are usually found joined together to form molecules that are essential components of the body. The last row of Table 1 briefly lists the primary importance of each of the four most common elements. We will be covering these in more detail over the next few weeks.

   After completing this objective, you should be able to answer questions such as:
   a) Define the terms "chemical element" and "trace element".
   b) Name, in order, the four elements that contribute the most to body weight? Enter the names and chemical symbols of these elements into the first two rows of Table 1.

2. **Define the term "atom" and describe the structure of an atom.**

   Read pages 29-32 in Martini & Nath (8th ed) OR pages 30-31 of Tortora & Derickson (12th ed)

   The smallest particle of an element, that still retains all the physical and chemical properties of that element, is called an **atom**. To understand the composition of an atom we will consider the electrical charge and the location of three types of structures called subatomic particles. At the centre of each atom is a dense region called a **nucleus.** The nucleus contains **protons**, which each have an electrical charge of +1, and **neutrons**, which are neutral (have no charge). The third type of subatomic particle is called an **electron**, and each has an electrical charge of –1. Electrons travel around the nucleus in complex patterns and at high speed. However, since groups of electrons occupy a series of distinct energy levels, it is convenient to think of the electrons as being in circular electron shells [see Figures 2-1 and 2-2 in Martini & Nath (8th ed p. 29 and p. 32) OR Figure 2.2 in Tortora & Derickson (12th ed p. 31)].

Each electron shell can hold up to a certain number of electrons: the shell nearest the nucleus holds a maximum of **2 electrons**, the next shell holds up to **8 electrons,** and the third shell holds up to **18 electrons.**

Atoms of different elements have different numbers of protons in their nucleus. For example, as shown in Figure 2-2 of Martini and Nath (8^{th} ed p. 32), each Hydrogen atom has one proton, while each Helium atom has 2, and each Lithium atom has 3. The number of neutrons in atoms of the same element can vary slightly, but is usually about equal to the number of protons. Finally, by definition, atoms are electrically neutral, therefore the number of electrons in an atom must the same as the number of protons.

***After completing this objective, you should be able to answer questions such as**:*

a) Explain what is meant by the term "electron shell".
b) Distinguish between an atom and an element.
c) What is the maximum number of electrons that can occupy the electron shell closest to the nucleus? The second and third shells?
d) Explain what is meant by "atomic number" and specify the atomic numbers for oxygen, carbon, hydrogen and nitrogen. (Complete row 4 of Table 1.)
e) Complete row 5 of Table 1 by drawing the electron shell models for atoms of oxygen, carbon and hydrogen.

3. Define the terms "molecule" and "compound".

Read p. 32 of Martini & Nath (8^{th} ed) OR p. 33 of Tortora & Derickson (12^{th} ed)

When **two or more atoms** form chemical bonds between them, they form a **molecule**. The atoms combining to form a molecule may be of the same element such as in oxygen gas, which consists of two oxygen atoms (O_2). However, a molecule may also consist of atoms of two or more different elements. For example, a water molecule consists of two hydrogen atoms and one oxygen atom (H_2O). Such a molecule, consisting of more than one element, is also called a **compound**.

After completing this objective, you should be able to answer questions such as:

a) Distinguish between a molecule and a compound.
b) Which of the chemicals listed below are compounds? Which are molecules?

CH_4 O_2 H_2O H_2 N

4. Describe the structure of ions and the formation of an ionic bond.

Atoms are generally stable (i.e chemically inactive) when their outmost shell (called the valence shell) is either full or has 8 electrons in it. If their valence shell is not full, atoms will tend to interact with other atoms to fill their shell. One way that atoms can interact is to transfer electrons. Generally, one atom gains 1 or a few electrons to fill its valance shell, while another atom loses those electrons to empty its outer shell. Since the number of protons in each atom does not change, atoms that have lost or gained electrons will become positively or negatively charged respectively. Such charged atoms are called **ions**.

When ions of opposite charges are in close proximity, they can form an electrostatic attraction between them. Such an attraction between ions is called an **ionic bond**. Ionic bonds are common in inorganic compounds and are the bonds found in most inorganic acids, bases and salts.

Read pp 32-33 and look at Figure 2-3 of Martini & Nath (8th ed) OR read p 32 and look at Figure 2.4 of Tortora & Derickson (12th ed)

After completing this reading, you should be able to answer questions such as:

a) Distinguish between an atom and an ion.
b) Distinguish between a cation and an anion.
c) What is the valence shell of an atom and why is it important?
d) Describe how an ionic bond is formed, using the formation of NaCl as an example.
e) If an atom has 7 electrons in it's valence shell, do you think it is more likely to become a cation or an anion? Justify your answer.

