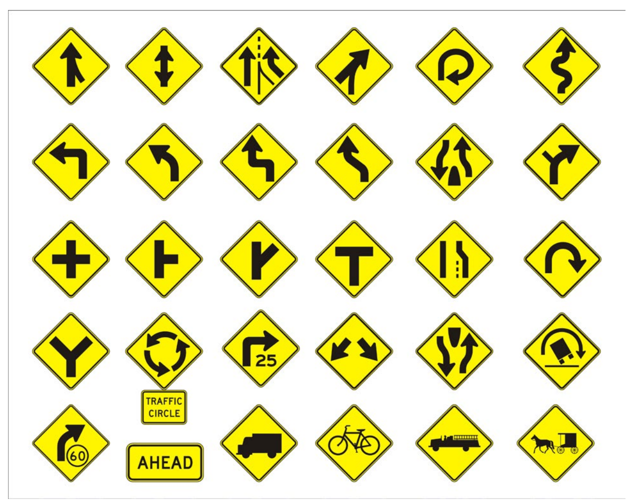
Chapter 2
The Structure of Matter and the Chemical Elements

One doesn't discover new lands without consenting to lose sight of the shore for a very long time.

Andre Gide
French Novelist and Essayist

In this chapter, we begin the journey that will lead you to an understanding of chemistry. Perhaps your ultimate educational goal is to know how the human body functions or to learn how the many parts of a shoreline ecosystem work together. You won't get very far in these studies without a basic knowledge of the chemical principles underlying them. Even before talking about basic chemical principles, though, you must learn some of the language of chemistry and develop an image of the physical world that will help you to think like a chemist.

Many important tasks in life require that you learn a new language and new skills. When you are learning to drive a car, for example, your driving instructor might tell you that when two cars reach a four-way stop at the same time, the driver on the left must yield the right of way. This statement won't mean anything to you unless you already know what a "four-way stop" is and what is meant by "yield" and "right of way". To drive safely, you need to learn which of the symbols you see on road signs means "lane merges ahead" or "steep grade". You need to learn procedures that will help you make lane changes and parallel park.



Chemistry, like driving a car, uses a language and skills of its own. Without a firm foundation in these fundamentals, a true understanding of chemistry is impossible. This chapter begins to construct that foundation by introducing some key aspects of the chemists' view of matter.

Review Skills

The presentation of information in this chapter assumes that you can already perform the tasks listed below. You can test your readiness to proceed by answering the Review Questions at the end of the chapter. This might also be a good time to read the Chapter Objectives, which precede the Review Questions.

- Define matter. *(Chapter 1 Glossary)*
- Write the SI base units for mass and length and their abbreviations. *(Section 1.4)*
- Using everyday examples, describe the general size of a meter and a gram. *(Section 1.4)*

2.1 Solids, Liquids, and Gases

A chemist's primary interest, as described in Chapter 1, is the behavior of matter, but to understand the behavior of matter, we must first understand its internal structure. What are the internal differences between the granite of Half Dome in Yosemite, the olive oil added to your pasta sauce, and the helium in a child's balloon? A simple model of the structure of matter will help us begin to answer this question.

A **model** is a simplified approximation of reality. For example, architects often build a model of a construction project before actual construction begins. The architect's model is not an exact description of the project, but it is still very useful as a representation of what the structure will be like. Scientific models are like the architects' models; they are simplified but useful representations of something real. In science, however, the models are not always physical entities. Sometimes they are sets of ideas instead.

In the last hundred years, there has been a tremendous increase in our understanding of the physical world, but much of that understanding is based on extremely complicated ideas and mathematics. The application of the most sophisticated forms of these modern ideas is difficult, and not very useful to those of us who are not well trained in modern physics and high-level mathematics. Therefore, scientists have developed simplified models for visualizing, explaining, and predicting physical phenomena. For example, we are about to examine a model that will help you visualize the tiny particles of the solid metal in a car's engine block, the liquid gasoline in the car's tank, and the gaseous exhaust fumes that escape from its tail pipe. The model will help you understand why **solids** have constant shape and volume at a constant temperature, why **liquids** have a constant volume but can change their shape, and why **gases** can easily change both their shape and volume. Our model of the structure of solids, liquids, and gases says that

Objective 2

- All matter is composed of tiny particles. (We will start by picturing these as tiny spheres.)
- These particles are in constant motion.

Objective 3

- The amount of motion is related to temperature. Increased temperature reflects increased motion.
- Solids, gases, and liquids differ in the freedom of motion of their particles and in how strongly the particles attract each other.

Solids

Why does the metal in a car's engine block retain its shape as you drive down the road while the fuel in the car's gas tank conforms to the shape of the tank? What's happening on the submicroscopic level when solid metal is melted to a liquid, and why can molten metal take the shape of a mold used to form an engine block? Our model will help us to answer these questions.

According to our model, the particles of a solid can be pictured as spheres held closely together by strong mutual attractions. (Figure 2.1). All the particles are in motion, bumping and tugging one another. Because they're so crowded and exert such strong mutual attractions, however, they only jostle in place. Picture yourself riding on particle 1 in Figure 2.1. An instant before the time captured in the figure, your particle was bumped by particle 3 and sent toward particle 5. (The curved lines in the figure represent the momentary direction of each particle's motion and its relative velocity.) This motion continues until the combination of a bump from particle 5 and tugging from particles 2, 3, and 4 quickly bring you back toward your original position. Perhaps your particle will now head toward particle 2 at a greater velocity than it had before, but again, a combination of bumps and tugs will send you back into the small space between the same particles. A ride on any of the particles in a solid would be a wild one, with constant changes in direction and velocity, but each particle will occupy the same small space and have the same neighbors.

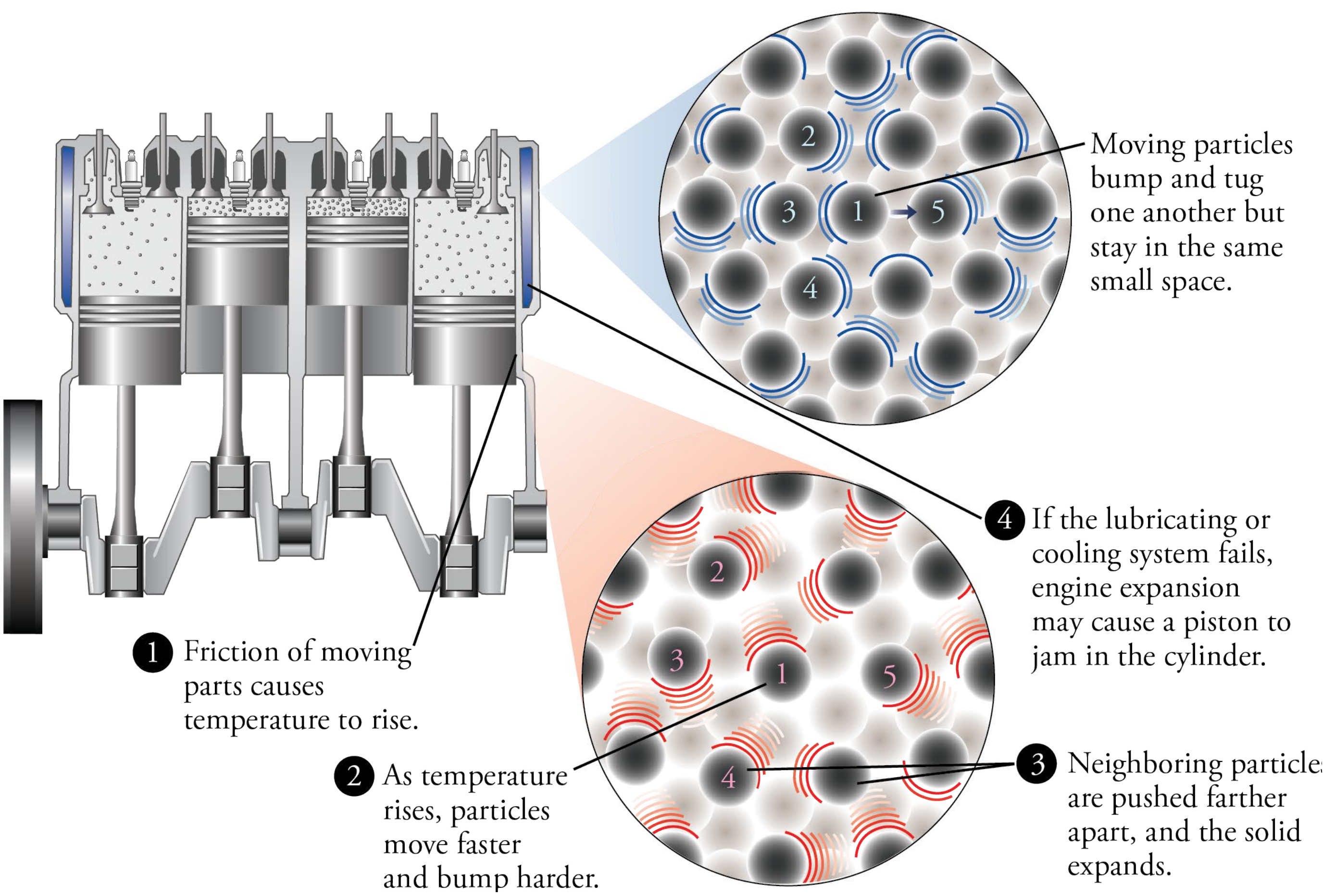
Objective 4

When a solid is heated, the average speed of the moving particles increases. Faster-moving particles collide more violently, causing each particle to push its neighbors farther away. Therefore, an increase in temperature usually causes a solid to expand somewhat (Figure 2.1).

Objective 5

Objective 2 Objective 4 Objective 5

Figure 2.1
Particles of a Solid



Liquids

If any solid is heated enough, the movements of the particles become sufficiently powerful to push the other particles around them completely out of position. Look again at Figure 2.1. If your particle is moving fast enough, it can push adjacent particles out of the way entirely and move to a new position. For those adjacent particles to make way for yours, however, they must push the other particles around them aside. In other words, for one particle to move out of its place in a solid, all of the particles must be able to move. The organized structure collapses, and the solid becomes a liquid.

Objective 6

Particles in a liquid are still close together, but there is generally more empty space between them than in a solid. Thus, when a solid substance melts to form a liquid, it usually expands to fill a slightly larger volume. Even so, attractions between the particles keep them a certain average distance apart, so the volume of the liquid stays constant at a constant temperature. On the other hand, because the particles in a liquid are moving faster and there is more empty space between them, the attractions are easily broken and reformed, and the particles change location freely. Eventually, each particle gets a complete tour of the container. This freedom of movement allows liquids to flow, taking on the shape of their container. It is this freedom of movement that allows liquid metal to be poured into a mold where it takes the shape of an engine block (Figure 2.2).

