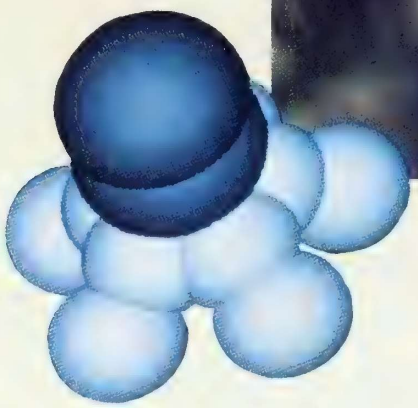
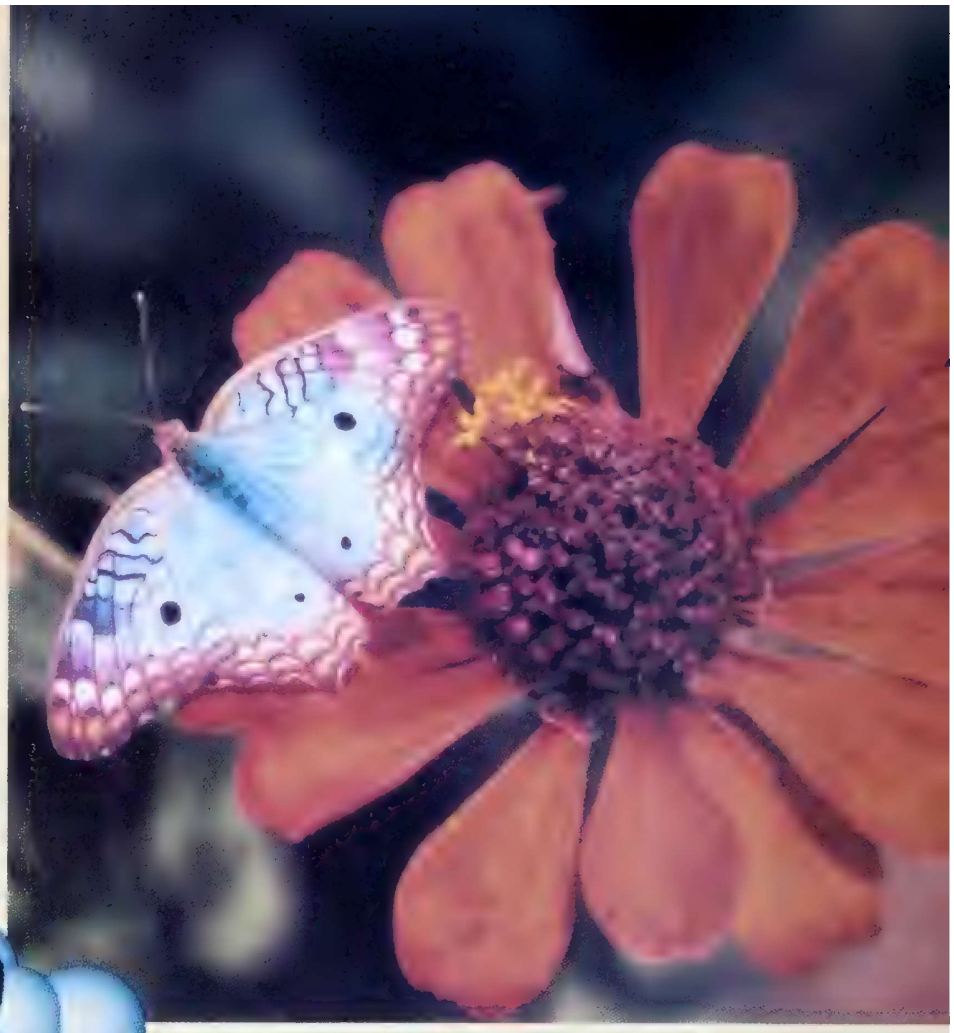
CHAPTER 3

Introduction to Chemistry





An understanding of life—in all its glorious forms—depends upon an understanding of the atomic nature of matter.

For many years, biology was a science that respected a fundamental distinction between the living and the nonliving worlds. Biologists studied organisms; physicists and chemists studied materials. In the twentieth century, however, this distinction has begun to fade. Biologists have gradually realized that a complete description of life must begin at the atomic level and then work up through the complex chemistry of the living cell. Indeed, one of the great scientific stories of this century is the manner in which the boundaries between biology and the physical sciences have become blurred. Biologists now appreciate that the starting point for an understanding of the nature of life is an understanding of the atom. In this chapter, you will do exactly as biologists have done—you will learn about the atomic structure of living and nonliving matter.

CHAPTER OUTLINE

3-1 Nature of Matter
- Properties of Matter
- Phases of Matter

3-2 Composition of Matter
- The Atom
- Chemical Elements
- Chemical Compounds

3-3 Interactions of Matter
- Ionic Bonds
- Covalent Bonds

3-4 Chemical Reactions

3-1 Nature of Matter

Section Objectives

- Identify several important properties of matter.
- Compare physical and chemical properties.

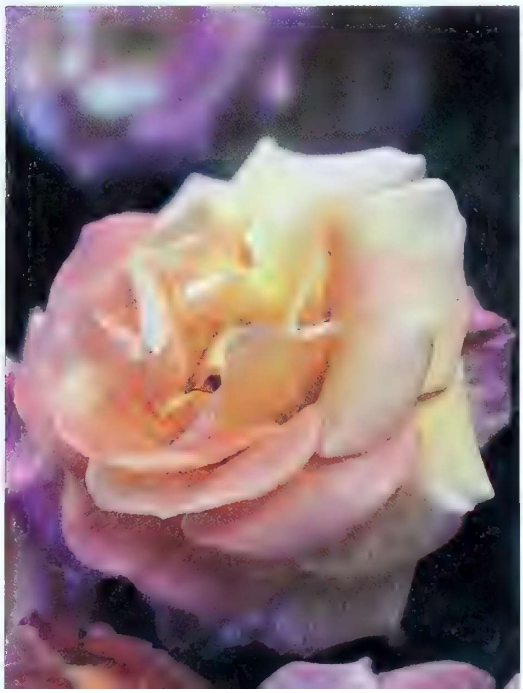
What are living things made of? Are there special substances that are found in living things but not in nonliving material? Is there a special "spirit" or "essence" that living things possess? Does life have a physical and chemical basis that we can hope to understand and describe in the same way we do something that is not alive, like an automobile engine or a calculator? To answer these questions, we must first examine the world around us . . . a world made up of matter and energy.

Properties of Matter

Matter is all around us. Almost everything we see, touch, taste, or smell is matter. And all forms of matter have properties, or characteristics, by which they are identified.

Certain properties of matter are **physical properties**. Two very important physical properties are used by scientists to define matter: Matter is anything that has mass and volume. Mass is the quantity of matter in an object. Volume is the amount of space matter takes up.

Mass is related to another important property of matter: weight. An object has weight because it has mass, but mass and weight are not the same thing. Weight is a measure of the force of gravity on an object. The greater the mass of an object, the greater the force of gravity on it, and the greater its weight. Thus we can say that the weight of an object is directly proportional to its mass.