. Describe the formation of a covalent bond.

The type of bond holding elements together in most organic molecules and some inorganic molecules, like water, is called a **covalent** bond. Unlike an ionic bond, when a covalent bond forms between two atoms, neither atom gains or loses electrons. Rather, the two atoms obtain the stable number of electrons in their valence shells by **sharing electrons**. The shared electrons form part of the outer shells of both atoms. For example, a hydrogen atom has only one electron and thus needs one more to fill its outer (first) electron shell. However, as illustrated in Figure 2-4a on p. 34 of Martini & Nath (8th ed) OR Figure 2.5a on p. 34 of Tortora & Derrickson (12th ed), if two hydrogen atoms each share their electron with each other, then both atoms can attain a full shell of 2 electrons. The shared electrons remain as part of the electron shell of both atoms, forming a **covalent bond** that links the two H atoms together to become a molecule of hydrogen gas (H_2).

Some atoms, such as carbon atoms, can share more than two electrons. The sharing of 4 electrons (2 pairs) is called a double covalent bond and the sharing of 6 electrons (3 pairs) is called a triple covalent bond.

Read page 34 and look at Figure 2-5 of Martini & Nath (8th ed) OR read pages 34-35 and look at Figure 2.5e of Tortora & Derickson (12th ed).

After completing this reading, you should be able to answer questions such *as:*

a) Describe the differences and similarities between covalent bonds and ionic bonds.

b) Draw the electron shell model for an atom of neon, which has the atomic number 10. If you have the Martini text you can check your answer on page 32.) Would you expect neon to be very chemically reactive? Why or why not? (hint: how many bonds does a Neon atom need to make to fill its valence shell?)

c) How many covalent bonds would you expect to be made by atoms of oxygen, carbon, hydrogen and nitrogen? Explain your answer based on the valence shells of the four elements. (Complete row 6 of Table 1.)

d) Describe the formation of a covalent bond, using the formation of a water molecule as an example. Draw an electron shell model of a water molecule and provide a complete explanation of how the formation of the two covalent bonds results in filling the valence shells of all three atoms.

e) Draw an electron shell model of the covalent bonding in CH_4 (i.e. one carbon atom covalently bonded to 4 hydrogen atoms). In the Tortora text you can check your answer on p. 34.

6. Distinguish between organic and inorganic molecules, name the four major types of organic molecules and specify their composition and main functions.

In Martini and Nath (8th ed): Read the section comparing organic and inorganic compounds on p. 40 and also look at Table 2-8 (p. 61)

OR

In Tortora & Derickson (12th ed): Read the introductory paragraphs about inorganic compounds (p. 39) and organic compounds (p. 34-35)

After completing this reading you should be able to answer questions such as:

a) What are the main differences between inorganic and organic compounds?

b) Name the four major classes of organic molecules and specify major function(s) for each. (We will study these further during the next few weeks.)

c) Do you agree or disagree with the statement "organic compounds must contain carbon but all carbon containing compounds are not organic"? Justify your answer, giving examples.

Table 2 : The Four Major Classes of Organic Molecules

Class	Groups	Composition	Functions
Carbohydrates	sugars, glycogen, starch	$(CH_2O)_n$	energy, cell recognition
Lipids	fats, steroids	$(CH_2)_n$, little O	membranes, hormones
Proteins		C, H, O, N, S	MANY! transport, enzymes
Nucleic acid	DNA, RNA	C, H, O, N, P	heredity, protein blueprints

7. **Describe how the bonding properties of carbon allow for a large amount of variation in the shape and size of organic molecules, explain the significance of this variation, and specify two additional characteristics of organic molecules that make them useful to living organisms.**

Each C atom can form four covalent bonds with other C atoms and/or with atoms of other elements such as H, O, and N. Hundreds of atoms of C and other elements can therefore be linked together to **form large, diverse and complex molecules**. One important biological concept is that structure and function are highly correlated. The variable and complex structures of organic molecules **allow for similarly varied and complex functions**. For example, the function of proteins like membrane proteins involved in transport and antibodies that protect our bodies from foreign substances, is directly dependent on the ability of the proteins to bind very specifically to one substance while excluding other very similar substances.

Another biologically useful characteristic of organic molecules is that they are generally **not soluble in water**. Coupled with the large size and complexity of the molecules, this makes them **useful as building materials and as boundaries** (membranes) between different fluid compartments. For example, membranes of the nucleus and other cellular structures are comprised mainly of lipids and proteins.

A third useful characteristic of organic compounds is that the covalent bonds that hold them together usually **give off energy** when they are broken. Organic molecules in the foods we eat are therefore good sources of stored energy.