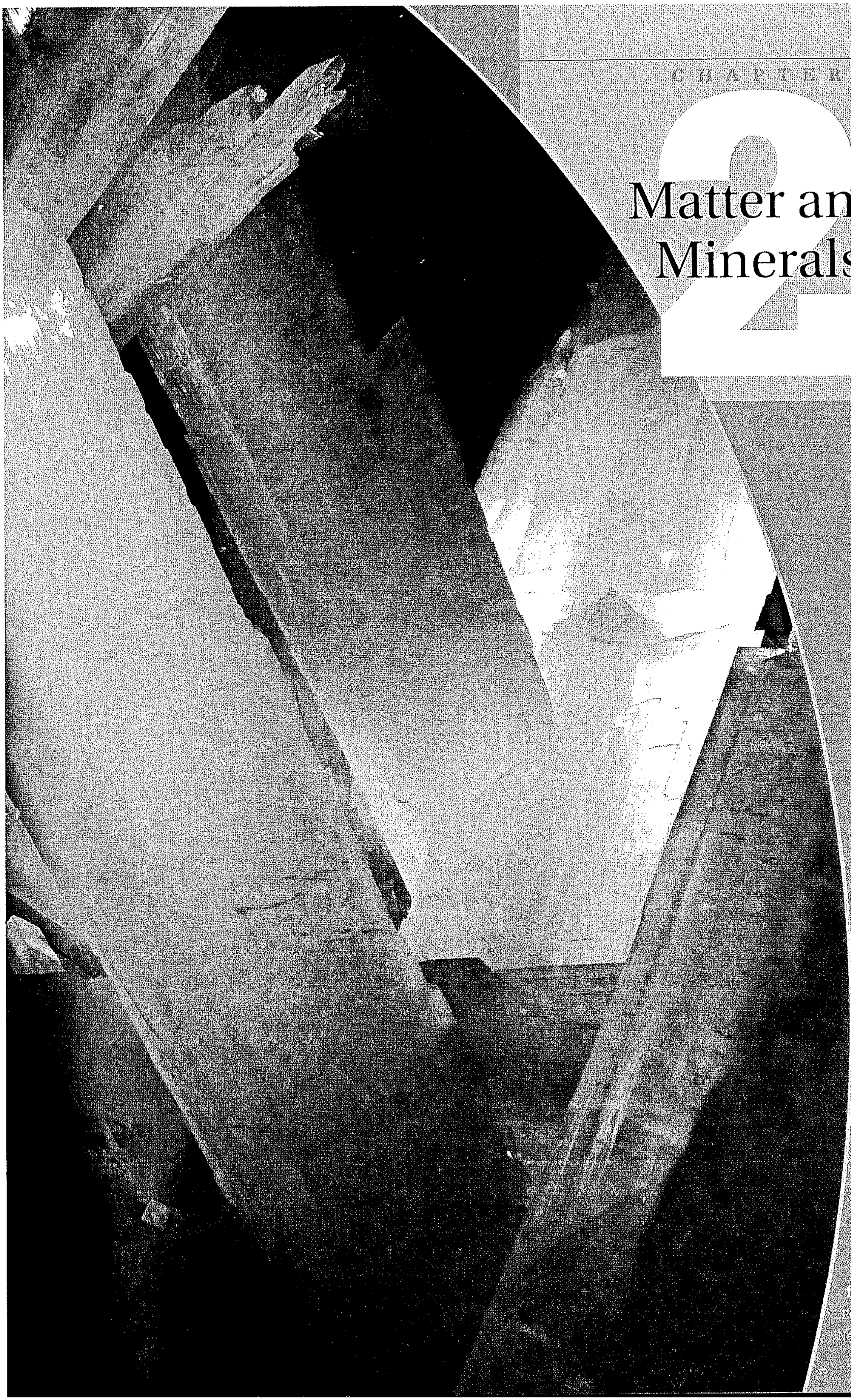
CHAPTER

2 Matter and Minerals



Cave of Crystals is a cave connected to Naica Mine in Chihuahua, Mexico. The main chamber contains giant gypsum crystals, some of the largest natural crystals ever found. (Photo by Carsten Peter/Speleoresearch & Films/National Geographic Stock)

Earth's crust and oceans are the source of a wide variety of useful and essential minerals. Most people are familiar with the common uses of many basic metals, including aluminum in bever age cans, copper in electrical wiring, and gold and silver in jewelry. But some people are not aware that pencil lead contains the greasy-feeling mineral graphite and that bath powders and many cosmetics contain the mineral talc. Moreover, many do not know that drill bits impregnated with diamonds are employed by dentists to drill through tooth enamel, or that the common mineral quartz is the source of silicon for computer chips. In fact, practically every manufactured product contains materials obtained from minerals.

FOCUS ON CONCEPTS

To assist you in learning the important concepts in this chapter, focus on the following questions:

- What are minerals, and how are they different from rocks?
- What are the smallest particles of matter?
- How do atoms bond?
- How do isotopes of the same element vary, and why are some isotopes radioactive?
- What are some of the physical and chemical properties of minerals? How can these properties be used to distinguish one mineral from another?
- What are the eight elements that make up most of Earth's continental crust?
- What is the most abundant mineral group?
- What do all silicate minerals have in common?
- What are *renewable* and *nonrenewable resources*?
- When is the term *ore* used with reference to a mineral?

Minerals: Building Blocks of Rocks

GEODe EARTH SCIENCE Earth Materials
▸ Minerals

We begin our discussion of Earth materials with an overview of **mineralogy** (*mineral* = mineral, *ology* = the study of) because minerals are the building blocks of rocks. In addition, minerals have been employed by humans for both useful and decorative purposes for thousands of years (**Figure 2.1**). The first minerals mined were flint and chert, which people fashioned into weapons and cutting tools. As early as 3700 B.C., Egyptians began mining gold, silver, and copper; and by 2200 B.C. humans discovered how to combine copper with tin to make bronze, a strong, hard alloy. Later, humans developed a process to extract iron from minerals such as hematite—a discovery that marked the decline of the Bronze Age. By about 800 B.C., iron-working technology had advanced to the point that weapons and many everyday objects were made of iron rather than copper, bronze, or wood. During the Middle Ages, mining of a variety of minerals was common throughout Europe and the impetus for the forma study of minerals was in place.

The term *mineral* is used in several different ways. Fo example, those concerned with health and fitness extol the benefits of vitamins and minerals. The mining industry typically uses the word when referring to anything taken out of the

FIGURE 2.1 Collection of well-developed quartz crystals found near Hot Springs, Arkansas. (Photo by Jeff Scovil)

ground, such as coal, iron ore, or sand and gravel. The guessing game known as "Twenty Questions" usually begins with the question, *Is it animal, vegetable, or mineral?* What criteria do geologists use to determine whether something is a mineral?

Geologists define **mineral** as *any naturally occurring inorganic solid that possesses an orderly crystalline structure and can be represented by a chemical formula.* Thus, Earth materials that are classified as minerals exhibit the following characteristics:

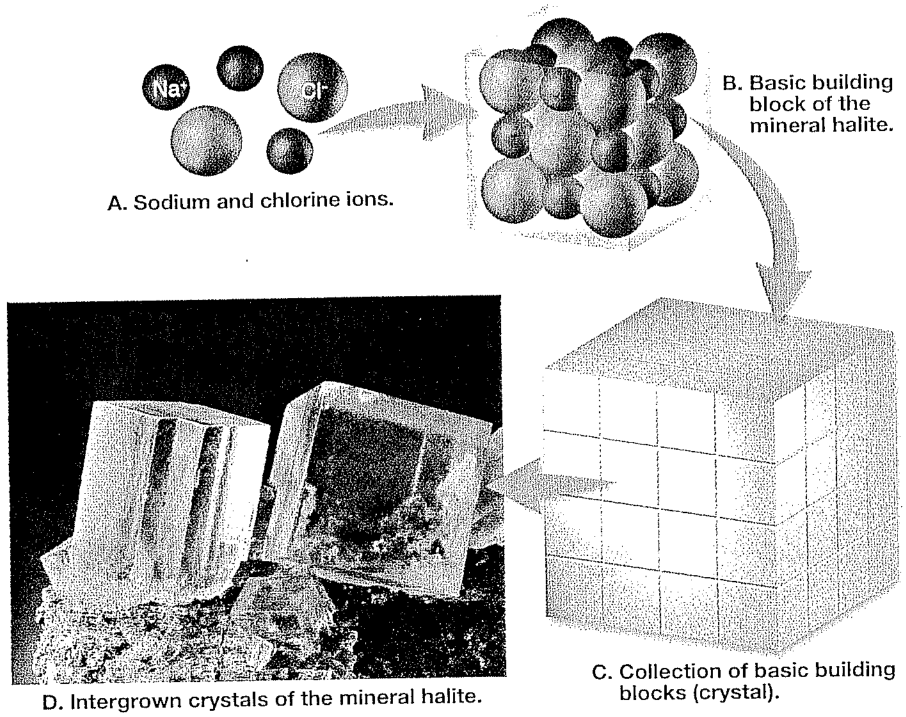


FIGURE 2.2 This diagram illustrates the orderly arrangement of sodium and chloride ions in the mineral halite. The arrangement of atoms into basic building blocks having a cubic shape results in regularly shaped cubic crystals. (Photo by Dennis Tasa)

1. **Naturally occurring.** Minerals form by natural, geologic processes. Synthetic materials, meaning those produced in a laboratory or by human intervention, are not considered minerals.
2. **Solid substance.** Only crystalline substances that are solid at temperatures encountered at Earth's surface are considered minerals. Ice (frozen water) fits this criterion and is considered a mineral, whereas liquid water and water vapor do not. The exception is mercury, which is found in its liquid form in nature.
3. **Orderly crystalline structure.** Minerals are crystalline substances, which means their atoms are arranged in an orderly, repetitive manner (Figure 2.2). This orderly packing of atoms is reflected in the regularly shaped objects called crystals. Some naturally occurring solids, such as volcanic glass (obsidian), lack a repetitive atomic structure and are not considered minerals.
4. **Generally inorganic.** Inorganic crystalline solids, such as ordinary table salt (halite), that are found naturally in the ground are considered minerals. Organic compounds, on the other hand, are generally not. Sugar, a crystalline solid like salt but which comes from sugarcane or sugar beets, is a common example of such an organic compound. Many marine animals secrete inorganic compounds, such as calcium carbonate (calcite), in the form of shells and coral reefs. If these materials are buried and become part of the rock record, they are considered minerals by geologists.
5. **Can be represented by a chemical formula.** Most minerals are chemical compounds having compositions that can be expressed by a chemical formula. For example, the common mineral quartz has the formula SiO_2, which indicates that quartz consists of silicon (Si) and oxygen (O) atoms in a ratio of one-to-two. This proportion of silicon to oxygen is true for any sample of pure quartz, regardless of its origin. However, the compositions of some minerals vary *within specific, well-defined limits.* This occurs because certain elements can substitute for others of similar size without changing the mineral's internal structure. An example is the mineral olivine, in which either the element magnesium (Mg) or iron (Fe) may occupy the same site in the crystal structure. Therefore, olivine's formula, $(Mg, Fe)_2SiO_4$, expresses variability in the relative amounts of magnesium and iron. However, the ratio of magnesium plus iron (Mg + Fe) to silicon (Si) and oxygen (O) remains fixed at 2:1:4.

In contrast to minerals, rocks are more loosely defined. Simply a **rock** is any solid that consists of an aggregate of minerals, pieces of preexisting rocks, or a mass of mineral-like matter such as natural glass. Some rocks are composed almost entirely of one mineral. A common example is the sedimentary rock *limestone*, which consists of impure masses of the mineral calcite. However, most rocks, like the common rock granite shown in Figure 2.3, occur as aggregates of several different minerals. The term *aggregate* implies that the minerals are joined in such a way that their individual properties are retained. Note that the mineral constituents of granite can be easily identified (Figure 2.3).

Some rocks are composed of nonmineral matter. These include the volcanic rocks *obsidian* and *pumice*, which are noncrystalline glassy substances, and *coal*, which consists of solid organic debris.

Although this chapter deals primarily with the nature of minerals, keep in mind that most rocks are simply aggregates of minerals. Because the properties of rocks are determined largely by the chemical composition and crystalline structure of the minerals contained within them, we will first consider these Earth materials. Then, in Chapter 3, we take a closer look at Earth's major rock groups.

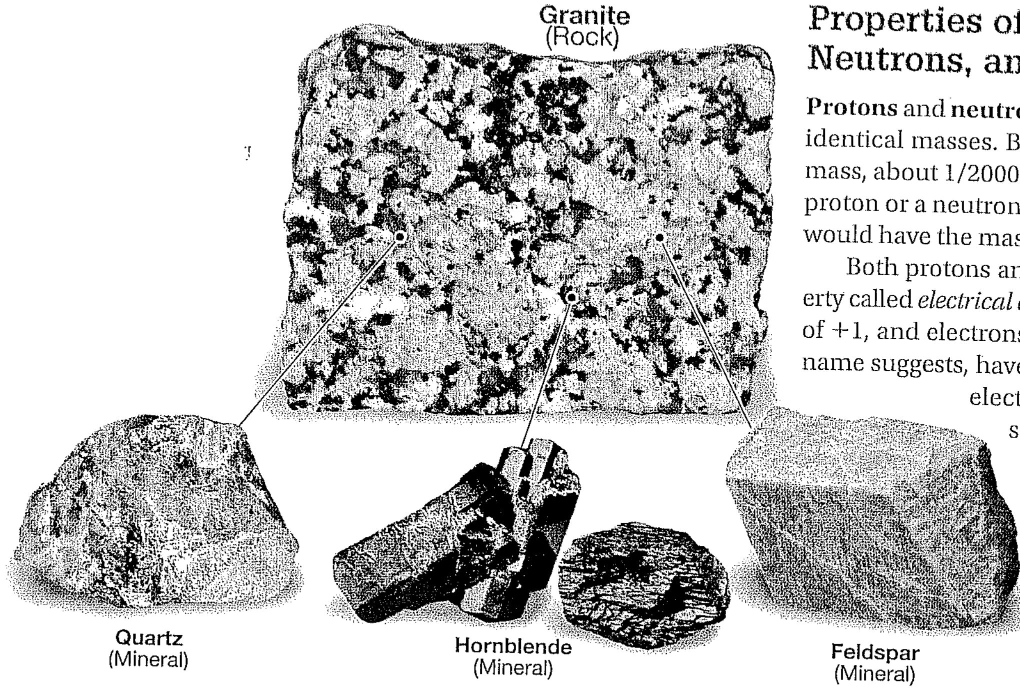


FIGURE 2.3 Most rocks are aggregates of two or more minerals. Shown here is a hand sample of the igneous rock granite and three of its major constituent minerals. (Photos by E. J. Tarbuck)

Properties of Protons, Neutrons, and Electrons

Protons and **neutrons** are very dense particles with almost identical masses. By contrast, **electrons** have a negligible mass, about 1/2000th that of a proton. For comparison, if a proton or a neutron had the mass of a baseball, an electron would have the mass of a single grain of rice.

