UNIT 1

Earth Materials

2

Matter and Minerals

FOCUS ON CONCEPTS

Each statement represents the primary learning objective for the corresponding major heading within the chapter. After you complete the chapter, you should be able to:

2.1 List the main characteristics that an Earth material must possess to be considered a mineral and describe each characteristic.

2.2 Compare and contrast the three primary particles contained in atoms.

2.3 Distinguish among ionic bonds, covalent bonds, and metallic bonds.

2.4 List and describe the properties used in mineral identification.

2.5 List the common silicate and nonsilicate minerals and describe what characterizes each group.

2.6 Discuss Earth's mineral resources in terms of renewability. Differentiate between mineral resources and ore deposits.

The Cave of Crystals, Chihuahua, Mexico, contains giant gypsum crystals, some of the largest natural crystals ever found. (Photo by Carsten Peter/Speleoresearch & Films/National Geographic/Getty Images)

EARTH'S CRUST AND OCEANS are home to a wide variety of useful and essential minerals. Most people are familiar with the common uses of many basic metals, including aluminum in beverage cans, copper in electrical wiring, and gold and silver in jewelry. However, 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 dentists use drill bits impregnated with diamonds to drill through tooth enamel. In fact, practically every manufactured product contains materials obtained from minerals.

In addition to the economic uses of rocks and minerals, every geologic process in some way depends on the properties of these basic Earth materials. Events such as volcanic eruptions, mountain building, weathering and erosion, and even earthquakes involve rocks and minerals. Consequently, a basic knowledge of Earth materials is essential to understanding all geologic phenomena.

2.1 Minerals: Building Blocks of Rocks

List the main characteristics that an Earth material must possess to be considered a mineral and describe each characteristic.

We begin our discussion of Earth materials with an overview of **mineralogy** (*mineral* = mineral, *ology* = study of) because minerals are the building blocks of rocks. Humans have used minerals for both practical and decorative purposes for thousands of years. For example, the common mineral quartz is the source of silicon for computer chips. The first Earth materials mined were flint and chert, which humans fashioned into weapons and cutting tools. As early as 3700 B.C.E. Egyptians began mining gold, silver, and copper. By 2200 B.C.E. humans had discovered how to combine copper with tin to make bronze—a strong, hard alloy. Later, a process was developed to extract iron from minerals such as hematite—a discovery that marked the decline of the Bronze Age. During the Middle Ages, mining of a variety of minerals became common, and the impetus for the formal study of minerals was in place.

▼ **Figure 2.1 Quartz crystals** A collection of well-developed quartz crystals found near Hot Springs, Arkansas.
(Photo by Jeffrey A. Scovil)

In everyday conversation, the term *mineral* is used in several different ways. For example, those concerned with health and fitness extol the benefits of vitamins and minerals. The mining industry typically uses the word *mineral* to refer to anything extracted from Earth, such as coal, iron ore, or sand and gravel. The guessing game *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 (**Figure 2.1**)?

Defining a Mineral

Geologists define **mineral** as *any naturally occurring inorganic solid that possesses an orderly crystalline structure and a definite chemical composition that allows for some variation*. Thus, Earth materials that are classified as minerals exhibit the following characteristics:

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. **Generally inorganic.** Inorganic crystalline solids, such as ordinary table salt (halite), that are found naturally in the ground are considered minerals. Organic compounds (that is, the kinds of carbon-containing compounds that are made by living things) are generally not considered minerals. Sugar, a crystalline solid like salt but extracted from

sugarcane or sugar beets, is a common example of 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, geologists consider them minerals.

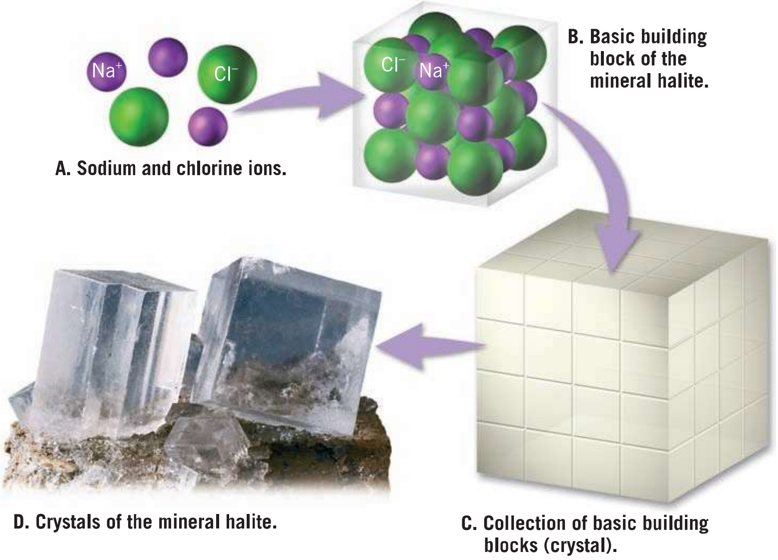
3. **Solid substance.** Only solid crystalline substances are considered minerals. Ice (frozen water) fits this criterion and is considered a mineral, whereas liquid water and water vapor do not.
4. **Orderly crystalline structure.** Minerals are crystalline substances, made up of atoms (or ions) that are arranged in an orderly, repetitive manner (**Figure 2.2**). This orderly packing of atoms is reflected in regularly shaped objects called *crystals*. Some naturally occurring solids, such as volcanic glass (obsidian), lack a repetitive atomic structure and are not considered minerals.
5. **Definite chemical composition that allows for some variation.** 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 1:2 ratio. This proportion of silicon to oxygen is true for any sample of pure quartz, regardless of its origin. However, the compositions of some minerals can 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.

What Is a Rock?

In contrast to minerals, rocks are more loosely defined. Simply, a **rock** is any solid mass of mineral or mineral-like matter that occurs naturally as part of our planet. Most rocks, like the sample of granite shown in **Figure 2.3**, are 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 different minerals that make up granite can be easily identified. However, some rocks are composed almost entirely of one mineral. A common example is the sedimentary rock *limestone*, which is an impure mass of the mineral calcite.

In addition, 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.



▲ **Figure 2.2 Arrangement of sodium and chloride ions in the mineral halite** The arrangement of atoms (ions) into basic building blocks that have a cubic shape results in regularly shaped cubic crystals. (Photo by Dennis Tasa)

CONCEPT CHECKS 2.1

1. List five characteristics of a mineral.
2. Based on the definition of mineral, which of the following—gold, liquid water, synthetic diamonds, ice, and wood—are *not* classified as minerals?
3. Define the term *rock*. How do rocks differ from minerals?

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

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2.2 Atoms: Building Blocks of Minerals

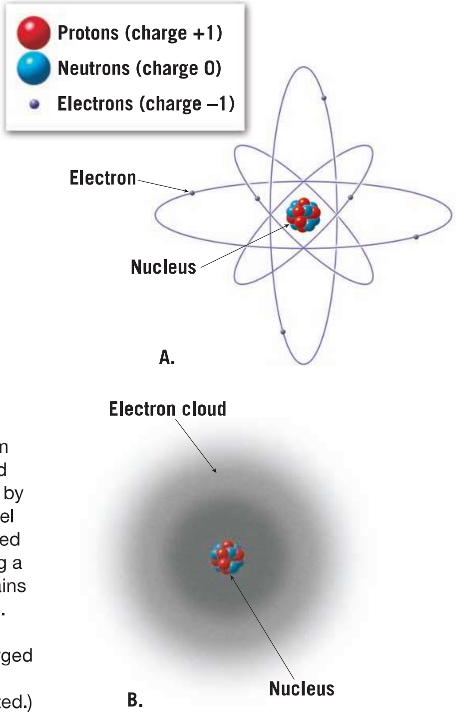
Compare and contrast the three primary particles contained in atoms.

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

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 1/2000 that of a proton. To visualize this difference, imagine a scale on which a proton or neutron has the mass of a baseball, whereas an electron has 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 charges of protons and electrons are equal in magnitude but opposite in polarity, so when these two particles are paired, the charges cancel each other out. Since matter typically contains equal numbers of positively charged protons and negatively charged electrons, most substances are electrically neutral.



▶ **Figure 2.4 Two models of an atom A.** Simplified view of an atom having a central nucleus composed of protons and neutrons, encircled by high-speed electrons. **B.** This model of an atom shows spherically shaped 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 occupied by negatively charged electrons. (The relative sizes of the nuclei shown are greatly exaggerated.)

