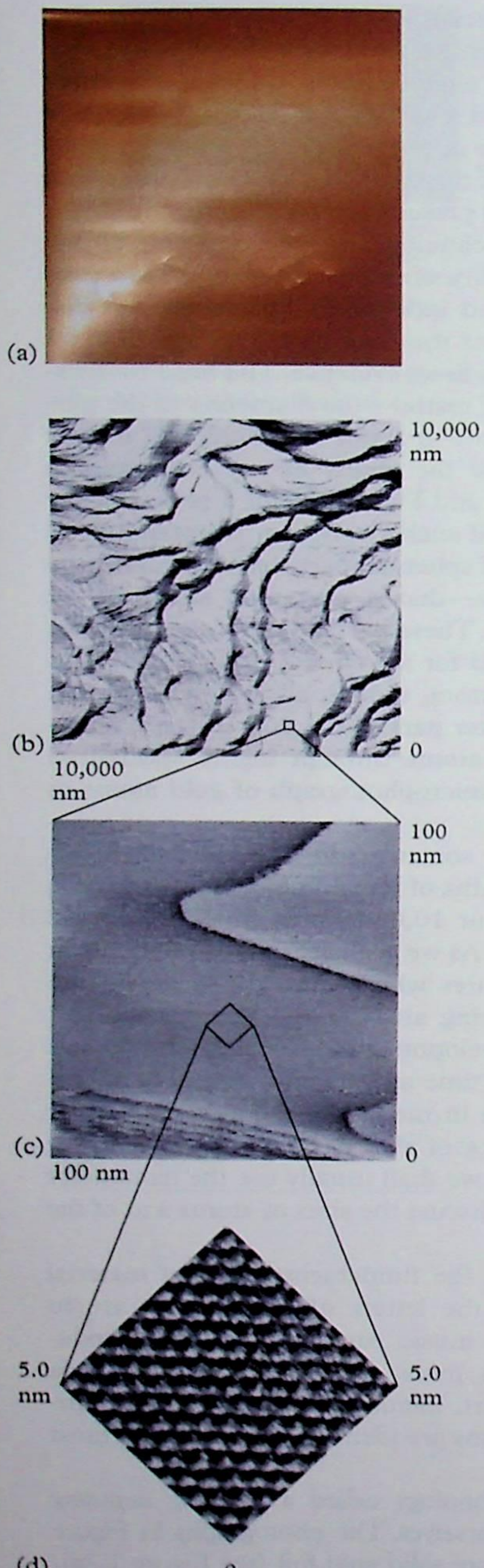


When we view a small segment of the foil's surface that is 10,000 nm × 10,000 nm (0.00001 meters × 0.00001 meters) in size (see Figure 1.2b), we see multiple terraces and steps on what initially appears to be a smooth surface, but no individual particles are evident. If we zoom in to view a small portion of a single terrace of the segment (see Figure 1.2c), the topology of the gold surface still appears mainly continuous. However, zooming down to view a portion measuring only 5 nm (5×10^{-9} meters) long and wide reveals a simple pattern of regular rows of identical spherical particles—these are individual atoms of gold, each one measuring about 0.3 nanometers (3×10^{-10} meters) in diameter (see Figure 1.2d)!

1.5 Different atomic arrangements produce different types of matter

As we shall see many times in this book, the location of its atoms relative to each other plays an important role in determining the properties of a substance. The spatial arrangement of the atoms in all metallic elements is particularly simple and uniform, and in many cases it is identical to that of gold. The surface layer of gold is illustrated by the photograph in Figure 1.2d and the schematic diagram in Figure 1.2e. The atoms, represented by green circles in Figure 1.2e, that touch any given atom, represented by a blue circle, are known as its **nearest neighbors.**

In general, the structure of solid metals consists of a regular, repeating pattern of particles that extends indefinitely in at least two directions and usually in all three. We say that such substances—gold, for example—have an **extended network** of atoms. As we shall see later, extended networks are also present in some materials that are not simple elements. The arrangement of atoms in most solid *nonmetals* is more complicated than the arrangement of atoms in metals; some examples of these structures will be discussed later. Although all solid metals have simple atomic arrangements of their atoms in the solid, several different patterns of arrangement are known. Metals also differ in some of their other properties, including size—for example, atoms of copper are smaller and lighter than atoms of gold.