Both protons and electrons share a fundamental property called *electrical charge*. Protons have an electrical charge of +1, and electrons have a charge of −1. Neutrons, as the name suggests, have no charge. The charge of protons and electrons are equal in magnitude but opposite in polarity, so when these two particles are paired, the charges cancel each other. Since matter typically contains equal numbers of positively charged protons and negatively charged electrons, most substances are electrically neutral.

In illustrations, electrons are sometimes shown orbiting the nucleus in a manner that resembles the planets of our solar system orbiting the Sun (Figure 2.4A). However, electrons do not actually behave this way. A more realistic depiction shows electrons as a cloud of negative charges surrounding a nucleus

CONCEPT CHECK 2.1

1. List five characteristics that classify an Earth material as a mineral.
2. Based on the definition of a mineral, which of the following materials are not classified as minerals, and why: gold, water, synthetic diamonds, ice, and wood.
3. Define the term *rock*. How do rocks differ from minerals?

Atoms: Building Blocks of Minerals

When minerals are carefully examined, even under optical microscopes, the innumerable tiny particles of their internal structures are not discernable. Nevertheless, all matter, including minerals, is composed of minute building blocks called **atoms**—the smallest particles that cannot be chemically split. Atoms in turn contain even smaller particles—*protons* and *neutrons* located in a central **nucleus** that is surrounded by *electrons* (Figure 2.4).

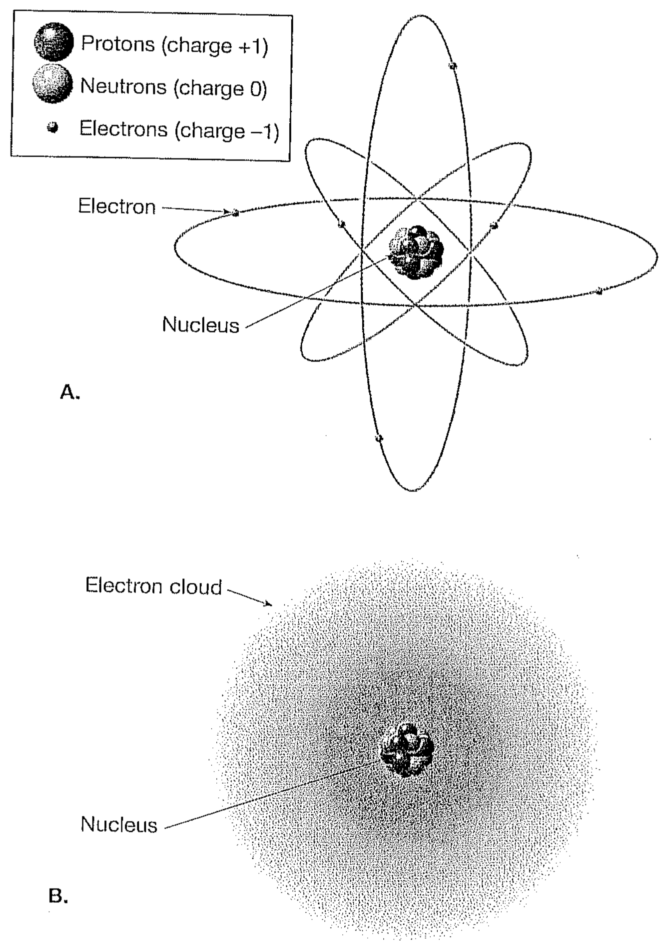


FIGURE 2.4 Two models of the atom. A. A very simplified view of the atom. The central nucleus consists of protons and neutrons encircled by high-speed electrons. B. This model of the atom shows electron clouds (shells) surrounding a central nucleus. The nucleus contains virtually all of the mass of the atom. The remainder of the atom is the space in which the light, negatively charged electrons reside. (The relative sizes of the nuclei shown are greatly exaggerated.)

Students Sometimes Ask...

Are the minerals you talked about in class the same as those found in dietary supplements?

Not ordinarily. From a geologic perspective, a mineral must be a *naturally occurring* crystalline solid. Minerals found in dietary supplements are human-made inorganic compounds that contain *elements* needed to sustain life. These dietary minerals typically contain elements that are metals—calcium, potassium, phosphorus, magnesium, and iron. It should also be noted that vitamins are *organic compounds* not *inorganic compounds*, like minerals.

(Figure 2.4B). Studies of the arrangements of electrons show that they move about the nucleus in regions called *principal shells*, each with an associated energy level. In addition, each shell can hold a specific number of electrons, with the outermost shell containing **valence electrons** that interact with other atoms to form chemical bonds.

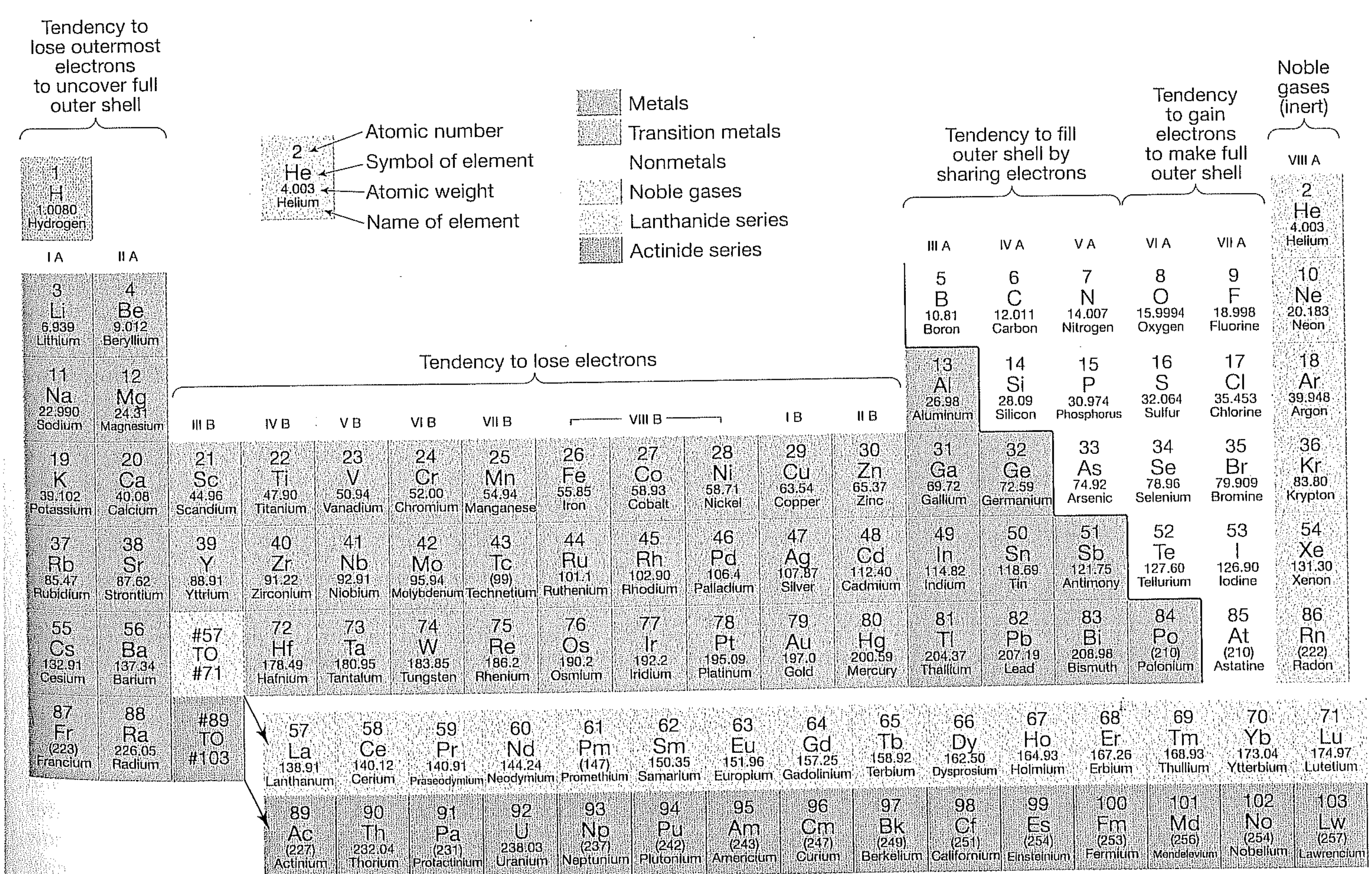
Most of the atoms in the universe (except hydrogen and helium) were created inside massive stars by nuclear fusion and released into interstellar space during hot, fiery supernova explosions. As this ejected material cooled, the newly formed nuclei attracted electrons to complete their atomic structure. At the temperatures found at Earth's surface, all free atoms (not bonded to other atoms) have a full complement of electrons—one for each proton in the nucleus.

Elements: Defined by Their Number of Protons

The simplest atoms have only one proton in their nuclei, whereas others have more than 100. The number of protons in the nucleus of an atom, called the **atomic number**, determines its chemical nature. All atoms with the same number of protons have the same chemical and physical properties. Together, a group of the same kind of atoms is called an **element**. There are about 90 naturally occurring elements and 23 that have been synthesized. You are probably familiar with the names of many elements including carbon, nitrogen, and oxygen. All carbon atoms have six protons, all nitrogen atoms have seven protons, and all oxygen atoms have eight protons.

Elements are organized so that those with similar properties line up in columns. This arrangement, called the **periodic table**, is shown in Figure 2.5. Each element has been assigned a one- or two-letter symbol. The atomic numbers and masses are also included for each element.

FIGURE 2.5 Periodic table of the elements.



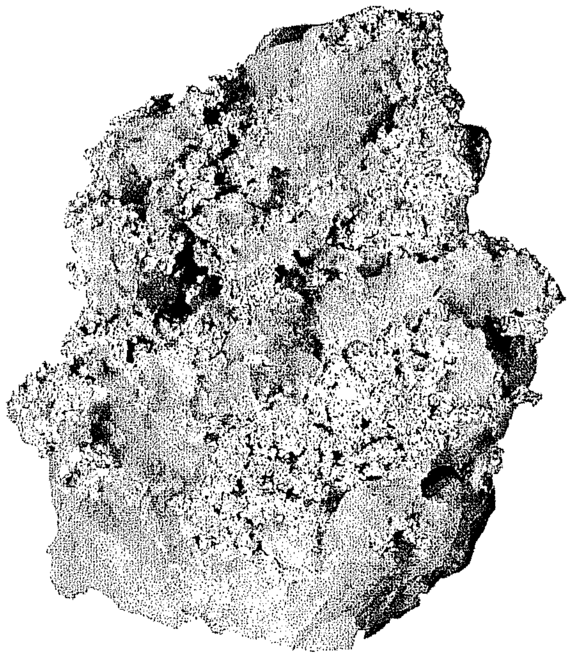


FIGURE 2.6 Gold mixed with quartz. Gold, silver, copper, and diamonds are naturally occurring minerals composed entirely of atoms of a single element.

Atoms of the naturally occurring elements are the basic building blocks of Earth's minerals. A few minerals, such as native copper, diamonds, and gold, are made entirely of atoms of only one element (Figure 2.6). However, most elements tend to join with atoms of other elements to form **chemical compounds**. Most minerals are chemical compounds composed of atoms of two or more elements.

CONCEPT CHECK 2.2

1. **List the three main particles of an atom and explain how they differ from one another.**
2. **Make a simple sketch of an atom and label its three main particles.**
3. **What is the significance of valence electrons?**

Why Atoms Bond

Except for a group of elements known as the noble gases, atoms bond to one another under the conditions (temperatures and pressures) that occur on Earth. Some atoms bond to form *ionic compounds*, some form *molecules*, and still others form *metallic substances*. Why does this happen? Experiments show that electrical forces hold atoms together and bond them to each other. These electrical attractions lower the total energy of the bonded atoms, which, in turn, generally makes them more stable. Consequently, atoms that are bonded in compounds tend to be more stable than atoms that are free (not bonded).

As was noted earlier, valence (outer shell) electrons are generally involved in chemical bonding. Figure 2.7 shows a shorthand way of representing the number of valence electrons. Notice that the elements in Group I have one valence electron, those in Group II have two valence electrons, and so on, up to eight valence elec trons in Group VIII.

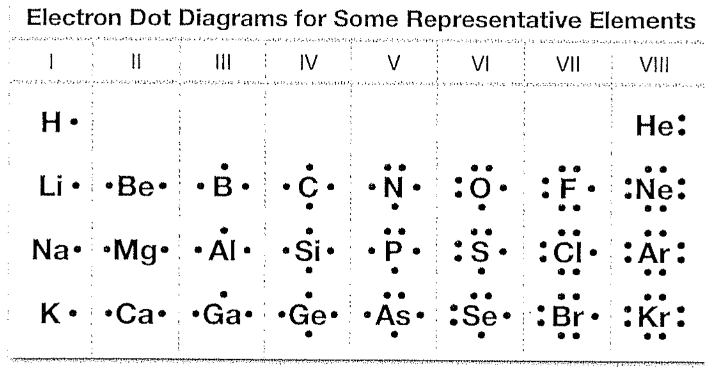


FIGURE 2.7 Dot diagrams for some representative elements. Each dc represents a valence electron found in the outermost principal shell.