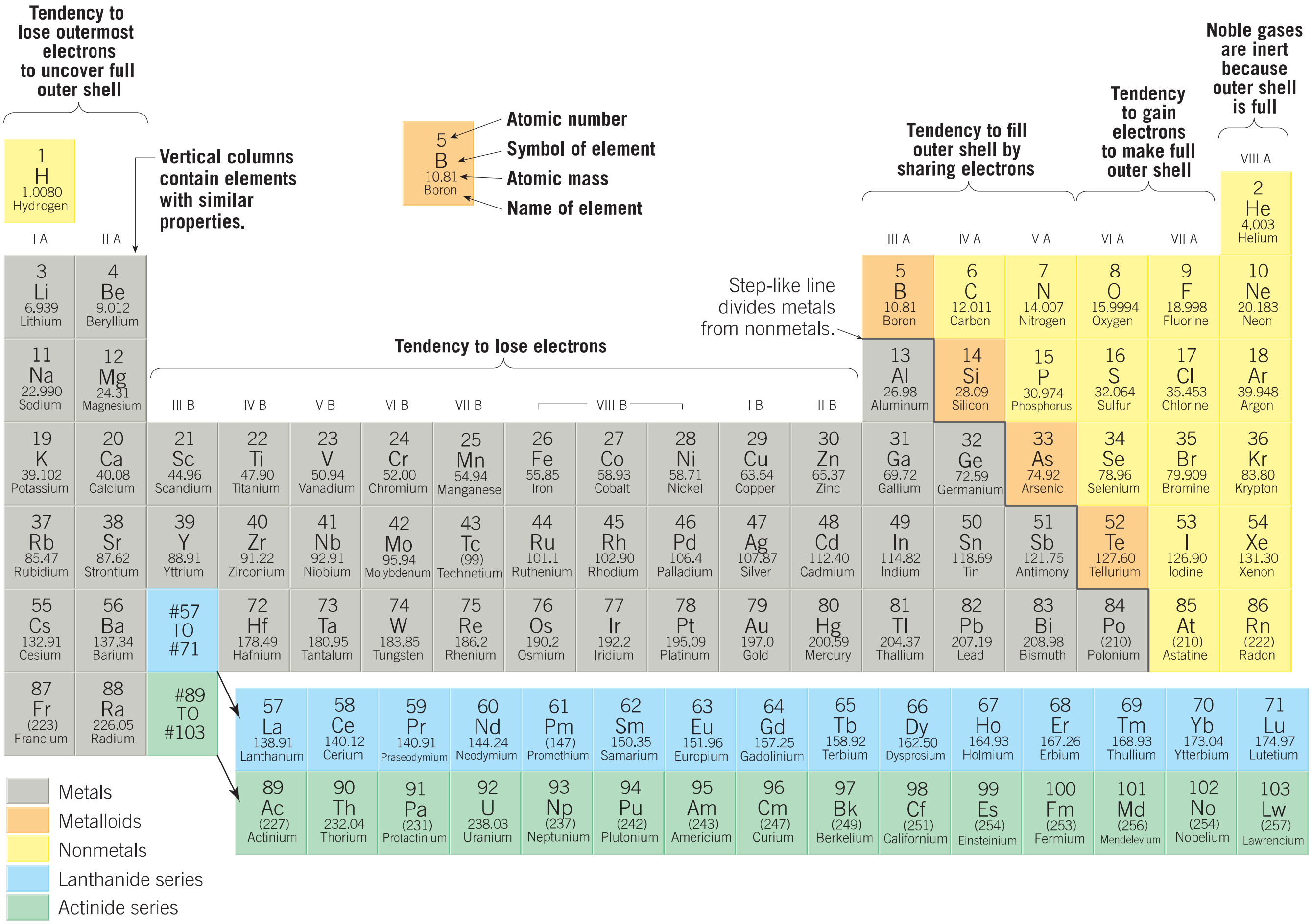
Illustrations sometimes show electrons orbiting the nucleus in a manner that resembles the planets of our solar system orbiting the Sun (see Figure 2.4A). However, electrons do not actually behave this way. A more realistic depiction would show electrons as a cloud of negative charges surrounding the nucleus (see 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 generally containing **valence electrons**. These electrons can be transferred to or shared 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 then 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, free atoms (those not bonded to other atoms) generally 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 1 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 the atom's chemical nature. All atoms with the same number of protons have the same chemical and physical properties; collectively they constitute an **element**. There are about 90 naturally occurring elements, and several more have been synthesized in the laboratory. You are probably familiar with the names of many elements, including carbon, nitrogen, and oxygen. All carbon atoms have 6 protons, whereas all nitrogen atoms have 7 protons, and all oxygen atoms have 8.

The **periodic table**, shown in **Figure 2.5**, is a tool scientists use to organize the known elements. In it, the elements with similar properties line up in columns, referred to as *groups*. Each element is assigned a one- or two-letter symbol. The atomic number and atomic mass for each element are also included in the periodic table.



I A	II A	III B	IV B	V B	VI B	VII B	VIII B			I B	II B	III A	IV A	V A	VI A	VII A	VIII A
1 H 1.0080 Hydrogen																	2 He 4.003 Helium
3 Li 6.939 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.011 Carbon	7 N 14.007 Nitrogen	8 O 15.9994 Oxygen	9 F 18.998 Fluorine	10 Ne 20.183 Neon
11 Na 22.990 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminum	14 Si 28.09 Silicon	15 P 30.974 Phosphorus	16 S 32.064 Sulfur	17 Cl 35.453 Chlorine	18 Ar 39.948 Argon
19 K 39.102 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.90 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.71 Nickel	29 Cu 63.54 Copper	30 Zn 65.37 Zinc	31 Ga 69.72 Gallium	32 Ge 72.59 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.909 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.94 Molybdenum	43 Tc (99) Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.90 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.87 Silver	48 Cd 112.40 Cadmium	49 In 114.82 Indium	50 Sn 118.69 Tin	51 Sb 121.75 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.30 Xenon
55 Cs 132.91 Cesium	56 Ba 137.34 Barium	#57 TO #71	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.85 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.09 Platinum	79 Au 197.0 Gold	80 Hg 200.59 Mercury	81 Tl 204.37 Thallium	82 Pb 207.19 Lead	83 Bi 208.98 Bismuth	84 Po (210) Polonium	85 At (210) Astatine	86 Rn (222) Radon
87 Fr (223) Francium	88 Ra 226.05 Radium	#89 TO #103															
			57 La 138.91 Lanthanum	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm (147) Promethium	62 Sm 150.35 Samarium	63 Eu 151.96 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.92 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.93 Holmium	68 Er 167.26 Erbium	69 Tm 168.93 Thullium	70 Yb 173.04 Ytterbium	71 Lu 174.97 Lutetium
			89 Ac (227) Actinium	90 Th 232.04 Thorium	91 Pa (231) Protactinium	92 U 238.03 Uranium	93 Np (237) Neptunium	94 Pu (242) Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (249) Berkelium	98 Cf (251) Californium	99 Es (254) Einsteinium	100 Fm (253) Fermium	101 Md (256) Mendelevium	102 No (254) Nobelium	103 Lw (257) Lawrencium

▲ **Figure 2.5** **Periodic table of the elements**

▼ **Figure 2.6** **Examples of minerals composed of a single element** (Photos by Dennis Tasa)


A. Gold on quartz **B. Sulfur** **C. Copper**

Atoms of the naturally occurring elements are the basic building blocks of Earth's minerals. Most elements join with other elements to form **chemical compounds**. Therefore, most minerals are chemical compounds composed of atoms of two or more elements. These include the minerals quartz (SiO_2), halite (NaCl), and calcite ($CaCO_3$). However, a few minerals, such as diamonds, sulfur, and native gold and copper, are made entirely of atoms of only one element (**Figure 2.6**). (A metal is called "native" when it is found in its pure form in nature; see GEOgraphics 2.1.)

CONCEPT CHECKS 2.2

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

GEOGRAPHICS 2.1

Gold

Gold has been treasured since long before recorded history for its beauty.

How valuable is gold?

$41,280

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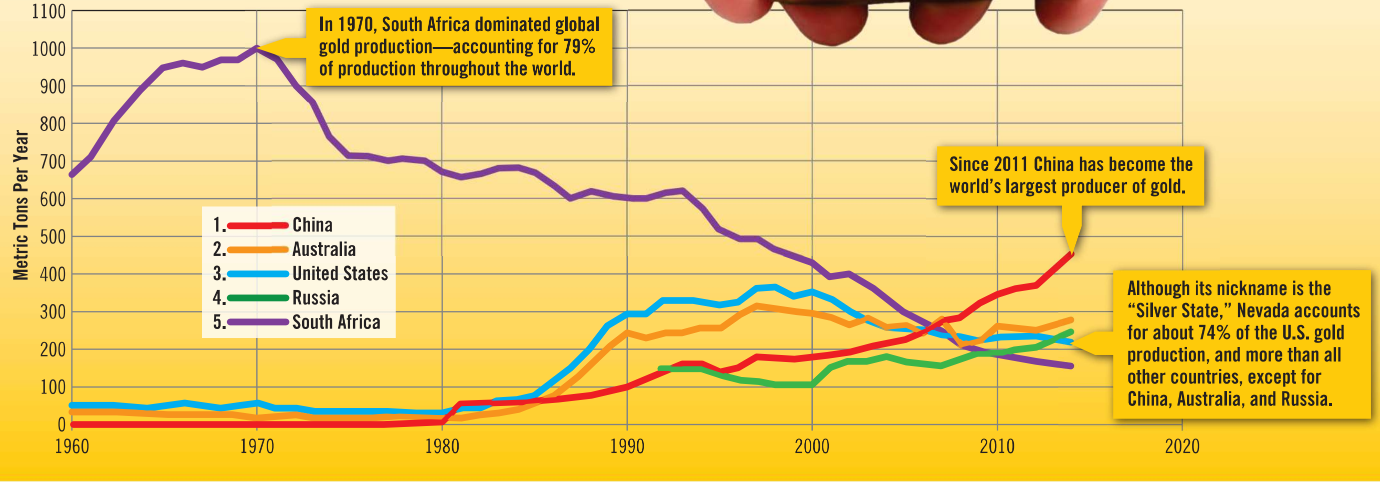
In early 2015, the value of one troy ounce of gold was about US$1,290. Based on that value, a 1000-gram (32-ounce) bar of gold, like the one shown, was worth $41,280. In 1970, the price of gold was less than $40 per troy ounce!