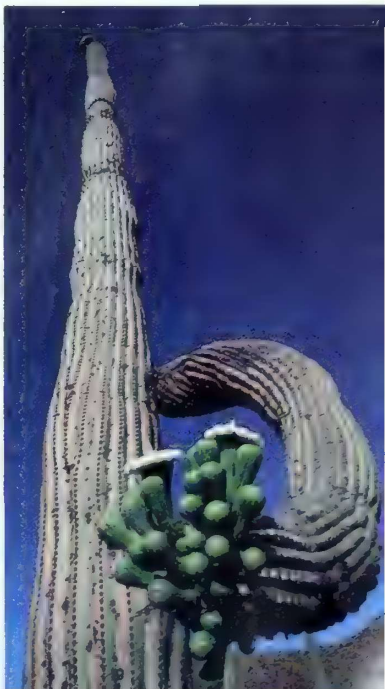


Figure 3-1 *The physical properties of matter are often all you need to observe in order to tell substances apart. Because of their physical properties, the rose and the cactus are easily distinguishable.*



Figure 3–2 *What physical properties would you use to distinguish coal from sugar? Do these two substances have any physical properties in common?*

Matter has other physical properties. These include color, odor, shape, texture, taste, and hardness. You know from experience that a lump of coal has a certain color, texture, and hardness. A lump of sugar has a different color, texture, and hardness. It even has a special taste. Two other important physical properties are melting point and boiling point. **Physical properties of matter can be observed and measured without permanently changing the identity of the matter.**

Matter has **chemical properties** also. **Chemical properties describe a substance's ability to change into another new substance as a result of a chemical change.** A chemical change is a process in which a substance is permanently altered. When a chemical change is completed, it is difficult, if not impossible, to reverse the process and get the starting material back. When coal burns, it undergoes a chemical change with oxygen to form other gases. Once a lump of coal has burned, it is no longer coal. And the gases produced cannot be converted back to coal. The chemical properties of a substance are determined by learning what sorts of chemical reactions the substance can undergo.

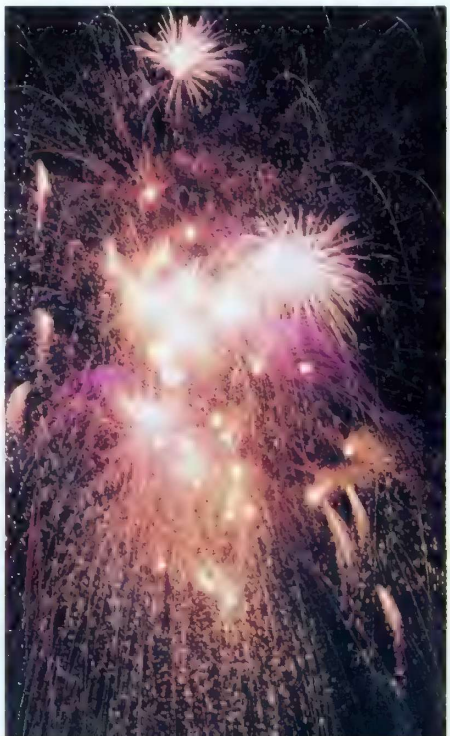
Phases of Matter

Ice, liquid water, and water vapor may seem very different to you. Certainly they have different appearances and uses. But actually they are all made of exactly the same substance in different states. These states are called **phases**. Phase is an important physical property of matter. Ice is the solid phase of water. Liquid water is the liquid phase. And water vapor is the gas phase.

The change from one phase of matter to another is a physical change because the substance is not altered. Water, regardless of its phase, is still water. Physical and chemical changes

Figure 3–3 *Chemical properties describe how a substance changes into other new substances as a result of a chemical change. What chemical changes can you identify in these photographs of a rusty nut and bolt (left), a fireworks display (center), and a delicious meal grilling on the barbecue (right)?*







are common in the world around us. And because living things, including ourselves, are made of matter, an understanding of these physical and chemical changes is important to biology.

3-1 SECTION REVIEW

1. Define the following terms: mass, weight, volume.
2. Compare a physical property and a chemical property. A physical change and a chemical change.
3. Using a piece of paper as an example, distinguish between the physical and chemical properties of matter.



Figure 3-4 *Phase is an important physical property of matter. Here you see water in its three phases: solid, liquid, and gas.*

3-2 Composition of Matter

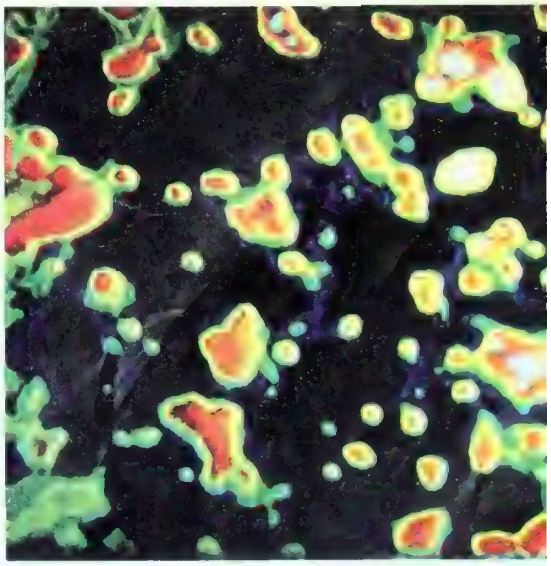
Section Objectives

- Describe the structure of an atom.
- Compare elements and compounds.
- Discuss the uses of radioactive isotopes.

Nearly 3000 years ago, the Greek philosopher Democritus challenged his students with a series of questions regarding the nature of matter. He picked up a small piece of salt, divided it into two fragments, and asked his students if each half was still salt. They said it was, and Democritus agreed. Could each half, he then asked, be divided into smaller and smaller pieces forever? Or was there a limit to the number of times a piece of matter could be divided? Democritus surprised his students with this novel idea by further arguing that there must be a tiny elementary particle that one could no longer divide and still call salt. He believed that all forms of matter were made up of basic, indivisible particles. He called these elementary particles **atoms**. The word atom comes from the Greek word *atomos*, meaning unable to be cut.

The approach of Democritus was philosophical rather than experimental. In part, this means that he was content to think about the problem but go no further. Scientists, however, must go further. They will speculate much as Democritus did, but then they will think of a way to test their ideas in an experiment. In the last 200 years, scientists have carefully studied Democritus' concept of the atomic nature of matter and have concluded that he was basically right. We now know that matter is indeed made up of small particles—not because it makes philosophical sense but because the evidence proves it. But we also now know that the atom itself is divisible and that particles smaller than the atom do exist!