Octet Rule

The noble gases (except helium) have very stable electro arrangements with eight valence electrons and, therefore, ten to lack chemical reactivity. Many other atoms gain, lose, or shar electrons during chemical reactions to end up with electro arrangements of the noble gases. This observation led to a chemical guideline known as the **octet rule**: *Atoms tend to gain lose, or share electrons until they are surrounded by eight valenc electrons.* Although there are exceptions to the octet rule, it is a useful rule of thumb for understanding chemical bonding.

When an atom's outer shell does not contain eight electrons it is likely to chemically bond to other atoms to fill its shell A **chemical bond** is the transfer or sharing of electrons that allow each atom to attain a full valence shell of electrons. Some atom do this by transferring all of their valence electrons to other atom so that an inner shell becomes the full valence shell.

When the valence electrons are transferred between the elements to form ions, the bond is an *ionic bond*. When the electron are shared between the atoms, the bond is a *covalent bond*. When the valence electrons are shared among all the atoms in a substance, the bonding is *metallic*. In any case, the bonding atom get stable electron configurations, which usually consist of eigh electrons in their outmost shells.

Ionic Bonds: Electrons Transferred

Perhaps the easiest type of bond to visualize is the *ionic bond*, in which one atom gives up one or more of its valence electrons to another atom to form **ions**—*positively and negatively charged atoms*. The atom that loses electrons becomes a positive ion, and the atom that gains electrons becomes a negative ion. Oppositely charged ions are strongly attracted to one another and join to form ionic compounds.

Consider the ionic bonding that occurs between sodium (Na) and chlorine (Cl) to produce sodium chloride, the mineral halite—common table salt. Notice in Figure 2.8A that sodium gives up its single valence electron to chlorine. As a result, sodium now has a stable configuration with eight electrons in its outermost

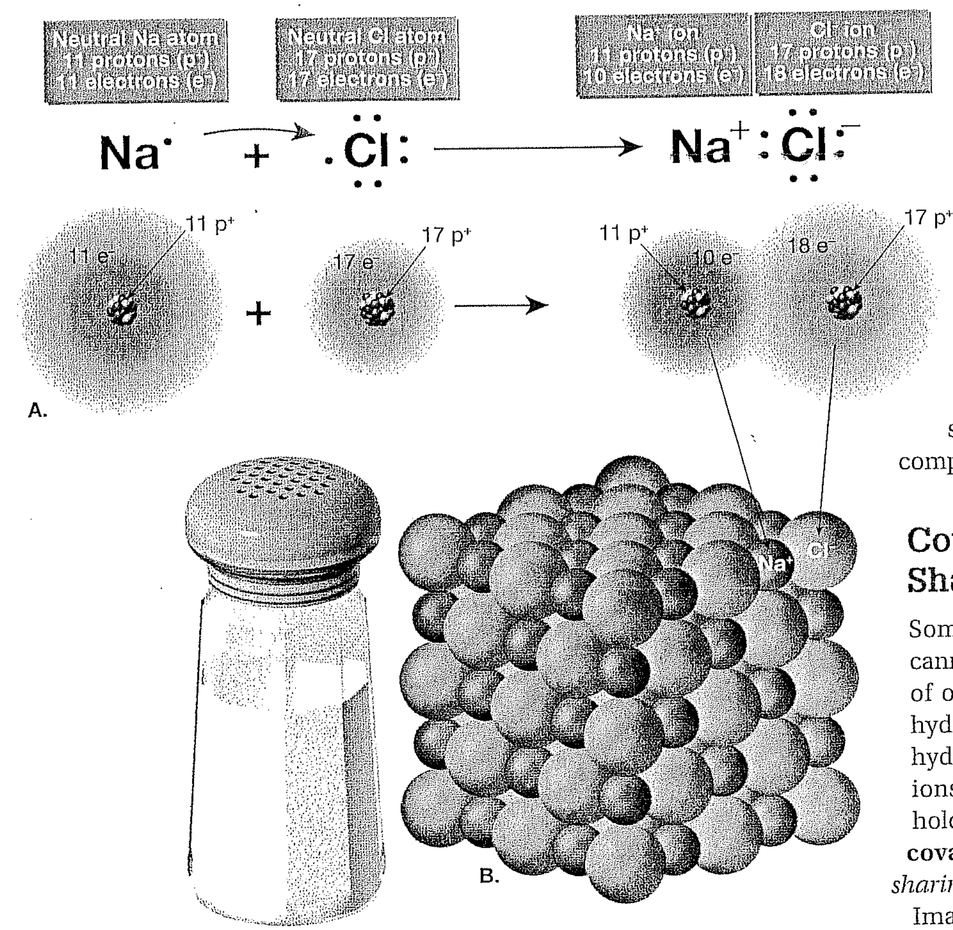


FIGURE 2.8 Chemical bonding of sodium chloride (table salt). A. Through the transfer of one electron in the outer shell of a sodium atom to a chlorine atom, sodium becomes a positive ion and chlorine a negative ion. B. Diagram illustrating the arrangement (packing) of sodium and chlorine ions in table salt.

shell. By acquiring the electron that sodium loses, chlorine (which has seven valence electrons) gains the eighth electron needed to complete its outermost shell. Thus, through the transfer of a single electron, both the sodium and chlorine atoms have acquired a stable electron configuration.

After electron transfer takes place, the atoms are no longer electrically neutral. By giving up one electron, a neutral sodium atom becomes positively charged (with 11 protons and 10 electrons). Similarly, by acquiring one electron, a neutral chlorine atom becomes negatively charged (with 17 protons and 18 electrons). We know that ions with like charges repel, and those with unlike charges attract. Thus, an **ionic bond** is the attraction of oppositely charged ions to one another, producing an electrically neutral compound.

Figure 2.8B illustrates the arrangement of sodium and chlorine ions in ordinary table salt. Notice that salt consists of alternating sodium and chlorine ions, positioned in such a manner that each positive ion is attracted to and surrounded on all sides by negative ions, and vice versa. This arrangement maximizes the attraction between ions with opposite charges while minimizing the repulsion between ions with identical charges. Thus, ionic compounds consist of an orderly arrangement of oppositely charged ions assembled in a definite ratio that provides overall electrical neutrality.

The properties of a chemical compound are dramatically different from the properties of the various elements comprising it. For example, sodium is a soft silvery metal that is extremely reactive and poisonous. If you were to consume even a small amount of elemental sodium, you would need immediate medical attention. Chlorine, a green poisonous gas, is so toxic that it was used as a chemical weapon during World War I. Together, however, these elements produce sodium chloride, a harmless flavor enhancer that we call table salt. Thus, when elements combine to form compounds their properties change significantly.

Covalent Bonds: Electrons Shared

Sometimes the forces that hold atoms together cannot be understood on the basis of the attraction of oppositely charged ions. One example is the hydrogen molecule (H_2), in which the two hydrogen atoms are held together tightly and no ions are present. The strong attractive force that holds two hydrogen atoms together results from a **covalent bond**, *a chemical bond formed by the sharing of a pair of electrons between atoms.*

Imagine two hydrogen atoms (each with one proton and one electron) approaching one another so that their electron clouds overlap (Figure 2.9). Once they meet, the electron configuration will change so that both electrons will primarily occupy the space between the atoms. In other words, the two electrons are shared by both hydrogen atoms and attracted simultaneously by the positive charge of the proton in the nucleus of each atom. The attraction between the electrons and both nuclei holds these atoms together. Although ions do not exist in hydrogen molecules, the force that holds these atoms together arises from the attraction of oppositely charged particles—protons in the nuclei and electrons shared by the atoms.

Metallic Bonds: Electrons Free to Move

In **metallic bonds**, the valence electrons are free to move from one atom to another so that all atoms share the available valence electrons. This type of bonding is found in metals such as copper, gold, aluminum, and silver, and in alloys such as brass and bronze. Metallic bonding accounts for the high electrical conductivity of metals, the ease with which metals are shaped, and numerous other special properties.

CONCEPT CHECK 2.3

1. **What is the difference between an atom and an ion?**
2. **What occurs in an atom to produce a positive ion? A negative ion?**
3. **Briefly distinguish between ionic and covalent bonding and the role that electrons play in both.**

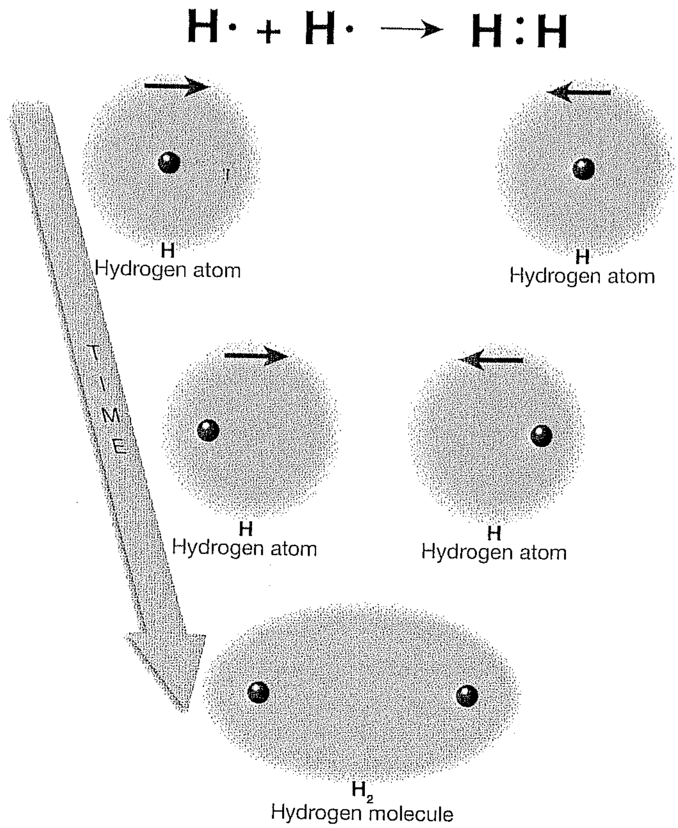


FIGURE 2.9 Formation of a covalent bond between two hydrogen atoms (H) to form a hydrogen molecule (H_2). When hydrogen atoms bond, the electrons are shared by both hydrogen atoms and attracted simultaneously by the positive charge of the proton in the nucleus of each atom. The attraction between electrons and both nuclei holds (bonds) these atoms together.

Isotopes and Radioactive Decay

The **mass number** of an atom is simply the total number of its protons and neutrons. All atoms of a particular element have the same number of protons, but they may have varying numbers of neutrons. Atoms with the same number of protons but different numbers of neutrons are **isotopes** of that element. Isotopes of the same element are labeled by placing the mass number after the element's name or symbol. For example, carbon has three well-known isotopes. One has a mass number of 12 (carbon-12), another has a mass number of 13 (carbon-13), and the third, carbon-14, has a mass number of 14. Carbon-12 must also have six neutrons to give it a mass number of 12. Carbon-14, on the other hand, has six protons plus eight neutrons to give it a mass number of 14.

In chemical behavior, all isotopes of the same element are nearly identical. To distinguish among them is like trying to differentiate identical twins, with one weighing slightly more than the other. Because isotopes of the same element exhibit the same chemical behavior, they often become parts of the same mineral. For example, when the mineral calcite ($CaCO_3$) forms, some of its carbon atoms are carbon-12, and some are carbon-14.

The nuclei of most atoms are stable. However, many elements do have isotopes in which the nuclei are unstable—carbon-14 is one example of an unstable isotope. In this context, *unstable* means that the nuclei change through a random process call **radioactive decay**. During radioactive decay, unstable isotop radiate energy and emit particles. The rates at which unstable is topes decay are measurable. Therefore, certain radioactive ator are used to determine the ages of fossils, rocks, and minera A discussion of radioactive decay and its applications in datii past geologic events appears in Chapter 11.

CONCEPT CHECK 2.4

1. What is an isotope?
2. Name one isotope of carbon that is unstable.
3. If the number of electrons in a neutral atom is 35 and its mas number is 80, calculate the following:
   a. the number of protons
   b. the atomic number
   c. the number of neutrons

Properties of Minerals

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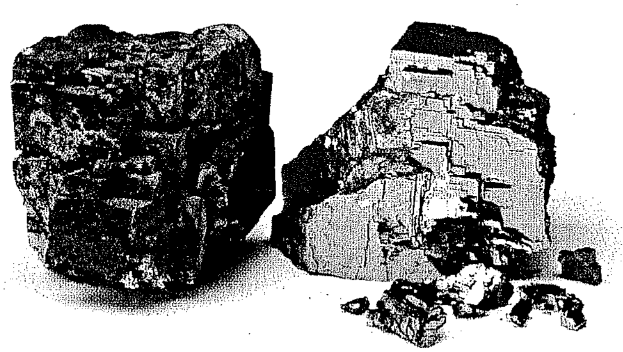
Minerals have definite crystalline structures and chemic compositions that give them unique sets of physical and chemic properties shared by all samples of that mineral. For example, a specimens of halite have the same hardness, the same density, an break in a similar manner. Because a mineral's internal structur and chemical composition are difficult to determine without th aid of sophisticated tests and equipment, the more easil recognized physical properties are frequently used in identificatior

Optical Properties

Of the many optical properties of minerals—their luster, thei ability to transmit light, their color, and their streak—are mos frequently used for mineral identification.