Where is the world's gold produced?



In 1970, South Africa dominated global gold production—accounting for 79% of production throughout the world.

Since 2011 China has become the world's largest producer of gold.

Although its nickname is the "Silver State," Nevada accounts for about 74% of the U.S. gold production, and more than all other countries, except for China, Australia, and Russia.

(Photo by D7INAMI7S/Shutterstock)

2.3 Why Atoms Bond

Distinguish among ionic bonds, covalent bonds, and metallic bonds.

Under the temperature and pressure conditions found on Earth, most elements do not occur in the form of individual atoms; instead, their atoms bond with other atoms. (A group of elements known as the noble gases are an exception.) 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, and this, 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).

The Octet Rule and Chemical Bonds

As 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 for some selected elements. Notice that the elements in Group I have one valence electron each, those in Group II have two valence electrons each, and so on, up to eight valence electron in Group VIII.

The noble gases have very stable electron arrangements with eight valence electrons (except helium, which has two) and, therefore, tend to lack chemical reactivity. Many other

Native gold

Because gold does not easily react with other elements, it often occurs as a native element in nuggets found in stream deposits or as grains in igneous rocks.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What are the uses of gold?

About 50% of gold is used in jewelry. Another 40% is used for currency and investment, and about 10% is used in industry, including electronic devices such as cell phones and televisions. Gold is also used in gourmet foods and cocktails as a decorative ingredient. Because metallic gold is one of the least reactive materials, it has no taste, provides no nutritional value, and leaves the human body unaltered.


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Questions:

1. What is the chemical symbol for gold?
2. What is the term for the property of tenacity, which allows gold to be easily hammered into different shapes?

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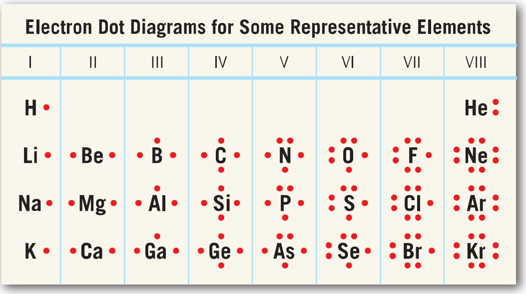


▲ **Figure 2.7** **Dot diagrams for certain elements** Each dot represents a valence electron found in the outermost principal shell.

atoms gain, lose, or share electrons during chemical reactions, ending up with electron 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 valence 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 achieve an octet in its outer shell. A **chemical bond** is a transfer or sharing of electrons that allows each atom to attain a full valence shell of electrons. Some atoms do this by transferring all their valence electrons to other atoms 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 electrons 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*.

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 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 the solid ionic compound sodium chloride—the mineral halite (common table salt). Notice in **Figure 2.8A** that a sodium atom gives up its single valence electron to chlorine and, as a result, becomes a positively charged sodium ion (Na^+). Chlorine, on the other hand, gains one electron and becomes a negatively charged chloride ion (Cl^-). We know that ions having unlike charges attract. Thus, an ionic bond is an attraction of oppositely charged ions to one another that produces an electrically neutral ionic compound.

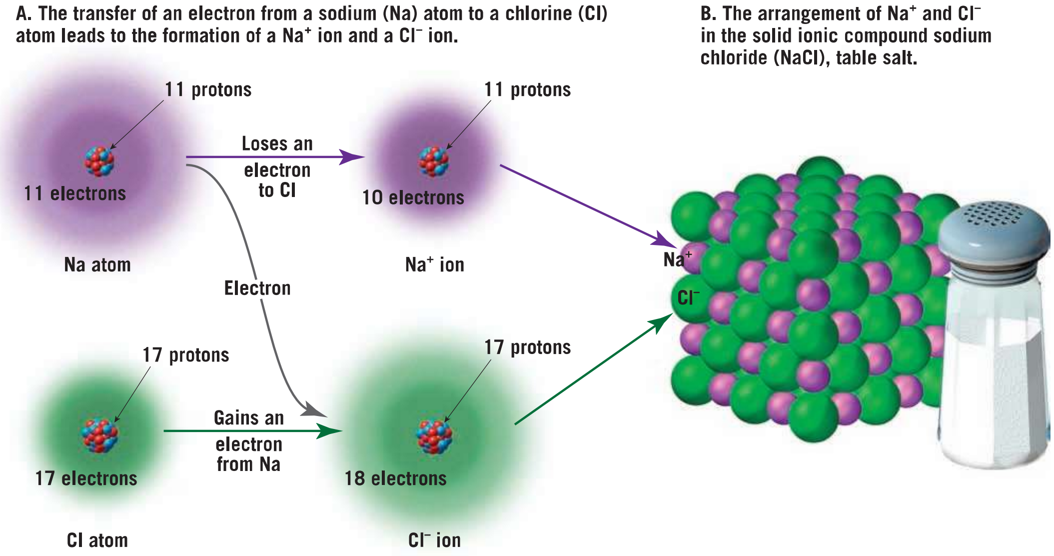
Figure 2.8B illustrates the arrangement of sodium and chlorine ions in ordinary table salt. Notice that salt consists of alternating sodium and chlorine ions, positioned so that each positive ion is attracted to and surrounded on all sides by negative ions and vice versa. This arrangement maximizes the 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, the edible flavor enhancer that we call table salt. Thus, when elements combine to form compounds, their properties change significantly.

Covalent Bonds: Electron Sharing

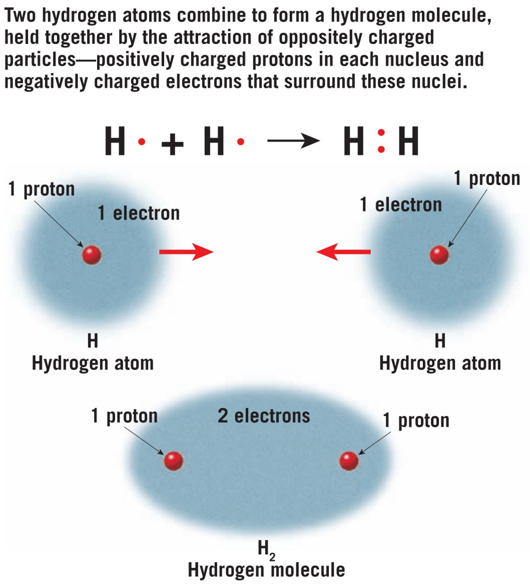
Sometimes the forces that hold atoms together cannot be understood on the basis of the attraction of oppositely charged ions. One example is the hydrogen molecule (H_2), in which the two hydrogen atoms are held together tightly and no ions are present. The strong attractive force that holds two hydrogen atoms together results from a **covalent bond**, a chemical bond formed by the *sharing* of one or more valance electrons between a pair of atoms. (Hydrogen is one of the exceptions to the octet rule: Its single shell is full with just two electrons.)

Imagine two hydrogen atoms (each with one proton and one electron) approaching one another, as shown in **Figure 2.9**. Once they meet, the electron configuration changes so that both electrons primarily occupy the space between the atoms. In other words, the two electrons are shared by both hydrogen atoms and are attracted simultaneously by the positive charge of the proton in the


A. The transfer of an electron from a sodium (Na) atom to a chlorine (Cl) atom leads to the formation of a Na^+ ion and a Cl^- ion.

B. The arrangement of Na^+ and Cl^- in the solid ionic compound sodium chloride (NaCl), table salt.

Figure 2.8 Formation of the ionic compound sodium chloride



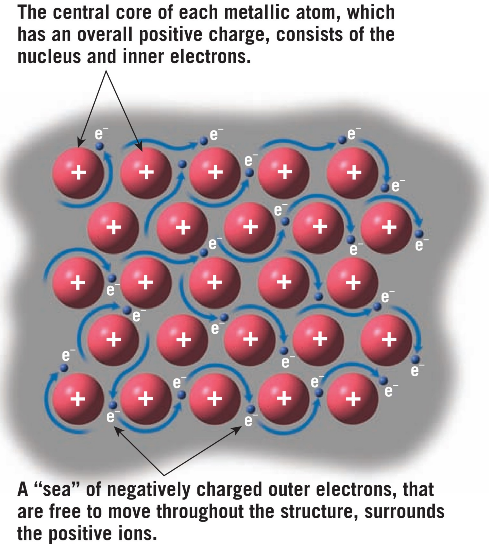
▲ **Figure 2.9 Formation of a covalent bond** When hydrogen atoms bond, the negatively charged electrons are shared by both hydrogen atoms and attracted simultaneously by the positive charge of the proton in the nucleus of each atom.

nucleus of each atom. In this situation the hydrogen atoms do not form ions; instead, the force that holds these atoms together arises from the attraction of oppositely charged particles—positively charged protons in the nuclei and negatively charged electrons that surround these nuclei.

