Chapter 1

Atoms, Molecules, Elements, Compounds, Mixtures, and States of Matter

Everything There Is

Chemistry is concerned primarily with matter and its transformations. **Matter** is anything that has mass and occupies space—the pages of this book, the ground beneath your feet, and the air that you feel as wind on your cheeks.

Chemistry is vitally involved in almost every aspect of your life—the food you eat; the clothes, jewelry, and makeup you wear; the computers, cars, and CDs you use; the drugs you might take, from aspirin to birth control pills; the quality of the air you breathe and of the water you drink. Chemistry involves the climate that you influence and the traits that you pass on to your children—indeed, the list goes on virtually indefinitely, as we shall see in this book. Chemistry is used in the development of computer chips, synthetic fibers, plastics, modern drugs, and perfumes. Progress in treating genetic diseases and in understanding how our actions create air pollution and modify the weather—all depend on the continuing exploration by chemists and other scientists of the nature of matter.

Understanding the structure of matter has allowed chemistry to create the myriad of new and useful materials that are so vital to our modern society and to its future. Indeed, most of the world's population would not be living today without the creation of synthetic fertilizers to increase food production. Currently, insights into the chemical behavior of biological matter, such as genes, are providing hope for new medical advances and raising concerns about the impact of introducing new and modified organisms into the environment. But not all of chemistry's achievements have been used exclusively to improve the lot of humanity. Knowledge of how matter works has also been applied, for example,

Whenever you see this icon in this chapter, go to www.whfreeman.com/chemistryinyourlife to the production of explosives and poisonous gases that have been used in warfare.

In this book, we shall explore the many ways in which chemistry affects *your* life. We shall see how the scientific method leads us to an understanding of the way matter is constructed and of how we can produce new substances having specific, desirable properties. We shall learn what occurs when living entities—including you—breathe, eat, exercise, and reproduce. We shall also consider some of the policy choices that will face you during your lifetime concerning such issues as the quality of your physical environment and the extent to which genetic engineering can modify living organisms. It is our aim to give you the scientific understanding that you will need to function as an informed citizen in the world.

We begin our exploration of chemistry by discussing the general nature of matter at its smallest level—the elements and the atoms that form them.

Elements

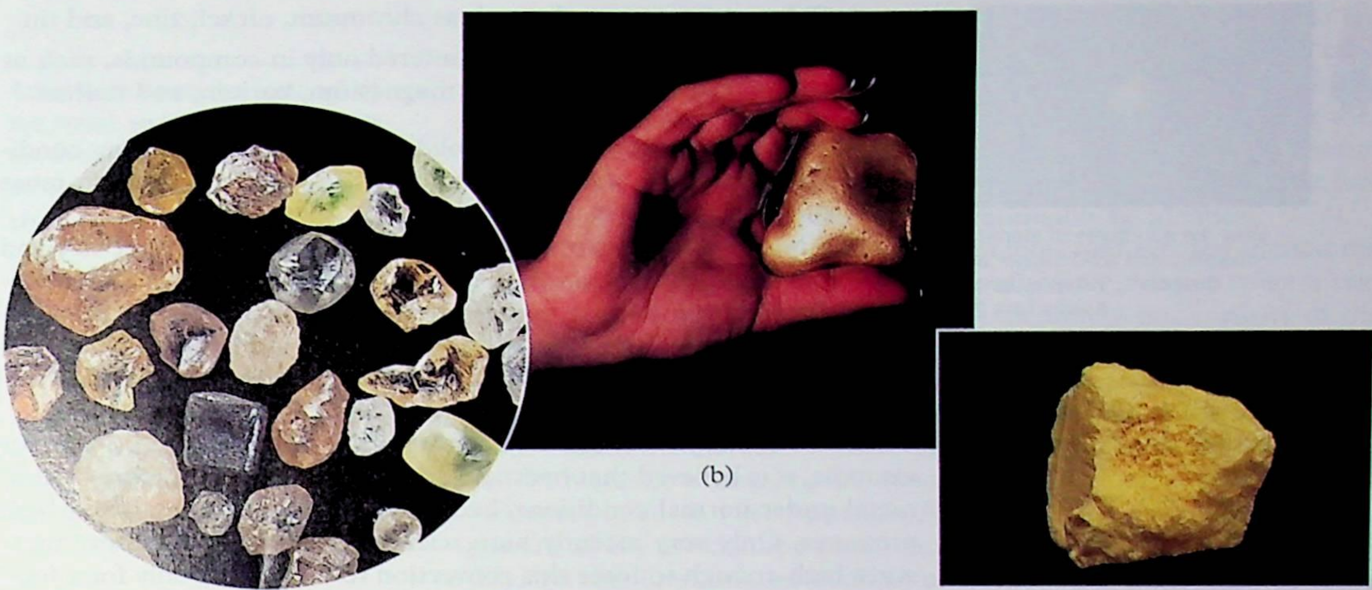
1.1 Elements are the fundamental types of matter