Figure 3-5 *This photograph of uranium atoms was taken with a scanning transmission electron microscope (STEM). The small dots are individual atoms. The larger patches are clusters of 2 to 20 atoms.*



The Atom

The basic unit of matter is the atom. Atoms are very, very small. Indeed, 100 million atoms placed side by side would form a row only 1 centimeter long—about the width of your pinky! Despite its extremely small size, the atom contains many



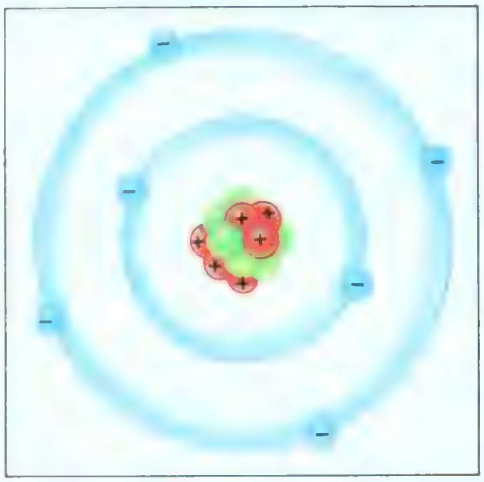


Figure 3–6 *This artist's conception of an atom shows the nucleus, with its protons and neutrons, and the series of energy levels, with their electrons, that surround it (top). The illustration shows an atom of the element carbon (bottom).*

smaller particles, known as subatomic particles. Scientists know about the existence of at least 200 different kinds of subatomic particles. The three principal subatomic particles are the proton, neutron, and electron.

ATOMIC STRUCTURE The center of the atom is called the **nucleus**. Although the nucleus is about a hundred thousand times smaller than the entire atom, it makes up 99.9 percent of the mass of the atom. The nucleus contains two different kinds of subatomic particles held together by special atomic forces. One of these particles is the **proton**. The proton is a positively charged particle. The other particle found in the nucleus is the **neutron**. The neutron is an electrically neutral particle. It has no charge at all. The proton and neutron are nearly equal in mass (1 atomic mass unit, or amu).

In addition to protons and neutrons, the atom contains another kind of subatomic particle called the **electron**. The electron is a negatively charged particle with a mass about 2000 times less than that of either the proton or neutron (1/1836 amu). Under normal circumstances, the number of negatively charged electrons in an atom is equal to the number of positively charged protons. Therefore, the atom as a whole is neutral; it is neither negatively nor positively charged.

Electrons are not found in the nucleus. They travel at high speeds throughout the atom in a series of distinct **energy levels**, or orbits, that surround the nucleus. The existence of electrons in distinct energy levels is very important in determining the chemical properties of an atom, as you will learn shortly.

ATOMIC NUMBER AND MASS NUMBER The number of protons in the nucleus of an atom is called the **atomic number**. The atomic number identifies an atom. Atoms of the same substance have the same atomic number. But atoms of different substances have different atomic numbers. Thus the atomic number of an atom of a substance is a unique quantity. An atom of hydrogen, which has only 1 proton, has an atomic number of 1. All hydrogen atoms—but only hydrogen atoms—have an atomic number of 1. Helium, with 2 protons in the nucleus of

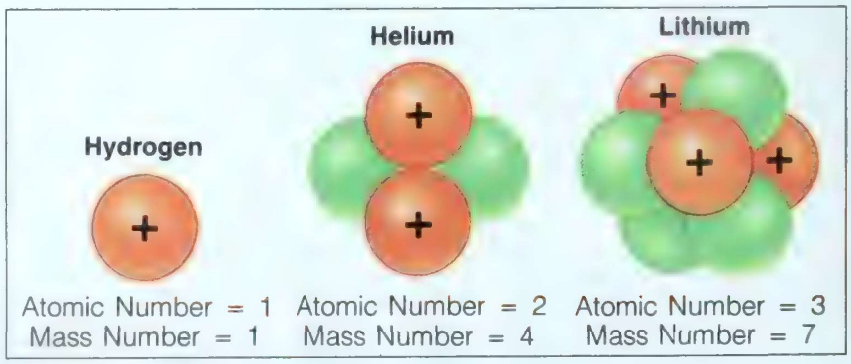


Figure 3–7 *The nuclei of hydrogen, helium, and lithium atoms all contain protons. Those of helium and lithium atoms also contain neutrons. Yet hydrogen, helium, and lithium are very different elements. Why?*

every atom, has an atomic number of 2. Uranium has an atomic number of 92. How many protons are in a uranium atom?

Although all subatomic particles contribute to the mass of an atom, protons and neutrons are much more massive than electrons. This explains why most of the mass of an atom is concentrated in the nucleus. Scientists often refer to the total number of protons and neutrons in the nucleus as the **mass number**. Hydrogen has a mass number of 1 because the only particle in the nucleus of a hydrogen atom is a proton. A helium atom has 2 protons and 2 neutrons in the nucleus. So the mass number of helium is 4.

Chemical Elements

As you read before, every substance in the world is made up of atoms. **Some substances, known as elements, consist entirely of one type of atom**. At present, scientists have identified 109 different **elements**. Of these 109 elements, 90 types are found in nature. The remaining 19 have been artificially produced by physicists using very special laboratory equipment. Each element can be represented by a chemical symbol. A chemical symbol is a shorthand way of representing an element. Each symbol consists of one or two letters, usually taken from the element's name. For example, the symbol for the element iodine is I. The symbol for hydrogen is H; for carbon, C. Scientists often use the Latin name of an element to create its symbol. For example, the symbol for lead is Pb, from the Latin word *plumbus*. You may recognize that word as the source for the English word plumbing, reflecting the fact that water pipes were once made of lead. Figure 3–8 lists some common elements and their symbols.

Most of the chemical elements are solids. Common examples include carbon, sulfur, phosphorus, sodium, calcium, and potassium. Some elements—such as oxygen, nitrogen, and chlorine—are gases. Only a few elements are liquids. Mercury and bromine are the most common examples.

ISOTOPES As you read, each element has an atomic number that is determined by the number of protons in the nucleus of its atoms. The atomic number of an element never changes. This means that the number of protons in the nucleus of every atom of the element is always the same. However, the number of neutrons can vary from one atom of the element to the next. For example, the most common form of hydrogen has 1 proton and no neutrons in its nucleus. Another form of hydrogen, sometimes known as deuterium, has 1 proton and 1 neutron in its nucleus. And a third form, tritium, has 1 proton and 2 neutrons in its nucleus. Although they have different mass numbers, each form of hydrogen has an atomic number of 1, a single proton in the nucleus, and a single electron. Each form is hydrogen. Atoms of the same element that have the

ELEMENTS IN THE HUMAN BODY

Element	Symbol	Mass (%)
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.3
Phosphorus	P	1.0
Sulfur	S	0.3
Sodium	Na	0.2
Magnesium	Mg	0.1
Silicon	Si	trace
Fluorine	F	trace

Figure 3–8 *This chart shows some of the elements in the human body, their symbol, and their percentage by mass. Which element makes up the greatest percentage? Which elements are found in only trace quantities?*

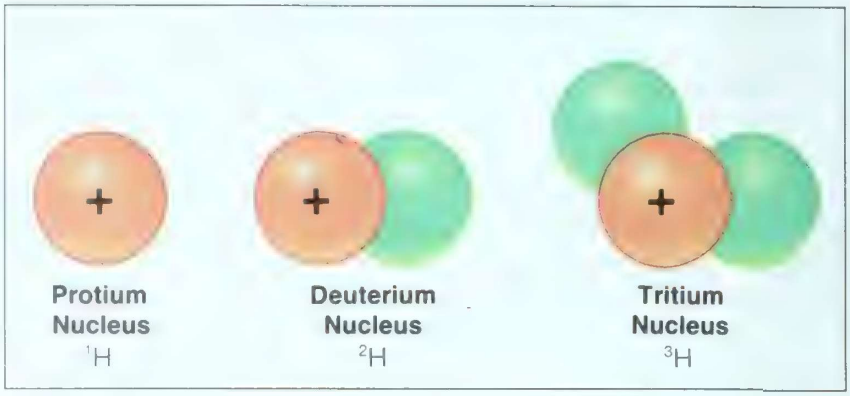


Figure 3–9 *The three isotopes of hydrogen are protium, deuterium, and tritium. Which isotope contains 2 neutrons? What is the atomic number of each isotope?*

same number of protons but different numbers of neutrons are known as **isotopes** of that element.