Metallic Bonds: Electrons Free to Move

A few minerals, such as native gold, silver, and copper, are made entirely of metal atoms packed tightly together in an orderly way. The bonding that holds these atoms together results from each atom contributing its valence electrons to a common pool of electrons, which freely move throughout the entire metallic structure. The contribution of one or more valence electrons leaves an array of positive ions immersed in a "sea" of valence electrons, as shown in Figure 2.10.

The attraction between this sea of negatively charged electrons and the positive ions produces the **metallic bonds** that give metals their unique properties. Metals are good conductors of electricity because the valence electrons are free to move from one atom to another. Metals are also *malleable*, which means they can be hammered into thin sheets, and *ductile*, which means they can be drawn into thin wires. By contrast, ionic and covalent solids tend to be *brittle* and fracture when stress is applied. Consider the difference between dropping a metal frying pan and a ceramic plate onto a concrete floor.



▲ **Figure 2.10 Metallic bonding** Metallic bonding is the result of each atom contributing its valence electrons to a common pool of electrons that are free to move throughout the entire metallic structure. The attraction between the "sea" of negatively charged electrons and the positive ions produces the metallic bonds that give metals their unique properties.

CONCEPT CHECKS 2.3

1. What is the difference between an atom and an ion?
2. How does an atom become a positive ion? A negative ion?
3. Briefly distinguish between ionic, covalent, and metallic bonding and discuss the role that electrons play in each.

EYE ON EARTH 2.1

The accompanying image shows one of the world's largest open-pit gold mine, located near Kalgoorlie, Australia. Known as the Super Pit, it originally consisted of a number of small underground mines that were consolidated into a single, open-pit mine. Each year, about 28 metric tons of gold are extracted from the 15 million metric tons of rock shattered by blasting and then transported to the surface.

QUESTION 1 *What is one environmental advantage of underground mining over open-pit mining?*

QUESTION 2 *For those employed at this mine, what change in working conditions would have occurred as it evolved from an underground mine to an open-pit mine?*

(Photo by McPhoto/Blickwinkel/AGE Fotostock)

2.4 Properties of Minerals

List and describe the properties used in mineral identification.

Minerals have definite crystalline structures and chemical compositions that give them unique sets of physical and chemical properties shared by all specimens of that mineral, regardless of when or where they formed. For example, two samples of the mineral quartz will be equally hard and equally dense, and they will break in a similar manner. However, the physical properties of individual samples may vary within specific limits due to ionic substitutions, inclusions of foreign elements (impurities), and defects in the crystalline structure.

Some mineral properties, called **diagnostic properties**, are particularly useful in identifying an unknown mineral. The mineral halite, for example has a salty taste. Because so few minerals share this property, a salty taste is considered a diagnostic property of halite. Other properties of certain minerals, particularly color, vary among different specimens of the same mineral. These properties are referred to as **ambiguous properties**.

▲ **SmartFigure 2.12 Color variations in minerals** Some minerals, such as fluorite, shown above, exhibit a variety of colors. (Photo by E. J. Tarbuck)

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Optical Properties

Of the many diagnostic properties of minerals, their optical characteristics such as luster, color, streak, and ability to transmit light are most frequently used for mineral identification.

Luster The appearance or quality of light reflected from the surface of a mineral is known as **luster**. Minerals that are shiny like a metal, regardless of color, are said to have a *metallic luster* (Figure 2.11A). Some metallic minerals, such as 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* (Figure 2.11B).

A. This freshly broken sample of galena displays a metallic luster.

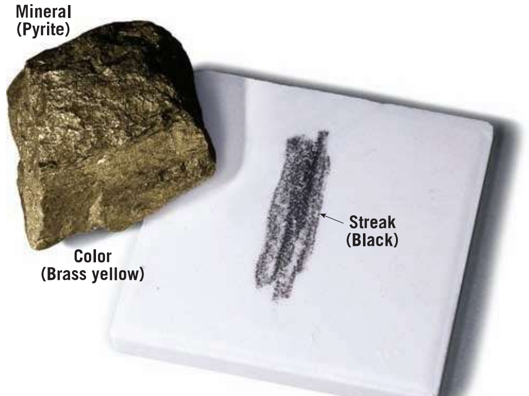
B. This sample of galena is tarnished and has a submetallic luster.

▲ **Figure 2.11 Metallic versus submetallic luster** (Photos courtesy of E. J. Tarbuck)

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

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 minerals fluorite and quartz, for example, give them a variety of tints, including pink, purple, yellow, white, gray, and even black (Figure 2.12). 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 a 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 2.13). Although a mineral's color may vary



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.

▲ **SmartFigure 2.13 Streak** (Photo by Dennis Tasa)

VIDEO
https://goo.gl/MdH5j9

from sample to sample, its streak is usually consistent in color. (Note that not all minerals produce a streak when rubbed across a streak plate. Quartz, for example, is harder than a porcelain streak plate and therefore leaves no streak.)

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.

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

Crystal Shape, or Habit

Mineralogists use the term **crystal shape,** or **habit**, to refer to the common or characteristic shape of individual crystals or aggregates of crystals. Some minerals tend to grow equally in all three dimensions, whereas others tend to be elongated in one direction or flattened if growth in one dimension is suppressed. The crystals of a few minerals can have a regular polygonal shape that is helpful in 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. Most minerals have just one common crystal shape, but a few, such as the pyrite samples shown in Figure 2.14, have two or more characteristic crystal shapes.

In addition, some mineral samples consist of numerous intergrown crystals exhibiting characteristic shapes that are useful for identification. Terms commonly used to describe these and other crystal habits include *equant* (equidimensional), *bladed*, *fibrous*, *tabular*, *cubic*, *prismatic*, *platy*, *blocky*, and *banded*. Some of these habits are pictured in Figure 2.15.


E.J. Tarbuck

Dennis Tasa

A. Fibrous

B. Bladed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C. Banded

D. Cubic crystals

▲ SmartFigure 2.15 **Some common crystal habits** **A.** Thin, rounded crystals that break into fibers. **B.** Elongated crystals that are flattened in one direction. **C.** Minerals that have stripes or bands of different color or texture. **D.** Groups of crystals that are cube shaped.

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Dennis Tasa

Dennis Tasa

Although most minerals exhibit only one common crystal shape, some, such as pyrite, have two or more characteristic habits.

▼ Figure 2.14 **Common crystal shapes of pyrite**

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 *hardness*, *cleavage*, *fracture*, and *tenacity* to describe mineral strength and how minerals break when stress is applied.

Hardness One of the most useful diagnostic properties is **hardness**, a measure of the resistance of a mineral to abrasion or scratching. This property is determined by rubbing a mineral of unknown hardness against one of known hardness or vice versa. A numerical value of hardness can be obtained by using the **Mohs scale** of hardness, which consists of 10 minerals arranged in order from 1 (softest) to 10 (hardest), as shown in Figure 2.16A. It should be noted that the Mohs scale is a relative ranking and does not imply that a mineral with a hardness of 2, such as gypsum, is twice as hard as mineral with a hardness of 1, like talc. In fact, gypsum is only slightly harder than talc, as Figure 2.16B indicates.

In the laboratory, common objects used to determine the hardness of a mineral can 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

▶ SmartFigure 2.16
Hardness scales A. The Mohs scale of hardness, with the hardnesses of some common objects. **B.** Relationship between the Mohs relative hardness scale and an absolute hardness scale.

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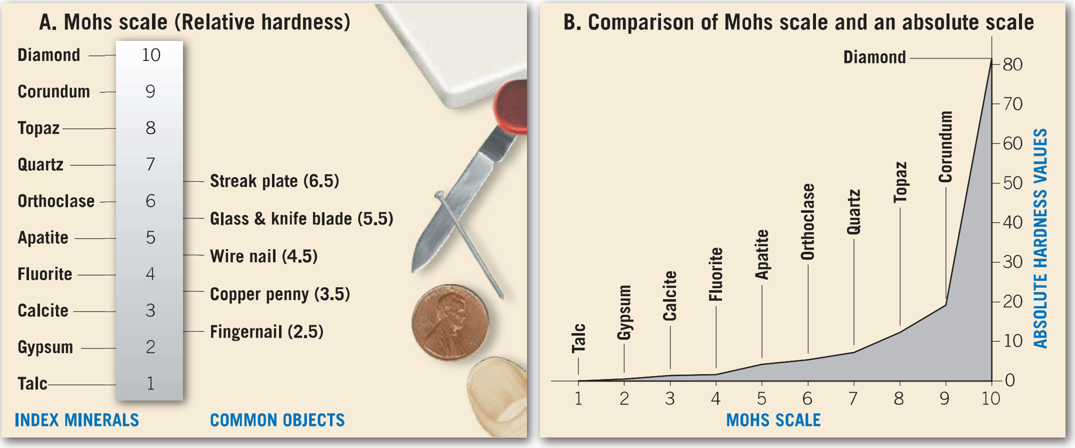

a hardness of 2, can be easily scratched with a fingernail. On the other hand, the mineral calcite, which has a hardness of 3, will scratch a fingernail but will not scratch glass. Quartz, one of the hardest common minerals, will easily scratch glass. Diamonds, hardest of all, scratch anything, including other diamonds.

