3.1 Composition of Matter

Everything in the universe is made up of matter. This includes all living things, from amebas to whales, from bacteria to giant sequoias. Matter is anything that occupies space and has mass. Mass is the quantity of matter an object has. The pull of gravity on the mass of an object gives the object the property of weight.

Changes in matter are essential to all life processes. For example, when an organism takes in food, it alters the physical and chemical properties of the food. Such changes allow the organism to make use of the nutrients in the food. By learning how changes in matter occur you will gain an understanding of organisms and how they adapt to the environment.

Section Objectives

- *Draw a model of the structure of the atom.*
- *Define* element, isotope, *and* radioisotope.
- *Define* compound, *and list two properties of compounds.*
- *Contrast two types of chemical bonds.*
- *Describe the experimental data on which Rutherford formulated his model of the atom.*

Atoms

The atom is the fundamental unit of matter. The nature and properties of atoms determine the structure and behavior of matter. Atoms are about 10 nm in diameter. Thus they can be observed only with a very powerful electron microscope, and even then the internal structure cannot be observed. However, through experimentation, scientists have developed models that describe the structure and behavior of the atom.

Figure 3-1 shows a simplified model of the atom. The various components that make up an atom are called subatomic particles. The central core, or nucleus, consists of two kinds of subatomic particles. One, the proton, has a positive electrical charge. The other, the neutron, has no electrical charge. Most of the mass of the atom is concentrated in the nucleus. Electrons are particles with a negative electrical charge that move about the nucleus at tremendous speeds. An atom has an equal number of protons and electrons. The electrical charges of these particles offset one another, so that the net electrical charge of the atom is zero.

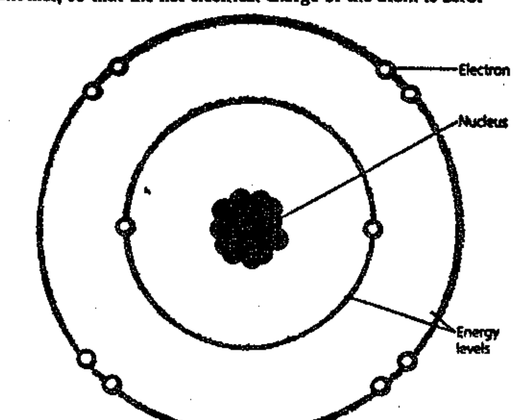


Figure 3-1 The electrons in this model of a neon atom are distributed into two energy levels. The innermost level holds a maximum of two electrons. The second level has a maximum of eight electrons.

Elements

Elements are substances that cannot be broken down chemically into simpler kinds of matter. Each element has a unique chemical symbol. More than 100 elements have been identified. Ninety-two elements occur in nature. The rest have been synthesized in physics laboratories.

Each atom of any element has the same number of protons. The number of protons in an atom is called the atomic number of the element. For example, since each atom of the element carbon has six protons, the atomic number of carbon is 6.

Isotopes

Although in any given element the number of protons in each atom is the same, the number of neutrons can vary. Atoms of the same element that differ in the number of neutrons they contain are called isotopes. Most elements have two or more isotopes. The mass number is the sum of the protons and neutrons in an atom. For each element shown in Figure 3-2 the mass number for the most common isotope is given just below the chemical symbol.

Radioisotopes

Some isotopes have unstable nuclei—that is, their nuclei tend to release particles or radiant energy or both. Such isotopes are called radioactive isotopes or radioisotopes. When the nucleus of a radioisotope emits radiation, the number of protons or neutrons in the nucleus is reduced.

Radioisotopes are useful in certain types of biological experiments because the radiation can be detected. A botanist, for example, can add a radioisotope of phosphorus to the soil. The botanist can trace the movement of phosphorus through the plant by measuring the radiation present in various parts of the plant at various times.

Compounds

Compounds consist of atoms of two or more elements that are joined by chemical bonds. In a compound the proportions of individual atoms are fixed. For example, in the compound water the atoms of hydrogen (H) and oxygen (O) are always in a proportion of 2 to 1. A chemical formula shows the kind and proportion of atoms that form a particular compound. The chemical formula for water is H_2O. A compound differs in physical and chemical properties from the elements that compose it. For example, in nature the element oxygen is usually found as a gas (O_2) and the element hydrogen is usually found as a gas (H_2). However, when oxygen gas and hydrogen gas combine, they form the compound water (H_2O), a liquid.

How elements combine to form compounds depends on the number and arrangement of the electrons in the atoms. Experiments show that higher-energy electrons are located at a greater distance from the nucleus than lower-energy electrons are. Thus scientists have developed a model of the atom in which electrons occupy discrete energy levels at varying distances from the nucleus. Figure 3-1 illustrates this model.