Isotopes of an element are represented by adding the number that indicates the mass number of that isotope to the atomic symbol. Thus, ordinary hydrogen is ^{1}H, deuterium is ^{2}H, and tritium is ^{3}H.

RADIOACTIVE ISOTOPES The nuclei of some atoms are unstable and will from time to time break down, releasing matter and/or energy that we call radiation. Atoms that emit radiation are said to be radioactive. Many elements have at least one radioactive isotope. All the isotopes of elements with atomic numbers greater than 83 are radioactive.

Radioactive isotopes have many practical uses. They are used to study living organisms, to diagnose and treat diseases, to sterilize foods, and to measure the ages of certain rocks.

Radioactive isotopes are frequently used as tracers. A tracer is a radioactive element whose pathway through the steps of a chemical reaction can be followed. An example of a tracer is phosphorus-32.

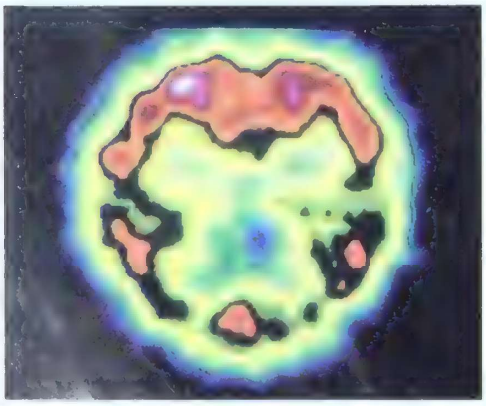
The nonradioactive element phosphorus is used in small amounts by both plants and animals. If phosphorus-32 is given to an organism, the organism will use the radioactive phosphorus just as it does the nonradioactive phosphorus. However, the path of the radioactive element can be traced, allowing scientists to learn how plants and animals use phosphorus.

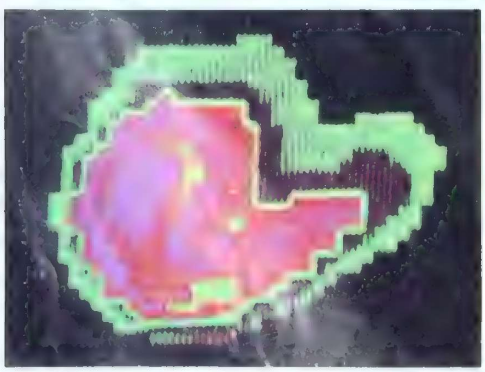
Tracers are extremely valuable in diagnosing diseases. Radioactive iodine, iodine-131, can be used to study the function of the thyroid gland, which absorbs iodine. Sodium-24 can be used to detect diseases of the circulatory system. Iron-59 can be used to study blood circulation.

Radioactive isotopes are also used to treat certain diseases. When administered carefully and in the proper amounts, radiation can kill cancer cells with minimal damage to healthy tissue. Cobalt-60 is used extensively in cancer radiation treatments. Carbon-14 has been used to treat brain tumors.

Radioactive isotopes can also be used to kill bacteria that cause food to spoil. Radiation is used to preserve the food that astronauts eat while on the moon and in orbit.

Figure 3–10 *Radioactive isotopes can be used as tracer elements to produce images such as this axial section through a normal brain (top) and this image of the heart (bottom).*





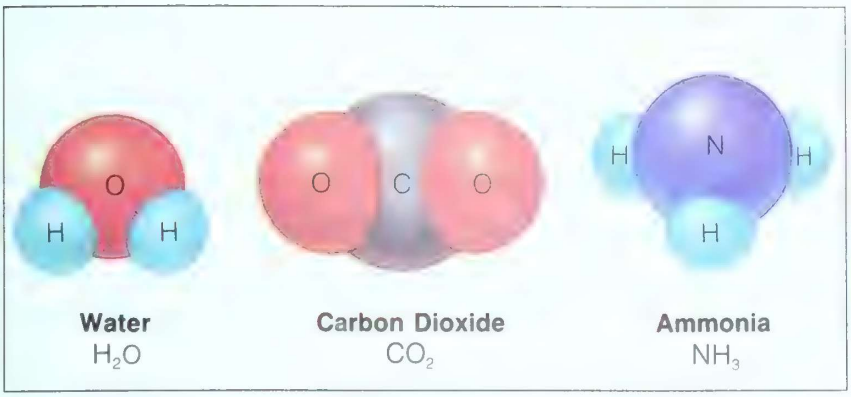


Figure 3–11 *As you can see from this diagram, compounds are made of two or more different atoms combined in definite proportions. The chemical formula for each compound indicates the elements that make up the compound and the number of atoms of each element.*

Another use of radioactive isotopes is in measuring the ages of certain rocks and the fossils they may contain. This use has increased our understanding of the evolution of life on Earth.

One of the difficulties in using radioactive materials is that these substances must be handled with great care. Radiation can damage or kill living things. So it is important that proper safety precautions be taken whenever radioactive isotopes are used. And it is also important that you be aware of and concerned about radioactive materials in the environment.

Chemical Compounds

When elements combine to form substances consisting of two or more different atoms, chemical compounds are produced. A chemical **compound** involves the combination of two or more different atoms in definite proportions. Most materials in the living world are compounds.

Just as elements are represented by chemical symbols, so too are compounds represented by a kind of shorthand. A chemical compound is represented by a chemical formula. A chemical formula consists of the chemical symbols for the elements that make up the compound. Water, which contains 2 atoms of hydrogen and 1 atom of oxygen, has the chemical formula H_2O. Table salt, made of sodium and chlorine, has the formula NaCl. What elements are present in the compound sulfuric acid, whose chemical formula is H_2SO_4?

3–2 SECTION REVIEW

1. Describe the structure of an atom. What is meant by atomic number? Mass number?
2. What is an element? How are elements represented?
3. What is an isotope? What are some uses of radioactive isotopes?
4. How is a compound different from an element?

Section Objectives

- Explain how electron arrangement determines an atom's reactivity.
- Describe the two types of chemical bonds.