Luster The appearance or quality of light reflected from th surface of a mineral is known as **luster**. Minerals that have th appearance of metals, regardless of color, are said to have a *metallic luster* (Figure 2.10). Some metallic minerals, such a

FIGURE 2.10 The freshly broken sample of galena (right) displays a metallic luster, while the sample on the left is tarnished and has a submetallic luster. (Photo courtesy of E. J. Tarbuck)



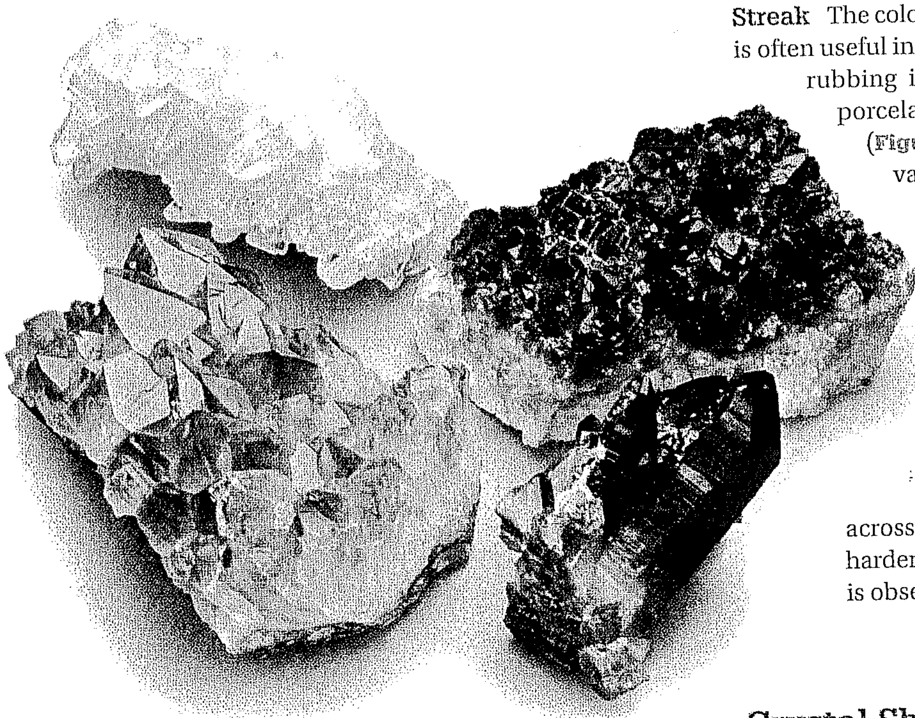


FIGURE 2.11 Quartz. Some minerals, such as quartz, occur in a variety of colors. These samples include crystal quartz (colorless), amethyst (purple quartz), citrine (yellow quartz), and smoky quartz (gray to black). (Photo courtesy of E. J. Tarbuck)

native copper and galena, develop a dull coating or tarnish when exposed to the atmosphere. Because they are not as shiny as samples with freshly broken surfaces, these samples are often said to exhibit a *submetallic luster*.

Most minerals have a *nonmetallic luster* and are described using various adjectives such as *vitreous* (*glassy*), *dull* or *earthy* (a dull appearance like soil), *pearly* (such as a pearl or the inside of a clamshell), *silky* (like satin cloth), or *greasy* (as though coated in oil).

The Ability to Transmit Light Another optical property used in the identification of minerals is the ability to transmit light. When no light is transmitted, the mineral is described as *opaque*; when light but not an image is transmitted through a mineral, it is said to be *translucent*. When both light and an image are visible through the sample, the mineral is described as *transparent*.

Color Although **color** is generally the most conspicuous characteristic of any mineral, it is considered a diagnostic property of only a few minerals. Slight impurities in the common mineral quartz, for example, give it a variety of tints including pink, purple, yellow, white, gray, and even black (Figure 2.11). Other minerals, such as tourmaline, also exhibit a variety of hues, with multiple colors sometimes occurring in the same sample. Thus, the use of color as a means of identification is often ambiguous or even misleading.

Streak The color of the mineral in powdered form, called **streak**, is often useful in identification. A mineral's streak is obtained by rubbing it across a *streak plate* (a piece of unglazed porcelain) and observing the color of the mark it leaves (Figure 2.12). Although the color of a mineral may vary from sample to sample, its streak is usually consistent in color.

Streak can also help distinguish between minerals with metallic luster and those with nonmetallic luster. Metallic minerals generally have a dense, dark streak, whereas minerals with nonmetallic luster typically have a light-colored streak.

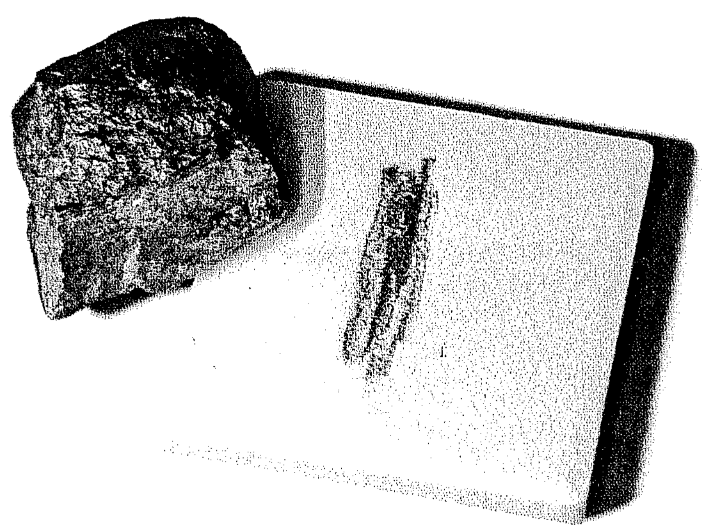
It should be noted that not all minerals produce a streak when rubbed across a streak plate. For example, the mineral quartz is harder than a porcelain streak plate. Therefore, no streak is observed using this method.

Crystal Shape or Habit

Mineralogists use the term **crystal shape** or **habit** to refer to the common or characteristic shape of a crystal or aggregate of crystals. A few minerals exhibit somewhat regular polygons that are helpful in their identification. For example, magnetite crystals sometimes occur as octahedrons, garnets often form dodecahedrons, and halite and fluorite crystals tend to grow as cubes or near cubes. While most minerals have only one common habit, a few have two or more characteristic crystal shapes such as the pyrite sample shown in Figure 2.13.

By contrast, some minerals rarely develop perfect geometric forms. Many of these, however, develop other characteristic shapes useful for identification. Some minerals tend to grow equally in all three dimensions, whereas others tend to be elongated in one

FIGURE 2.12 Although the color of a mineral is not always helpful in identification, the streak, which is the color of the powdered mineral, can be very useful. (Photo by Dennis Tasa)



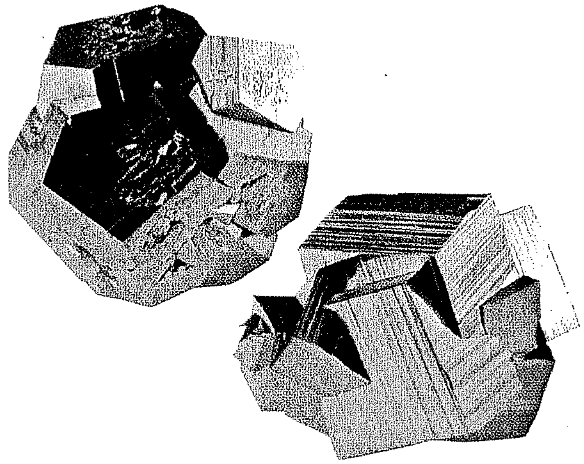


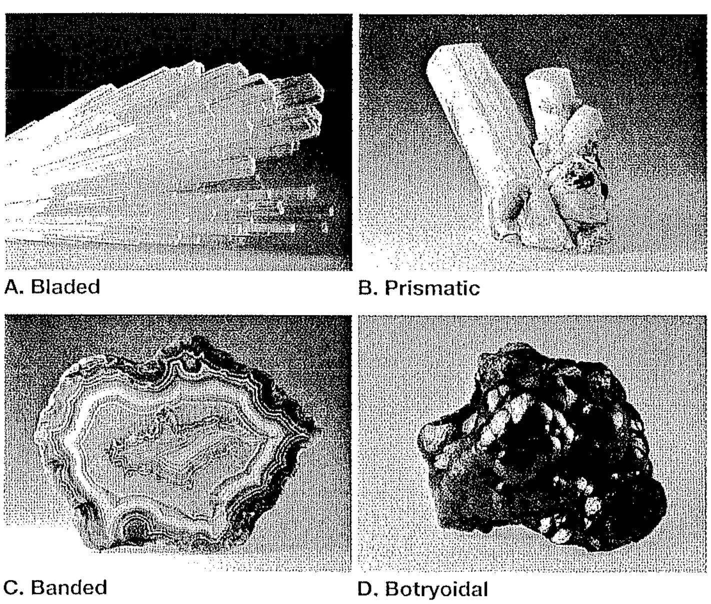
FIGURE 2.13 Although most minerals exhibit only one common crystal shape, some, such as pyrite, have two or more characteristic habits. (Photos by Dennis Tasa)

direction, or flattened if growth in one dimension is suppressed. Commonly used terms to describe these and other crystal habits include *equant* (equidimensional), *bladed*, *fibrous*, *tabular*, *prismatic*, *platy*, *blocky*, and *botryoidal*. Some of these habits are pictured in Figure 2.14.

Mineral Strength

How easily minerals break or deform under stress is determined by the type and strength of the chemical bonds that hold the crystals together. Mineralogists use terms including *tenacity*, *hardness*, *cleavage*, and *fracture* to describe mineral strength and how minerals break when stress is applied.

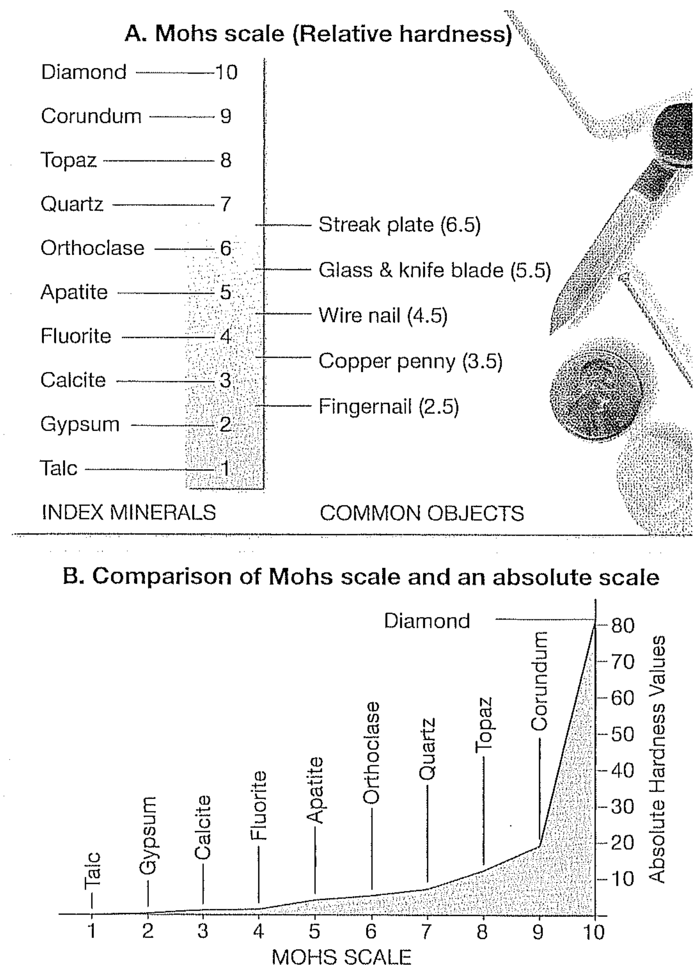
FIGURE 2.14 Some common crystal habits. A. *Bladed*. Elongated crystals that are flattened in one direction. B. *Prismatic*. Elongated crystals with faces that are parallel to a common direction. C. *Banded*. Minerals that have stripes or bands of different color or texture. D. *Botryoidal*. Groups of intergrown crystals resembling a bunch of grapes. (Photos by Dennis Tasa)



Tenacity The term **tenacity** describes a mineral's toughne or its resistance to breaking or deforming. Minerals that a ionically bonded, such as fluorite and halite, tend to be *brit* and shatter into small pieces when struck. By contrast, miner with metallic bonds, such as native copper, are *malleable*, easily hammered into different shapes. Minerals, includi gypsum and talc, that can be cut into thin shavings a described as *sectile*. Still others, notably the micas, are *elas* and will bend and snap back to their original shape after t stress is released.

Hardness One of the most useful diagnostic properties **hardness**, a measure of the resistance of a mineral to abrasion scratching. This property is determined by rubbing a mineral unknown hardness against one of known hardness, or vice ver A numerical value of hardness can be obtained by using t **Mohs scale** of hardness, which consists of 10 minerals arrang in order from 1 (softest) to 10 (hardest), as shown in Figure 2.1 It should be noted that the Mohs scale is a relative ranking, a it does not imply that mineral number 2, gypsum, is twice as ha

FIGURE 2.15 Hardness scales. A. Mohs scale of hardness, with the hardness of some common objects. B. Relationship between Mohs relative hardness scale and an absolute hardness scale.



Students Sometimes Ask...

Are there any artificial materials harder than diamonds?

Yes, but you won't be seeing them anytime soon. A hard form of carbon nitride (C_3N_4), described in 1989 and synthesized in a laboratory shortly thereafter, may be harder than diamond but hasn't been produced in large enough amounts for a proper test. In 1999, researchers discovered that a form of carbon made from fused spheres of 20 and 28 carbon atoms—relatives of the famous "buckyballs"—also could be as hard as a diamond. These materials are expensive to produce, so diamonds continue to be used as abrasives and in certain kinds of cutting tools. Synthetic diamonds, produced since 1955, are now widely used in these industrial applications.

as mineral 1, talc. In fact, gypsum is only slightly harder than talc, as Figure 2.15B indicates.

In the laboratory, other common objects can be used to determine the hardness of a mineral. These include a human fingernail, which has a hardness of about 2.5, a copper penny (3.5), and a piece of glass (5.5). The mineral gypsum, which has a hardness of 2, can be easily scratched with a fingernail. On the other hand, the mineral calcite, which has a hardness of 3, will scratch a fingernail but will not scratch glass. Quartz, one of the hardest common minerals, will easily scratch glass. Diamonds, hardest of all, scratch anything, including other diamonds.

Cleavage In the crystal structure of many minerals, some atomic bonds are weaker than others. It is along these weak bonds that minerals tend to break when they are stressed. **Cleavage** (*Kleiben* = carve) is the tendency of a mineral to break (cleave) along planes of weak bonding. Not all minerals have cleavage, but those that do can be identified by the relatively smooth, flat surfaces that are produced when the mineral is broken.