▼ SmartFigure 2.17
Micas exhibit perfect cleavage The thin sheets shown here exhibit one plane of cleavage. (Photo by Chip Clark/Fundamental Photographs)

ANIMATION
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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 2.17). 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 2.18).

Each cleavage surface that has a different orientation is counted as a different direction of cleavage. For example, some minerals, such as halite, cleave to form six-sided cubes. Because a cube is defined by three different sets of parallel planes that intersect at 90-degree angles, cleavage for the mineral halite 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 breaks into pieces that all have the same geometry. By contrast, the smooth-sided quartz crystals shown in Figure 2.1 do not have cleavage. 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** (Figure 2.19A). When minerals fracture, most produce uneven surfaces and are described as exhibiting *irregular fracture*. However, some minerals, including quartz, sometimes break into smooth, curved surfaces resembling broken glass. Such breaks are called *conchoidal fractures* (Figure 2.19B). Still other minerals exhibit fractures that produce splinters or fibers referred to as *splintery fracture* and *fibrous fracture*, respectively.

Tenacity The term **tenacity** describes how a mineral responds to stress—for instance, whether it tends to break in a brittle fashion or bend elastically. As mentioned earlier, nonmetallic minerals such as quartz and minerals that are ionically bonded, such as fluorite and halite, tend to be *brittle* and fracture or exhibit cleavage when struck. By contrast, native metals, such as copper and gold, are *malleable*, which means they can be hammered without breaking. In addition, minerals that can be cut into thin shavings, including gypsum and talc, are described as *sectile*. Still others, notably the micas, are *elastic* and bend and snap back to their original shape after stress is released.

◀ **SmartFigure 2.18 Cleavage directions exhibited by minerals** (Photos by E. J. Tarbuck and Dennis Tasa)

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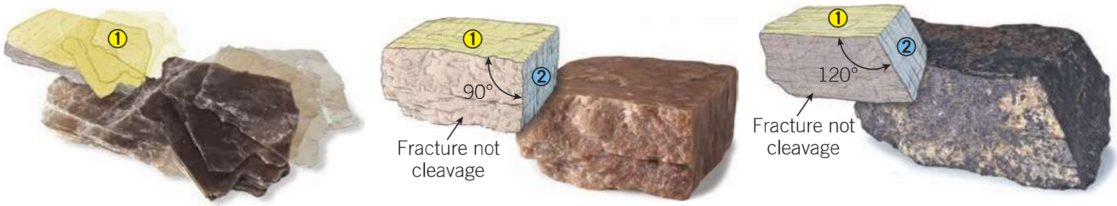
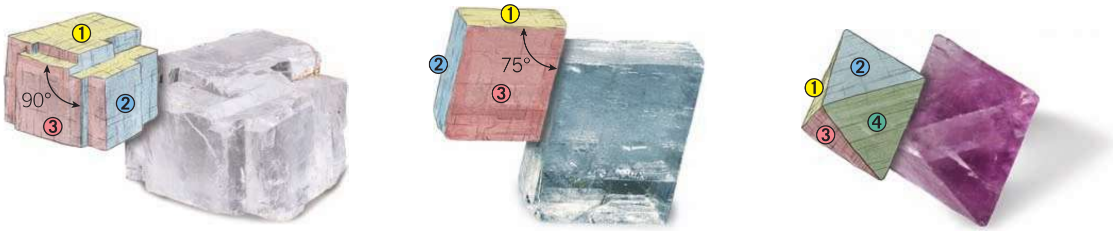


A. Cleavage in one direction. Example: Muscovite

B. Cleavage in two directions at 90° angles. Example: Feldspar

C. Cleavage in two directions not at 90° angles. Example: Hornblende



D. Cleavage in three directions at 90° angles. Example: Halite

E. Cleavage in three directions not at 90° angles. Example: Calcite

F. Cleavage in four directions. Example: Fluorite

Density and Specific Gravity

Density, an important property of matter, is defined as mass per unit volume. 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.

Most common minerals have a specific gravity 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 of quartz. Galena, an ore from which lead is extracted, has a specific gravity of roughly 7.5, whereas 24-karat gold has a specific gravity of approximately 20.

With a little practice, you can estimate the specific gravity of a mineral by hefting it in your hand. Does this mineral feel about as "heavy" as similarly 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. Further, the streaks of many sulfur-bearing minerals smell like rotten eggs. A few minerals, such as magnetite, have high iron content and can be picked up with a magnet, while some varieties (such as lodestone) are themselves natural magnets and will pick up small iron-based objects such as pins and paper clips (see Figure 2.32F, page 50).

Moreover, some minerals exhibit special optical properties. For example, when a transparent piece of calcite is placed over printed text, the letters appear twice. This optical property is known as *double refraction* (**Figure 2.20**).

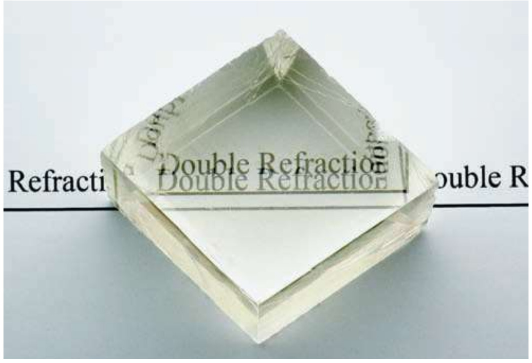
One very simple chemical test to detect carbonate minerals involves placing a drop of dilute hydrochloric

▼ **Figure 2.19 Irregular versus conchoidal fracture** (Photos by E. J. Tarbuck)

A. Irregular fracture (Quartz)

B. Conchoidal fracture (Quartz)

▼ **Figure 2.20 Double refraction** This sample of calcite exhibits double refraction. (Photo by Chip Clark/Fundamental Photographs)



EYE ON EARTH 2.2

Glass bottles, like most other manufactured products, contain substances obtained from minerals extracted from Earth's crust and oceans. The primary ingredient in commercially produced glass bottles is the mineral quartz. Glass also contains lesser amounts of the mineral calcite. (Photo by Chris Brignell/Shutterstock)

QUESTION 1 *In what mineral group does quartz belong?*

QUESTION 2 *Glass beer bottles are usually clear, green, or brown. Based on what you know about the mineral quartz is colored, what do glass manufacturers do to make bottles green and brown?*

QUESTION 3 *Why did some brewers color their glass bottles, rather than use clear glass. (Hint:Search the Internet.)*

acid from a dropper bottle onto a freshly broken mineral surface. Samples containing carbonate minerals will effervesce (fizz) as carbon dioxide gas is released (**Figure 2.21**). This test is especially useful in identifying calcite, a common carbonate mineral.

◀ **SmartFigure 2.21 Calcite reacting with a weak acid** (Photo by Chip Clark/ Fundamental Photographs)

VIDEO
https://goo.gl/5L3gns

CONCEPT CHECKS 2.4

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 differentiates cleavage from fracture?
4. What is meant by a mineral's *tenacity*? List three terms that describe tenacity.
5. Describe a simple chemical test useful in identifying the mineral calcite.

2.5 Mineral Groups

List the common silicate and nonsilicate minerals and describe what characterizes each group.

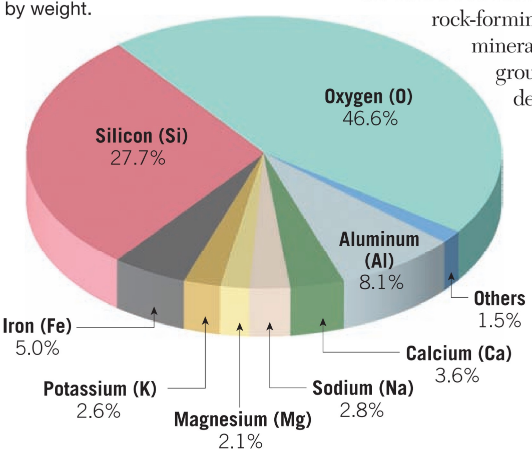
More than 4000 minerals have been named, and several new ones are identified each year. Fortunately for students who are beginning to study minerals, no more than a few dozen are abundant. Collectively, these few make up most of the rocks of Earth's crust and are therefore generally known as the **rock-forming minerals**.