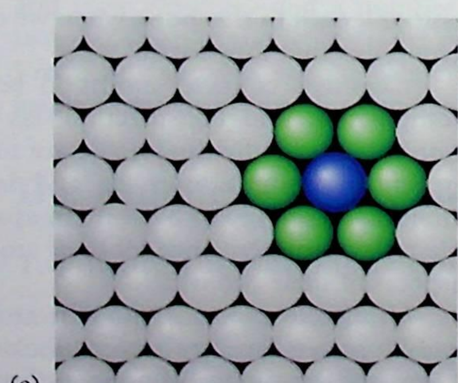
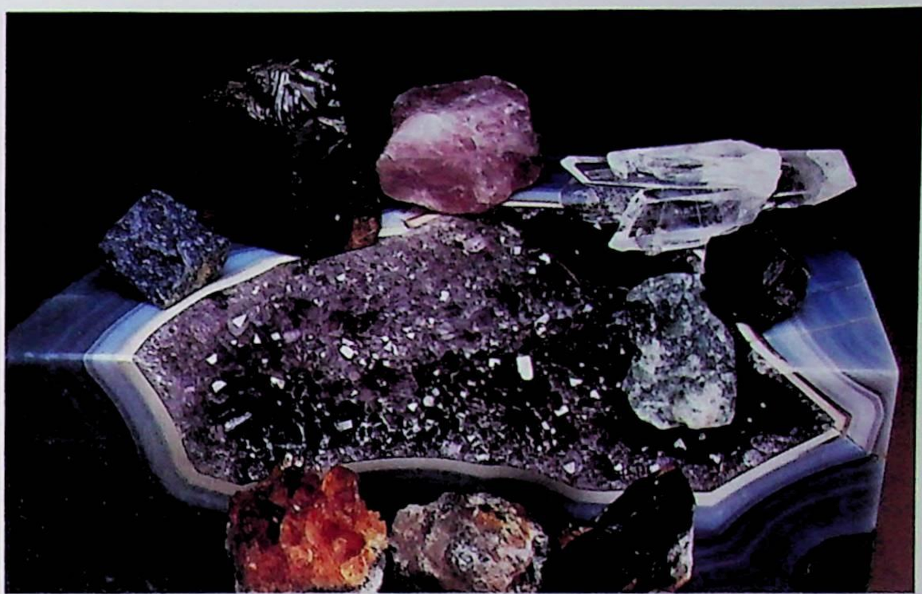


Figure 1.2 A piece of gold foil at different levels of magnification. *(Part a, George Semple for W. H. Freeman and Company; parts b, c, and d, Jacek Lipkowski/Canadian Chemical Society)*

Figure 1.3 Different types of crystals. *(Kristen Brochmann/Fundamental Photographs)*



View the structures of copper metal, crystalline sodium chloride, and the solid sulfur at Chapter 1: Visualizations: Media Link 4.

When very large numbers of particles are arranged in a regular pattern, with the same distances between nearest neighbors throughout, the solid they collectively form is a **crystal** (see Figure 1.3). In size, crystals range from those too small to see with the naked eye to those that measure a meter across! The solid form of most metals is crystalline. Many other substances, some with extended networks and others with alternative arrangements of particles, also form crystals. Some substances also form, under certain conditions, an alternative type of solid in which the arrangement of particles is much less ordered. The solids produced by such an arrangement are called **amorphous,** and they are not crystals because of their lack of order. Amorphous solids usually lack the shiny, clear quality associated with materials in the crystalline solid state. The element silicon, for example, occurs in both a crystalline and an amorphous form in the solid state (see Figure 1.4).