The simplest type of cleavage is exhibited by the micas (**Figure 2.16**). Because these minerals have very weak bonds in one direction, they cleave to form thin, flat sheets. Some minerals have excellent cleavage in one, two, three, or more directions, whereas others exhibit fair or poor cleavage, and still others have no cleavage at all. When minerals break evenly in more than one direction, cleavage is described by *the number of cleavage directions and the angle(s) at which they meet* (**Figure 2.17**).

Each cleavage surface that has a different orientation is counted as a different direction of cleavage. For example, some minerals cleave to form six-sided cubes. Because cubes are defined by three different sets of parallel planes that intersect at 90-degree angles, cleavage is described as *three directions of cleavage that meet at 90 degrees.*

Do not confuse cleavage with crystal shape. When a mineral exhibits cleavage, it will break into pieces that all have the same geometry. By contrast, the smooth-sided quartz crystals shown in Figure 2.1 (p. 00) illustrate crystal shape rather than cleavage.

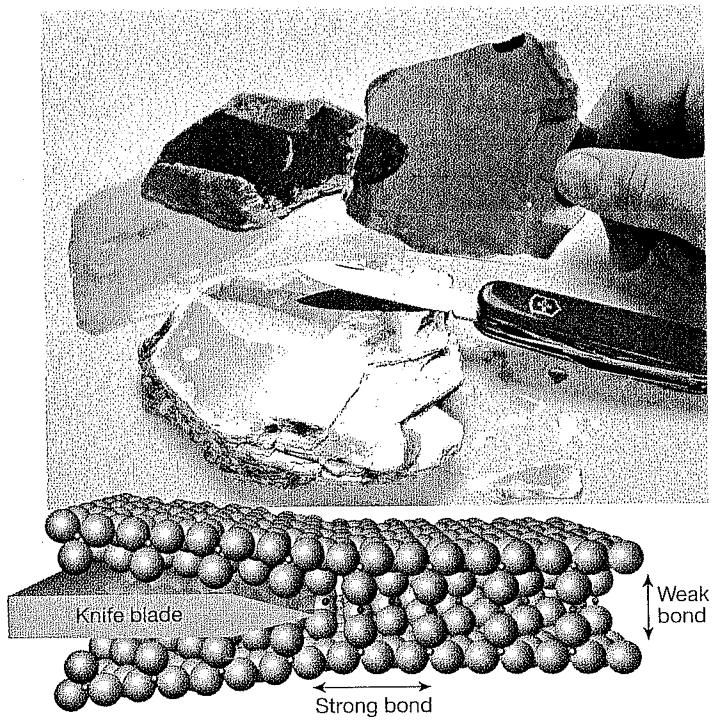


FIGURE 2.16 The thin sheets shown here were produced by splitting a mica (muscovite) crystal parallel to its perfect cleavage. (Photo by Chip Clark)

If broken, they fracture into shapes that do not resemble one another or the original crystals.

Fracture Minerals having chemical bonds that are equally, or nearly equally, strong in all directions exhibit a property called **fracture**. When minerals fracture, most produce uneven surfaces and are described as exhibiting *irregular fracture*. However, some minerals, such as quartz, break into smooth, curved surfaces resembling broken glass. Such breaks are called *conchoidal fractures* (**Figure 2.18**). Still other minerals exhibit fractures that produce splinters or fibers that are referred to as *splintery* and *fibrous fracture*, respectively.

Density and Specific Gravity

Density, an important property of matter, is defined as mass per unit of volume and is often expressed in grams per cubic centimeter (g/cm^3). Mineralogists often use a related measure called **specific gravity** to describe the density of minerals. Specific gravity is a number representing the ratio of a mineral's weight to the weight of an equal volume of water. The specific gravity of water equals 1.

Most common rock-forming minerals have a specific gravity of between 2 and 3. For example, quartz has a specific gravity of 2.65. By contrast, some metallic minerals such as pyrite, native copper, and magnetite are more than twice as dense and thus have more than twice the specific gravity as quartz. Galena, an ore of lead, has a specific gravity of roughly 7.5, whereas the specific gravity of 24-karat gold is approximately 20.

With a little practice, you can estimate the specific gravity of a mineral by hefting it in your hand. Ask yourself, does this mineral

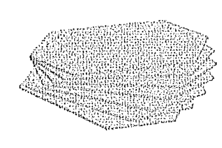
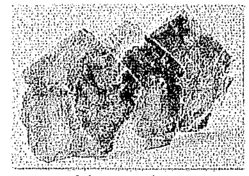
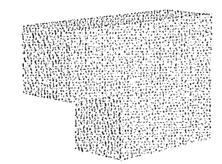
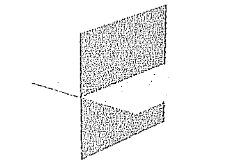
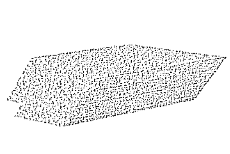
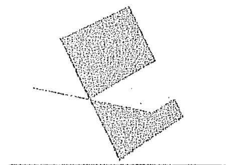
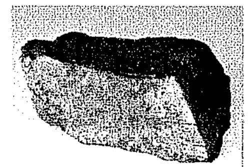
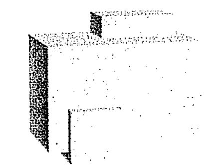
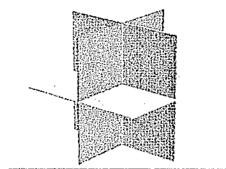
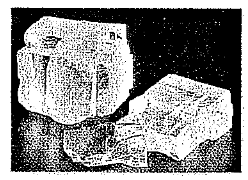
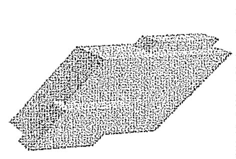
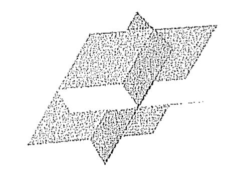
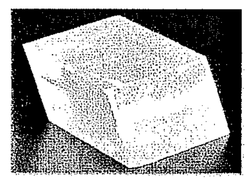
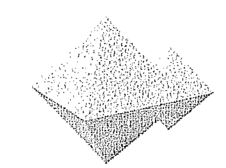
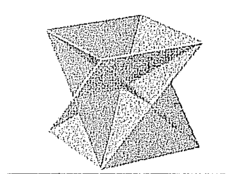
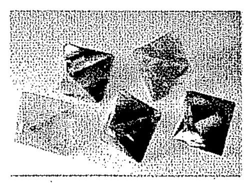
Number of Cleavage Directions	Shape	Sketch	Directions of Cleavage	Sample
1	Flat sheets			 Muscovite
2 at 90°	Elongated form with rectangle cross section (prism)			 Feldspar
2 not at 90°	Elongated form with parallelogram cross section (prism)			 Hornblende
3 at 90°	Cube			 Halite
3 not at 90°	Rhombohedron			 Calcite
4	Octahedron			 Fluorite

FIGURE 2.17 Common cleavage directions exhibited by minerals. (Photos by E. J. Tarbuck and Dennis Tasa)

feel about as "heavy" as similar-sized rocks you have handled? If the answer is "yes," the specific gravity of the sample will likely be between 2.5 and 3.

Other Properties of Minerals

In addition to the properties discussed thus far, some minerals can be recognized by other distinctive properties. For example, halite is ordinary salt, so it can be quickly identified through taste. Talc and graphite both have distinctive feels; talc feels soapy, and graphite feels greasy. Furthermore, the streaks of many sulfur-bearing minerals emit odors like rotten eggs. A f minerals, such as magnetite, have a high iron content and can picked up with a magnet, while some varieties (lodestone) a natural magnets and will pick up small iron-based objects su as pins and paper clips (see Figure 2.25A, p. 43).

Moreover, some minerals exhibit special optical properti For example, when a transparent piece of calcite is placed ov printed text, the letters appear twice. This optical property known as *double refraction* (Figure 2.19).

One very simple chemical test involves placing a drop of dilu hydrochloric acid from a dropper bottle onto a freshly brok

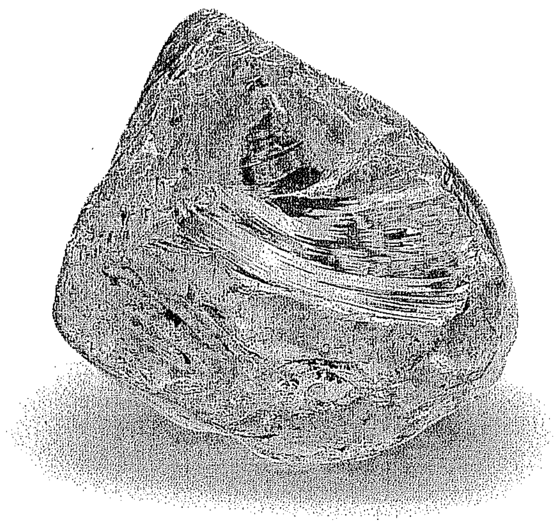


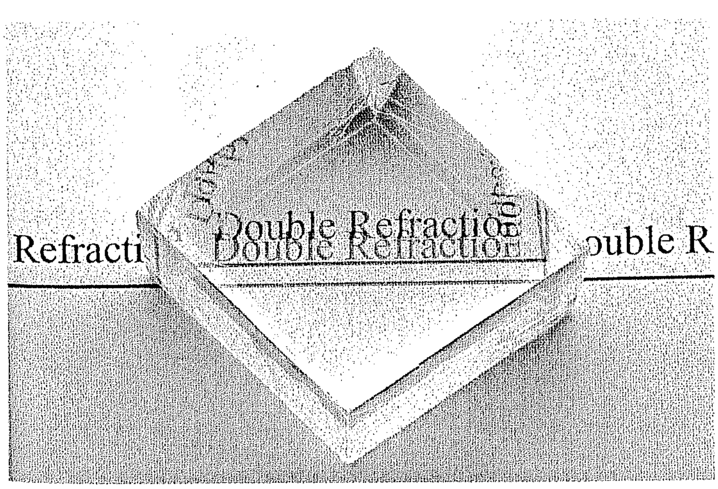
FIGURE 2.18 Conchoidal fracture. The smooth, curved surfaces result when minerals break in a glasslike manner. (Photo courtesy of E. J. Tarbuck)

mineral surface. Using this technique, certain minerals, called carbonates, will effervesce (fizz) as carbon dioxide gas is released (**Figure 2.20**). This test is especially useful in identifying the common carbonate mineral calcite.

CONCEPT CHECK 2.5

1. Define *luster.*
2. Why is color not always a useful property in mineral identification? Give an example of a mineral that supports your answer.
3. What is meant when we refer to a mineral's tenacity? List three terms that describe tenacity.
4. What differentiates cleavage from fracture?
5. What simple chemical test is useful in the identification of the mineral calcite?

FIGURE 2.19 Double refraction illustrated by the mineral calcite. (Photo by Chip Clark)



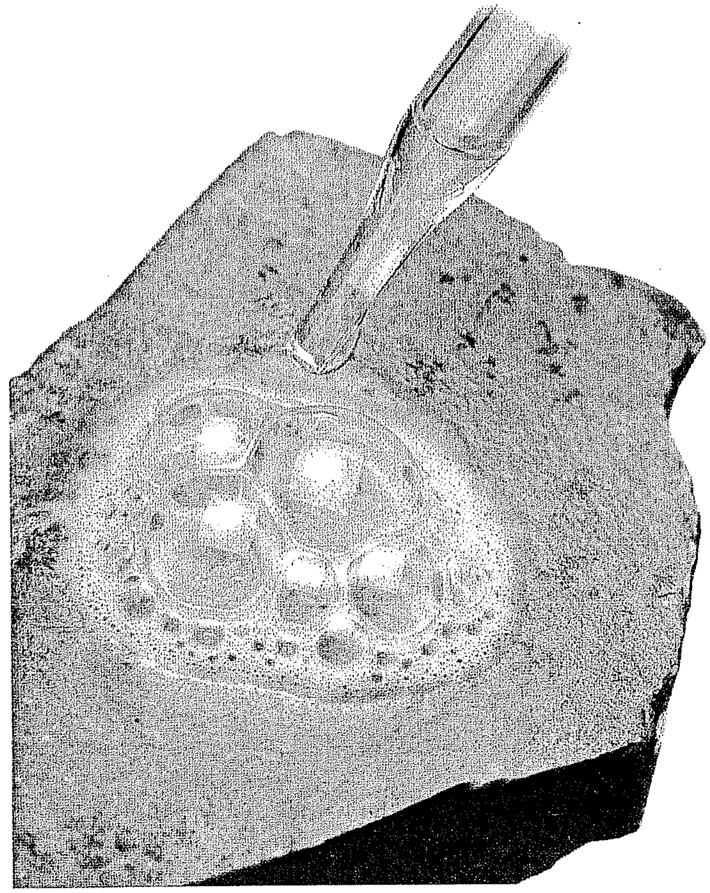


FIGURE 2.20 Calcite reacting with a weak acid. (Photo by Chip Clark)

Mineral Groups

GEODe EARTH SCIENCE
Earth Materials
▸ Minerals

Over 4,000 minerals have been named, and several new ones are identified each year. Fortunately, for students who are beginning to study minerals, no more than a few dozen are abundant! Collectively, these few make up most of the rocks of Earth's crust and, as such, are often referred to as the **rock-forming minerals.**

Although less abundant, many other minerals are used extensively in the manufacture of products and are called *economic minerals.* However, rock-forming minerals and economic minerals are not mutually exclusive groups. When found in large deposits, some rock-forming minerals are economically significant. One example is the mineral calcite, which is the primary component of the sedimentary rock limestone and has many uses including being used in the production of cement.