Although less abundant, many other minerals are used extensively in the manufacture of products; these 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 calcite, a mineral that is the primary component of the sedimentary rock limestone. Among calcite's many uses is cement production.

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 2.22**). These elements, in order of most to least abundant, are oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg). As shown in Figure 2.22, oxygen and silicon are by far the most common 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 in the category **nonsilicates**. Although not as common as silicates, some nonsilicate minerals are very important economically. They provide us with iron and aluminum to build automobiles, gypsum for plaster and drywall for home construction, and copper wire that carries electricity and connects us to the Internet. In addition to their economic importance, these groups include minerals that are major constituents in sediments and sedimentary rocks.

▼ **Figure 2.22 The eight most abundant elements in Earth's continental crust** The numbers represent percentages by weight.



Silicate Minerals

Every silicate mineral 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** (SiO_4^{4-}). This structure consists of four oxygen ions that are covalently bonded to a comparatively smaller silicon ion, forming a tetrahedron—a pyramid shape with four identical faces (Figure 2.23). In some minerals, the tetrahedra are joined into chains, sheets, or three-dimensional networks by sharing oxygen atoms (Figure 2.24). 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), and calcium (Ca).

Major groups of silicate minerals and common examples are given in Figure 2.24. The *feldspars* are by far the most plentiful group, comprising about 51 percent of Earth's crust. *Quartz*, the second-most-abundant mineral in the continental crust, is the only common mineral made completely of silicon and oxygen.

Notice in Figure 2.24 that each mineral *group* has a particular silicate *structure*. A relationship exists between this internal structure of a mineral and the *cleavage* it exhibits. Because the silicon–oxygen bonds are strong, silicate minerals tend to cleave between the silicon–oxygen structures rather than across them. For example, the micas have a sheet structure and thus tend to cleave into flat plates (see the muscovite in Figure 2.17). Quartz has equally strong silicon–oxygen bonds in all directions; therefore, it has no cleavage but fractures instead.

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

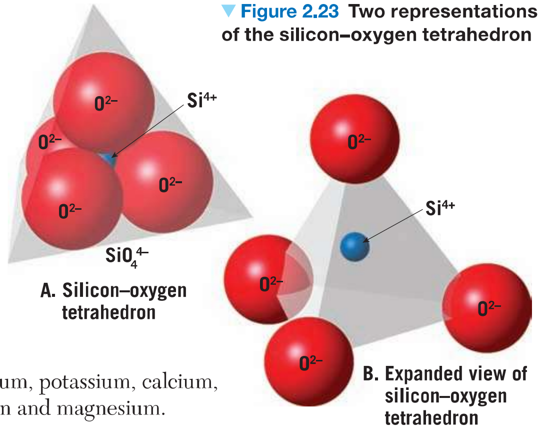
In addition, some silicate minerals form at Earth's surface from the weathered (disintegrated) products of other silicate minerals. Clay minerals are an example. Still other silicate minerals are formed under the extreme pressures associated with mountain building. Each silicate mineral, therefore, has a structure and a chemical composition that *indicate the conditions under which it formed*. Thus, by carefully examining the mineral makeup of rocks, geologists can often determine the circumstances under which the rocks formed.

We will now examine some of the most common silicate minerals, which are divided into two major groups based on their chemical composition.

Common Light Silicate Minerals

The **light silicate minerals** are generally light in color and are noticeably less dense than the dark silicates. These differences are mainly attributable to the presence or absence of iron and magnesium, which are "heavy" elements. The light silicates contain varying amounts of aluminum, potassium, calcium, and sodium rather than iron and magnesium.

▼ **Figure 2.23 Two representations of the silicon–oxygen tetrahedron**



A. Silicon–oxygen tetrahedron

B. Expanded view of silicon–oxygen tetrahedron

Feldspar Group

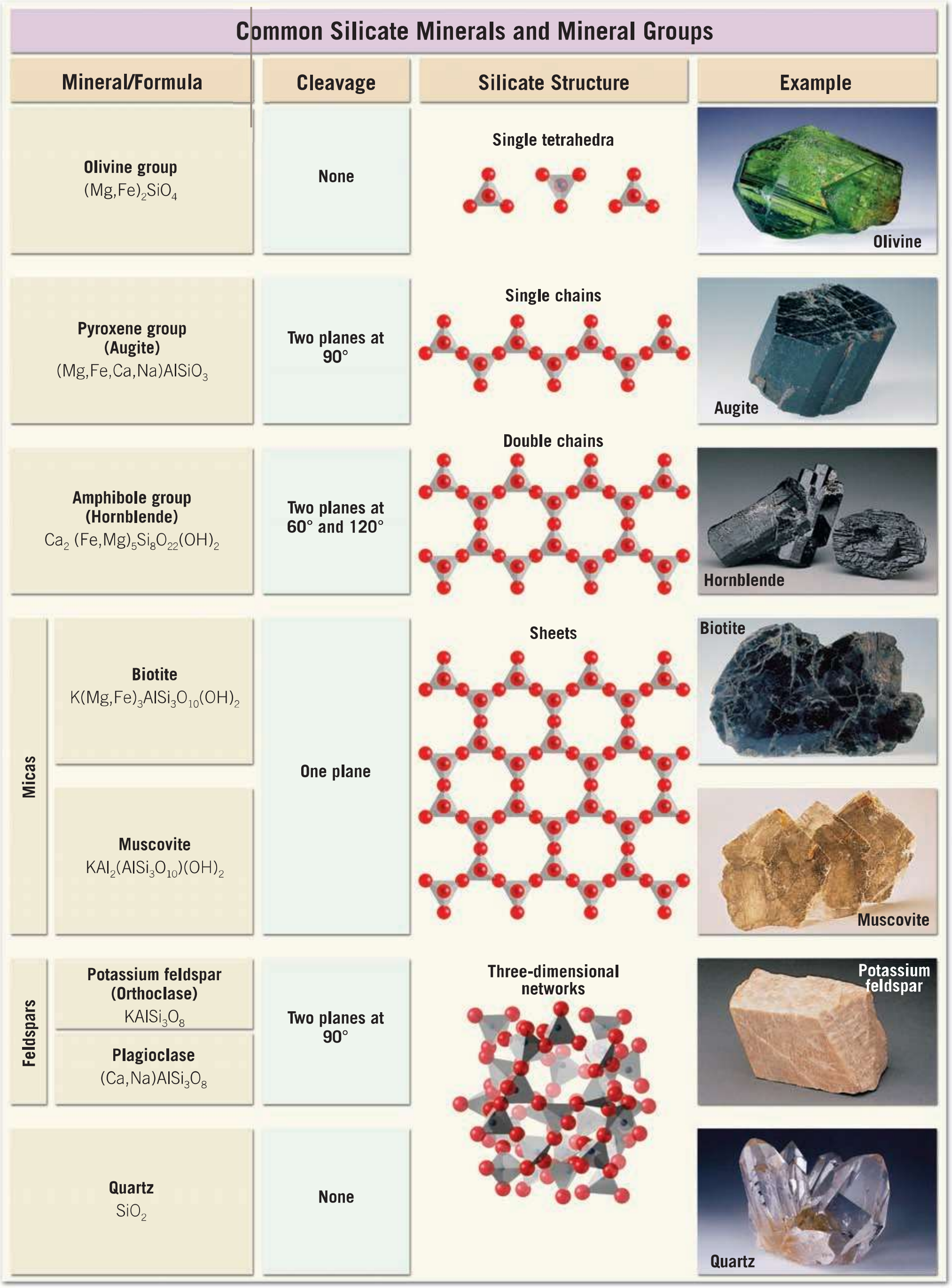
Feldspar minerals are by far the most plentiful silicate group in Earth's crust, comprising about 51 percent of the crust (Figure 2.25). Their abundance can be partially explained by the fact that they can form under a wide range of temperatures and pressures. Two different feldspar structures exist (Figure 2.26). One group of feldspar minerals contains potassium ions in its structure and is therefore termed **potassium feldspar** (Figure 2.26A,B). The other group, called **plagioclase feldspar**, contains both sodium and calcium ions that freely substitute for one another, depending on the environment during crystallization (Figure 2.26C,D). Despite these differences, all feldspar minerals have similar physical properties. They have two planes of cleavage meeting at or near 90-degree angles, are relatively hard (6 on the Mohs scale), and have a luster that ranges from glassy to pearly. As a component in igneous rocks, feldspar crystals can be identified by their rectangular shape and rather smooth, shiny faces.

Potassium feldspar is usually light cream, salmon pink, or occasionally blue-green in color. The plagioclase feldspars, on the other hand, range in color from gray to blue-gray or sometimes black. However, color should not be used to distinguish these groups, as the only way to distinguish the feldspars by looking at them is through the presence of a multitude of fine parallel lines, called *striations*. Striations are found on some cleavage planes of plagioclase feldspar but are not present on potassium feldspar (see Figure 2.26B,D).