Compounds and Mixtures

1.6 Compounds are composed of elements in a fixed ratio and cannot be easily separated into their components

When observed at the level of atoms, some substances are found to consist of a simple repeating pattern of the atoms of two elements, usually one of them a metal and the other a nonmetal. A common example is table salt, whose scientific name is sodium chloride. A schematic representation of the repeating pattern in salt is shown in Figure 1.5. The smaller spheres represent atoms of the element sodium and the larger spheres represent atoms of chlorine. As the illustration suggests, the repeating pattern

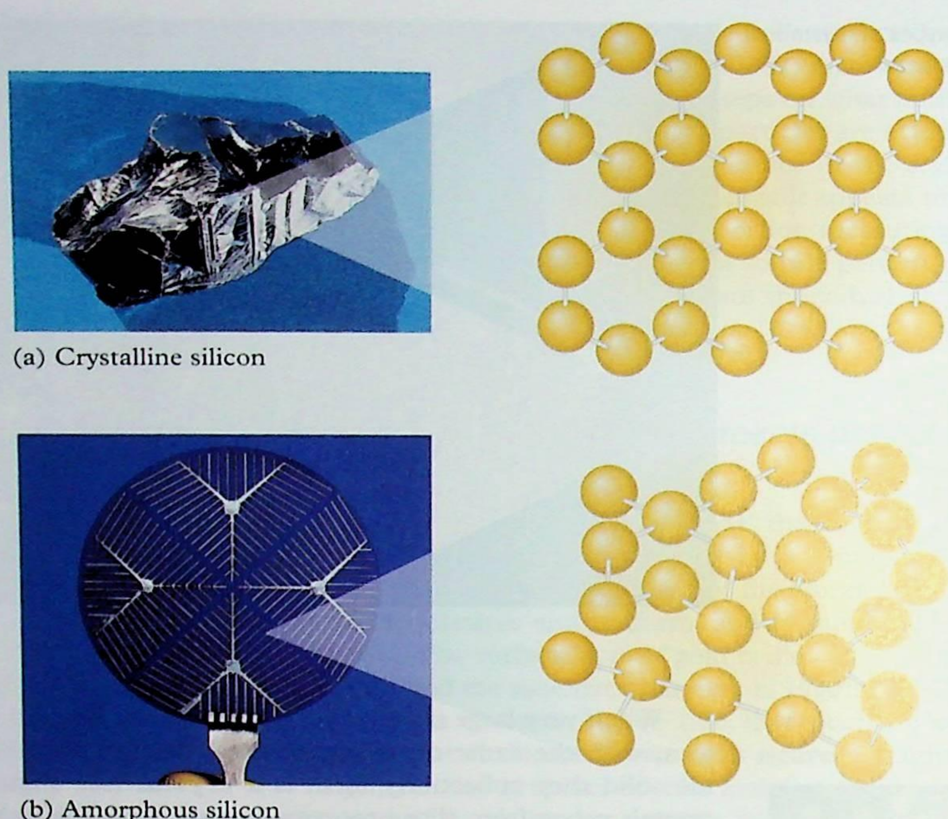


Figure 1.4 (a) Crystalline silicon. (b) Photovoltaic solar cell made of amorphous silicon. *(Part a photo, Jeff J. Daly/Visuals Unlimited; part b photo, Rosenfield Images Ltd./Rainbow)*

extends almost indefinitely in three dimensions. This means salt has an extended network structure at the atomic level. Salt exists as crystals, because it consists of a *uniform* extended network structure.

Salt is but one of a huge number of substances that are composed of repeating units of several types of atoms in a simple ratio of small integers (whole numbers) such as 1:1, 2:1, and so on. Such substances maintain this fixed ratio of atoms throughout their structure, and, consequently, macroscopic samples of them also have the same total ratio of atoms. Thus, even a grain of salt that is large enough to see with the naked eye contains sodium and chlorine atoms in the 1:1 ratio.

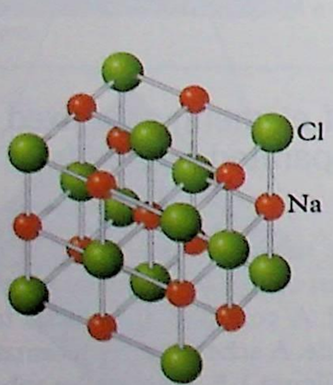


Figure 1.5 Atomic-level structure of sodium chloride.