It is worth noting that *only eight elements* make up the vast majority of the rock-forming minerals and represent more than 98 percent (by weight) of the continental crust (**Figure 2.21**). These elements, in order of abundance from most to least, are oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg). As shown in Figure 2.21, silicon and oxygen are by far the most common

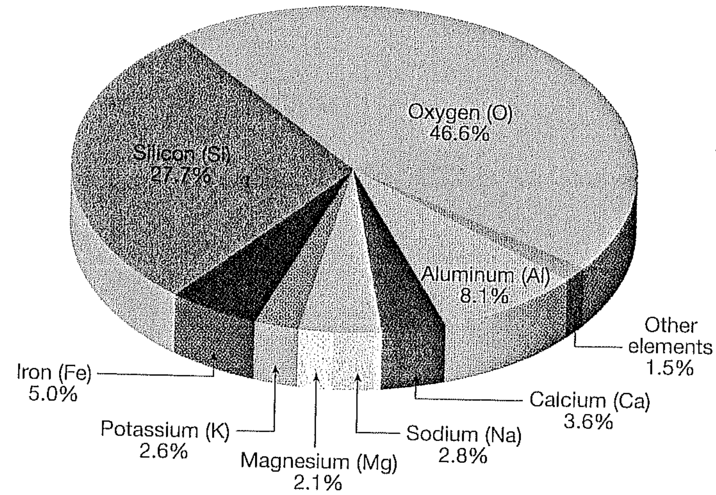


FIGURE 2.21 Relative abundance of the eight most common elements in the continental crust.

elements in Earth's crust. Furthermore, these two elements readily combine to form the basic "building block" for the most common mineral group, the **silicates**. More than 800 silicate minerals are known, and they account for more than 90 percent of Earth's crust.

Because other mineral groups are far less abundant in Earth's crust than the silicates, they are often grouped together under the heading **nonsilicates**. Although not as common as silicates, some nonsilicate minerals are very important economically. They provide us with iron and aluminum to build our automobiles, gypsum for plaster and drywall for home construction, and copper wire that carries electricity and connects us to the Internet. Some common nonsilicate mineral groups include the carbonates, sulfates, and halides. In addition to their economic importance, these mineral groups include members that are major constituents in sediments and sedimentary rocks.

We first discuss the most common mineral group, the silicates, and then consider some of the prominent nonsilicate mineral groups.

Silicate Minerals

Each of the silicate minerals contains oxygen and silicon atoms. Except for a few silicate minerals such as quartz, most silicate minerals also contain one or more additional elements in their crystalline structure. These elements give rise to the great variety of silicate minerals and their varied properties.

All silicates have the same fundamental building block, the **silicon–oxygen tetrahedron** (*tetra* = four, *hedra* = a base). This structure consists of four oxygen atoms surrounding a much smaller silicon atom, as shown in **Figure 2.22**. In some minerals, the tetrahedra are joined into chains, sheets, or three-dimensional networks by sharing oxygen atoms (**Figure 2.23**). These larger silicate structures are then connected to one another by other elements. The primary elements that join silicate structures are iron (Fe), magnesium (Mg), potassium (K), sodium (Na), a calcium (Ca).

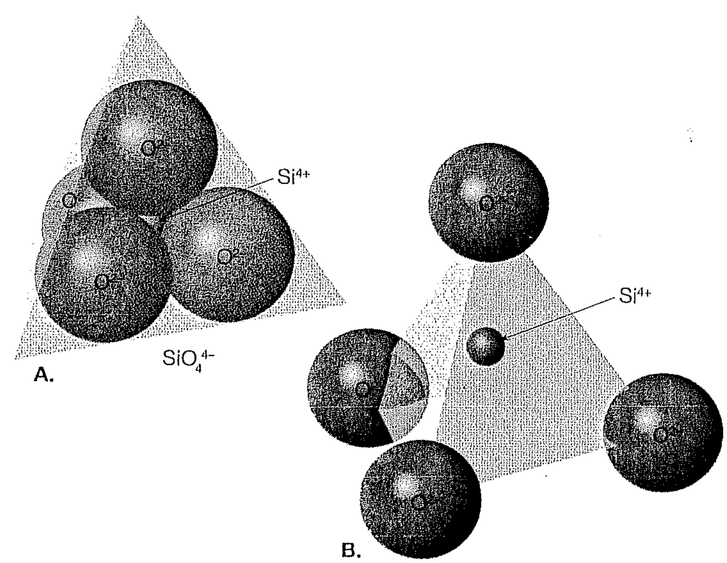
Major groups of silicate minerals and common examples a given in Figure 2.23. The **feldspars** are by far the most plenti group, comprising over 50 percent of Earth's crust. **Quartz**, t second most abundant mineral in the continental crust, is t only common mineral made completely of silicon and oxygen

Notice in Figure 2.23 that each mineral *group* has a particul silicate *structure*. A relationship exists between this intern structure of a mineral and the *cleavage* it exhibits. Because t silicon–oxygen bonds are strong, silicate minerals tend to clea between the silicon–oxygen structures rather than across the For example, the micas have a sheet structure and thus tend cleave into flat plates (see muscovite in Figure 2.16). Quartz, whi has equally strong silicon–oxygen bonds in all directions, has r cleavage but fractures instead.

How do silicate minerals form? Most crystallize from molte rock as it cools. This cooling can occur at or near Earth's surfa (low temperature and pressure) or at great depths (high tempe ature and pressure). The *environment* during crystallization an the *chemical composition of the molten rock* mainly determir which minerals are produced. For example, the silicate miner olivine crystallizes at high temperatures (about 1200°C [2200°F] whereas quartz crystallizes at much lower temperatures (abou 700°C [1300°F]).

In addition, some silicate minerals form at Earth's surface fro the weathered products of other silicate minerals. Clay mineral are an example. Still other silicate minerals are formed under th extreme pressures associated with mountain building. Each sili cate mineral, therefore, has a structure and a chemical compositio that *indicate the conditions under which it formed*. Thus, by carefull examining the mineral makeup of rocks, geologists can often deter mine the circumstances under which the rocks formed.

FIGURE 2.22 Two representations of the silicon–oxygen tetrahedron **A.** The four large spheres represent oxygen ions, and the blue sphere represents a silicon ion. The spheres are drawn in proportion to the radii of the ions. **B.** An expanded view of the tetrahedron that has an oxygen ion at each of the four corners.



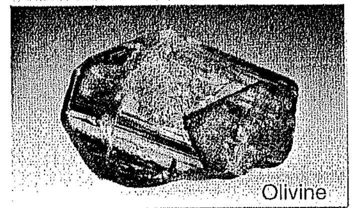
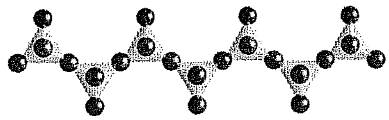
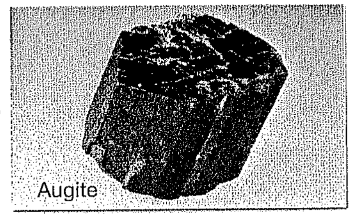
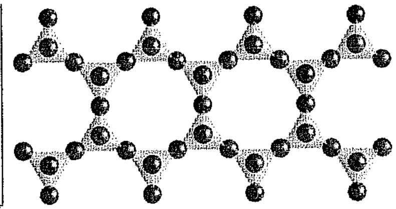
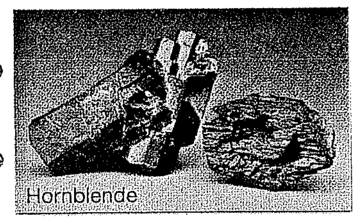
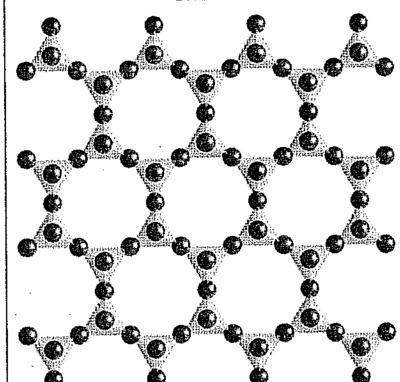
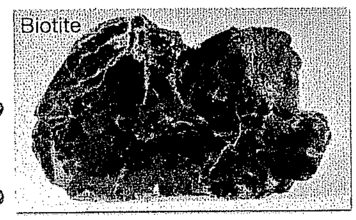
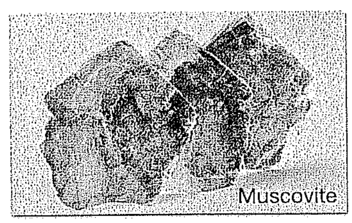
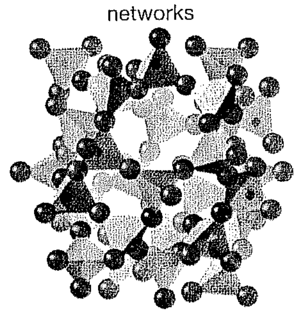
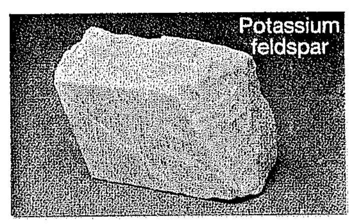
	Mineral/Formula	Cleavage	Silicate Structure	Example
	Olivine group $(Mg, Fe)_2SiO_4$	None	Single tetrahedrons 	
	Pyroxene group (Augite) $(Mg,Fe)SiO_3$	Two planes at 90°	Single chains 	
	Amphibole group (Hornblende) $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains 	
Micas	Biotite $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets 	
Micas	Muscovite $KAl_2(AlSi_3O_{10})(OH)_2$	One plane	Sheets	
Feldspars	Potassium feldspar (Orthoclase) $KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks 	
Feldspars	Plagioclase $(Ca,Na)AlSi_3O_8$	Two planes at 90°	Three-dimensional networks	
	Quartz SiO_2	None	Three-dimensional networks	

FIGURE 2.23 Common silicate minerals. Note that the complexity of the silicate structure increases from top to bottom. (Photos by Dennis Tasa and E. J. Tarbuck)

Students Sometimes Ask...

Are these silicates the same materials used in silicon computer chips and silicone breast implants?

Not really, but all three contain the element silicon (Si). Furthermore, the source of silicon for numerous products, including computer chips and breast implants, comes from silicate minerals. Pure silicon (without the oxygen that silicates have) is used to make computer chips, giving rise to the term "Silicon Valley" for the high-tech region of San Francisco, California's south bay area, where many of these devices are designed. Manufacturers of computer chips engrave silicon wafers with incredibly narrow conductive lines, squeezing millions of circuits into every fingernail-size chip.

Silicone—the material used in breast implants—is a silicon–oxygen polymer gel that feels rubbery and is water repellent, chemically inert, and stable at extreme temperatures. Concern about the long-term safety of these implants limited their use after 1992.

Important Nonsilicate Minerals

Although nonsilicates make up only about 8 percent of Earth crust, some minerals, such as gypsum, calcite, and halite, are majc constituents in sedimentary rocks. Furthermore, many others aı important economically. **Table 2.1** lists some of the nonsilicat mineral classes and a few examples of each. Some of the mo: common nonsilicate minerals belong to one of three classes (minerals—the carbonates (CO_3^{2-}), the sulfates (SO_4^{2-}), and th halides (Cl^{1-}, F^{1-}, B^{1-}).

The carbonate minerals are much simpler structurall than the silicates. This mineral group is composed of the caı bonate ion (CO_3^{2-}) and one or more kinds of positive ions. Th most common carbonate mineral is *calcite,* $CaCO_3$ (calciur carbonate). This mineral is the major constituent in two wel known rocks: limestone and marble. Limestone has man uses, including as road aggregate, as building stone, and a the main ingredient in Portland cement. Marble is use decoratively.

Two other nonsilicate minerals frequently found in sedi mentary rocks are *halite* and *gypsum.* Both minerals are com monly found in thick layers that are the last vestiges of ancier

TABLE 2.1 Common Nonsilicate Mineral Groups

Mineral Groups [key ion(s) or element(s)]	Mineral Name	Chemical Formula	Economic Use
Carbonates (CO_3^{2-})	Calcite	$CaCO_3$	Portland cement, lime
	Dolomite	$CaMg(CO_3)_2$	Portland cement, lime
Halides (Cl^-, F^-, Br^-)	Halite	$NaCl$	Common salt
	Fluorite (Fluorspar)	CaF_2	Hydrofluoric acid production, steelmaking
	Sylvite	KCl	Fertilizer
Oxides (O^{2-})	Hematite	Fe_2O_3	Ore of iron, pigment
	Magnetite	Fe_3O_4	Ore of iron
	Corundum	Al_2O_3	Gemstone, abrasive
	Ice	H_2O	Solid form of water
Sulfides (S^{2-})	Galena	PbS	Ore of lead
	Sphalerite	ZnS	Ore of zinc
	Pyrite	FeS_2	Sulfuric acid production
	Chalcopyrite	$CuFeS_2$	Ore of copper
	Cinnabar	HgS	Ore of mercury
Sulfates (SO_4^{2-})	Gypsum	$CaSO_4 \cdot 2H_2O$	Plaster
	Anhydrite	$CaSO_4$	Plaster
	Barite	$BaSO_4$	Drilling mud
Native elements (single elements)	Gold	Au	Trade, jewelry
	Copper	Cu	Electrical conductor
	Diamond	C	Gemstone, abrasive
	Sulfur	S	Sulfa drugs, chemicals
	Graphite	C	Pencil lead, dry lubricant
	Silver	Ag	Jewelry, photography
	Platinum	Pt	Catalyst