Quartz

Quartz (SiO_2) is the second-most-abundant mineral in the continental crust and the only common silicate mineral that consists entirely of silicon and oxygen. In quartz, a three-dimensional framework is developed through the complete sharing of oxygen by adjacent silicon atoms (see Figure 2.24). Thus, all the bonds in quartz are of the strong silicon–oxygen type. Consequently, quartz is hard, resists weathering, and does not have cleavage.

When broken, quartz generally exhibits conchoidal fracture. When pure, quartz is clear and, if allowed to



▶ **SmartFigure 2.24**
Common silicate minerals Note that the complexity of the silicate structure increases from the top of the chart to the bottom. (Photos by Dennis Tasa and E. J. Tarbuck)

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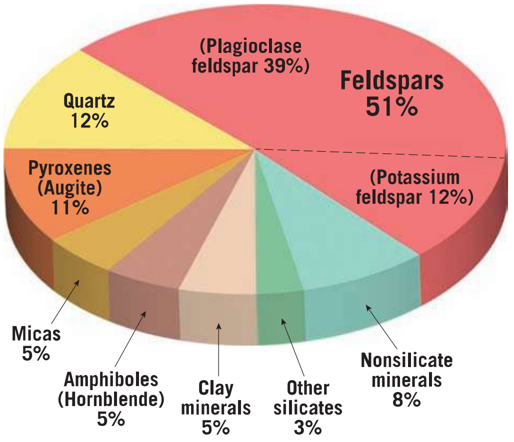
Common Silicate Minerals and Mineral Groups

	Mineral/Formula	Cleavage	Silicate Structure	Example
	Olivine group $(Mg,Fe)_2SiO_4$	None	Single tetrahedra	Olivine
	Pyroxene group (Augite) $(Mg,Fe,Ca,Na)AlSiO_3$	Two planes at 90°	Single chains	Augite
	Amphibole group (Hornblende) $Ca_2 (Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains	Hornblende
Micas	**Biotite** $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets	Biotite
	Muscovite $KAl_2(AlSi_3O_{10})(OH)_2$			Muscovite
Feldspars	**Potassium feldspar (Orthoclase)** $KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks	Potassium feldspar
	Plagioclase $(Ca,Na)AlSi_3O_8$			
	Quartz SiO_2	None		Quartz

grow without interference, will develop hexagonal crystals that develop pyramid-shaped ends. However, like most other clear minerals, quartz is often colored by inclusions of various ions (impurities) and often forms without developing good crystal faces. The most common varieties of quartz are milky (white), smoky (gray), rose (pink), amethyst (purple), citrine (yellow to brown), and rock crystal (clear) (**Figure 2.27**).



▲ **Figure 2.25 Mineral composition of Earth's crust** Feldspar minerals make up about 51 percent of Earth's crust, and all silicate minerals combined make up about 92 percent of Earth's crust.


Potassium Feldspar

A. Potassium feldspar crystal (orthoclase)

B. Potassium feldspar showing cleavage (orthoclase)

Plagioclase Feldspar

C. Sodium-rich plagioclase feldspar (albite)

D. Plagioclase feldspar showing striations (labradorite)

◀ **Figure 2.26 Some common feldspar minerals A.** Characteristic crystal form of potassium feldspar. **B.** Most salmon-colored feldspar belongs to the potassium feldspar subgroup. (though some are light cream in color). **C.** Sodium-rich plagioclase feldspar tends to be light in color with a pearly luster. **D.** Calcium-rich plagioclase feldspar tends to be gray, blue-gray, or black in color. Labradorite, the sample shown here, exhibits striations on one of its crystal faces. (Photos by Dennis Tasa and E. J. Tarbuck)

Muscovite

Muscovite is a common member of the mica family. It is light in color and has a pearly luster (see Figure 2.17). Like other micas, muscovite has excellent cleavage in one direction. In thin sheets, muscovite is clear, a property that accounts for its use as window "glass" during the Middle Ages. Because muscovite is very shiny, it can often be identified by the sparkle it gives a rock. If you have ever looked closely at beach sand, you may have seen the glimmering brilliance of the mica flakes scattered among the other sand grains.

Clay Minerals

Clay is a term used to describe a category of complex minerals that, like the micas, have a sheet structure. Unlike other common silicates, most clay minerals originate as products of the chemical breakdown (chemical weathering) of other silicate minerals. Thus, clay minerals make up a large percentage of the surface material we call soil. (Weathering and soils are discussed in detail in Chapter 8.) Because of soil's importance to agriculture, and because of its role as a supporting material for buildings, clay minerals are extremely important to humans. In addition, clays account for nearly half the volume of sedimentary rocks. Clay minerals are generally very fine grained, which makes them difficult to identify unless they are studied microscopically. Clays are most common in shales, mudstones, and other sedimentary rocks.

One of the most common clay minerals is *kaolinite* (**Figure 2.28**), which is used in the manufacture of fine china and as a coating for high-gloss paper, such as that used in this textbook. Further, some clay minerals absorb large amounts of water, which allows them to swell to several times their normal size. These clays have been used commercially in a variety of ingenious ways, including as an additive to thicken milkshakes in fast-food restaurants.


A. Smoky quartz

B. Rose quartz

C. Milky quartz

D. Amethyst

▲ **Figure 2.27 Quartz, the second-most-common mineral in Earth's crust, has many varieties A.** Smoky quartz is commonly found in coarse-grained igneous rocks. **B.** Rose quartz owes its color to small amounts of titanium. **C.** Milky quartz often occurs in veins, which occasionally contain gold. **D.** Amethyst, a purple variety of quartz often used in jewelry, is the birthstone for February. (Photos by Dennis Tasa and E. J. Tarbuck)

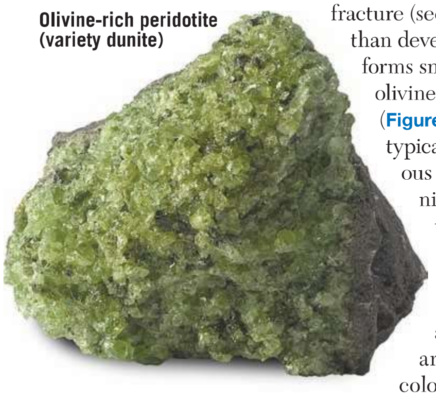
Common Dark Silicate Minerals

Dark silicate minerals contain ions of iron and/or magnesium in their structure. Because of their iron content, these silicates are dark in color and have a greater specific gravity than the light silicates.

Olivine Group

Olivine, a family of high-temperature silicate minerals, are black to olive green in color and have a glassy luster and a conchoidal

▼ **Figure 2.28 Kaolinite** Kaolinite is a common clay mineral formed by weathering of feldspar minerals. (Photo by Dennis Tasa)



▲ **Figure 2.29 Olivine** Commonly black to olive green in color, olivine has a glassy luster and is often granular in appearance. Olivine is commonly found in the igneous rock basalt. (Photo by Dennis Tasa)

fracture (see Figure 2.24, upper-right). Rather than develop large crystals, olivine commonly forms small, rounded crystals that give olivine-rich rocks a granular appearance (**Figure 2.29**). Olivine and related forms are typically found in basalt, a common igneous rock of the oceanic crust and volcanic areas on the continents; they are thought to constitute up to 50 percent of Earth's upper mantle.

Pyroxene Group The *pyroxenes* are a group of diverse minerals that are important components of dark-colored igneous rocks. The most common member, **augite**, is a black, opaque mineral with two directions of cleavage that meet at nearly a 90-degree angle. Augite is one of the dominant minerals in basalt (**Figure 2.30A**).

Amphibole Group **Hornblende** is the most common member of a chemically complex group of minerals called *amphiboles* (**Figure 2.30B**). Hornblende is usually dark green to black in color, and except for its cleavage angles, which are about 60 degrees and 120 degrees, it is very similar in appearance to augite. In a rock, hornblende often forms elongated crystals. This helps distinguish it from pyroxene, which forms rather blocky crystals. Hornblende is found in igneous rocks, where it often makes up the dark portion of an otherwise light-colored rock (see Figure 2.3).

Biotite **Biotite** is a dark, iron-rich member of the mica family (see Figure 2.24). Like other micas, biotite possesses a sheet structure that gives it excellent cleavage in one direction. Biotite also has a shiny black appearance that helps distinguish it from the other dark ferromagnesian minerals. Like hornblende, biotite is a common constituent of igneous rocks, including the rock granite.

▼ **Figure 2.30 Augite and hornblende** These dark-colored silicate minerals are common constituents of a variety of igneous rocks. (Photos by E. J. Tarbuck)

Garnet **Garnet** is similar to olivine in that its structure is composed of individual tetrahedra linked by metallic ions. Also like olivine, garnet has a glassy luster, lacks cleavage, and exhibits conchoidal fracture. Although the colors of garnet are varied, this mineral is most often brown to deep red. Well-developed garnet crystals have 12 diamond-shaped faces and are most commonly found in metamorphic rocks (**Figure 2.31**).