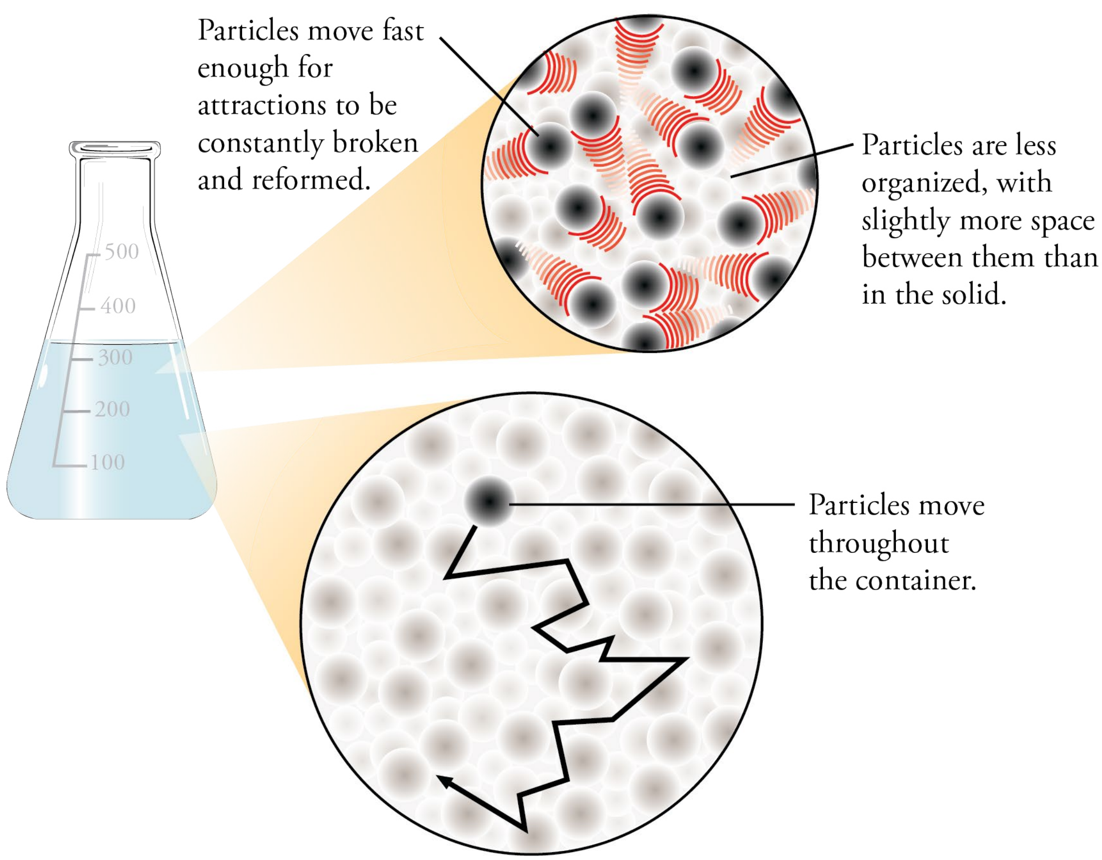
Objective 7

Objective 2

Objective 8

Figure 2.2
Particles of a Liquid

Objective 2



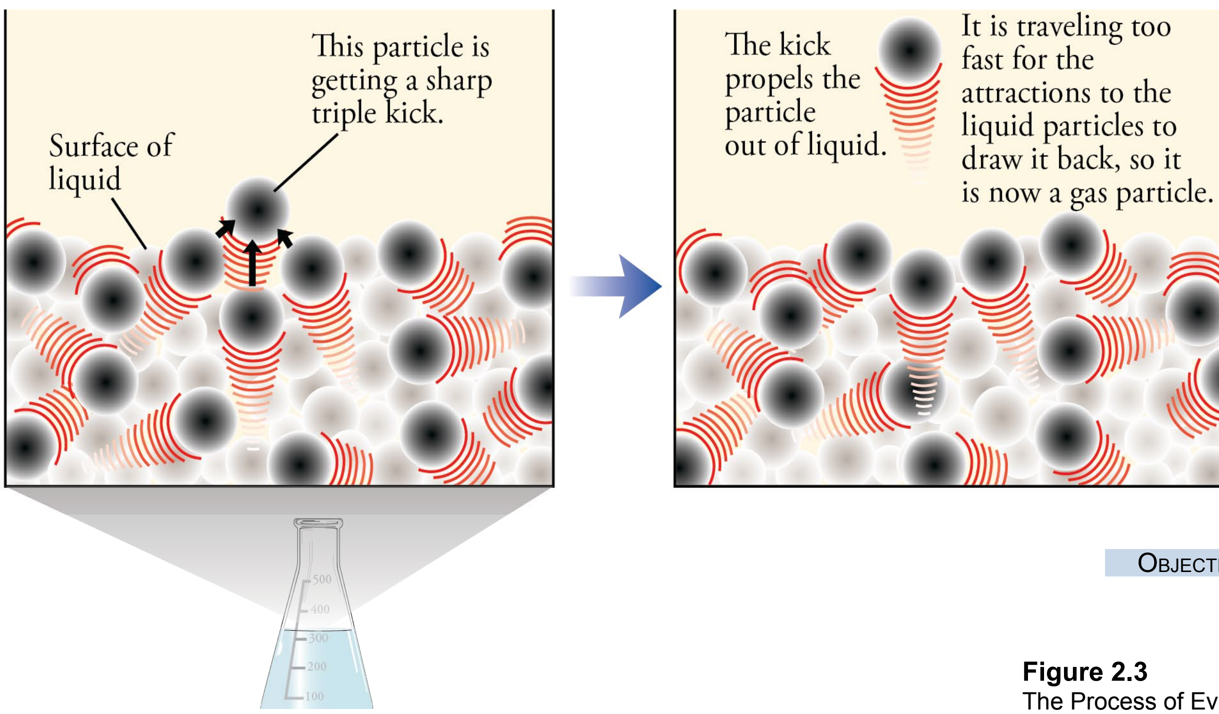
Gases

If you've ever spilled gasoline while filling your car, you know how quickly the smell finds your nose. Our model can help you understand why.

Objective 9

Picture yourself riding on a particle in liquid gasoline. Because the particle is moving throughout the liquid, it will eventually come to the liquid's surface. Its direction of movement may carry it beyond the surface into the space above the liquid, but the attraction of the particles behind it will most likely draw it back again. On the other hand, if your particle is moving fast enough, it can move far enough away from the other particles to break the attractions pulling it back. This is the process by which liquid is converted to gas. The conversion of liquid to gas is called **vaporization** or **evaporation** (Figure 2.3).

You might also have noticed, while pumping gasoline, that the fumes smell stronger on a hot day than on a cold day. When the gasoline's temperature is higher, its particles are moving faster and are therefore more likely to escape from the liquid, so that more of them reach your nose.



Objective 9

Figure 2.3
The Process of Evaporation

Objective 2

The particles of a gas are much farther apart than in a solid or liquid. In the air around us, for example, the average distance between particles is about ten times the diameter of each particle. This leads to the gas particles themselves taking up only about 0.1% of the total volume. The other 99.9% of the total volume is empty space. In contrast, the particles of a liquid fill about 70% of the liquid's total volume. According to the model, each particle in a gas moves freely in a straight-line path until it collides with another gas particle or with the particles of a liquid or solid. The particles are usually moving fast enough to break any attraction that might form between them, so after two particles collide, they bounce off each other and continue on their way alone.

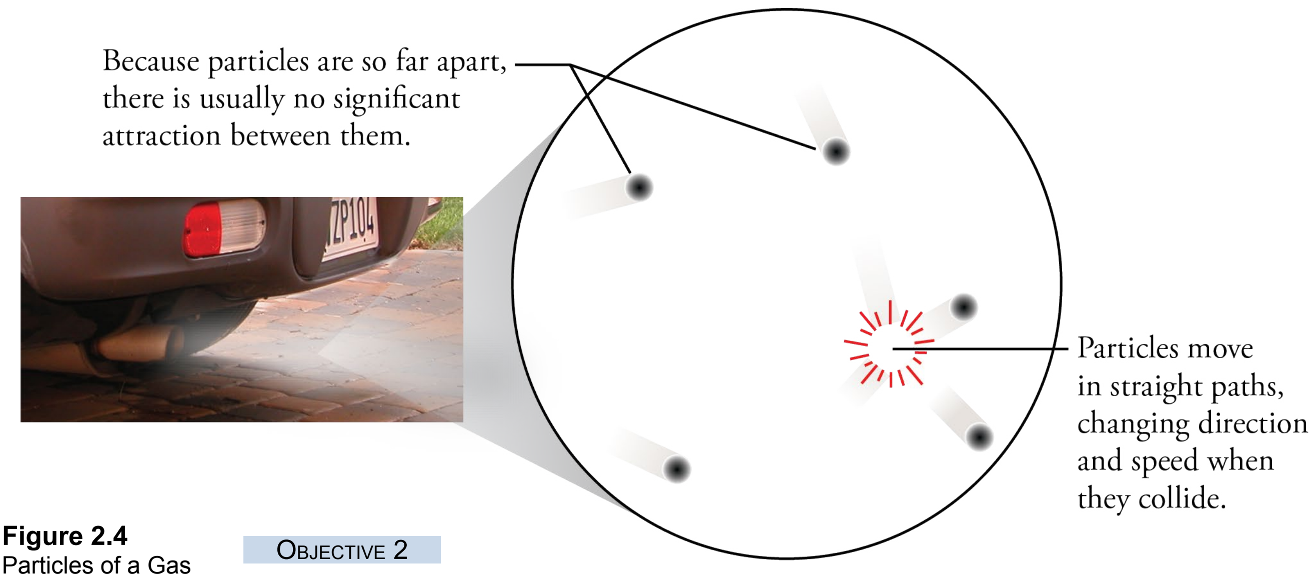


Figure 2.4
Particles of a Gas

OBJECTIVE 2

OBJECTIVE 2

Picture yourself riding on a gas particle at the instant captured in Figure 2.4. You are so far away from any other particles that you think you are alone in the container. An instant later, you collide with a particle that seems to have come out of nowhere. The collision changes your direction and velocity. In the next instant, you are again moving freely, as if your particle was the only one in the universe.

OBJECTIVE 10

Unlike the liquid, which has a constant volume, the rapid, ever-changing, and unrestricted movement of the gas particles allows gases to expand to fill any shape or volume of container. This movement also allows our cars' exhaust gases to move freely out of the cars and into the air we breathe.

You can review the information in this section and see particles of solids, liquids, and gases in motion at the textbook's Web site.

2.2 The Chemical Elements

Chemists, like curious children, learn about the world around them by taking things apart. Instead of dissecting music boxes and battery-operated rabbits, however, they attempt to dismantle matter, because their goal is to understand the substances from which things are made. The model of the structure of matter presented in the last section describes the behavior of the particles in a solid, a liquid, or a gas. But what about the nature of the particles themselves? Are all the particles in a solid, liquid, or gas identical? And what are the particles made of? We begin our search for the answers to these questions by analyzing a simple glass of water with table salt dissolved in it.

We can separate this salt water into simpler components in a series of steps. First, heating can separate the salt and the water; the water will evaporate, leaving the salt behind. If we do the heating in what chemists call a distillation apparatus, the water vapor can be cooled back to its liquid form and collected in a separate container (Figure 2.5). Next, the water can be broken down into two even simpler substances–hydrogen gas and oxygen gas–by running an electric current through it. Also, we can melt the dry salt and then run an electric current through it, which causes it to break down into sodium metal and chlorine gas.

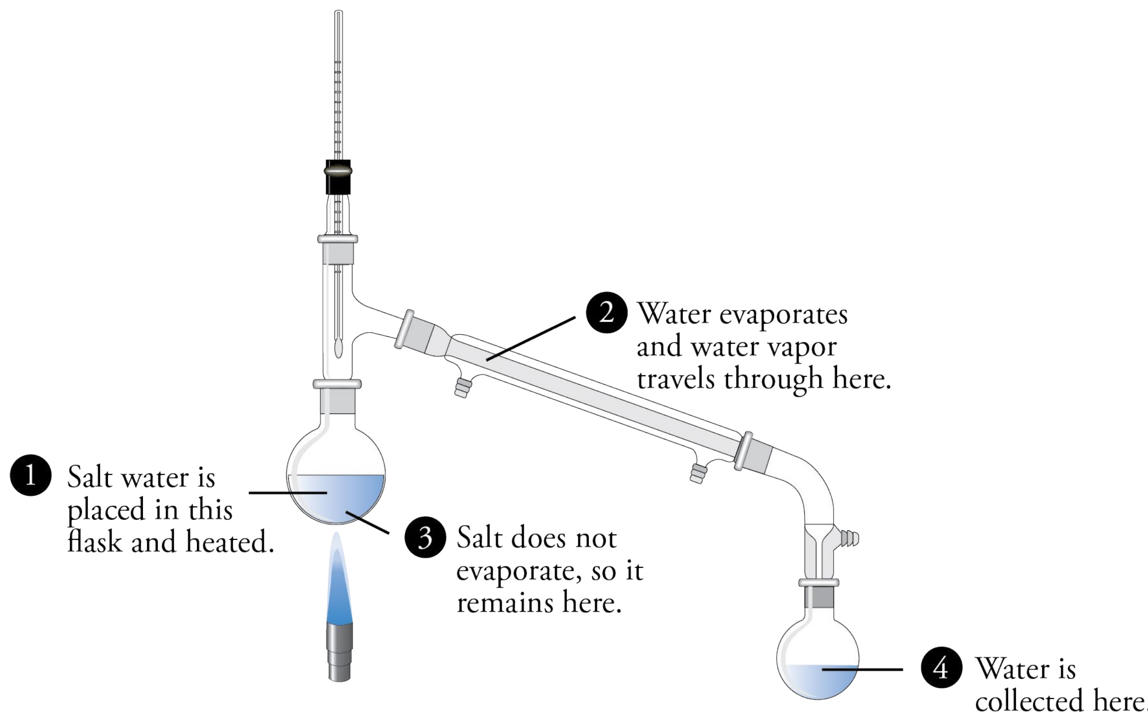


Figure 2.5
Distillation
Water can be separated from salt water on a small scale using a laboratory distillation apparatus.

Thus the salt water can be converted into four simple substances: hydrogen, oxygen, sodium, and chlorine (Figure 2.6 on the next page). Chemists are unable to convert these four substances into simpler ones. They are four of the building blocks of matter that we call **elements**, substances that cannot be chemically converted into simpler ones. (We will get a more precise definition of elements after we have explored their structure in more detail.)

The rest of this chapter is devoted to describing some common elements. Water, which consists of the elements hydrogen and oxygen, and salt, which consists of the elements sodium and chlorine, are examples of chemical compounds, which are described in Chapter 3. The mixture of salt and water is an example of a solution. Mixtures and solutions are described in Chapter 4.