According to the model each energy level can hold only a certain number of electrons. For example, the level nearest the nucleus can hold only two electrons. The next level can hold up to eight electrons. Most elements are most stable when the outermost energy level contains eight electrons. An important exception relevant to biology is hydrogen, which is most stable when its outer energy level contains two electrons. Aside from helium, neon, and a few other elements, most elements do not have such a stable configuration of electrons in their atoms. Hence most elements undergo reactions that cause their atoms to become stable. These reactions involve forming bonds with other atoms.

Ionic Bonds

Figure 3-4 shows how sodium and chlorine bond to form table salt. Note that the sodium atom has one electron in its outer energy level and that the chlorine atom has seven electrons in its outer energy level. Remember that most atoms are stable when their outer energy level contains eight electrons.

The diagram shows that when sodium and chlorine interact, the outer electron of the sodium atom moves to the chlorine atom. Afterward sodium and chlorine each have eight electrons in their outer energy level. In this process each atom becomes an ion—an atom or a polyatomic particle with an electrical charge. Sodium has lost an electron, and thus it becomes a positively charged ion, abbreviated as Na^+. Chlorine has gained an electron. Thus it becomes a negatively charged ion, chloride, abbreviated as Cl^-.

Because positive and negative charges attract each other, the sodium ion and the chloride ion attract each other and form a bond based on this attraction. Such a bond is an ionic bond. The resultant compound, in this case NaCl, is an ionic compound.

Ions are important in a number of biological processes. The elements that plants absorb from the soil—such as magnesium, nitrogen, iron, phosphorus, potassium, and calcium—are all in ionic form. Sodium and potassium ions play a major role in the transmission of nerve impulses in the human body.

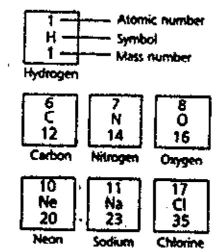
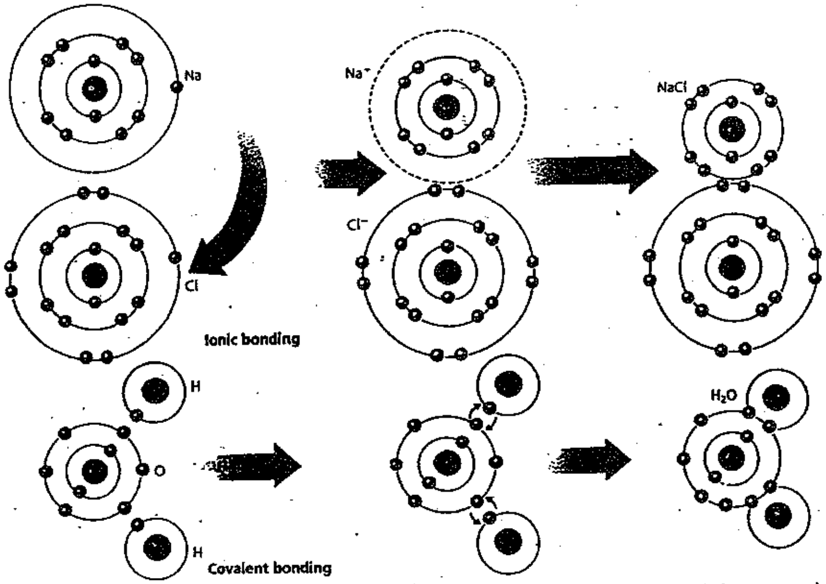


Figure 3-2 The chemical symbol, atomic number, and mass number of six common elements are shown here. What is the mass number of sodium? How many neutrons does sodium have?



Covalent Bonds

A covalent bond forms when two atoms share one or more pairs of electrons. Water is made up of one oxygen atom and two hydrogen atoms held together by covalent bonds. Since hydrogen has one electron, it needs another to give it the stable arrangement of two electrons in its outer energy level. Since oxygen has six electrons in its outer energy level, it needs two more electrons to give it the stable arrangement of eight electrons. The hydrogen and oxygen atoms gain stability by sharing pairs of electrons.

A molecule is a group of atoms held together by covalent bonds. Many substances important in biology are molecules, including carbon dioxide (CO_2) and water. A molecule can be represented either by a chemical formula, such as H_2O, or by a structural formula, such as H—O—H. The structural formula shows the arrangement of atoms in the molecule.

Figure 3-4 Table salt forms through the ionic bonding of sodium ions and chlorine ions (top). Water forms through the covalent bonding of hydrogen atoms and oxygen atoms (bottom).

3.1 Composition of Matter
Section Review

Name: ____________ **Date:** ________ **Hour:** ________

1. Define element, isotope, and radioisotope. ____________

2. How are subatomic particles (electrons, neutrons, protons) arranged in the atom?

3. What are two characteristics of all compounds? ____________

4. How does an ionic bond differ from a covalent bond? ____________

5. How would medical researchers use radioactive substances to trace the movement of substances in the body? ____________