Picture a bottle of oil-and-vinegar salad dressing that has been sitting on the shelf for a while, or a can of paint that hasn't been used for months. Under the influence of gravity, the mixtures that were uniformly smooth when you were using them have spontaneously separated into two layers. Why is it that a number of common types of matter separate like this into simpler, usually more uniform components? Throughout the ages chemists have been interested in separating all sorts of natural materials into their fundamental constituents. The techniques they have used to extract the individual components of the materials range from simply filtering liquid-solid mixtures or evaporating liquids to isolate solids dissolved in them, to harsher procedures including strong heating or exposure to intense light or to other chemicals.

About 100 substances have resisted *all* attempts to split them into two or more stable components. These fundamental substances are known as **elements** (see Figure 1.1). Most of the matter you deal with in your everyday life is *not* in its elemental form. However, three common examples of elements that you have probably seen are carbon in the form of diamonds, aluminum in the form of foil, and gold in the form of 24K jewelry. In addition to discovering that elements cannot be decomposed, chemists have also found that *all other substances are composed of combinations of two or more elements*. Thus *elements are the fundamental types of matter.* All known materials are either elements or, more commonly, are a combination of several elements. For example, table sugar is a combination of the three elements carbon, hydrogen, and oxygen, whereas water combines only hydrogen and oxygen. Complex materials such as soil and living cells contain dozens of elements. In human bodies, the most vital elements include hydrogen, carbon, oxygen, nitrogen, sulfur and phosphorus (see Table 1.1).

Table 1.1 The top 10 elements in your body

Element name	Percent of your body
Oxygen	64.6%
Carbon	18.0%
Hydrogen	10.0%
Nitrogen	3.1%
Calcium	1.9%
Phosphorus	1.1%
Chlorine	0.40%
Potassium	0.36%
Sulfur	0.25%
Sodium	0.11%



(a) (b) (c)

Figure 1.1 Samples of some naturally occurring elements. (a) Uncut diamonds from Zaire. (b) Gold nugget. (c) Sulfur. *(Part a, Charles D. Winters; part b, Pascal Goetgheluck/Science Photo Library/Photo Researchers; part c, Mark A. Schneider/Photo Researchers)*

Mirrors are pieces of glass coated on one side with a reflecting metal such as silver.

1.2 Elements are classified as metals or nonmetals

What are the 100 or so materials that are called elements? Many of them are materials commonly known as **metals.** When asked to list the properties of metals, most people would use terms such as *shiny* and *hard*. Scientists have their own list, which runs as follows:

View the metallic properties, malleability and luster, at Chapter 1: Visualizations: Media Link 1.

- *Shiny:* Metals possess a characteristic luster. Metals reflect light that is shined upon their surfaces.
- *Opaque:* Metals do not allow light to pass through them.
- *Malleable:* Metals can be hammered into shapes without fracturing.
- *Ductile:* A sample of the metal can be drawn into wire.
- *Conductive:* Metals conduct both heat and electricity.

You are familiar with many metals, such as gold, silver, iron, aluminum, and tin. You may be less familiar with other elements that are also metals, such as palladium, cadmium, vanadium, and cesium. We can categorize metals into several types having common characteristics or uses:

The names of most metals end in *-um* or *-ium*. An exception is helium, which is not a metal.

- Coinage metals such as gold, silver, and copper
- Structural metals such as iron, aluminum, and lead

View the structures of atomic, metallic, and solid copper at Chapter 1: Visualizations: Media Link 2.

Several other metals, such as cesium, melt just above room temperature.

- Shiny common metals, such as chromium, nickel, zinc, and tin
- Metals that are usually encountered only in compounds, such as sodium, potassium, calcium, magnesium, barium, and radium

All the metallic elements are solid under normal, everyday conditions except mercury, which is a liquid. We will discuss metals in more detail later in the chapter.

Although most elements are metals, a sizable minority are not and are simply termed **nonmetals.** The best-known nonmetals are hydrogen, helium, carbon, nitrogen, oxygen, fluorine, neon, silicon, phosphorus, sulfur, chlorine, argon, radon, bromine, and iodine. These elements generally do not have the characteristics of metals: they are not particularly shiny, malleable, or good conductors of heat and electricity.

Some elements change their nature under extreme conditions. For example, it is believed that hydrogen, a gas that most definitely is a nonmetal under normal conditions, becomes a metal under extremely high pressures. Only very recently have scientists been able to achieve pressures high enough to force this conversion to occur, and only for a fraction of a second. However, it is believed that in the interior of the planet Jupiter—which consists primarily of liquid and gaseous hydrogen—the pressure exerted from the matter that lies above is so great that hydrogen exists in a liquid metallic form.