3–3 Interactions of Matter

Chemical compounds are formed by the interactions of individual atoms. These interactions involve the combining of atoms of elements in a process known as **chemical bonding**. Chemical bonds are formed in very definite ways. The atoms combine according to certain rules. Such rules are determined by the number of electrons that surround the atomic nucleus—more specifically, the electrons found in the outermost energy level.

Each energy level in an atom can hold only a certain number of electrons. The first, or innermost, energy level can hold only 2 electrons. The second energy level can hold 8 electrons, as can the third when it is an outermost energy level. Figure 3–12 illustrates the arrangement of electrons in the first three energy levels.

When the outermost energy level of an atom contains the maximum number of electrons, the level is full, or complete. Atoms that have filled outermost energy levels are very stable, or unreactive. Such atoms usually do not combine with other atoms to form compounds. They do not form chemical bonds.

In order to achieve stability, an atom will either gain, lose, or share electrons. In other words, an atom will bond with another atom if the bonding gives both atoms complete outermost energy levels.

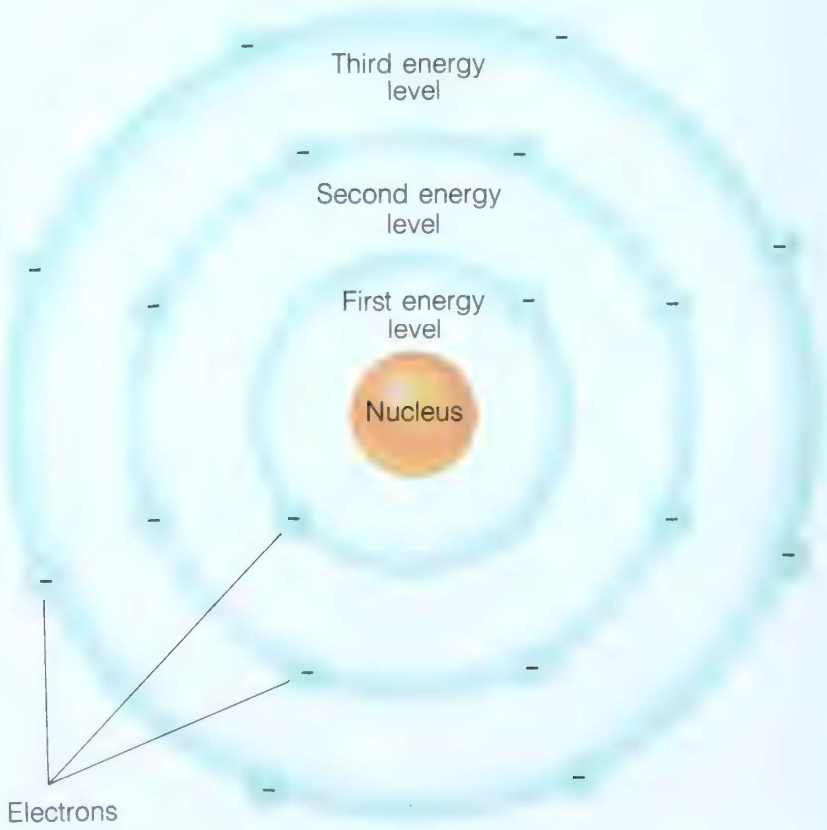


Figure 3–12 *Each energy level in an atom can hold only a certain number of electrons. When the outermost energy level is holding its maximum number of electrons, it is complete, and the atom is stable.*

Ionic Bonds

One way a complete outermost energy level can be achieved is by the transfer of electrons from one atom to another. A bond that involves a transfer of electrons is called an **ionic bond**. An ionic bond, or electron-transfer bond, gets its name from the word **ion**, which means charged particle. Ions are formed when an ionic bond occurs.

A sodium atom has only 1 electron in its outermost energy level, so it can lose that electron very easily. The loss of an electron from a sodium atom produces a sodium ion (Na^+), which has a positive charge. Similarly, chlorine needs only 1 electron to fill its outermost energy level, so it grabs an extra electron easily—possibly from a nearby sodium atom. The addition of an electron to a chlorine atom produces a negatively charged chloride ion (Cl^-). These two ions, now oppositely charged, have a strong attraction for each other—much like opposite poles of a magnet. The strong attraction between oppositely charged ions that have been formed by the transfer of electrons holds the ions together in an ionic bond.

Covalent Bonds

A chemical bond formed by the sharing of electrons is known as a **covalent bond**. By sharing electrons, each atom

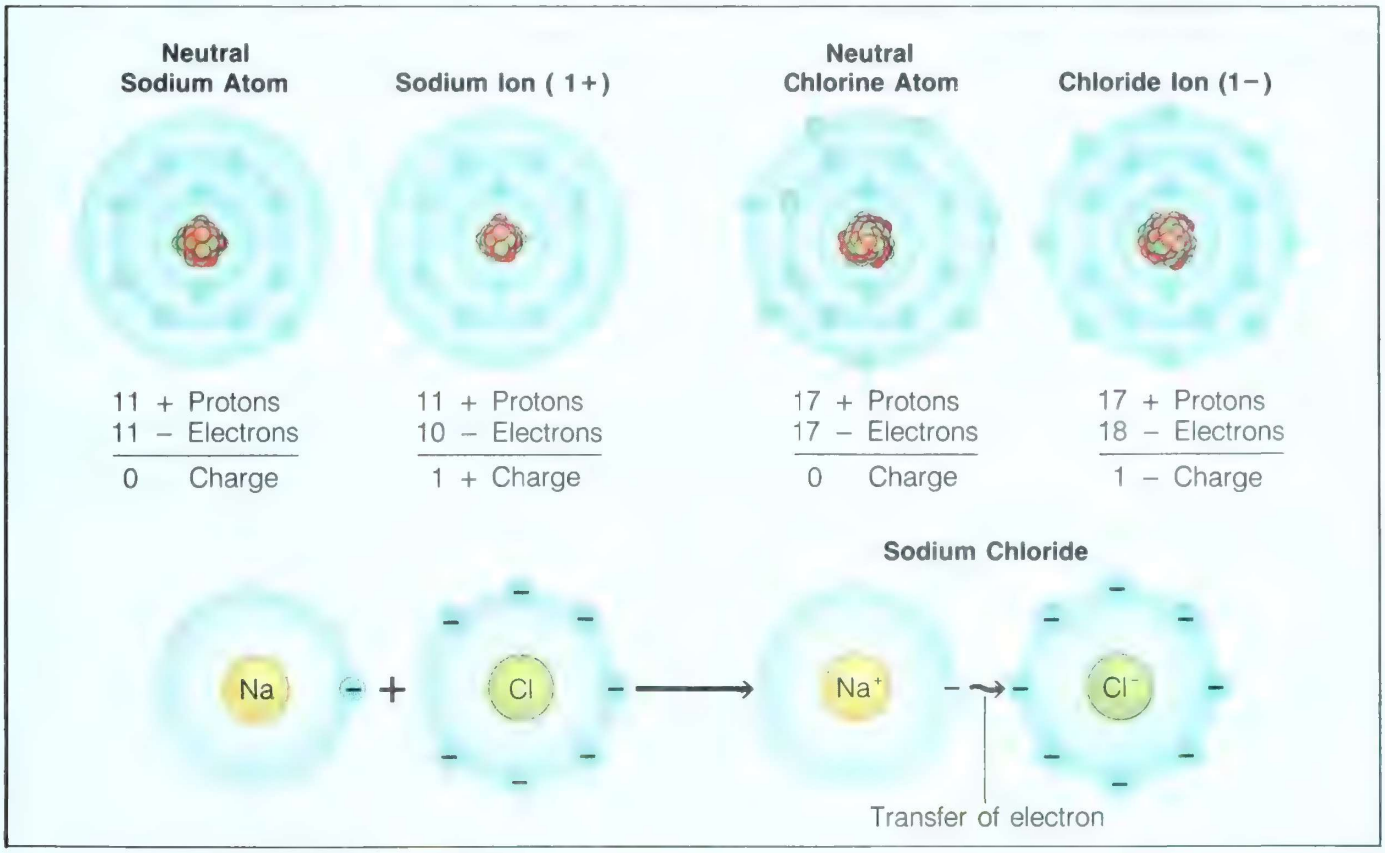
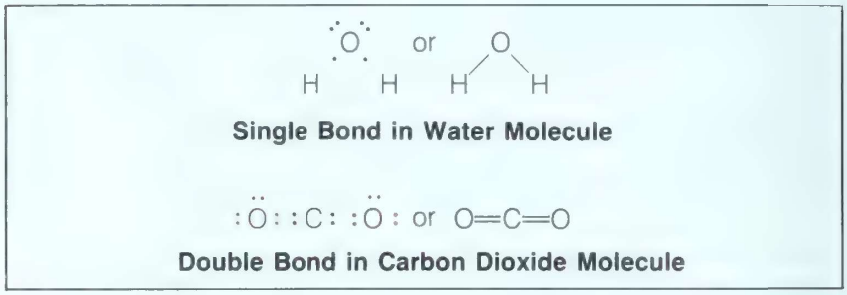