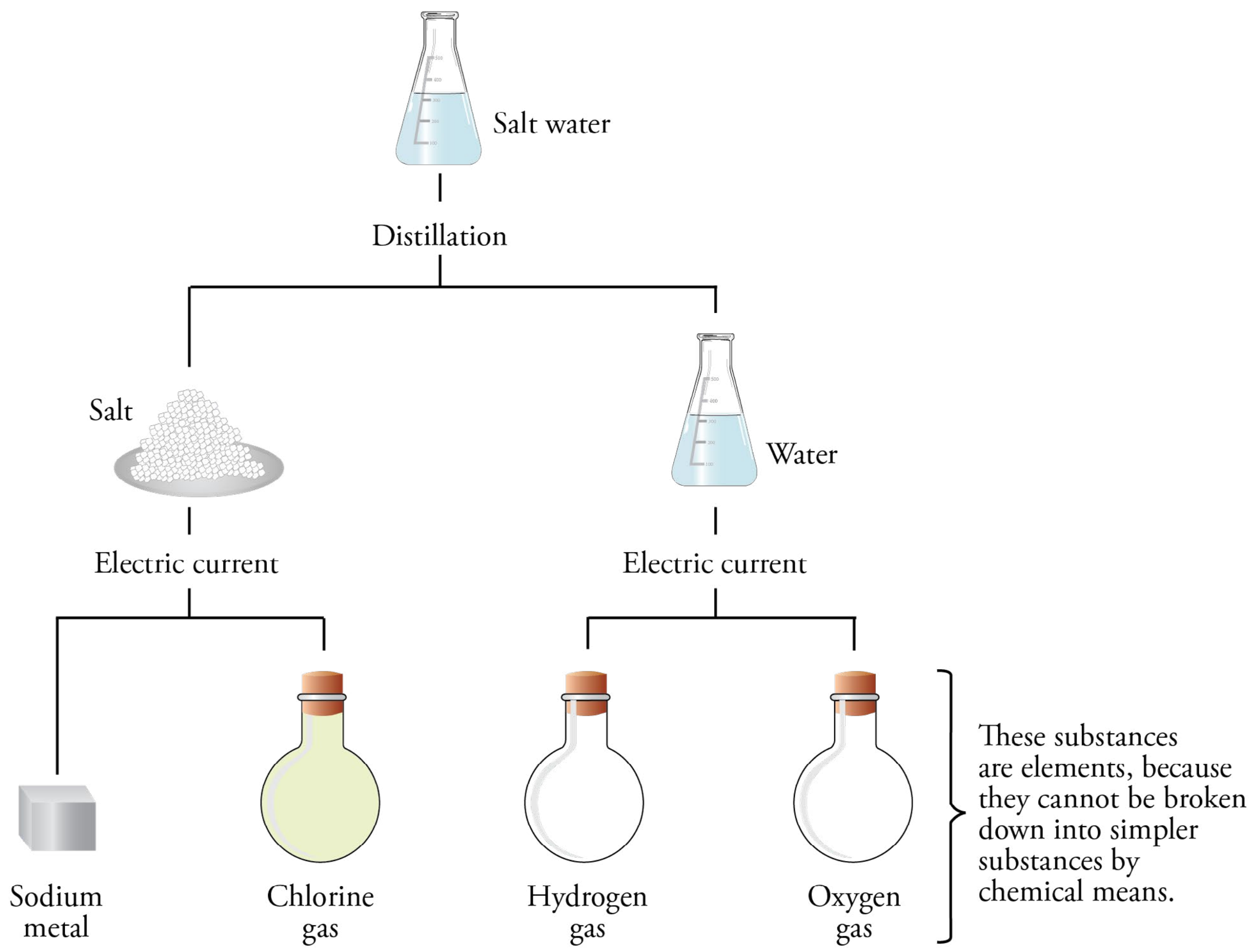


Figure 2.6
Separation of Salt Water into Four Substances

Millions of simple and complex substances are found in nature or produced in the chemical laboratory, but the total number of elements that combine to form these substances is much, much smaller. By the year 2014, 118 elements had been discovered, but 28 of these elements are not found naturally on the earth, and chemists do not generally work with them. Of these 28 elements, 2 or 3 might exist in stars, but the rest are not thought to exist outside the physicist's laboratory. (See Special Topic 2.1: *Why Create New Elements*?) Some of the elements found in nature are unstable; that is, they exist for a limited time and then turn into other elements in a process called radioactive decay. Of the 83 stable elements found in nature, many are rare and will not be mentioned in this text. The most important elements for our purposes are listed on Table 2.1.

Each of the elements is known by a name and a symbol. The names were assigned in several ways. Some of the elements, such as francium and californium, were named to honor the places where they were discovered. Some have been named to honor important scientists. An element discovered in 1982 has been named meitnerium to honor Lise Meitner (1878-1968), the Austrian-Swedish physicist and mathematician who discovered the element protactinium and made major contributions to the understanding of nuclear fission. Some names reflect the source from which scientists first isolated the element. The name hydrogen came from the combination of the Greek words for "water"(*hydro*) and "forming" (*genes*). Some elements, such as the purple element iodine, are named for their appearance. Iodos means violet in Greek.

The symbols for the elements were chosen in equally varied ways. Some are the first letter of the element's name. For example, C represents carbon. Other symbols are formed from the first letter and a later letter in the name. When two letters are used, the first is capitalized and the second remains lowercase. Cl is used for chlorine and Co for cobalt. Some of the symbols come from earlier, Latin names for elements. For example, Na for sodium comes from the Latin natrium, and Au for gold comes from the Latin aurum, which means shining dawn. The most recently discovered elements have not been officially named yet. They are given temporary names and three-letter symbols.

In your study of chemistry, it will be useful to learn the names and symbols for as many of the elements in Table 2.1 as you can. Ask your instructor which of the element names and symbols you will be expected to know for your exams.

Lise Meitner
Courtesy of Hahn-Meitner Institute

Jewelry can be made from the elements gold, silver, copper, and carbon in the diamond form.

Table 2.1
Common Elements

OBJECTIVE 11

Element	Symbol	Element	Symbol	Element	Symbol
aluminum	Al	gold	Au	oxygen	O
argon	Ar	helium	He	phosphorus	P
barium	Ba	hydrogen	H	platinum	Pt
beryllium	Be	iodine	I	potassium	K
boron	B	iron	Fe	silicon	Si
bromine	Br	lead	Pb	silver	Ag
cadmium	Cd	lithium	Li	sodium	Na
calcium	Ca	magnesium	Mg	strontium	Sr
carbon	C	manganese	Mn	sulfur	S
chlorine	Cl	mercury	Hg	tin	Sn
chromium	Cr	neon	Ne	uranium	U
copper	Cu	nickel	Ni	xenon	Xe
fluorine	F	nitrogen	N	zinc	Zn

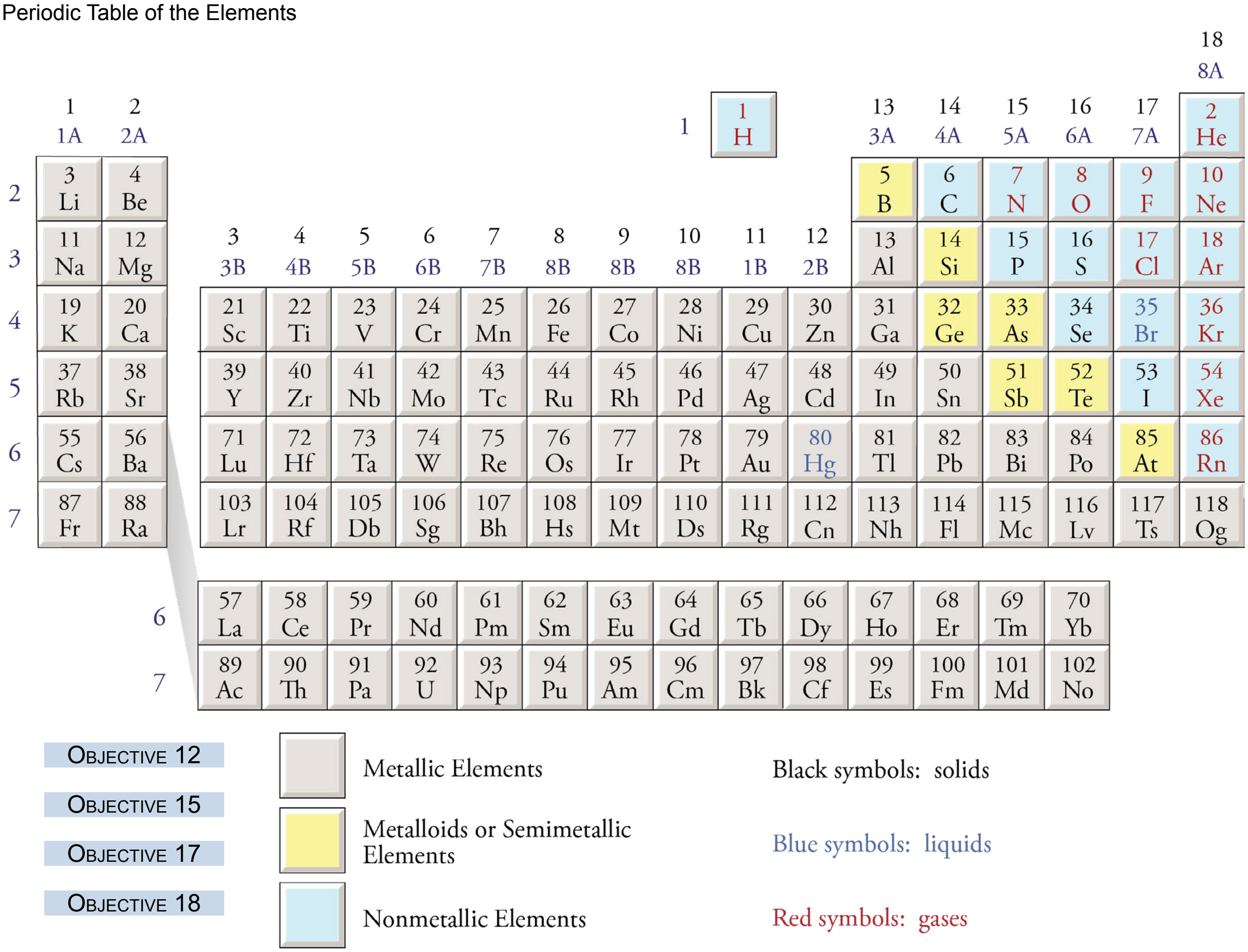
You can practice converting between element names and symbols at the textbook's Web site.

2.3 The Periodic Table of the Elements

Hanging on the wall of every chemistry laboratory, and emblazoned on many a chemist's favorite mug or T-shirt, is one of chemistry's most important basic tools, the periodic table of the elements (Figure 2.7). This table is like the map of the world on the wall of every geography classroom. If a geography instructor points to a country on the map, its location alone will tell you what the climate would be like and perhaps some of the characteristics of the culture. Likewise, you may not be familiar with the element potassium, but we shall see that the position of its symbol, K, on the periodic table, tells us that this element is very similar to sodium and that it will react with the element chlorine to form a substance that is very similar to table salt.

The elements are organized on the periodic table in a way that makes it easy to find important information about them. You will quickly come to appreciate how useful the table is when you know just a few of the details of its arrangement.

Figure 2.7
Periodic Table of the Elements



Objective 12

Objective 15

Objective 17

Objective 18

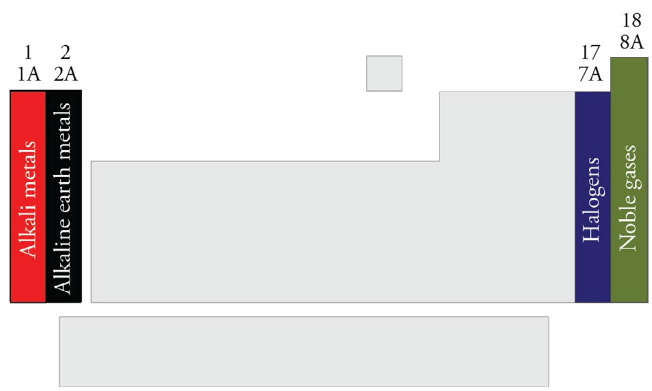
The periodic table is arranged in such a way that elements in the same vertical column have similar characteristics. Therefore, it is often useful to refer to all the elements in a given column as a **group** or **family**. Each group has a number, and some have a group name. For example, the last column on the right is group 18, and the elements in this column are called noble gases.

In the United States, there are two common conventions for numbering the columns (Figure 2.7). Check with your instructor to find out which numbering system you are expected to know. Objective 12

- **Groups 1 to 18**: The vertical columns can be numbered from 1 to 18. This text will use this numbering convention most often.
- **Groups A and B**: Some of the groups are also commonly described with a number and the letter A or B. For example, sometimes the group headed by N will be called group 15 and sometimes group 5A. The group headed by Zn can be called 12 or 2B. Because this convention is useful and is common, you will see it used in this text also. Some chemists use Roman numerals with the A- and B-group convention.

In short, the group headed by N can be 15, 5A, or VA. The group headed by Zn can be 12, 2B, or IIB.

The groups in the first two and last two columns are the ones that have names as well as numbers. You should learn these names; they are used often in chemistry. Objective 13



Most of the elements are classified as **metals**, which means they have the following characteristics.

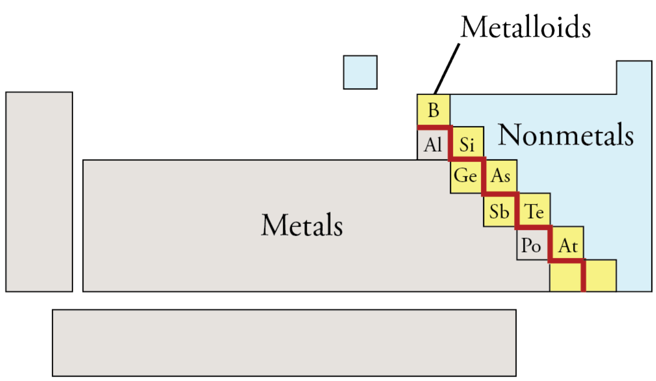
- Metals have a shiny metallic luster.
- Metals conduct heat well and in the solid form conduct electric currents. Objective 14
- Metals are **malleable**, which means they are capable of being extended or shaped by the blows of a hammer. (For example, gold, Au, can be hammered into very thin sheets without breaking.)

There is more variation in the characteristics of the **nonmetal** elements. Some of them are gases at room temperature and pressure, some are solids, and one is a liquid. They have different colors and different textures. The definitive quality shared by all nonmetals is that they do not have the characteristics mentioned above for metals. For example, sulfur is a dull yellow solid that does not conduct heat or electric currents well and is not malleable. It shatters into pieces when hit with a hammer.

Sulfur is brittle, not malleable. When solid sulfur is hammered, it shatters into many pieces (far right).