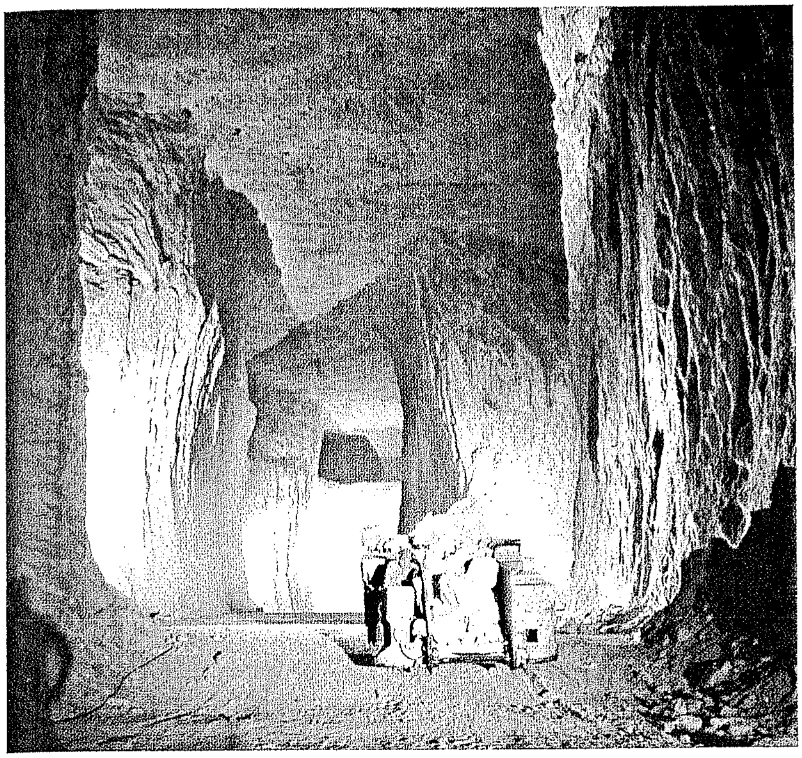
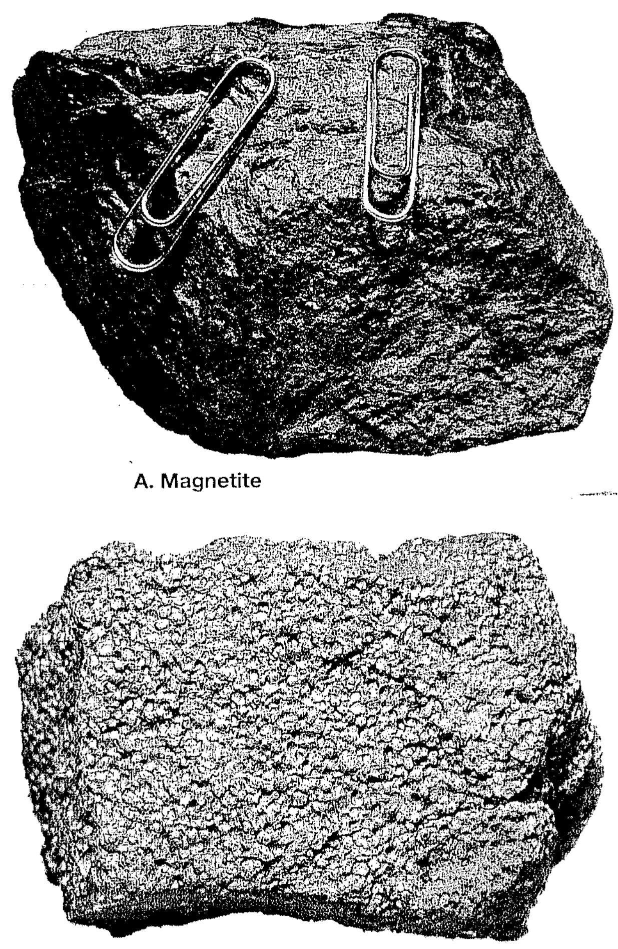


FIGURE 2.24 Thick bed of halite (salt) at an underground mine in Grand Saline, Texas. Note person for scale. (Photo by Tom Bochsler)

seas that have long since evaporated (Figure 2.24). Like limestone, both are important nonmetallic resources. Halite is the mineral name for common table salt (NaCl). Gypsum ($CaSO_4 \cdot 2H_2O$), which is calcium sulfate with water bound into the structure, is the mineral of which plaster and other similar building materials are composed.

Most nonsilicate mineral classes contain members that are prized for their economic value. This includes the oxides, whose members hematite and magnetite are important ores of iron (Figure 2.25). Also significant are the sulfides, which are basically compounds of sulfur (S) and one or more metals. Examples of important sulfide minerals include galena (lead), sphalerite (zinc), and chalcopyrite (copper). In addition, native elements, including gold, silver, and carbon (diamonds), plus a host of other nonsilicate minerals—fluorite (flux in making steel), corundum (gemstone, abrasive), and uraninite (a uranium source)—are important economically (see Box 2.1).

FIGURE 2.25 Magnetite (A) and hematite (B) are both oxides and are both important ores of iron. (Photos by E. J. Tarbuck)



A. Magnetite

B. Hematite

Students Sometimes Ask...

According to the textbook, thick beds of halite and gypsum formed when ancient seas evaporated. Has this happened in the recent past?

Yes. During the past 6 million years, the Mediterranean Sea may have dried up and then refilled several times. When 65 percent of seawater evaporates, the mineral gypsum begins to precipitate, meaning it comes out of solution and settles to the bottom. When 90 percent of the water is gone, halite crystals form, followed by salts of potassium and magnesium. Deep-sea drilling in the Mediterranean has encountered thick deposits of gypsum and salt (mostly halite) sitting one atop the other to a maximum thickness of 2 kilometers (1.2 miles). These deposits are inferred to have resulted from tectonic events that periodically closed and reopened the connection between the Atlantic Ocean and the Mediterranean Sea (the modern-day Straits of Gibraltar) over the past several million years. During periods when the Mediterranean was cut off from the Atlantic, the warm and dry climate in this region caused the Mediterranean to nearly "dry up." Then, when the connection to the Atlantic was opened, the Mediterranean basin would refill with seawater of normal salinity. This cycle was repeated over and over again, producing the layers of gypsum and salt found on the Mediterranean seafloor.

Box 2.1

UNDERSTANDING EARTH

Gemstones

Precious stones have been prized since antiquity. But misinformation abounds regarding gems and their mineral makeup. This stems partly from the ancient practice of grouping precious stones by color rather than mineral makeup. For example, *rubies* and red *spinels* are very similar in color, but they are completely different minerals. Classifying by color led to the more common spinels being passed off to royalty as rubies. Even today, with modern identification techniques, common *yellow quartz* is sometimes sold as the more valuable gemstone *topaz*.

Naming Gemstones

Most precious stones are given names that differ from their parent mineral. For example, *sapphire* is one of two gems that are varieties of the same mineral, *corundum*. Trace elements can produce vivid sapphires of nearly every color (**Figure 2.A**). Tiny amounts of titanium and iron in corundum produce the most prized blue sapphires. When the mineral corundum contains a sufficient quantity of chromium, it exhibits a brilliant red color, and the gem is called *ruby*. Furthermore, if a specimen is not suitable as a gem, it simply goes by the mineral name *corundum*. Because of its hardness, corundum that is not of gem quality is often crushed and sold as an abrasive.

To summarize, when corundum exhibits a red hue, it is called *ruby*, but if it exhibits any other color, the gem is called *sapphire*. Whereas corundum is the base mineral for two gems, quartz is the parent of more than a dozen gems. **Table 2.A** lists some well-known gemstones and their parent minerals.

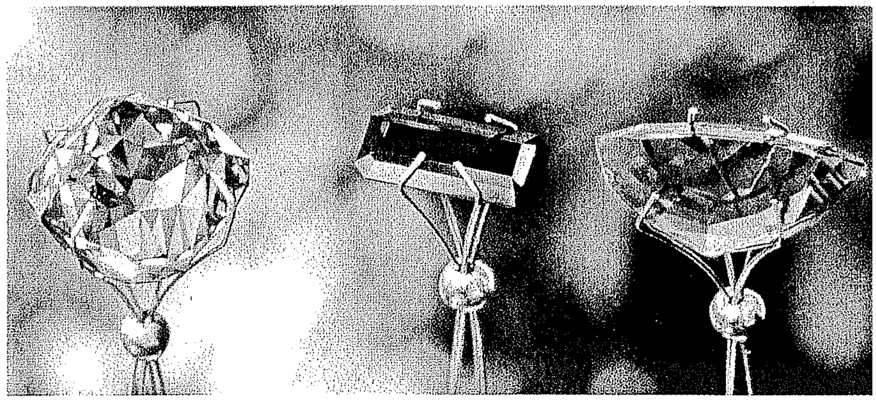


FIGURE 2.A Australian sapphires depicting variations in cuts and colors. (Photo by Fred Ward, Black Star)

What Constitutes a Gemstone?

When found in their natural state, most gemstones are dull and would be passed over by most people as "just another rock." Gems must be cut and polished by experienced professionals before their true beauty is displayed (Figure 2.A). (One of the methods used to shape a gemstone is *cleaving*, the act of splitting the mineral along one of its planes of weakness, or cleavage.) Only those mineral specimens that are of such quality that they can command a price in excess of the cost of processing are considered gemstones.

Gemstones can be divided into two categories: precious and semiprecious. A *precious* gem has beauty, durability, and rarity, whereas a *semiprecious* gem generally has only one or two of these qualities. The gems traditionally held in highest esteem are diamonds, rubies, sapphires, emeralds, and some varieties of opal (Table 2.A). All other gemstones are classified as semiprecious. However, large high-quality specimens of semiprecious stones often command a very high price.

Today, translucent stones with evenly tinted colors are preferred. The most favore hues are red, blue, green, purple, rose, and yellow. The most prized stones are pigeon-blood rubies, blue sapphires, grass-green emeralds, and canary-yellow diamonds. Col orless gems are generally less than desirab except for diamonds that display "flashes o color" known as *brilliance*.

The durability of a gem depends on its hardness; that is, its resistance to abrasion by objects normally encountered in everyda living. For good durability, gems should be as hard or harder than quartz as defined by the Mohs scale of hardness. One notable exception is opal, which is comparatively soft (hardness 5–6.5) and brittle. Opal's esteem comes from its "fire," which is a dis play of a variety of brilliant colors, includinc greens, blues, and reds.

It seems to be human nature to treasure that which is rare. In the case of gemstones large, high-quality specimens are much rar than smaller stones. Thus, large rubies, dia monds, and emeralds, which are rare in addition to being beautiful and durable, command the very highest prices.

TABLE 2.A Important Gemstones

Gem	Mineral Name	Prized Hues	Gem	Mineral Name	Prized Hues
Precious			**Semiprecious**		
Diamond	Diamond	Colorless, yellows	Garnet	Garnet	Reds, greens
Emerald	Beryl	Greens	Jade	Jadeite or nephrite	Greens
Opal	Opal	Brilliant hues	Moonstone	Feldspar	Transparent blues
Ruby	Corundum	Reds	Peridot	Olivine	Olive greens
Sapphire	Corundum	Blues	Smoky quartz	Quartz	Browns
Semiprecious			Spinel	Spinel	Reds
Alexandrite	Chrysoberyl	Variable	Topaz	Topaz	Purples, reds
Amethyst	Quartz	Purples	Tourmaline	Tourmaline	Reds, blue-greens
Cat's-eye	Chrysoberyl	Yellows	Turquoise	Turquoise	Blues
Chalcedony	Quartz (agate)	Banded	Zircon	Zircon	Reds
Citrine	Quartz	Yellows			

CONCEPT CHECK 2.6

1. List the eight most common elements in Earth's crust in order of abundance (most to least).
2. Explain the difference between the terms *silicon* and *silicate*.
3. Draw a sketch of the silicon–oxygen tetrahedron.
4. What is the most abundant mineral in Earth's crust?
5. List six common nonsilicate mineral groups. What key ion(s) or element(s) define each group?
6. What is the most common carbonate mineral?
7. List eight common nonsilicate minerals and their economic uses.

Natural Resources

Earth's crust and oceans are the source of a wide variety of useful and essential materials that have played a crucial role in the development of civilization. From the first use of clay to make pottery nearly 10,000 years ago, the use of Earth materials has expanded resulting in more complex societies. Today, practically every manufactured product contains materials obtained from minerals. Table 2.1 lists some of the most economically important mineral groups.

Renewable versus Nonrenewable Resources

Resources are commonly divided into two broad categories. Some are classified as **renewable**, which means that they can be replenished over relatively short time spans. Common examples are plants and animals for food, natural fibers for clothing, and forest products for lumber and paper. Energy from flowing water, wind, and the Sun are also considered renewable (Figure 2.26).

By contrast, many other basic resources are classified as **nonrenewable**. Important metals such as iron, aluminum, and copper fall into this category, as do our most important fuels: oil, natural gas, and coal. Although these and other resources continue to form, the processes that create them are so slow that significant deposits take millions of years to accumulate. In essence, Earth contains fixed quantities of these substances. When the present supplies are mined or pumped from the ground, there will be no more. Although some nonrenewable resources, such as aluminum, can be used over and over again, others, such as oil, cannot be recycled.