Figure 3–13 *The formation of a positive sodium ion involves the loss of an electron by a sodium atom. The formation of a negative chloride ion involves the gain of an electron by a chlorine atom. The transfer of an electron produces oppositely charged ions that are strongly attracted and held together in an ionic bond. Because only the electrons in the outermost energy level are involved in bonding, only this level has been shown in the bottom diagram.*

fills up its outermost energy level. So the shared electrons are in the outermost energy level of both atoms at the same time. This produces a strong bond that is characteristic of most of the chemicals found in living organisms.

Covalent bonds can be single, double, or triple, depending on the number of electrons that are shared in the bond. The covalent bond between hydrogen and oxygen in water (H_2O) is a single bond. A single pair of electrons is shared between the oxygen atom and each of the 2 hydrogen atoms. In the compound carbon dioxide (CO_2), the carbon atom shares two pairs of electrons, or a total of 4 electrons, with each of the oxygen atoms in the compound. The carbon-oxygen bond in carbon dioxide is a double bond.

Figure 3–14 *The bonding in molecules can be represented by electron-dot formulas and by structural formulas. An electron-dot formula shows the electron pairs involved in the bonding. A single bond involves one pair of electrons; a double bond involves two. In a structural formula, a dash (–) is used to represent a pair of shared electrons, or a single bond. How is a double bond represented?*



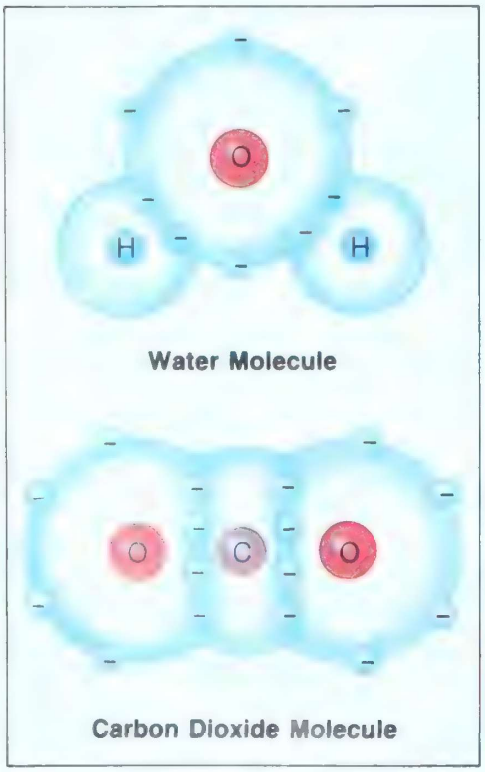
Single Bond in Water Molecule

Double Bond in Carbon Dioxide Molecule

In a covalent bond, a relatively small number of atoms are involved in the sharing of electrons. The combination of atoms that results forms a separate unit called a **molecule**. A molecule is the smallest particle of a covalently bonded compound. In addition to water and carbon dioxide, some other common covalent compounds are sugar ($C_6H_{12}O_6$) and ammonia (NH_3).

Regardless of the type of bond formed, atoms change their physical and chemical properties when they form a compound. For example, sodium is a silvery metal that reacts explosively with water. Chlorine is a poisonous greenish gas, which was responsible for the deaths of many soldiers in World War I. Neither element in its pure form can be used by your body. Yet they combine to form sodium chloride (NaCl), or table salt, a solid that dissolves easily in water, is not poisonous, and is essential to most living things. It also tastes great on a pretzel!

Figure 3–15 *A covalent bond involves the sharing of electrons. How many double bonds are there in a molecule of carbon dioxide?*



3–3 SECTION REVIEW

1. Describe the arrangement of electrons in the first three energy levels.
2. Compare an ionic bond to a covalent bond.
3. An oxygen atom has 6 electrons in its outermost energy level. A hydrogen atom has 1. Describe how the covalent bonds in the water molecule enable each atom to achieve a complete outermost energy level and, therefore, stability.

SCIENCE, TECHNOLOGY, AND SOCIETY **BREAKTHROUGH**

A Do-It-Yourself Poison

Each year they cause more than $5 billion in damage to crops and livestock. They are a threat to human health because they can transmit certain diseases. And in order to eliminate them, poisonous substances that may endanger our health as well as the health of our environment must be used. What are these pests who have created economic, environmental, and safety problems? Insects!

Farmers and gardeners use insecticides to protect their plants and animals against insects. Insecticides are compounds that kill insects in a variety of ways. Some kill insects that eat the chemical compounds. Others kill insects upon contact. Certain insecticides produce lethal vapors and gases. Still others kill by infecting insects with deadly diseases.

Although many insecticides are effective in the battles against insect infestation, they often have profound effects on the environment and other living things. Until recently, people had to balance the benefits of insecticide use against possible damage to planet Earth. Now a new class of insecticides that affect only their target and pose little danger to us has been developed.