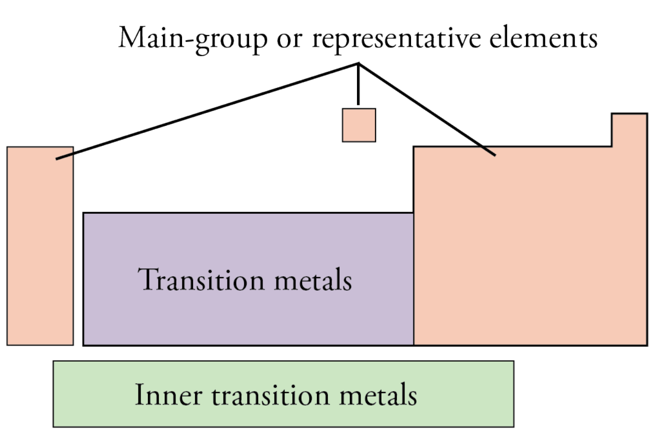
Gold, like other metals, is malleable; it can be hammered into thin sheets (far right).

A few of the elements have some but not all of the characteristics of metals. These elements are classified as **metalloids** or **semimetals**. Authorities disagree to some extent concerning which elements belong in this category, but the elements in yellow boxes in the image on the left are commonly classified as metalloids.



Objective 15

The portion of the periodic table that contains the metallic elements is shown here in gray, and the portion that contains the nonmetallic elements is shown in light blue. The stair-step line that starts between B and Al on the periodic table and descends between Al and Si, Si and Ge, and so on separates the metallic elements from the nonmetallic elements. The metals are below and to the left of this line, and the nonmetals are above and to the right of it. Most of the elements that have two sides of their box forming part of the stair-step line are metalloids. Aluminum and polonium are usually considered metals.



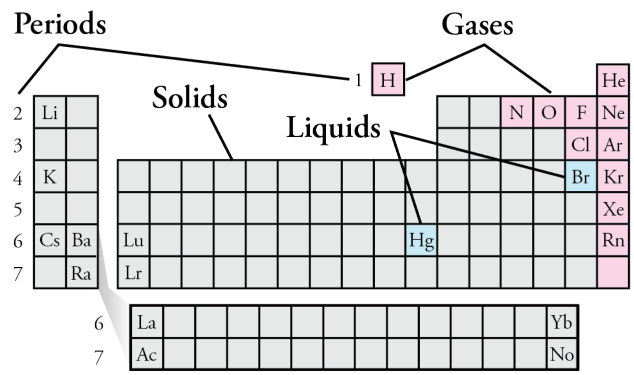
Objective 16

It is often useful to refer to whole blocks of elements on the periodic table. The elements in groups 1, 2, and 13 through 18 (the "A" groups) are sometimes called the **representative elements**. They are also called the **main-group elements**. The elements in groups 3 through 12 (the "B" groups) are often called the **transition metals**. The 28 elements at the bottom of the table are called **inner transition metals**.

The horizontal rows on the periodic table are called **periods**. There are seven periods in all. The first period contains only two elements, hydrogen[1], H, and helium, He. The second period contains eight elements: lithium, Li, through neon, Ne. The fourth period consists of eighteen elements: potassium, K, through krypton, Kr.

Objective 17

Note that the sixth period begins with cesium, Cs, which is element number 55, and barium, Ba, which is number 56, and then there is a gap which is followed by lutetium, Lu, element 71. The gap represents the proper location of the first row of the inner transition metals—that is, lanthanum, La, which is element number 57, through ytterbium, Yb, which is element 70. These elements belong in the sixth period. Similarly, the second row of inner transition metals, the elements actinium, Ac, through nobelium, No, belong in the seventh period between radium, Ra, and lawrencium, Lr.



At room temperature (20 °C) and normal pressures, most of the elements are solid, two of them are liquid (Hg and Br), and eleven are gas (H, N, O, F, Cl, and the noble gases).

Objective 18

Iodine is a solid, bromine is a liquid, and chlorine is a gas. Most elements are solid at room temperature.

[1] The symbol for hydrogen is placed in different positions on different periodic tables. On some, it is placed in group 1, and on other tables, it is found at the top of group 17. Although there are reasons for placing it in these positions, there are also reasons why it does not belong in either position. Therefore, on our periodic table, it is separate from both groups.

Exercise 2.1 - Elements and the Periodic Table

Objective 12
Objective 15
Objective 16
Objective 17
Objective 18

Complete the following table.

Name	Symbol	Group number	Metal, nonmetal, or metalloid?	Representative element, transition metal, or inner transition metal?	Number for period	Solid, liquid, or gas?[a]
	Al					
silicon						
	Ni					
sulfur						
	F					
potassium						
	Hg					
uranium		(no group number				
	Mn					
calcium						
		17			4	
		1B			5	
		14	nonmetal			

[a]At room temperature and pressure

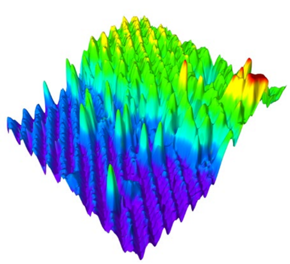
Exercise 2.2 - Group Names and the Periodic Table

Objective 13

Write the name of the group on the periodic table to which each of the following elements belongs.

a. helium
b. Cl
c. magnesium
d. Na

2.4 The Structure of the Elements



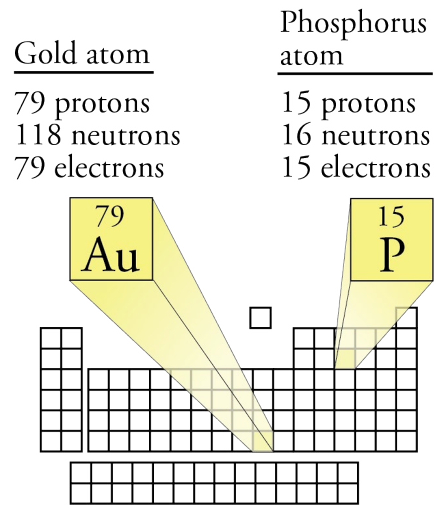
A Scanning Tunneling Microscope Image of Silicon Atoms
Created by Benjamin Grosser, Director of the Imaging Technology Group at the Beckman Institute from data supplied by Joe Lyding

What makes one element different from another? To understand the answer to this question, you need to know about their internal structure. If you were to cut a piece of pure gold in half, and then divide one of those halves in half again and divide one of those halves in half, and continue to do that over and over, eventually the portion remaining could not be further divided and still be gold. This portion is a gold atom. The element gold consists of gold atoms, the element carbon consists of carbon atoms, and so on. To understand what makes one element different from another, we need to look inside the atom.

The Atom

The **atom** is the smallest part of the element that retains the chemical characteristics of the element itself. (You will be better prepared to understand descriptions of the elements' chemical characteristics after reading more of this book. For now, it is enough to know that the chemical characteristics of an element include how it combines with other elements to form more complex substances.) For our purposes, we can think of the atom as a sphere with a diameter of about 10^{-10} meters. This is about a million times smaller than the diameter of the period at the end of this sentence. If the atoms in your body were an inch in diameter, you would have to worry about bumping your head on the moon.

Because atoms are so small, there are a tremendous number of them in even a small sample of an element. A ½-carat diamond contains about 5×10^{21} atoms of carbon. If these atoms, tiny as they are, were arranged in a straight line with each one touching its neighbors, the line would stretch from here to the sun.



If we could look inside the gold atom, we would find that it is composed of three types of particles: protons, neutrons, and electrons.[2] Every gold atom in nature, for example, has 79 protons, 79 electrons, and 118 neutrons. Gold is different from phosphorus, because natural phosphorus atoms have 15 protons, 15 electrons, and 16 neutrons.

The particles within the atom are *extremely* tiny. A penny weighs about 2.5 grams, and a neutron, which is the most massive of the particles in the atom, weighs only 1.6750×10^{-24} grams. The protons have about the same mass as the neutrons, but the electrons have about 2000 times less mass. Because the masses of the particles are so small, a more convenient unit of measurement has been devised for them. An **atomic mass unit** (also called the unified mass unit) is 1/12 the mass of a carbon atom that has 6 protons, 6 neutrons, and 6 electrons. The modern abbreviation for atomic mass unit is u, but amu is commonly used.

Objective 19

Protons have a positive charge, **electrons** have a negative charge, and **neutrons** have no charge. Charge, a fundamental property of matter, is difficult to describe. Most definitions focus less on what it *is* than on what it *does*. For example, we know that objects of opposite charge attract each other, and objects of the same charge repel each other. An electron has a charge that is opposite but equal in magnitude to the charge of a proton. We arbitrarily assign the electron a charge of −1, so the charge of a proton is considered to be +1.

The Nucleus

Objective 20

Modern atomic theory tells us that even though the protons and neutrons represent most of the *mass* of the atom, they actually occupy a very small part of the *volume* of the atom. These particles cling together to form the incredibly small core of the atom called the **nucleus**. Compared to the typical atom's diameter, which we described earlier as being about 10^{-10} meters, the diameter of a typical nucleus is about 10^{-15} meters. Thus, almost all the mass of the atom and all of its positive charge are found in a nucleus of about 1/100,000 the diameter of the atom itself. If an atom were the size of the earth, the diameter of the nucleus would be just a little longer than the length of a football field. If the nuclei of the atoms in your body were about an inch in diameter, you'd have to stand on the dark side of the earth to avoid burning your hair in the sun.

[2] The physicists will tell you that the proton and neutron are themselves composed of simpler particles. Because it is not useful to the chemist to describe atoms in terms of these more fundamental particles, they will not be described here.

The Electron

If I seem unusually clear to you, you must have misunderstood what I said.

Alan Greenspan, former head of the Federal Reserve Board

Objective 20

It is probably as meaningless to discuss how much room an electron takes up as to discuss how much room a fear, an anxiety, or an uncertainty takes up.

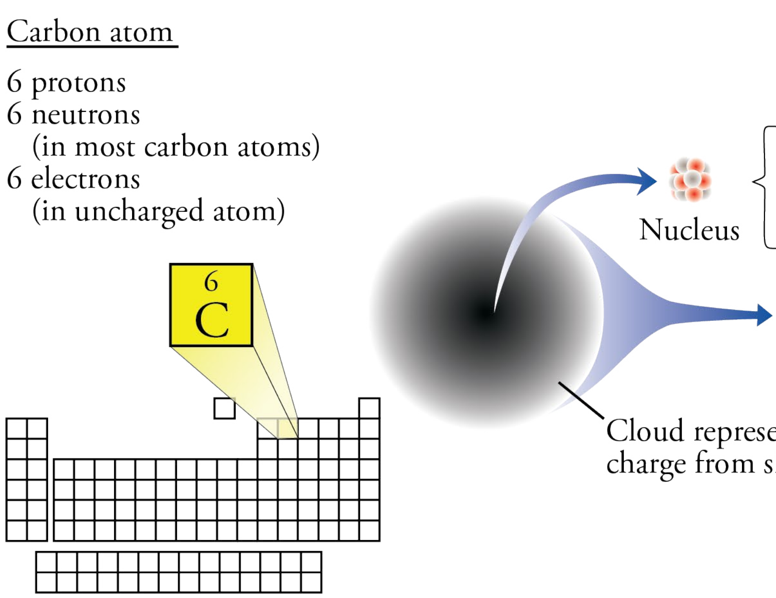
Sir James Hopwood Jeans,
English mathematician, physicist and astronomer
(1877-1946)

Describing the modern view of the electron may not be as difficult as explaining the U.S. Federal Reserve Board's monetary policy, but it is still a significant challenge. We do *not* think that electrons are spherical particles orbiting around the nucleus like planets around the sun. Scientists agree that electrons are outside the nucleus, but how to describe what they are doing out there or even what they *are* turns out to be a difficult task. Until the nature of electrons is described in more detail in Chapter 11, we will disregard the question of what electrons are and how they move and focus our attention only on the negative charge that they generate. We can visualize each electron as generating a cloud of negative charge that surrounds the nucleus. In Figure 2.8, we use the element carbon as an example.

Most of the carbon atoms in a diamond in a necklace have 6 protons, 6 neutrons, and 6 electrons. The protons and neutrons are in the nucleus, which is surrounded by a cloud of negative charge created by the 6 electrons. You will learn more about the shapes and sizes of different atoms' electron clouds in Chapter 11. For now, we will continue to picture the electron clouds of all the atoms as spherical (Figure 2.8).