1.3 Each element has its own symbol

Three-letter symbols are used temporarily for new synthetic elements before a final name has been agreed on.

For convenience, each element has been assigned a shorthand symbol, consisting of one or two letters, only the first of which is capitalized. Often the elemental symbol is based upon its English name. For example, the first letter of the English name is used for the elements Boron (B), Carbon (C), Fluorine (F), Hydrogen (H), Iodine (I), Nitrogen (N), Oxygen (O), Phosphorus (P), Sulfur (S), and Uranium (U). Common elements that have symbols corresponding to the first two letters of their name include Helium (He), Neon (Ne), Calcium (Ca), Nickel (Ni), Bromine (Br), and Argon (Ar). For many other elements with two-letter symbols, the second letter occurs somewhere in the English name—an example is Zn for Zinc. Still other elements have symbols based upon their Latin name—an example is Na, for sodium (from the Latin *natrium*). A complete list of elements and their symbols—and a number whose significance will become clear later—is given in the table on the page facing the back cover of this book. Frequently you will see the elements arranged in the periodic table (see inside front cover), which we will explain in Chapter 3.

The Atomic Nature of Matter

1.4 Matter is ultimately discrete, not continuous

Let's look a bit more closely at what it means to say that elements are the fundamental types of matter. Using a pair of scissors, you can cut a piece of aluminum foil into small pieces. In turn, you can cut each such piece

Actually, in doing the "cutting" of the metal, you'd have to keep the foil in an oxygen-free atmosphere, as the surface of aluminum easily combines with oxygen.

into even smaller ones. With more specialized tools, it is possible to split even tiny bits of the aluminum into smaller ones, all of which still retain the properties that define the element aluminum. As far back as the time of the ancient Greeks, philosophers and scientists wondered whether there was any *limit* to the splitting of matter into smaller and smaller amounts that would still retain the properties of the larger units. At this lower limit of division, all the tiny particles would presumably be identical.

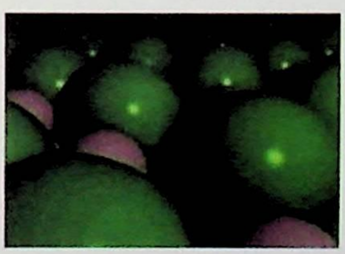
Through the power of modern technology, we have determined that there *is* indeed a limit to the divisibility of matter. Matter is *not* a continuous substance that can be divided indefinitely but consists of discrete, or separate, units. This confirms the view long held by scientists and based on extensive amounts of indirect evidence. The limit to divisibility occurs when the dimensions of matter—the diameters of the particles—reach the incredibly small values of about 0.0000000001 meters (10^{-10} meters), a distance far below the ability of any conventional "scissors" to cut it. (See Appendix A and Figure A.1 for a review of the powers of 10, or scientific notation, if such symbolism is unfamiliar to you.) At this limit, matter consists of spherical particles that cannot be split into two or more identical parts—that is, parts that are all of the same size and that behave identically. These particles are called **atoms,** a name derived from the Greek word for *indivisible.* Until recently, no one had ever actually observed an atom, though all indirect evidence pointed to their existence. In the latter part of the 20th century, scientists were able to "see" individual atoms through highly specialized types of microscopes. You can see a microphotograph of gold atoms in Figure 1.2d.

By contrast, the width of a human hair is about 0.0001 meter.

Atoms of different elements vary somewhat in size, but their diameters all fall in the range of a few tenths of a nanometer (nm), which is 10^{-9} meters. (This diameter is about 10,000 times smaller than the diameter of a human red blood cell.) As we shall see, atoms often attach themselves together to form structures whose dimensions are in the nanometer region. One of the exciting areas of modern science and engineering is *nanotechnology*, the development of incredibly tiny devices to manipulate matter one atom at a time and thereby assemble microscopic computers, machines for use in medicine, and other futuristic materials. Because of the importance of such structures to chemistry and to newly developing technology, we shall usually use the nanometer unit of length in this book when we discuss the sizes of atoms and of the groupings that they form.

A tenth of a nanometer is 10^{-10} meters.

Chemists consider atoms to be the fundamental unit of material composition and construction—as the letters of an alphabet are to words and as individual notes are to music. Atoms are essentially indestructible, both in number and in mass, unless we use very large amounts of energy to blast them apart. Elements are a particularly simple type of matter, since all their atoms are identical in size and in most aspects of their behavior.



View the atomic structures of hydrogen, carbon, nitrogen, oxygen, sulfur, copper, and silver at Chapter 1: Visualizations: Media Link 3.

Using the piece of modern technology called a *scanning tunneling microscope*, we can "see" atoms for ourselves. The photographs in Figure 1.2 are of the surface of a piece of pure solid gold foil (see Figure 1.2a).