Scientists working at the State University of New York at Stony Brook combined polysterols—special compounds manufactured by plants—with the element fluorine to produce a new group of compounds called 29-fluorophytosterols. These compounds are harmless to most organisms—ourselves included! But inside an insect's body, special chemicals called enzymes can act on the fluorophytosterols and break them down to produce fluoroacetate, a deadly poison. For insects unfortunate enough to have the special enzymes, this new class of insecticide spells doom!

In and of themselves, 29-fluorophytosterols are harmless, presenting little danger to most living things. But the chemical composition and bodily processes of insects render these compounds deadly! By applying a knowledge of basic chemistry to the workings of living systems, scientists were able to develop exactly the compound they sought: a safe and effective insecticide.

3–4 Chemical Reactions

Section Objectives

- Identify the substances involved in a chemical reaction.
- Describe the role of energy in chemical reactions.

You have learned that two types of bonds can exist between atoms and that compounds with different chemical and physical properties can be formed by the transfer or sharing of electrons. Whenever a chemical bond is formed, a chemical change takes place. Any process in which a chemical change occurs is known as a **chemical reaction**.

Chemical reactions occur all the time and are very much a part of your daily life. Some chemical reactions occur slowly, such as the combination of iron and oxygen to form rust. Others occur quickly. When hydrogen gas is ignited in the presence of oxygen, the reaction is rapid and explosive.

In any chemical reaction there are always two kinds of substances: the substances that are present before the change and the substances that are formed by the change. The elements or

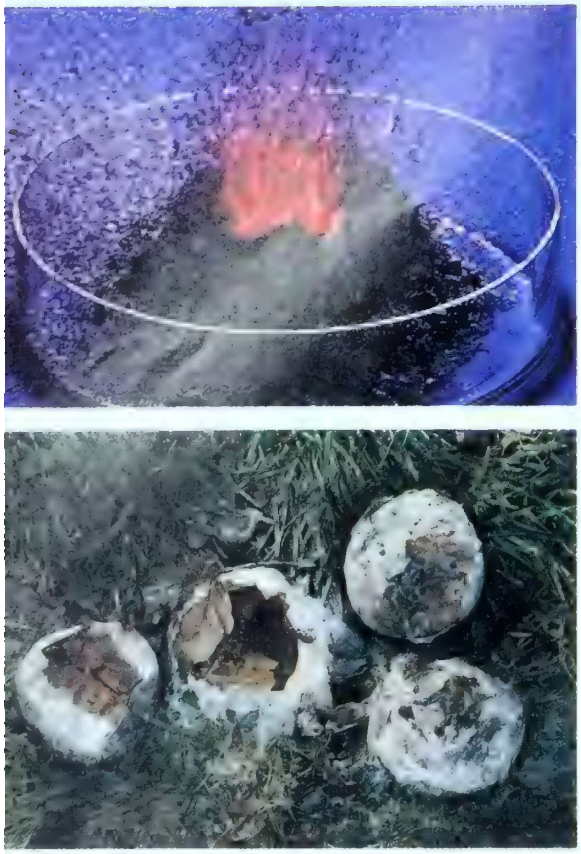


Figure 3–16 *Chemical reactions are many and varied. Here you see two examples: the heating of ammonium dichromate (top) and the decaying of apples (bottom). A chemical reaction always involves a change in the properties and in the energy of the substances involved.*

compounds that enter into a chemical reaction are known as reactants. The elements or compounds produced by a chemical reaction are known as products.

A chemical reaction can be described by using a shorthand method known as a chemical equation. In a chemical equation, symbols and formulas are used to represent reactants and products. And an arrow, which is read "yields," shows the direction of the reaction. Let us use the chemical reaction involving the combination of hydrogen and oxygen to form water to illustrate a chemical equation.

$$\underset{\text{oxygen}}{O_2} + \underset{\text{hydrogen}}{2H_2} \rightarrow \underset{\text{water}}{2H_2O}$$

Chemical reactions are reversible. In principle, any chemical reaction can run in either direction. For example, it is possible for the reaction we have just described to run in reverse.

$$\underset{\text{water}}{2H_2O} \rightarrow \underset{\text{oxygen}}{O_2} + \underset{\text{hydrogen}}{2H_2}$$

This generally does not occur however. Why? Because there is an important difference between the two chemical reactions. When oxygen gas and hydrogen gas burn to form water vapor, an enormous amount of energy is released in the form of heat, light, and sound. But water, on the other hand, does not spontaneously decompose to form hydrogen gas and oxygen gas. In fact, the only convenient way to drive the reaction in this direction is to run an electric current through the water to decompose it. Thus, in one direction the reaction produces energy; in the other direction, it requires energy.

Chemists have learned that the most important factor in determining whether a reaction will occur is the flow of energy. Chemical reactions that release energy will occur spontaneously. Chemical reactions that require energy will not occur without a source of energy.

What significance does this have for you and the other living things that share your world? All living things carry on both kinds of reactions in order to stay alive. The energy needed to grow tall, to read, to think, and even to dream comes from chemical reactions that occur in your body when you digest the food you eat. In the following chapters, you will explore these reactions and the flow of energy necessary for life.

3–4 SECTION REVIEW

1. What is a chemical reaction? A chemical equation?
2. What is a reactant? A product?
3. Describe the role of energy in chemical reactions.
4. Why is it important that energy-absorbing and energy-releasing reactions take place in living things?

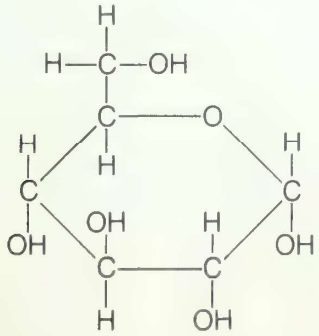
STRUCTURAL FORMULAS

Molecules are too small to be seen, yet we draw their pictures anyway. The reason for doing this is simple: In living things, a great many important things happen at the molecular level, and we need a way of representing these events. How shall we draw these pictures of molecules? And once drawn, what do they mean? Let's begin by considering glucose, a simple sugar.

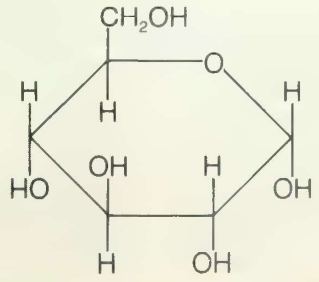
One way to represent glucose is to write its molecular formula:

$$C_6H_{12}O_6$$

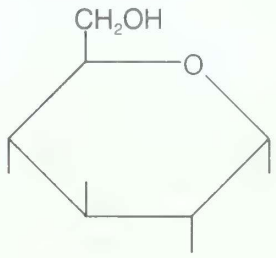
This formula tells us how many atoms of each element are in a molecule of glucose. But it does not indicate how the atoms are arranged. To do that, we need to draw a structural formula for the glucose molecule:



Chemists often try to simplify structural formulas. One way of doing this is to leave nearly all of the carbons out of the picture. However, everybody knows they're still there! Now the molecule looks like this:



Sometimes chemists draw the same molecule in an even simpler fashion, like this:



Each drawing is useful because it provides important information. For example, we can see that the glucose molecule is folded to form a ring and that the -OH groups (hydroxyl groups) project from one side or the other of that ring into space. None of the structural formulas, however, actually looks like a real molecule of glucose:



The key idea to remember about chemical formulas and structural formulas is that they are representations. Representations are useful and informative. They help us to visualize things that are hard to explain.