Figure 2.8
The Carbon Atom

Objective 19 Objective 20 Objective 21



Particle	Charge	Mass
proton	+1	1.00728 u (1.6726×10^{-24} g)
neutron	0	1.00867 u (1.6750×10^{-24} g)
e^- electron	−1	0.000549 u (9.1096×10^{-28} g)

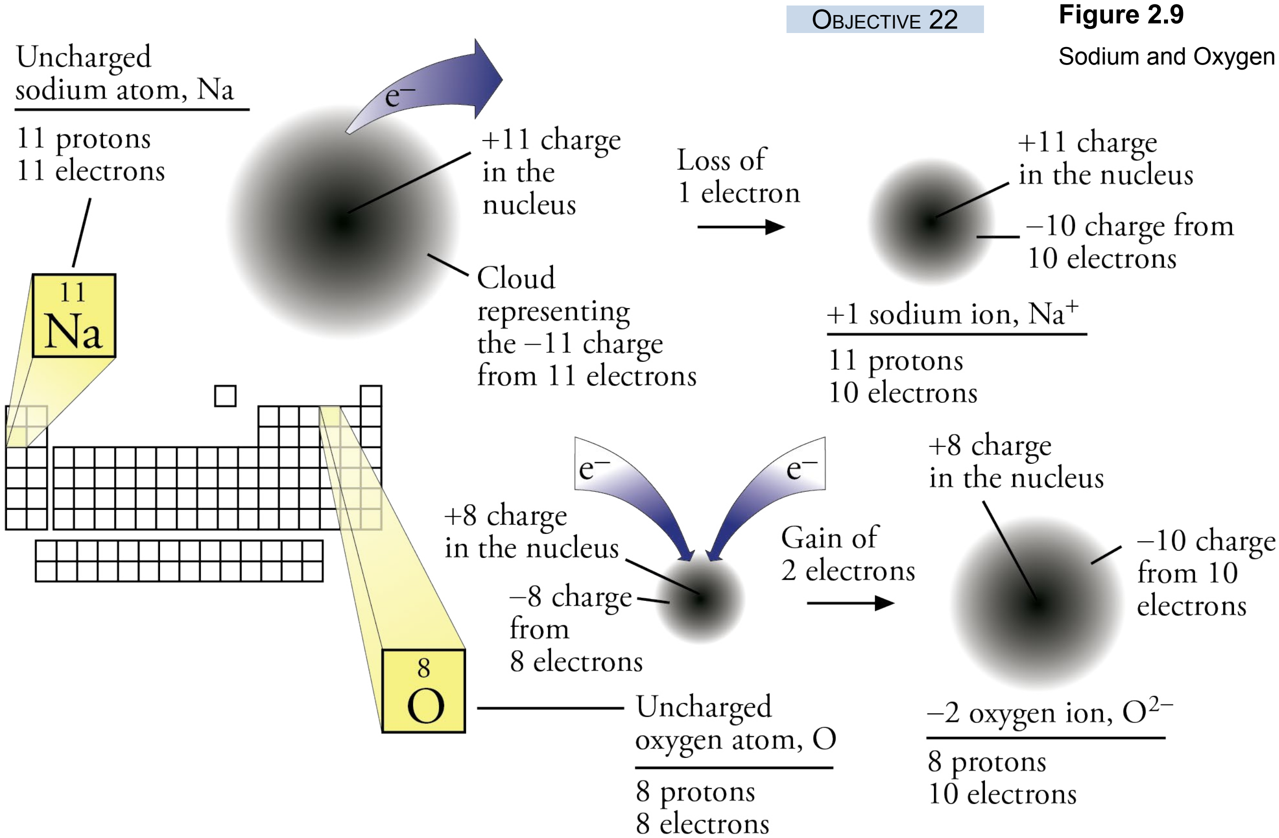
Ions

Sometimes, when the elements form more complex substances, their atoms lose or gain electrons. Before this change, the atoms have an equal number of protons and electrons, and because protons and electrons have an equal but opposite charge, these atoms are initially uncharged overall. When an uncharged atom gains or loses one or more electrons, it forms a charged particle, called an **ion**. For example, when an atom loses one or more electrons, it will have more protons than electrons and more plus charge than minus charge. Thus, it will have an overall positive charge. An atom that becomes a positively charged ion is called a **cation**. For example, uncharged sodium atoms have 11 protons and 11 electrons. They commonly lose one of these electrons to form +1 cations. A sodium cation's overall charge is +1 because its 11 protons have a charge of +11, and its remaining 10 electrons have a charge of −10. The sum of +11 and −10 is +1 (Figure 2.9). The symbol for a specific cation is written with the charge as a superscript on the right side of the element symbol. If the charge is +1, the convention is to write + (without the 1), so the symbol for the +1 sodium cation is Na^+. Aluminum atoms commonly lose 3 of their electrons to form +3 cations. The cations are +3 because each aluminum cation has a charge of +13 from its 13 protons and a charge of −10 from its 10 remaining electrons. The sum is +3. The symbol for this cation is Al^{3+}. (Notice that the 3 comes before the +.) OBJECTIVE 22

Some atoms can gain electrons. When an atom gains one or more electrons, it will have more electrons than protons and more minus charge than plus charge. An atom that becomes negatively charged due to an excess of electrons is called an **anion**, a negatively charged ion. For example, uncharged chlorine atoms have 17 protons and 17 electrons. They commonly gain 1 electron to form −1 anions. The anions are −1 because their 17 protons have a charge of +17, and their 18 electrons have a charge of −18, giving a sum of −1. The anion's symbol is Cl^-, again without the 1. As illustrated in Figure 2.9, oxygen atoms commonly form anions with a −2 charge, O^{2-}, by gaining 2 electrons and therefore changing from eight protons and 8 electrons to 8 protons (+8) and ten electrons (−10). OBJECTIVE 22

OBJECTIVE 22

Figure 2.9
Sodium and Oxygen Ions



Example 2.1 - Cations and Anions

Objective 22

Identify each of the following as a cation or an anion, and determine the charge on each.

a. A nitrogen atom with 7 protons and 10 electrons.
b. A gold atom with 79 protons and 78 electrons.

Solution

a. 7 protons have a +7 charge, and 10 electrons have a −10 total charge for a sum of **−3**. Therefore, a nitrogen atom with 7 protons and 10 electrons is an **anion**.
b. 79 protons have a total charge of +79, and 78 electrons have a −78 total charge for a sum of **+1**. Therefore, a gold atom with 79 protons and 78 electrons is a **cation**.

Exercise 2.3 - Cations and Anions

Objective 22

Identify each of the following as a cation or an anion, and determine the charge on each.

a. a magnesium atom with 12 protons and 10 electrons.
b. a fluorine atom with 9 protons and 10 electrons.

Isotopes

Although all of the atoms of a specific element have the same number of protons (and the same number of electrons in uncharged atoms), they do not necessarily all have the same number of neutrons. For example, when the hydrogen atoms in a normal sample of hydrogen gas are analyzed, we find that of every 5000 atoms, 4999 have 1 proton and 1 electron, but 1 in 5000 of these atoms has 1 proton, 1 neutron, and 1 electron. This form of hydrogen is often called deuterium. Moreover, if you collected water from the cooling pond of a nuclear power plant, you would find that a very small fraction of its hydrogen atoms have 1 proton, 2 neutrons, and 1 electron (Figure 2.10). This last form of hydrogen, often called tritium, is unstable and therefore radioactive.

All of these atoms are hydrogen atoms because they have the chemical characteristics of hydrogen. For example, they all combine with oxygen atoms to form water. The chemical characteristics of an atom are determined by its number of protons (which is equal to the number of electrons if the atom is uncharged) and not by its number of neutrons. Because atoms are assigned to elements based on their chemical characteristics, an **element** can be defined as a substance whose atoms have the same number of protons. When an element has two or more species of atoms, each with the same number of protons but a different number of neutrons, the different species are called **isotopes**.

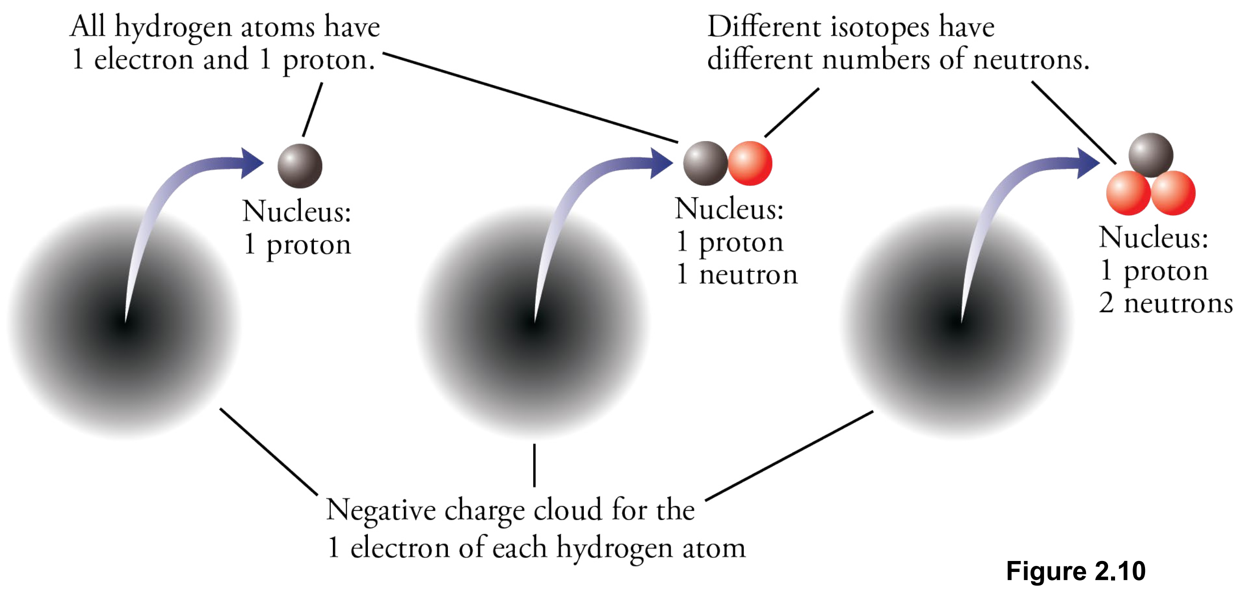


Figure 2.10
Isotopes of Hydrogen

Atomic Number and Mass Number

Objective 23

The number of protons in an atom—which is also the number of electrons in an uncharged atom—is known as the element's **atomic number**. The atomic number can be found above each of the elements' symbols on the periodic table. Because it displays the atomic numbers, the periodic table can be used to determine the number of protons and electrons in an uncharged atom of any element. For example, the atomic number of phosphorus is 15, so we know there are 15 protons and 15 electrons in each uncharged atom of phosphorus.

The sum of the numbers of protons and neutrons in the nucleus of an atom is called the atom's **mass number**. **Isotopes** have the same atomic number but different mass numbers. To distinguish one isotope from another, the symbol for the element is often followed by the mass number of the isotope. For example, the mass number of the most common isotope of hydrogen, with one proton and no neutrons, is 1, so its symbol is H-1. The other natural isotope of hydrogen, with one proton and one neutron, has a mass number of 2 and a symbol of H-2. Tritium, H-3, the radioactive form of hydrogen, has a mass number of 3. All of these isotopes of hydrogen have an atomic number of 1.

Nineteen of the elements found in nature have only one naturally occurring form. For example, all the aluminum atoms found in nature have 13 protons and 14 neutrons. Their mass number is 27.

Number of Protons	+	Number of Neutrons	=	Mass Number
13	+	14	=	27

The other naturally occurring elements are composed of more than one isotope. For example, in a sample of the element tin, Sn, all the atoms have 50 protons, but tin atoms can have 62, 64, 65, 66, 67, 68, 69, 70, 72, or 74 neutrons. Thus tin has 10 natural isotopes with mass numbers of 112, 114, 115, 116, 117, 118, 119, 120, 122, and 124 (Figure 2.11).

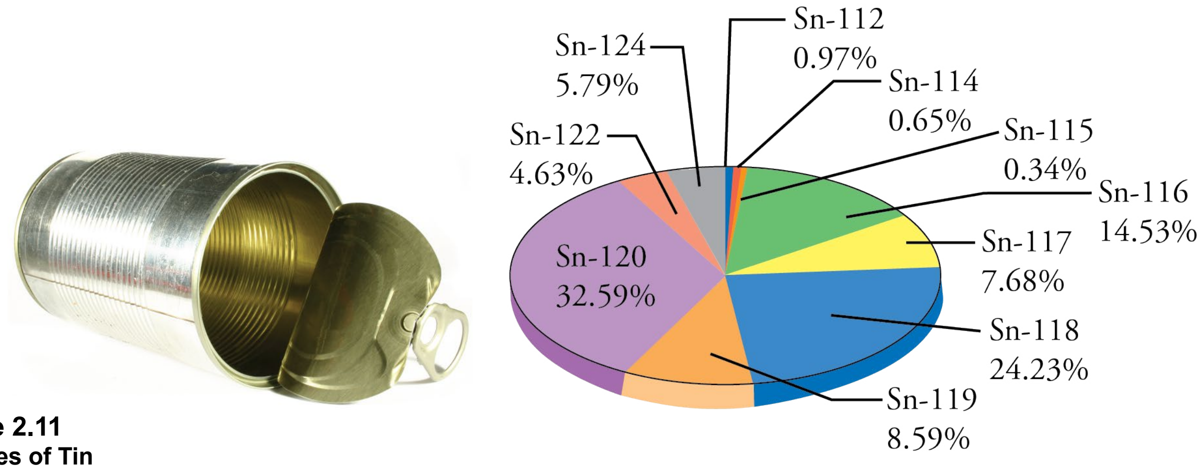


Figure 2.11
Isotopes of Tin
The tin in this tin can is composed of ten different isotopes.

Learn about a special notation used to describe isotopes at the textbook's Web site.

SPECIAL TOPIC 2.1 Why Create New Elements?

At the Gesellschaft fur Schwerionenforschung (GSI), or Society for Heavy-Ion Research, in Germany, scientists create new elements by bombarding one kind of atom with another kind in the expectation that some of them will fuse. For example, for two weeks in 1994, the scientists bombarded a lead-208 target with a beam of nickel-62 atoms, producing four atoms of element 110, with a mass number of 269. Likewise, during 18 days in December of that year, they bombarded a bismuth-209 target with nickel-64 atoms, creating three atoms of element 111, with a mass number of 272.

Some of the best minds in physics are working on such projects, and spending large amounts of money on the necessary equipment. Yet the newly created atoms are so unstable that they decay into other elements in less than a second. Do these results justify all of the time, money, and brainpower being poured into them? Would scientists' efforts be better spent elsewhere? Why do they do it?