Materials that consist of two or more types of atoms in a fixed ratio, with uniform composition throughout, and that *cannot* easily be separated into their pure component elements are called **compounds.** Millions of examples of compounds are known—including common substances such as table sugar, starch, water, and dry ice as well as salt. Some compounds occur in nature, and many others have been produced synthetically in the laboratory. Most compounds are combinations of several nonmetals or of metals and nonmetals. Matter that is composed exclusively of one particular element or compound is known as a **pure substance.** It has a uniform composition down to the atomic level.

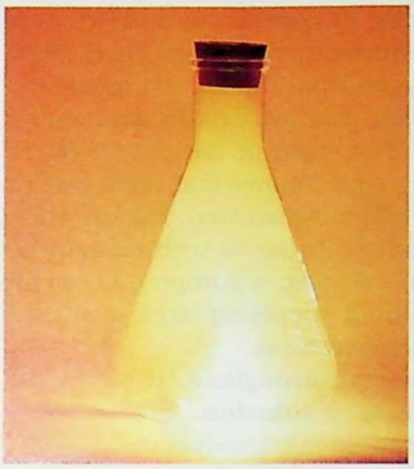


Figure 1.6 Sodium metal and chlorine gas combining to form table salt, sodium chloride. *(Chip Clark)*

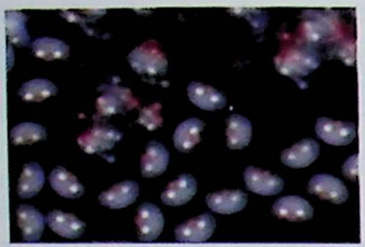
Usually, the characteristics of a compound are radically different from those of the individual elements of which the compound is composed. Formation of a compound is accompanied in many instances by the evolution of substantial amounts of energy in the form of heat or light. The compound forms by combining together only a specific ratio of the component elements. For example, when samples of the elements sodium, a shiny metal, and chlorine, a yellowish-green gas, are brought into contact, heat and light are emitted (see Figure 1.6). The sodium and chlorine become transformed into common salt, a material which has the physical characteristics of neither of the individual elements!

The ratio of sodium to chlorine atoms is always 1:1 in any sample of sodium chloride. Any sodium or chlorine in excess of the amounts required to give the 1:1 atom ratio in salt would remain untransformed and could be separated from the newly formed salt. The properties of most pure substances do not depend upon how much of the elements were mixed together in the first place, although in some cases several different substances can be formed by the same elements depending upon the proportions initially present in the mixture. Interestingly, we encounter no pure substances made of the elements sodium and chlorine in which the atomic ratio is *other* than 1:1.

Another example of a compound is arsenic oxide. This powdery substance is quite poisonous and was a common agent used for murder and suicide from Roman times to the Middle Ages. One of its component elements is oxygen, a gas that we depend upon for life. The other element, arsenic, is a grayish solid that is called a **metalloid** since it has some of the properties of a metal and some of a nonmetal. Most compounds of arsenic are toxic in some way to humans. For example, arsenic compounds dissolved in drinking water from wells in countries such as India, Chile, and Taiwan cause skin cancer. Although elemental arsenic itself is also toxic, when people speak of "arsenic" as being poisonous, they are usually referring to its compounds.

1.7 Mixtures contain substances in no fixed proportion, and their formation involves no fundamental change at the atomic level

In contrast to the formation of a compound, it is often possible to mix together two or more pure substances in almost any proportion without any fundamental change occurring at the atomic level. No substantial gain or loss of energy, whether in the form of light or heat, accompanies the process. Such combinations of pure substances are called **mixtures.** In many cases, their properties are the average of those of the substances that constitute the mixture. For example, air consists of a mixture predominantly of the elements nitrogen and oxygen in an atomic ratio of about 78:21, and it has properties that are similar to the weighted average of the properties of the two pure elements. It is also possible to prepare mixtures having proportions of 75:21, or 78:18, or any other values of nitrogen to oxygen, by simply mixing appropriate samples of the pure elements. Mixtures having ratios that differ slightly from 78:21 have