Now try your hand at drawing structural formulas for the following compounds: CH_4 methane; CCl_2F_2 Freon; $C_2H_4(OH)_2$ ethylene glycol or antifreeze; C_2H_6 ethane.

LABORATORY INVESTIGATION

IDENTIFYING ELEMENTS BY DENSITY

PROBLEM

How do the densities of different elements compare?

MATERIALS *(per group)*

aluminum metal
zinc metal
unknown metal sample
graduated cylinder
balance

PROCEDURE

1. Density is mass per unit volume. In this laboratory investigation, you will measure the density of two elements, zinc and aluminum. Copy the data table shown below onto a separate sheet of paper to record your observations.
2. Using a balance, measure the mass of a small sample of aluminum metal (about 40 g). Record the mass in the data table.
3. Measure the volume of the aluminum metal using the following procedure: Fill a 100-mL graduated cylinder halfway with water and record the initial volume in your data table. Put the aluminum metal into the graduated cylinder. This will cause the water level to rise. Record the final volume of water. Find the volume of the aluminum by subtracting the initial volume of the water from the final volume of the water. Record the result.
4. Calculate the density of the aluminum by dividing the aluminum's mass by its volume: $D = M/V$. Record the result.
5. Find the density of a small sample of zinc metal by measuring its mass and volume according to the same procedure you used for aluminum.
6. Measure the density of an unknown sample of metal. Use your results to determine whether the unknown metal is aluminum or zinc.

OBSERVATIONS

1. How do the densities of aluminum and zinc compare?
2. What are some observable properties of aluminum and zinc?

ANALYSIS AND CONCLUSIONS

1. Is the unknown metal aluminum or zinc? How do you know?
2. Is density a physical or a chemical property? How can you tell?
3. Can density be used to help identify elements? Explain your answer.

Element	Mass (g)	Volume (mL)			Density (g/mL)
		Initial	Final	Metal	
Aluminum					
Zinc					
Unknown					

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

3–1 Nature of Matter

- Two important properties—mass and volume—are used to define matter.
- Physical properties of matter can be observed and measured without permanently changing the identity of the matter. Chemical properties describe a substance's ability to change into another new substance as a result of a chemical change.

3–2 Composition of Matter

- The basic unit of matter is the atom. The nucleus of the atom contains positively charged protons and electrically neutral neutrons. Energy levels outside the nucleus contain negatively charged electrons.
- The number of protons in the nucleus of an atom is called the atomic number.
- Substances that consist entirely of one type of atom are called elements. Atoms of the same element that have the same number of protons but different numbers of neutrons are called isotopes.
- A chemical compound consists of two or more different atoms chemically combined in definite proportions.

3–3 Interactions of Matter

- The combining of atoms of elements is known as chemical bonding. An ionic bond involves a transfer of electrons between atoms. A covalent bond involves the sharing of electrons.

3–4 Chemical Reactions

- In any chemical reaction, reactants combine to yield products.
- Although chemical reactions are reversible in principle, they occur spontaneously only in the direction that produces energy.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review the definition.

3–1 Nature of Matter
physical property
chemical property
phase

3-2 Composition of Matter
atom
nucleus
proton
neutron
electron
energy-level
atomic number
mass number
element
isotope
compound

3-3 Interactions of Matter
chemical bonding
ionic bond
ion
covalent bond
molecule

3-4 Chemical Reactions
chemical reaction

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. Substances that enter into a chemical reaction are known as
   a. reactants.
   b. catalysts.
   c. products.
   d. isotopes.
2. Two important physical properties used to define matter are
   a. taste and smell.
   b. mass and volume.
   c. weight and boiling point.
   d. mass and freezing point.
3. The nucleus of an atom contains
   a. electrons and protons.
   b. electrons and neutrons.
   c. protons, electrons, and neutrons.
   d. protons and neutrons.
4. A substance consisting of two or more different elements chemically combined is a(an)
   a. molecule.
   b. crystal.
   c. compound.
   d. isotope.
5. An atom with an atomic number of 8 has
   a. 8 protons.
   b. 4 protons plus 4 neutrons.
   c. 4 protons plus 4 electrons.
   d. 4 neutrons plus 4 electrons.
6. Which is true of carbon-12 and carbon-14?
   a. They have the same number of neutrons.
   b. They have the same number of protons.
   c. They have the same mass number.
   d. They are isotopes of different elements.
7. A shorthand way of representing an element is a chemical
   a. formula.
   b. reaction.
   c. property.
   d. symbol.
8. Radioactive isotopes are used
   a. as tracers.
   b. to diagnose disease.
   c. to treat disease.
   d. to do all of these.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. Chemical properties describe a substance's ability to undergo a chemical change.
2. The sharing of electrons is characteristic of ionic bonds.
3. Any process in which a chemical change occurs is known as a chemical formula.
4. The number of protons in the nucleus of an atom is called the mass number.
5. Chemical reactions that absorb energy will occur spontaneously.
6. The amount of space an object takes up is known as weight.
7. Atoms that have complete outermost energy levels are said to be very stable.
8. The positively charged subatomic particle is the electron.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

1. energy level, proton, nucleus, neutron
2. oxygen, sodium, carbon dioxide, mercury
3. solid, mass, liquid, gas
4. 2, second energy level, 8, third energy level
5. molecule, electron transfer, covalent bond, water
6. color, phase, ability to burn, texture
7. products, physical change, reactants, yields
8. Democritus, atom, divisible particle, Greek philosopher

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Describe two important differences between physical and chemical properties.
2. Identify each of the following changes as either a physical change or a chemical change:
   a. melting butter
   b. boiling water
   c. digesting food
   d. baking brownies
   e. exploding TNT
   f. dissolving sugar
   g. burning fuel oil
3. Describe the subatomic particles found in the atom. Be sure to include their charge, mass, and location in your description.
4. What is the atomic number of an element? What is its significance?
5. Nitrogen-14 and nitrogen-15 are isotopes of the element nitrogen. Describe how atoms of these isotopes differ from each other.
6. What is a radioactive isotope? Describe three uses of radioactive isotopes.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Relating facts** Explain why the use of radioactive isotopes has both advantages and disadvantages.
2. **Developing a model** Draw a diagram of the electron arrangement for the following elements based on their atomic number: lithium (3), carbon (6), fluorine (9), magnesium (12), phosphorus (15), argon (18).
3. **Identifying patterns** Explain why the element neon, with an atomic number of 10, is unreactive.
4. **Synthesizing concepts** Explain the role of energy in chemical reactions.
5. **Applying concepts** A basic principle of electricity is "like charges repel and opposite charges attract." How does the organization of particles in an atom illustrate this principle? How does it refute it?
6. **Using the writing process** The time is 3000 years ago. The Greek philosopher Democritus has proposed that all matter is made up of atoms. Write a brief speech supporting or refuting the concept of indivisible atoms.