One of the reasons these scientists devote themselves to the creation of new elements is to test their theories about matter. For example, the current model being used to describe the nucleus of the atom suggests there are "magic" numbers of protons and neutrons that lead to relatively stable isotopes. The numbers 82, 126, and 208 are all magic numbers, exemplified by the extreme stability of lead-208, which has 82 protons and 126 neutrons. Other magic numbers suggest that an atom with 114 protons and 184 neutrons would also be especially stable. Researchers at the Flerov Laboratory of Nuclear Reactions in Dubna, Russia, were able to make two isotopes of element 114 (with 173 and 175 neutrons) by bombarding plutonium targets with calcium atoms. Both isotopes, particularly the heavier one, were significantly more stable than other isotopes of comparable size.

The technology developed to create these new elements is also being used for medical purposes. In a joint project with the Heidelberg Radiology Clinic and the German Cancer Research Center, GSI has constructed a heavy-ion therapy unit for the treatment of inoperable cancers. Here, the same equipment used to accelerate beams of heavy atoms toward a target in order to make new elements is put to work shooting beams of carbon atoms at tumors. When used on deep-seated, irradiation-resistant tumors, the carbon-particle beam is thought to be superior to the traditional radiation therapy. Because the heavier carbon atoms are less likely to scatter, and because they release most of their energy at the end of their path, they are easier to focus on the cancerous tumor.

2.5 Common Elements

Most people look at a gold nugget and see a shiny metallic substance that can be melted down and made into jewelry. A chemist looks at a substance such as gold and visualizes the internal structure responsible for those external characteristics. Now that we have discussed some of the general features of atoms and elements, we can return to the model of solid, liquid, and gas structures presented in Section 2.1 and continue in our quest to visualize the particle nature of matter.

Gas, Liquid, and Solid Elements

In Section 2.1, we pictured gases as independent spherical particles moving in straight-line paths in a container that is mostly empty space. This image is most accurate for the noble gases (He, Ne, Ar, Kr, Xe, and Rn): each noble gas particle consists of a single atom. When we picture the helium gas in a helium-filled balloon, each of the particles in our image is a helium atom containing two protons and two neutrons in a tiny nucleus surrounded by a cloud of negative charge generated by two electrons (Figure 2.12).

Objective 24

Figure 2.12
Helium Gas

Objective 24

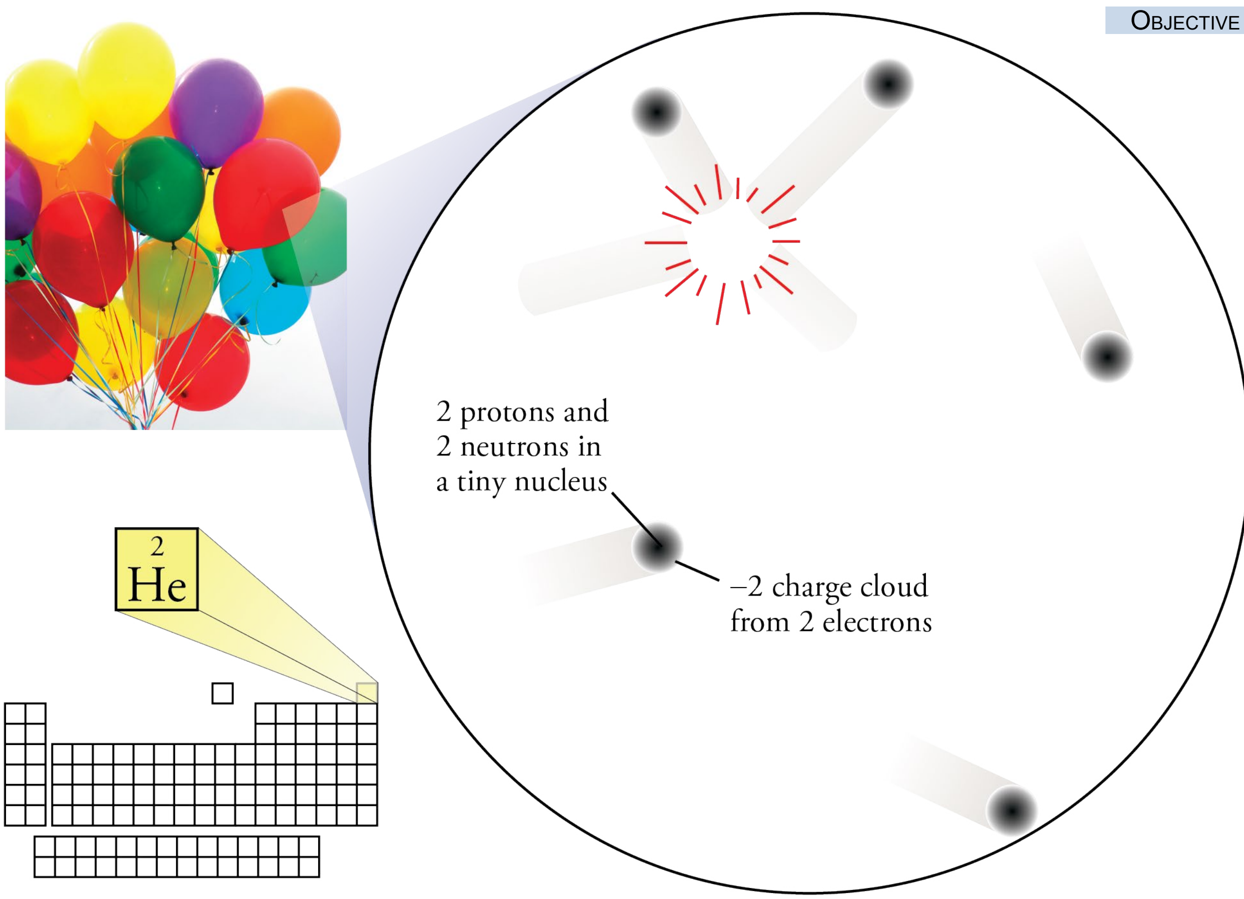
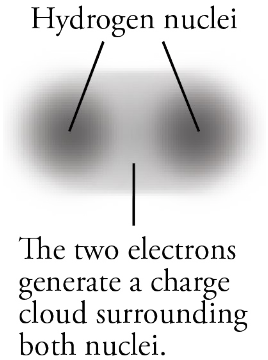
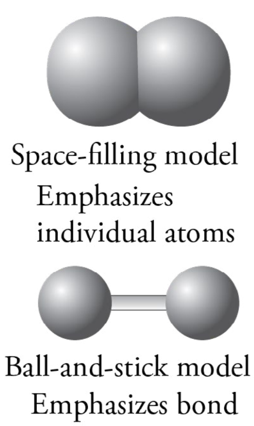


Figure 2.13
Hydrogen Electron Cloud



Objective 25

Figure 2.14
Molecular Models



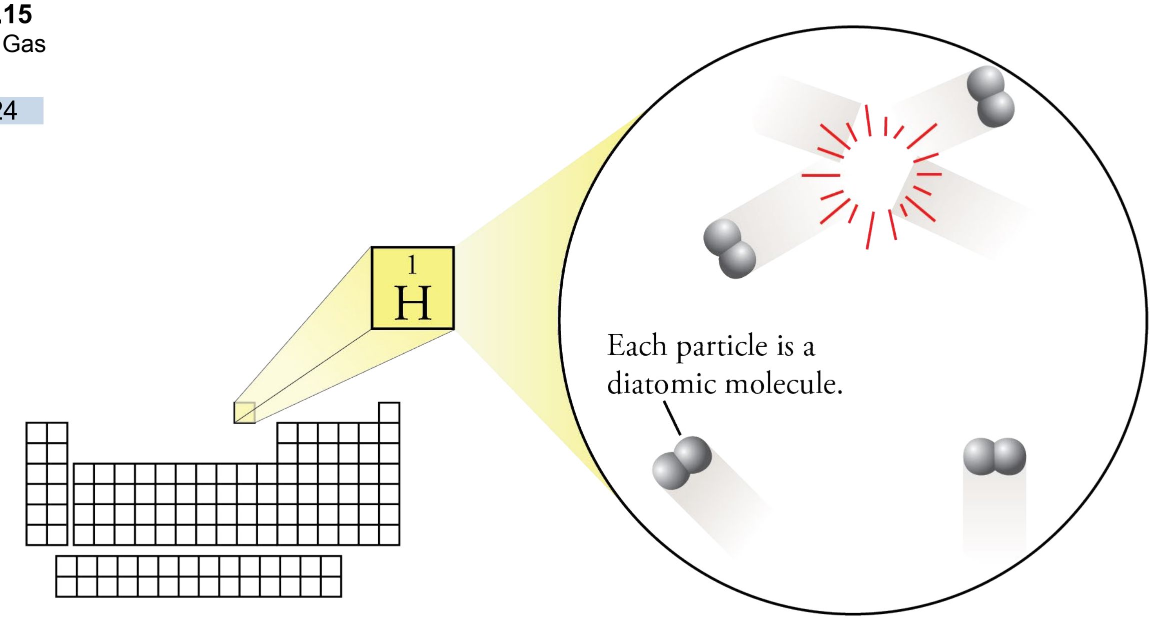
The particles in hydrogen gas are quite different. Instead of the single atoms found in helium gas, the particles in hydrogen gas are pairs of hydrogen atoms. Each hydrogen atom has only one electron, and single, or "unpaired," electrons are less stable than electrons that are present as pairs. (*Stability* is a relative term that describes the resistance to change. A stable system is less likely to change than an unstable system.) To gain the greater stability conferred by pairing, the single electron of one hydrogen atom can pair up with a single electron of another hydrogen atom. The two electrons are then shared between the two hydrogen atoms and create a bond that holds the atoms together. Thus hydrogen gas is described as H_2. We call this bond between atoms due to the sharing of two electrons a **covalent bond**. The pair of hydrogen atoms is a **molecule**, which is an uncharged collection of atoms held together with covalent bonds. Two hydrogen atoms combine to form one hydrogen molecule.

The negative charge-cloud created by the electrons in the covalent bond between hydrogen atoms surrounds both of the hydrogen nuclei (Figure 2.13). Even though the shape depicted in Figure 2.13 is a better description of the H_2 molecule's electron cloud, there are two other common ways of illustrating the H_2 molecule. The first image in Figure 2.14 shows a **space-filling model**. This type of model emphasizes individual atoms in the molecule more than the image in Figure 2.13 does but still provides a somewhat realistic idea of the electron-charge clouds that surround the atoms. The second image in Figure 2.14 is a **ball-and-stick model**, in which balls represent atoms and sticks represent covalent bonds. This model gives greater emphasis to the bond that holds the hydrogen atoms together.

Combining space-filling molecular models with our gas model, Figure 2.15 depicts hydrogen gas as being very similar to helium gas, except each of the particles is a hydrogen molecule.

Figure 2.15
Hydrogen Gas

Objective 24



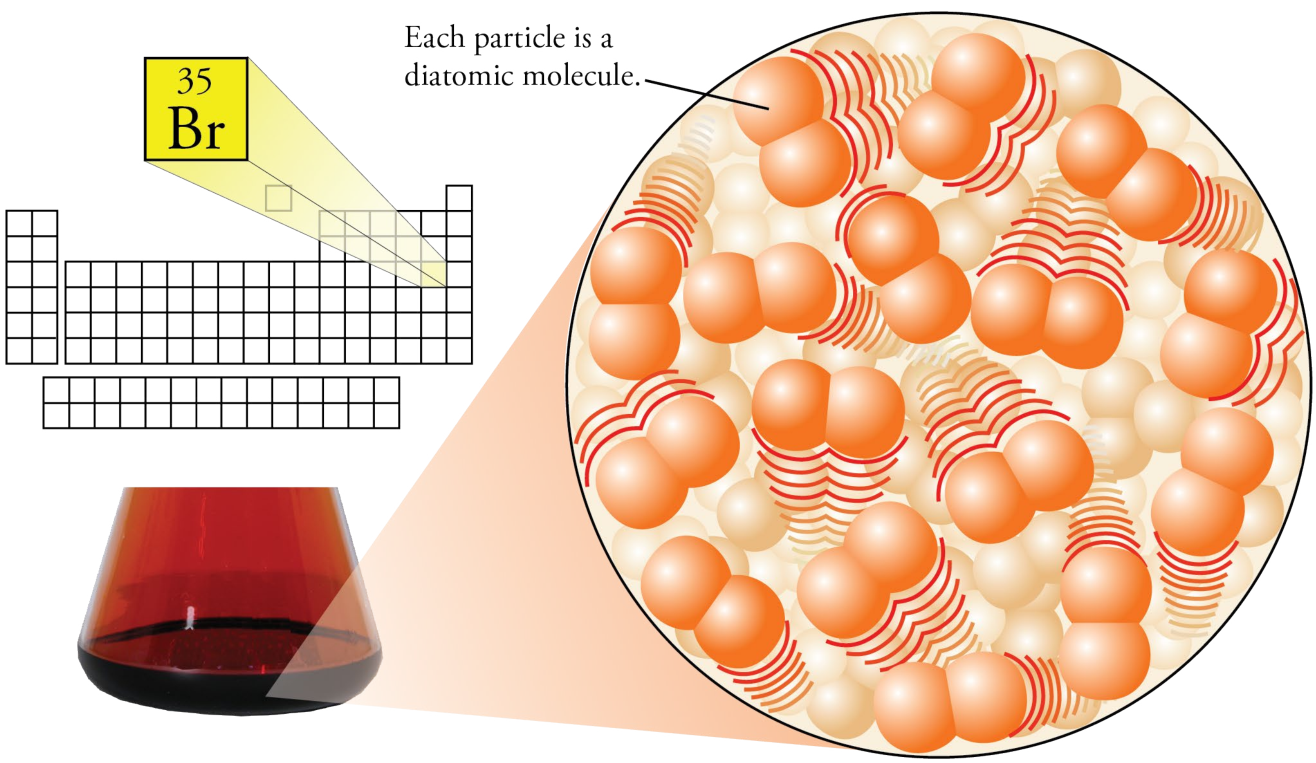
Because hydrogen molecules are composed of two atoms, they are called **diatomic**. The elements nitrogen, oxygen, fluorine, chlorine, bromine, and iodine are also composed of diatomic molecules, so they are described as N_2, O_2, F_2, Cl_2, Br_2, and I_2. Like the hydrogen atoms in H_2 molecules, the two atoms in each of these molecules are held together by a covalent bond that is due to the sharing of two electrons. Nitrogen, oxygen, fluorine, and chlorine are gases at room temperature and pressure, so a depiction of gaseous N_2, O_2, F_2, and Cl_2 would be very similar to the image of H_2 in Figure 2.15.