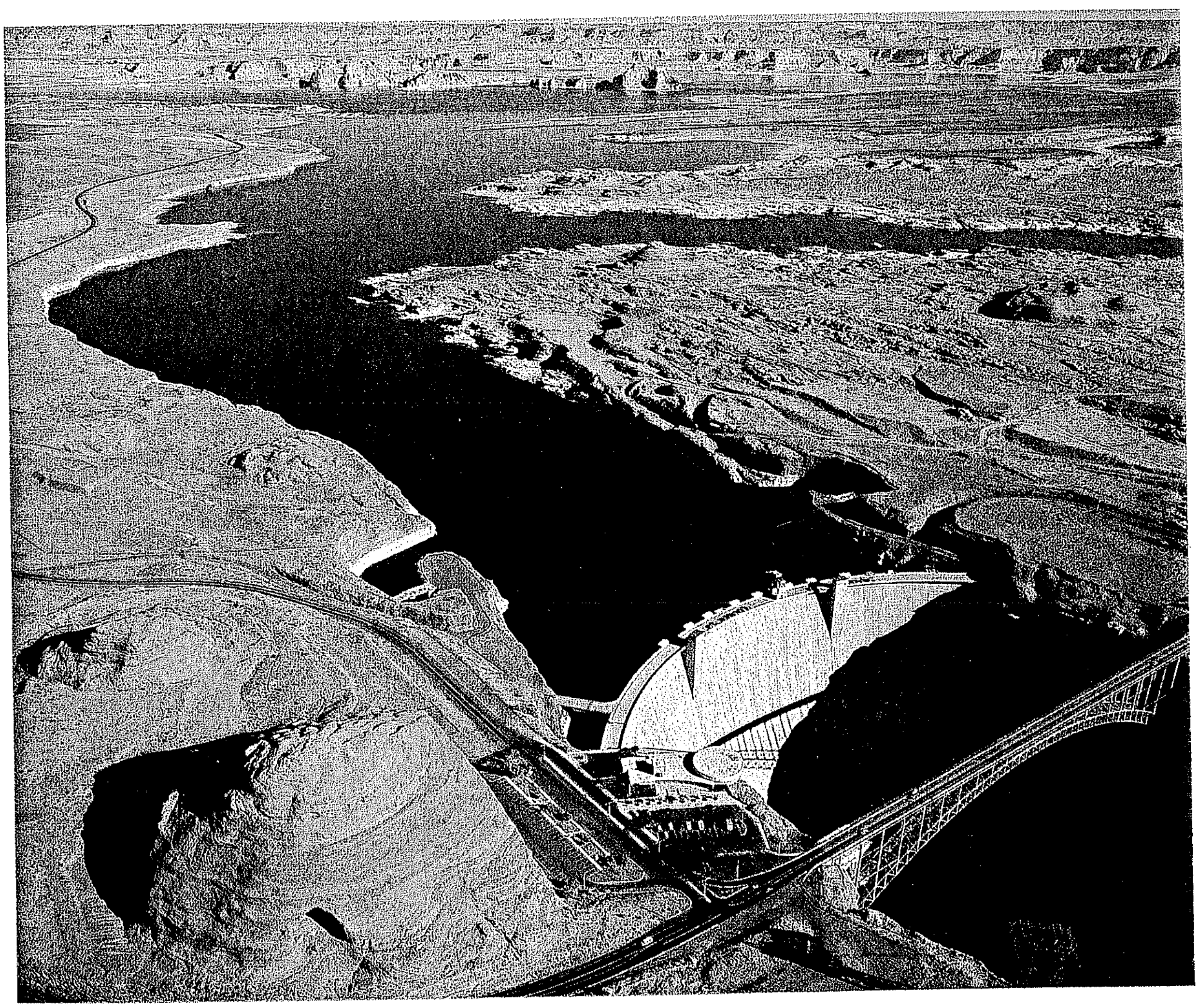


FIGURE 2.26 Hydroelectric power is one example of a renewable resource. Lake Powell is the reservoir that was created when Glen Canyon Dam was built across the Colorado River. As water in the reservoir is released, it drives turbines and produces electricity. (Photo by Michael Collier)

Mineral Resources

Mineral resources are those occurrences of useful minerals that are formed in such quantities that eventual extraction is reasonably certain. Resources include deposits from which minerals can be presently extracted profitably, as well as known deposits that are not yet economically or technologically recoverable.

An **ore** or **ore deposit** is a naturally occurring concentration of one or more metallic minerals that can be extracted economically (see Figure 2.25). In common usage, the term ore is also applied to some nonmetallic minerals such as fluorite and sulfur. However, materials used for such purposes as building stone, road aggregate, abrasives, ceramics, and fertilizers are not usually called ores; rather, they are classified as industrial rocks and minerals.

Recall that more than 98 percent of Earth's crust is composed of only eight elements, and except for oxygen and silicon, all other elements make up a relatively small fraction of common crustal rocks (see Figure 2.21). Indeed, the natural concentrations of many elements are exceedingly small. A deposit containing the average percentage of a valuable element such as gold has no economic value, because the cost of extracting it greatly exceeds the value (the gold that could be recovered.

To have economic value, an element must be concentrated abov the level of its average crustal abundance. For example, copper make up about 0.0135 percent of the crust. For a deposit to be considere as copper ore, it must contain a concentration that is about 100 time this amount. Aluminum, on the other hand, represents 8.13 percen of the crust and can be extracted profitably when it is found in con centrations only about four times its average crustal percentage.

It is important to realize that a deposit may become profitab to extract or lose its profitability because of economic changes. demand for a metal increases and prices rise sufficiently, the statu of a previously unprofitable deposit changes, and it becomes an or The status of unprofitable deposits may also change if a technolog ical advance allows the ore to be extracted at a lower cost than befor

Conversely, changing economic factors can turn a once pro itable ore deposit into an unprofitable deposit that can no longe be called an ore. This situation was illustrated at the copper min ing operation located at Bingham Canyon, Utah, one of the large open-pit mines on Earth (Figure 2.27). Mining was halted the

FIGURE 2.27 Aerial view of Bingham Canyon copper mine near Salt Lake City, Utah. Although the amount of copper in the rock is less than 1 percen the huge volume of material removed and processed each day (about 200,000 tons) yields enough metal to be profitable. (Photo by Michael Collier)

in 1985 because outmoded equipment had driven the cost of extracting the copper beyond the current selling price. The owners responded by replacing an antiquated 1,000-car railroad with conveyor belts and pipelines for transporting the ore and waste. These devices achieved a cost reduction of nearly 30 percent and returned this mining operation to profitability.

Over the years, geologists have been keenly interested in learning how natural processes produce localized concentrations of essential minerals. One well-established fact is that occurrences of valuable mineral resources are closely related to the rock cycle. That is, the mechanisms that generate igneous, sedimentary, and metamorphic rocks, including the processes of weathering and erosion, play a major role in producing concentrated accumulations of useful elements.

Moreover, with the development of the theory of plate tectonics, geologists have added another tool for understanding the processes by which one rock is transformed into another. As these rock-forming processes are examined in the following chapters, we consider their role in producing some of our important mineral resources.

CONCEPT CHECK 2.7

1 **List three examples of renewable and three examples of nonrenewable resources.**
2 **Compare and contrast a *mineral resource* and an *ore deposit.***
3 **What might cause a mineral deposit that previously could not be mined profitably to become reclassified as an ore?**

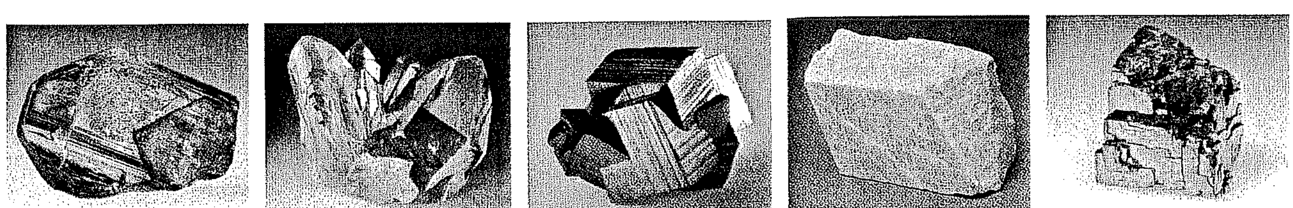
GIVE IT SOME THOUGHT

1. Using the geologic definition of *mineral* as your guide, determine which of the items on the list are minerals and which are not. If an item is not a mineral, explain why not.
   - **a.** gold nugget
   - **b.** seawater
   - **c.** quartz
   - **d.** cubic zirconia
   - **e.** obsidian
   - **f.** ruby
   - **g.** glacial ice
   - **h.** amber

   Refer to the Periodic Table of the Elements (Figure 2.5) to help you answer questions 2, 3, and 4.
2. If the number of protons in a neutral atom is 92 and its mass number is 238:
   - **a.** What is the name of that element?
   - **b.** How many electrons does it have?
   - **c.** How many neutrons does it have?
3. Which element is more likely to form chemical bonds: xenon (Xe) or sodium (Na)? Explain why.
4. The information below refers to three isotopes of the element potassium. Using this information, determine the appropriate number of protons and neutrons for each isotope. Label each isotope in the manner used in the chapter.

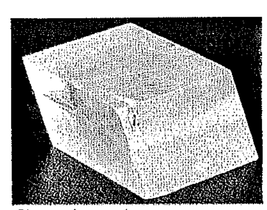
Atomic Number = 19	Atomic Number = 19	Atomic Number = 19
Mass Number = 39	Mass Number = 40	Mass Number = 41

5. Referring to the accompanying photos of five minerals, determine which of these specimens exhibit a metallic luster and which have a nonmetallic luster.



A. B. C. D. E.

6. Examine the accompanying photo of a mineral that has several smooth, flat surfaces that resulted when the specimen was broken.
   - **a.** How many flat surfaces are present on this specimen?
   - **b.** How many *different directions* of cleavage does this specimen have?
   - **c.** Do the cleavage directions meet at 90-degree angles?



Cleaved sample

7. Gold has a specific gravity of almost 20. A 5-gallon bucket of water weighs 40 pounds. How much would a 5-gallon bucket of gold weigh?
8. Do an Internet search to determine what mineral(s) are extracted from the ground during the manufacturing of the following products:
   a. stainless steel utensils
   b. cat litter
   c. Tums brand antacid tablets
   d. lithium batteries
   e. aluminum beverage cans
9. Most states have designated a state mineral, rock, or gemstone to promote interest in the state's natural resources. Describe your state mineral, rock, or gemstone and explain why it was selected. If your state does not have a state mineral, rock, or gemstone, select one from a state adjacent to yours.

In Review Chapter 2 Matter and Minerals

- A *mineral* is any naturally occurring inorganic solid that possesses an orderly crystalline structure and can be represented by a chemical formula. Most *rocks* are aggregates composed of two or more minerals.
- All matter, including minerals, is composed of minute particles called *atoms*—the building blocks of minerals. Each atom has a *nucleus*, which contains *protons* (particles with positive electrical charges) and *neutrons* (particles with neutral electrical charges). Surrounding the nucleus of an atom in regions called *principal shells* are *electrons*, which have negative electrical charges. The number of protons in an atom's nucleus determines its *atomic number* and the name of the element. An *element* is a large collection of electrically neutral atoms, all having the same atomic number.
- Atoms combine to form ionic compounds, molecules, or metallic substances. Atoms bond by either gaining, losing, or sharing electrons with other atoms. In *ionic bonding*, one or more electrons are transferred from one atom to another, giving the atoms a net positive or negative charge. The resulting electrically charged atoms are called *ions*. Ionic compounds consist of oppositely charged ions assembled in a regular, crystalline structure that allows for the maximum attraction of ions, given their sizes. Another type of bond, the *covalent bond*, is produced when atoms share electrons.
- *Isotopes* are variants of the same element that have a different *mass number* (the total number of neutrons plus protons found in an atom's nucleus). Some isotopes are unstable and disintegrate naturally through a process called *radioactivity*.
- The properties of minerals include *crystal shape* (*habit*), *luster*, *color*, *streak*, *tenacity*, *hardness*, *cleavage*, *fracture*, and *density* or *specific gravity*. In addition, a number of special physical and chemical properties (*taste*, *smell*, *elasticity*, *feel*, *magnetism*, *double refraction*, and *chemical reaction to hydrochloric acid*) are useful in identifying certain minerals. Each mineral has a unique set of properties that can be used for identification.
- Of the nearly 4,000 minerals, no more than a few dozen make up most of the rocks of Earth's crust and, as such, are classified as rock-forming minerals. Eight elements (oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium) make up the bulk of these minerals and represent over 98 percent (by weight) of Earth's continental crust.
- The most common mineral group is the *silicates*. All silicate minerals have the negatively charged *silicon–oxygen tetrahedron* as their fundamental building block. In some silicate minerals the tetrahedra are joined in chains (the pyroxene and amphibole groups); in others, the tetrahedra are arranged into sheets (the micas—biotite and muscovite), or three-dimensional networks (the feldspars and quartz). The tetrahedra and various silicate structures are often bonded together by the positive ions of iron, magnesium, potassium, sodium, aluminum, and calcium. Each silicate mineral has a structure and a chemical composition that indicates the conditions under which it formed.
- The *nonsilicate* mineral groups, which contain several economically important minerals, include the *oxides* (e.g., the mineral hematite, mined for iron), *sulfides* (e.g., the mineral sphalerite, mined for zinc, and the mineral galena, mined for lead), *sulfates*, *halides*, and *native elements* (e.g., gold and silver). The more common nonsilicate rock-forming minerals include the *carbonate minerals*, calcite and dolomite. Two other nonsilicate minerals frequently found in sedimentary rocks are halite and gypsum.
- Mineral resources are those occurrences of useful minerals ultimately available commercially. Resources include already identified deposits from which minerals can be extracted profitably, called *reserves*, as well as known deposits that are not yet economically or technologically recoverable. Deposits inferred to exist, but not yet discovered, are also considered mineral resources. The term *ore* is used to denote those useful metallic minerals that can be mined for a profit, as well as some nonmetallic minerals, such as fluorite and sulfur, that contain useful substances.

Key Terms

atom (p. 30)
atomic number (p. 31)
chemical bond (p. 32)
chemical compound (p. 32)
cleavage (p. 37)
color (p. 35)
covalent bond (p. 33)
crystal shape (p. 35)
density (p. 37)
electron (p. 30)
element (p. 31)
feldspars (p. 40)
fracture (p. 37)
habit (p. 35)
hardness (p. 36)
ion (p. 32)
ionic bond (p. 33)
isotope (p. 34)
luster (p. 34)
mass number (p. 34)
metallic bond (p. 33)
mineral (p. 29)
mineral resource (p. 46)
mineralogy (p. 28)
Mohs scale (p. 36)
neutron (p. 30)
nonrenewable resources (p. 45)
nonsilicates (p. 40)
nucleus (p. 30)
octet rule (p. 32)
ore (p. 46)
ore deposit (p. 46)
periodic table (p. 31)
proton (p. 30)
quartz (p. 40)
radioactive decay (p. 34)
renewable resources (p. 45)
rock (p. 29)
rock-forming minerals (p. 39)
silicate (p. 40)
silicon–oxygen tetrahedron (p. 40)
specific gravity (p. 37)
streak (p. 35)
tenacity (p. 36)
valence electron (p. 31)

Examining the Earth System

1. Perhaps one of the most significant interrelationships between humans and the Earth system involves the extraction, refinement, and distribution of the planet's mineral wealth. To help you understand these associations, begin by thoroughly researching a mineral commodity that is mined in your local region or state. (You might find useful the information at these United States Geological Survey [USGS] Websites: **http://minerals.er.usgs.gov/minerals/pubs/state/** and **http://minerals.er.usgs.gov:80/minerals/pubs/mcs/**) What products are made from this mineral? Do you use any of these products? Describe the mining and refining of the mineral and the local impact these processes have on each of Earth's spheres (atmosphere, hydrosphere, solid Earth, and biosphere). Are any of the effects negative? If so, what, if anything, is being done to end or minimize the damage?
2. Referring to the mineral you described above, in your opinion does the environmental impact of extracting this mineral outweigh the benefits derived from its products?

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