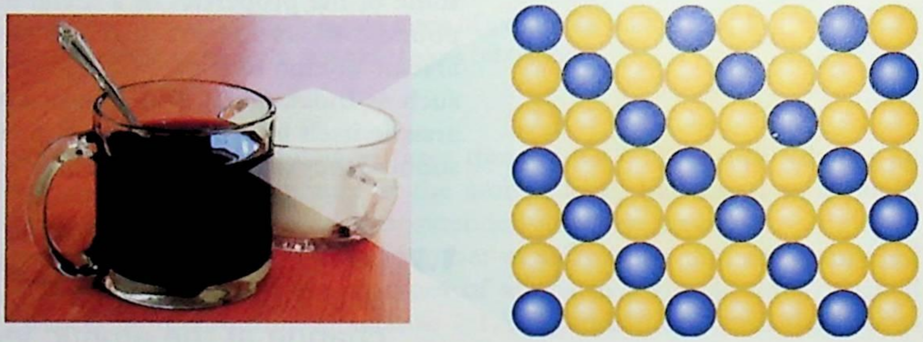
View sodium chloride and sugar dissolving in water at Chapter 1: Visualizations: Media Link 5.

properties only slightly different from that of natural air. Indeed, even the air you exhale has a higher ratio of nitrogen to oxygen than 78:21 since your lungs extract some of the oxygen from the air you inhale.

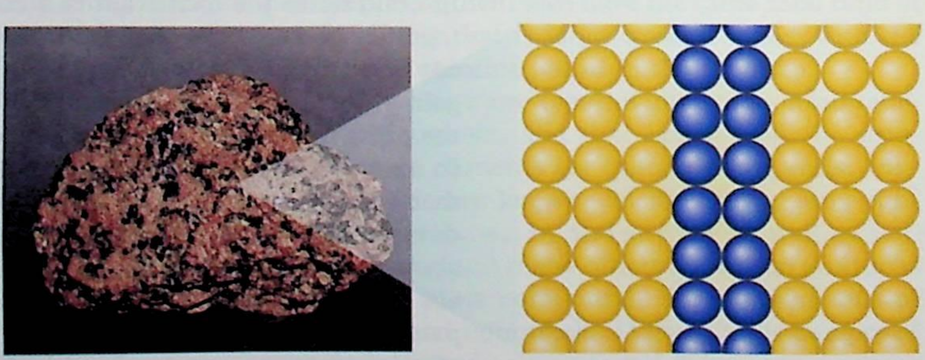
Similarly, you may know by experience that you can dissolve almost any proportion of sugar or salt in water. The sugar or salt can be recovered upon evaporation of the pure water, so it follows that there was no fundamental change in its composition when it dissolved. Indeed, most mixtures can be resolved into separate pure substances without subjecting the material to harsh conditions. In contrast, a compound usually cannot be resolved into its elements without supplying large quantities of energy—for example, by using high temperatures.

If a mixture has a uniform composition throughout, it is called a **homogeneous mixture,** better known as a **solution.** For example, adding some salt to water and mixing thoroughly produces a solution. In practice, the term *solution* is usually used for liquids, though some solid solutions exist. An example of a solid homogeneous mixture is jewelry gold, in which some silver and copper are also present. When a substance readily dissolves in another, we say it is **soluble** in it. When a substance does not dissolve at all, it is said to be **insoluble.** If only a tiny amount will dissolve, leaving the bulk of the substance separate from the solution, we say it is "practically insoluble."

When you add sugar to black coffee and stir the mixture thoroughly, you obtain a solution, since it is uniform throughout (see Figure 1.7a).



(a) A homogeneous mixture: coffee with sugar completely dissolved in it



(b) A heterogeneous mixture: granite that contains visibly different types of rock

Figure 1.7 (a) Homogeneous and (b) heterogeneous mixtures. *(Part a photo, George Semple for W. H. Freeman and Company; part b photo, Joyce Photographics/Photo Researchers)*