Objective 26

Bromine, which is a liquid at room temperature, is pictured like the liquid shown in Figure 2.2, except that each of the particles is a diatomic molecule (Figure 2.16).

Objective 24

Figure 2.16
Liquid Bromine, Br_2



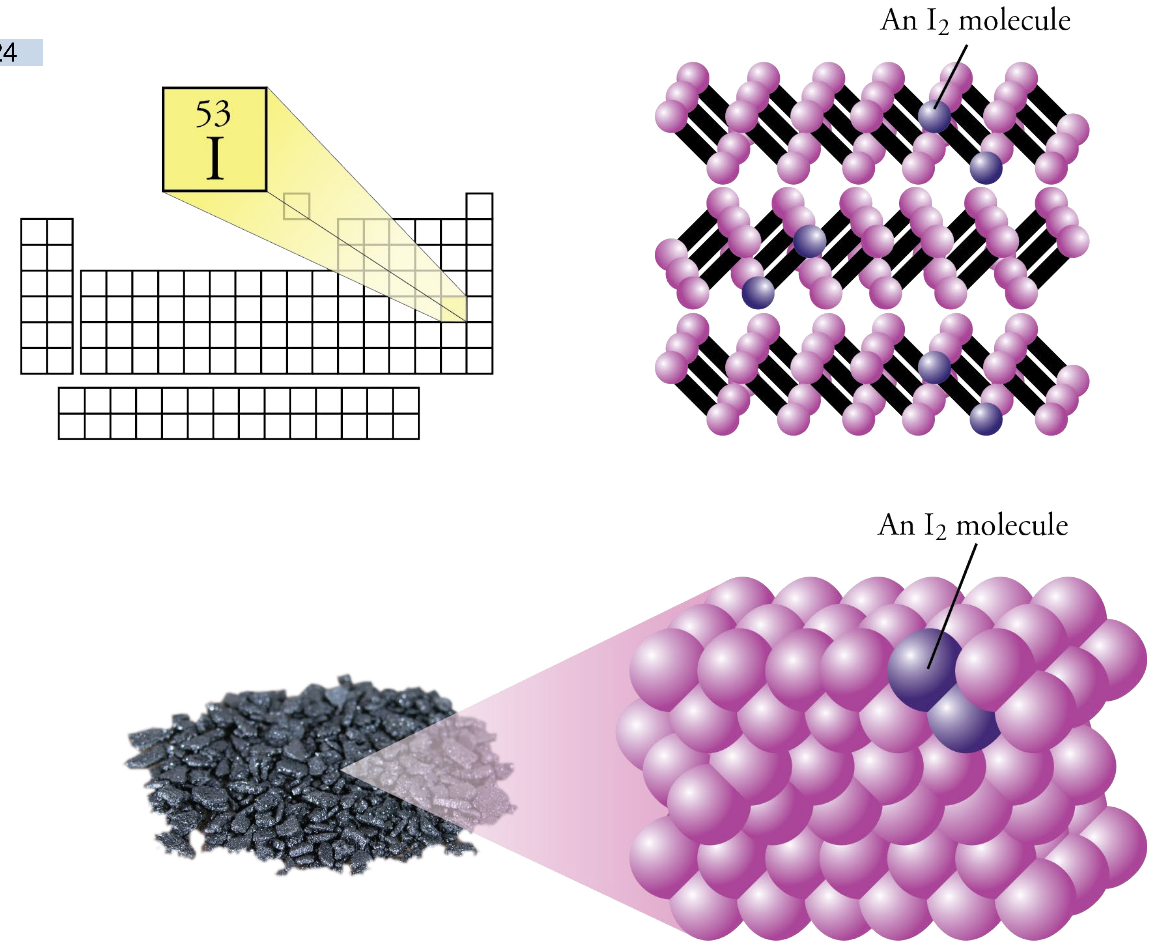
Solid iodine consists of a very ordered arrangement of I_2 molecules. In order to give a clearer idea of this arrangement, the first image in Figure 2.17 on the next page shows each I_2 molecule as a ball-and-stick model. The second image shows the close packing of these molecules in the iodine solid. Remember that the particles of any

Objective 24

substance, including solid iodine, are in constant motion. The solid structure presented in Figure 2.1 applies to iodine, except we must think of each particle in it as being an I_2 molecule.

Figure 2.17
Solid Iodine, I_2

Objective 24



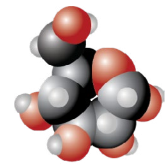
You can review the information in this section and see particles of neon, oxygen, bromine, and iodine in motion at the textbook's Web site.

Metallic Elements

The metallic elements are used for a lot more than building bridges and making jewelry. Platinum is used in a car's catalytic converter to help decrease air pollution. Titanium is mixed with other metals to construct orthopedic appliances, such as artificial hip joints. Zinc is used to make dry cell batteries. Some of the characteristics of metallic elements that give them such wide applications can be explained by an *expanded* version of the model of solids presented in Section 2.1. (One of the characteristics of a useful model is that it can be expanded to describe, explain, and predict a greater variety of phenomena.)

Objective 27

According to the expanded model, each atom in a metallic solid has released one or more electrons, and these electrons move freely throughout the solid. When the atoms lose the electrons, they become cations. The cations form the structure we associate with solids, and the released electrons flow between them like water flows between islands in the ocean. This model, often called the *sea of electrons* model, can be used to explain some of the definitive characteristics of metals. For example, the freely moving electrons make metallic elements good conductors of electric currents.

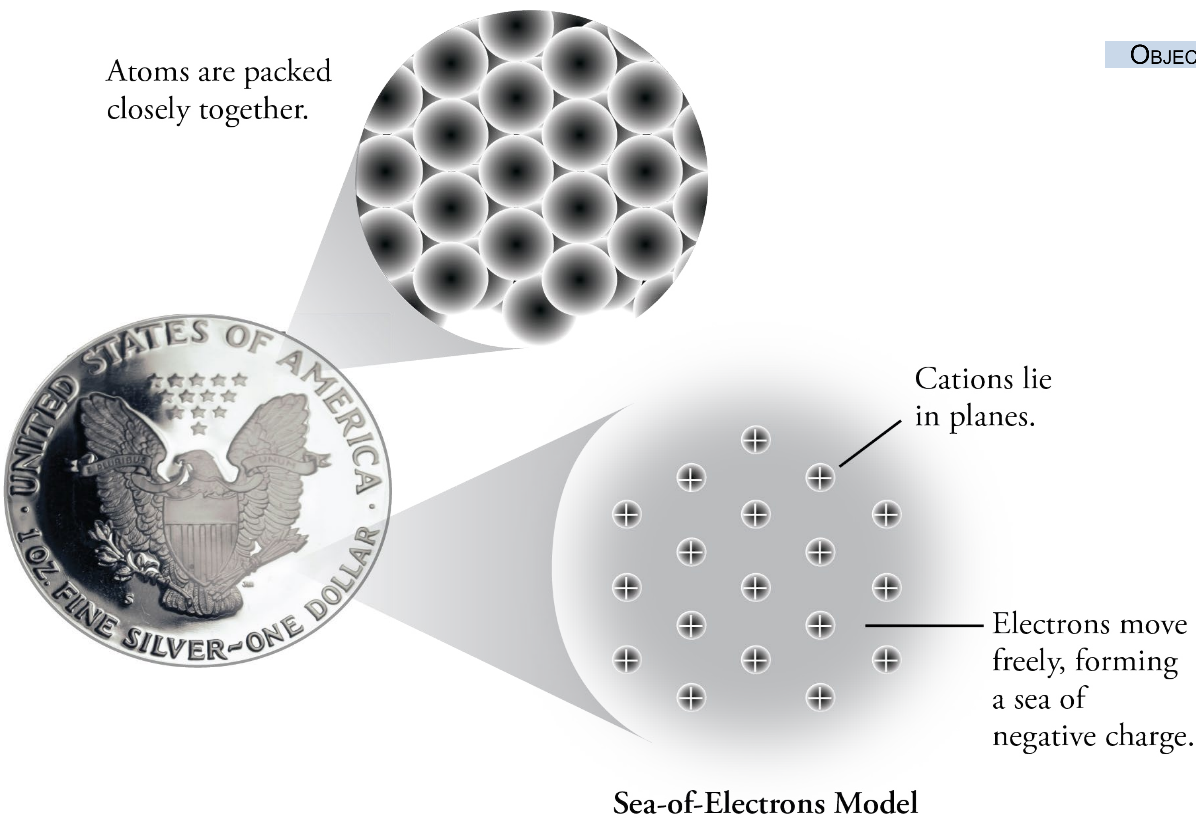


Web Structures

Figure 2.18 shows a typical arrangement of atoms in a metallic solid and also shows how you might visualize one plane of this structure. Try to picture a cloud of negative charge, produced by mobile electrons, surrounding the cations in the solid.

Figure 2.18
Typical Structure of a Metallic solid

Objective 27



You have just completed your first big step on the road to understanding chemistry. The new knowledge of the elements that you have gained from this chapter will help you with Chapter 3, where you will learn how elements combine to form more complex substances. An understanding of elements and the substances they form will prepare you to learn about the chemical changes that these substances undergo in yourself and in the world around you.

Chapter Glossary

Model A simplified approximation of reality.

Solid The state in which a substance has a definite shape and volume at a constant temperature.

Liquid The state in which a substance has a constant volume at a constant temperature but can change its shape.

Gas The state in which a substance can easily change shape and volume.

Evaporation or vaporization The conversion of a liquid to a gas.

Element A substance that cannot be chemically converted into simpler substances; a substance in which all of the atoms have the same number of protons and therefore the same chemical characteristics.

Group All the elements in a given column on the periodic table; also called a *family*.

Family All the elements in a given column on the periodic table; also called a *group*.

Metals The elements that (1) have a metallic luster, (2) conduct heat and electric currents well, and (3) are malleable.

Malleable Capable of being extended or shaped by the blows of a hammer.

Nonmetals The elements that do not have the characteristics of metals. Some of the nonmetals are gases at room temperature and pressure, some are solids, and one is a liquid. Various colors and textures occur among the nonmetals.

Metalloids or semimetals The elements that have some but not all of the characteristics of metals.

Representative elements The elements in groups 1, 2, and 13 through 18 (the "A" groups) on the periodic table; also called *main-group elements*.

Main-group elements The elements in groups 1, 2, and 13 through 18 (the "A" groups) on the periodic table; also called *representative elements*.

Transition metals The elements in groups 3 through 12 (the "B" groups) on the periodic table.

Inner transition elements The 28 elements at the bottom of the periodic table.

Periods The horizontal rows on the periodic table.

Atom The smallest part of an element that retains the chemical characteristics of the element.

Atomic mass unit (u or amu) Unit of measurement for the masses of particles; 1/12 the mass of a carbon atom that has 6 protons, 6 neutrons, and 6 electrons.

Proton A positively charged particle found in the nucleus of an atom.

Electron A negatively charged particle found outside the nucleus of an atom.

Neutron An uncharged particle found in the nucleus of an atom.

Nucleus The extremely small, positively charged core of the atom.

Ion Any charged particle, whether positively or negatively charged.

Cation An ion formed from an atom that has lost one or more electrons and thus has become positively charged.

Anion An ion formed from an atom that has gained one or more electrons and thus has become negatively charged.

Isotopes Atoms that have the same number of protons but different numbers of neutrons. They have the same atomic number but different mass numbers.

Atomic number The number of protons in an atom's nucleus. It establishes the element's identity.

Mass number The sum of the number of protons and neutrons in an atom's nucleus.

Covalent bond A link between atoms that results from their sharing two electrons.

Molecule An uncharged collection of atoms held together with covalent bonds.

Space-filling model A way of representing a molecule to show a somewhat realistic image of the electron-charge clouds that surround the molecule's atoms.

Ball-and-stick model A representation of a molecule that uses balls for atoms and sticks for covalent bonds.

Diatomic Composed of paired atoms. The diatomic elements are H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2.

You can test yourself on the glossary terms at the textbook's Web site.

Chapter Objectives

The goal of this chapter is to teach you to do the following.

1. Define all of the terms in the Chapter Glossary.

Section 2.1 Solids, Liquids, and Gases

2. Describe solids, liquids, and gases in terms of the particle nature of matter, the degree of motion of the particles, and the degree of attraction between the particles.
3. Describe the relationship between temperature and particle motion.
4. Explain why solids have a definite shape and volume at a constant temperature.
5. Explain why solids usually expand when heated.
6. Describe the structural changes that occur when a solid is converted into a liquid by heating.
7. Explain why most substances expand when they change from a solid to a liquid.
8. Explain why liquids adjust to take the shape of their container and why they have a constant volume at a constant temperature.
9. Describe the structural changes that occur in the conversion of a liquid to a gas.
10. Explain why gases expand to take the shape and volume of their container.

Section 2.2 The Chemical Elements

11. Give the names and symbols for the common elements. (Check with your instructor to find out which names and symbols you need to know.)

Section 2.3 The Periodic Table of the Elements

12. Given a periodic table, identify the number of the group to which each element belongs. (Check with your instructor to find out which numbering system you are expected to know.)

13. Given a periodic table, identify the alkali metals, alkaline earth metals, halogens, and noble gases.
14. List the characteristics of metals.
15. Given a periodic table, classify each element as a metal, nonmetal, or metalloid (semimetal).
16. Given a periodic table, classify each element as a representative element (or main-group element), a transition metal, or an inner transition metal.
17. Given a periodic table, write or identify the number of the period on the table to which each element belongs.
18. Classify each element as a solid, liquid, or gas at room temperature.

Section 2.4 The Structure of the Elements

19. Give the abbreviations, charges, and *relative* masses of protons, neutrons, and electrons.
20. Describe the nuclear model of the atom, including the general location of the protons, neutrons, and electrons, the relative size of the nucleus compared to the size of the atom, and the modern description of the electron.
21. Describe the carbon atom, including a rough sketch that shows the negative charge created by its electrons.
22. Given the number of protons and electrons in a cation or anion, determine its charge.
23. Given an isotope's atomic number, state the number of protons in each of its atoms, and vice versa.

Section 2.5 Common Elements

24. Describe the following substances in terms of the nature of the particles that form their structure: the noble gases, hydrogen gas, nitrogen gas, oxygen gas, fluorine gas, chlorine gas, bromine liquid, and iodine solid.
25. Describe the hydrogen molecule, including a rough sketch of the charge cloud created by its electrons.
26. List the diatomic elements (H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2).
27. Describe the "sea of electrons" model for metallic structure.

Review Questions

1. Define the term matter.
2. Look around you. What do you see that has a length of about a meter? What do you see that has a mass of about a gram?

Key Ideas

Complete the following statements by writing one of these words or phrases in each blank.

10^{-10}	gas
10^{-15}	liquid
1/100,000	loses
28	molecule
118	motion
0.1%	neutrons
70%	particles
99.9%	protons
atomic numbers	rapid, ever-changing, and unrestricted
attract	repel
chemical	simplified but useful
cloud	simpler
empty space	single atom
escape	solid
expand	straight-line path
expands	sun
extended or shaped	temperature
flow	ten times
gains	vertical column

3. Scientific models are like architects' models; they are ______________ representations of something real.
4. According to the model presented in this chapter, all matter is composed of tiny ______________.
5. According to the model presented in this chapter, particles of matter are in constant ______________.
6. According to the model presented in this chapter, the amount of motion of particles is proportional to ______________.
7. Solids, gases, and liquids differ in the freedom of motion of their particles and in how strongly the particles ______________ each other.
8. An increase in temperature usually causes a solid to ______________ somewhat.
9. Particles in a liquid are still close together, but there is generally more ______________ between them than in a solid. Thus, when a solid substance melts to form a liquid, it usually ______________ to fill a slightly larger volume.
10. The freedom of movement of particles in a liquid allows liquids to ______________, taking on the shape of their container.
11. When a liquid's temperature is higher, its particles are moving faster and are therefore more likely to ______________ from the liquid.
12. The average distance between particles in a gas is about ______________ the diameter of each particle. This leads to the gas particles themselves taking up only about ______________ of the total volume. The other ______________ of the total volume is empty space. In contrast, the particles of a liquid fill about ______________ of the liquid's total volume.

13. According to our model, each particle in a gas moves freely in a(n) ______________ until it collides with another gas particle or with the particles of a liquid or solid.
14. A liquid has a constant volume, but the ______________ movement of the gas particles allows gases to expand to fill a container of any shape or volume.
15. Elements are substances that cannot be chemically converted into ______________ ones.
16. By the year 2014, ______________ elements had been discovered, but ______________ of these elements are not found naturally on the earth, and chemists do not generally work with them.
17. The periodic table is arranged in such a way that elements in the same ______________ have similar characteristics.
18. Metals are malleable, which means they are capable of being ______________ by the blows of a hammer.
19. At room temperature (20 °C) and normal pressures, most of the elements are ______________, two of them are ______________ (Hg and Br), and eleven are ______________ (H, N, O, F, Cl, and the noble gases).
20. For our purposes, we can think of the atom as a sphere with a diameter of about ______________ meter.
21. A ½-carat diamond contains about 5×10^{21} atoms of carbon. If these atoms, tiny as they are, were arranged in a straight line with each one touching its neighbors, the line would stretch from here to the ______________.
22. We know that objects of opposite charge attract each other and that objects of the same charge ______________ each other.
23. The diameter of a typical nucleus is about ______________ meter.
24. Nearly all the mass of the atom and all of its positive charge are found in a nucleus of about ______________ the diameter of the atom itself.
25. Chemists use a model for electrons in which each electron is visualized as generating a(n) ______________ of negative charge that surrounds the nucleus.
26. When an atom ______________ one or more electrons, it will have more protons than electrons and more plus charge than minus charge. Thus it becomes a cation, which is an ion with a positive charge.
27. When an atom ______________ one or more electrons, it then has more electrons than protons and more minus charge than plus charge. Thus it becomes an anion, which is an ion with a negative charge.
28. Although all of the atoms of a specific element have the same number of ______________ (and the same number of electrons in uncharged atoms), they do not necessarily all have the same number of ______________.
29. Atoms are assigned to elements on the basis of their ______________ characteristics.
30. Because it displays the ______________, the periodic table can be used to determine the number of protons and electrons in an uncharged atom of any element.
31. Each noble gas particle consists of a(n) ______________.
32. Hydrogen gas is very similar to helium gas, except that each of the particles is a hydrogen ______________.

Chapter Problems

Section 2.1 Solids, Liquids, and Gases

For each of the questions in this section, illustrate your written answers with simple drawings of the particles that form the structures of the substances mentioned. You do not need to be specific about the nature of the particles. Think of them as simple spheres, and draw them as circles.

OBJECTIVE 2
OBJECTIVE 3
OBJECTIVE 4
OBJECTIVE 6

33. If you heat white sugar very carefully, it will melt.
  a. Before you begin to heat the sugar, the sugar granules maintain a constant shape and volume. Why?
  b. As you begin to heat the solid sugar, what changes are taking place in its structure?
  c. What happens to the sugar's structure when sugar melts?

OBJECTIVE 5

34. If the pistons and cylinders in your car engine get too hot, the pistons can get stuck in the cylinders, causing major damage to the engine. Why does this happen?

35. Ethylene glycol, an automobile coolant and antifreeze, is commonly mixed with water and added to car radiators. Because it freezes at a lower temperature than water and boils at a higher temperature than water, it helps to keep the liquid in your radiator from freezing or boiling.

OBJECTIVE 2
OBJECTIVE 3
OBJECTIVE 8
OBJECTIVE 9

  a. At a constant temperature, liquid ethylene glycol maintains a constant volume but takes on the shape of its container. Why?
  b. The ethylene glycol-water mixture in your car's radiator heats up as you drive. What is happening to the particles in the liquid?
  c. If you spill some engine coolant on your driveway, it evaporates without leaving any residue. Describe the process of evaporation of liquid ethylene glycol, and explain what happens to the ethylene glycol particles that you spilled.

OBJECTIVE 2
OBJECTIVE 9
OBJECTIVE 10

36. When a small container of liquid ammonia is opened in a classroom, in a short time everyone in the room can smell it.
  a. Describe the changes that take place when liquid ammonia vaporizes to form a gas.
  b. Why does the gaseous ammonia expand to fill the whole room?
  c. Why does the gaseous ammonia occupy a much greater volume than the liquid ammonia?

37. As the summer sun heats up the air at the beach, what is changing for the air particles?

38. A drop of food coloring is added to water. With time, it spreads evenly through the water so that the mixture is all the same color.
  a. Describe what is happening to the food coloring and water particles as the coloring spreads into the water.
  b. When a drop of food coloring is added to two bowls of water, one at 20 °C and the other at 30 °C, the coloring spreads more quickly in the bowl at the higher temperature. Why?

39. A gaseous mixture of air and gasoline enters the cylinders of a car engine and is compressed into a smaller volume before being ignited. Explain why gases can be compressed.

Section 2.2 The Chemical Elements and Section 2.3 The Periodic Table

Objective 11

40. Write the chemical symbols that represent the following elements.

a. chlorine
b. zinc
c. phosphorus
d. uranium

Objective 11

41. Write the chemical symbols that represent the following elements.

a. hydrogen
b. calcium
c. mercury
d. xenon

Objective 11

42. Write the chemical symbols that represent the following elements.

a. iodine
b. platinum
c. boron
d. gold

Objective 11

43. Write the element names that correspond to the following symbols.

a. C b. Cu c. Ne d. K

Objective 11

44. Write the element names that correspond to the following symbols.

a. O b. Br c. N d. Si

Objective 11

45. Write the element names that correspond to the following symbols.

a. Ba b. F c. Sr d. Cr

Objective 11
Objective 12
Objective 15
Objective 16
Objective 17

46. Complete the following table.

Element name	Element symbol	Group number on periodic table	Metal, nonmetal, or metalloid?	Representative element, transition metal, or inner transition metal?	Number for period
	Na				
tin					
	He				
nickel					
	Ag				
aluminum					
	Si				
		16			3
		2B			6

Objective 11
Objective 12
Objective 15
Objective 16
Objective 17

47. Complete the following table.

Element name	Element symbol	Group number on periodic table	Metal, nonmetal, or metalloid?	Representative element, transition metal, or inner transition metal?	Number for period
	Mg				
lead					
argon					
	Cd				
chromium					
	Fe				
		7B			4
		1A			2
		18			5

48. Write the name of the group or family to which each of the following belongs. OBJECTIVE 13
    a. bromine
    b. neon
    c. potassium
    d. beryllium

49. Write the name of the group or family to which each of the following belongs. OBJECTIVE 13
    a. strontium
    b. lithium
    c. iodine
    d. xenon

50. Identify each of the following elements as a solid, a liquid, or a gas at room temperature and pressure. OBJECTIVE 18
    a. krypton, Kr
    b. Br
    c. antimony, Sb
    d. F
    e. germanium, Ge
    f. S

51. Identify each of the following elements as a solid, a liquid, or a gas at room temperature and pressure. OBJECTIVE 18
    a. chlorine
    b. Se
    c. mercury
    d. W
    e. xenon
    f. As

52. Which two of the following elements would you expect to be most similar: lithium, aluminum, iodine, oxygen, and potassium?

53. Which two of the following elements would you expect to be most similar: nitrogen, chlorine, barium, fluorine, and sulfur?

54. Write the name and symbol for the elements that fit the following descriptions.
    a. the halogen in the third period
    b. the alkali metal in the fourth period
    c. the metalloid in the third period

55. Write the name and symbol for the elements that fit the following descriptions.
    a. the noble gas in the fifth period
    b. the alkaline earth metal in the sixth period
    c. the representative element in group 3A and the third period

56. Which element would you expect to be malleable, manganese or phosphorus? Why?

57. Which element would you expect to conduct electric currents well, aluminum or iodine? Why?

Section 2.4 The Structure of the Elements

58. Describe the nuclear model of the atom, including the general location of the protons, neutrons, and electrons; the relative size of the nucleus compared to the size of the atom; and the modern description of the electron. OBJECTIVE 20

59. Describe the carbon atom, and make a rough sketch. OBJECTIVE 21

60. Identify each of the following as a cation or an anion, and determine the charge on each. OBJECTIVE 22
    a. A lithium ion with 3 protons and 2 electrons
    b. A sulfur ion with 16 protons and 18 electrons

Objective 22

61. Identify each of the following as a cation or an anion, and determine the charge on each.
    a. An iodine ion with 53 protons and 54 electrons
    b. An iron ion with 26 protons and 23 electrons
62. Write definitions of the terms *atomic number* and *mass number*. Which of these can vary without changing the element? Why? Which of these cannot vary without changing the element? Why?
63. Write the atomic number for each of the following elements.
    a. oxygen
    b. Mg
    c. uranium
    d. Li
    e. lead
    f. Mn
64. Write the atomic number for each of the following elements.
    a. sodium
    b. As
    c. strontium
    d. Pu
    e. iron
    f. Se
65. Explain how two atoms of oxygen can be different.
66. Write the name and symbol for the elements that fit the following descriptions.
    a. 27 protons in the nucleus of each atom.
    b. 50 electrons in each uncharged atom.
    c. 18 electrons in each +2 cation.
    d. 10 electrons in each −1 anion.
67. Write the name and symbol for the elements that fit the following descriptions.
    a. 78 protons in the nucleus of each atom.
    b. 42 electrons in each uncharged atom.
    c. 80 electrons in each +3 cation.
    d. 18 electrons in each −2 anion.

Section 2.5 Common Elements

Objective 25

68. Describe the hydrogen molecule, including a rough sketch of the electron-charge cloud created by its electrons.
69. Write definitions for the terms *atom* and *molecule* and use them to explain the difference between hydrogen atoms and hydrogen molecules.

Objective 24

70. Describe the structure of each of the following substances, including a description of the nature of the particles that form each structure.
    a. neon gas
    b. bromine liquid
    c. nitrogen gas

Objective 24

71. Describe the structure of each of the following substances, including a description of the nature of the particles that form each structure.
    a. chlorine gas
    b. iodine solid
    c. argon gas

Objective 27

72. Describe the *sea-of-electrons* model for metallic solids.

Discussion Question

73. When you heat solid iodine, it goes directly from solid to gas. Describe the process by which iodine particles escape from the solid to the gas form. What characteristics must iodine particles have to be able to escape? Draw a picture to illustrate your answer.