Important Nonsilicate Minerals

Although the nonsilicates make up only about 8 percent of Earth's crust, some nonsilicate minerals, such as gypsum, calcite, and halite, occur as constituents in sedimentary rocks in significant amounts. Many nonsilicates are also economically important.

▶ **Figure 2.31 Well-formed garnet crystal** Garnets come in a variety of colors and are commonly found in mica-rich metamorphic rocks. (Photo by E. J. Tarbuck)

Nonsilicate minerals are typically divided into groups based on the negatively charged ion or complex ion that the members have in common. For example, the *oxides* contain negative oxygen ions (O^{2-}), which bond to one or more kinds of positive ions. Thus, within each mineral group, the basic structure and type of bonding is similar. As a result, the minerals in each group have similar physical properties that are useful in mineral identification. **Figure 2.32** lists some of the major nonsilicate mineral groups and includes a few examples of each.

Some of the most common nonsilicate minerals belong to one of three classes of minerals: the carbonates (CO_3^{2-}), the sulfates (SO_4^{2-}), and the halides (Cl^{1-}, F^{1-}, Br^{1-}). The carbonate minerals, which are much simpler structurally than the silicates, are composed of the carbonate ion (CO_3^{2-}) and one or more kinds of positive ions. The two most common carbonate minerals are **calcite**, $CaCO_3$ (calcium carbonate), and **dolomite**, $CaMg(CO_3)_2$ (calcium/magnesium carbonate) (Figure 2.32A,B). Calcite and dolomite are usually found together as the primary constituents in the sedimentary rocks limestone and dolostone. When calcite is the dominant mineral, the rock is called *limestone*, whereas *dolostone* results from a predominance of dolomite. Limestone is used in road aggregate and as a building stone, and it is the main ingredient in Portland cement.

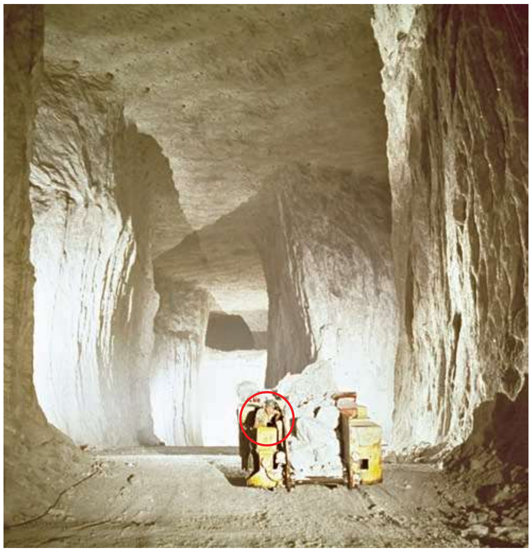
Two other nonsilicate minerals frequently found in sedimentary rocks are **halite** and **gypsum** (Figure 2.32C, I). Both of these minerals are commonly found in thick layers that are the last vestiges of ancient seas that have long since evaporated (**Figure 2.33**). Like limestone, both halite and gypsum 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 from 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 (see Figure 2.32E,F). Also significant are the sulfides, which are basically compounds of sulfur (S) and one or more metals.

Common Nonsilicate Mineral Groups

Mineral Group (key ion(s) or element(s))	Mineral Name	Chemical Formula	Economic Use	Examples
Carbonates (CO_3^{2-})	Calcite Dolomite	$CaCO_3$ $CaMg(CO_3)_2$	Portland cement, lime Portland cement, lime	 **A. Calcite**  **B. Dolomite**
Halides $(Cl^{1-}, F^{1-}, Br^{1-})$	Halite Fluorite Sylvite	$NaCl$ CaF_2 KCl	Common salt Used in steel making Used as fertilizer	 **C. Halite**  **D. Fluorite**
Oxides (O^{2-})	Hematite Magnetite Corundum Ice	Fe_2O_3 Fe_3O_4 Al_2O_3 H_2O	Ore of iron, pigment Ore of iron Gemstone, abrasive Solid form of water	 **E. Hematite**  **F. Magnetite**
Sulfides (S^{2-})	Galena Sphalerite Pyrite Chalcopyrite Cinnabar	PbS ZnS FeS_2 $CuFeS_2$ HgS	Ore of lead Ore of zinc Sulfuric acid production Ore of copper Ore of mercury	 **G. Galena**  **H. Chalcopyrite**
Sulfates (SO_4^{2-})	Gypsum Anhydrite Barite	$CaSO_4 \cdot 2H_2O$ $CaSO_4$ $BaSO_4$	Plaster Plaster Drilling mud	 **I. Gypsum**  **J. Anhydrite**
Native elements (single elements)	Gold Copper Diamond Graphite Sulfur Silver	Au Cu C C S Ag	Trade, jewelry Electrical conductor Gemstone, abrasive Pencil lead Sulfa drugs, chemicals Jewelry, photography	 **K. Copper**  **L. Sulfur**

▲ **Figure 2.32 Important nonsilicate mineral groups** (Photos by Dennis Tasa and E. J. Tarbuck)



◀ **Figure 2.33 Thick bed of halite exposed in an underground mine** In this halite (salt) mine in Grand Saline, Texas, note the person for scale. (Photo by Tom Bochsler/Pearson Education)

Important sulfide minerals include galena (lead), sphalerite (zinc), and chalcopyrite (copper). In addition, native elements—including gold, silver, and carbon (diamonds)—are economically important, as are a host of other nonsilicate minerals—fluorite (flux in making steel), corundum (gemstone, abrasive), and uraninite (a uranium source). See GEOGraphics 2.2 for more information on gemstones.

CONCEPT CHECKS 2.5

1. List the eight most common elements in Earth's crust.
2. Sketch the silicon–oxygen tetrahedron and label its parts.
3. What is the most abundant mineral in Earth's crust?
4. What is the most common carbonate mineral?
5. List six common nonsilicate minerals and their economic uses.

2.6 Minerals: A Nonrenewable Resource

Discuss Earth's mineral resources in terms of renewability. Differentiate between mineral resources and ore deposits.

Earth's crust and oceans are the source of a wide variety of useful and valuable materials. From the first use of rocks such as flint and obsidian to make tools thousands of years ago, the use of Earth materials has expanded, resulting in more complex societies and our modern civilization. The mineral and energy resources we extract from Earth's crust are the raw materials from which we make all the products we use.

Natural resources are typically grouped into broad categories according to (1) their ability to be regenerated (renewable or nonrenewable) or (2) their origin or type. Here we will consider mineral resources. However, other natural resources are indispensable to humans, including air, water, and solar energy.

▼ **Figure 2.34 Solar energy is renewable** The Ivanpah Solar Electric Generating System is a solar thermal plant located in California's Mojave Desert, southwest of Las Vegas. It consists of 173,500 heliostats (mirrors that move so they reflect sunlight at a target), each with two mirrors that focus solar energy on boilers located on one of three centralized towers. The boilers, in turn, generate steam, which turns turbines that generate electricity. (Photo by Steve Proehl/Getty Images/Corbis Documentary)

Renewable Versus Nonrenewable Resources

Resources classified as **renewable** can be replenished over relatively short time spans. Common examples are corn used for food and for making ethanol, natural fibers such as cotton for clothing, and forest products for lumber and paper. Energy from flowing water, wind, and the Sun are also considered renewable (Figure 2.34).

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 widely used fuels: petroleum, natural gas, and coal. Although these and other resources form continuously, the processes that create them are so slow that significant deposits take millions of years to accumulate. Thus, for all practical purposes, Earth contains fixed quantities of these substances. The present supplies will be depleted as they are mined or pumped from the ground. Although some nonrenewable resources, such as the aluminum we use for containers, can be recycled, others, such as the oil burned for fuel, cannot.

Mineral Resources and Ore Deposits

Today, practically every manufactured product contains materials obtained from minerals. Figure 2.32 lists some of the most economically important mineral groups. **Mineral resources** are occurrences of useful minerals that are formed in such quantities that eventual extraction is reasonably certain. Mineral resources include deposits of metallic minerals that can be presently extracted profitably, as well as known deposits that are not yet economically or technologically recoverable. Materials used for such purposes as building stone, road aggregate, abrasives, ceramics, and fertilizers are not usually called mineral resources; rather, they are classified as *industrial rocks and minerals*.

An **ore deposit** is a naturally occurring concentration of one or more metallic minerals that can be extracted economically. In common usage, the term *ore* is also applied to some nonmetallic minerals such as fluorite and sulfur. 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 2.22). Indeed, the natural concentrations of many elements are exceedingly small. A deposit containing the average concentration of an element such as gold has no economic value because the cost of extracting it greatly exceeds the value of the gold that could be recovered.

In order to have economic value, an ore deposit must be highly concentrated. For example, copper makes up about 0.0068 percent of the crust. For a deposit to be considered a copper ore, it must contain a concentration of copper that is about 100 times this amount, or about 0.68 percent. Aluminum, on the other hand, represents about 8.1 percent of the crust and can be extracted profitably when it is found in concentrations 3 or 4 times that amount.

It is important to understand that due to economic or technological changes, a deposit may either become profitable to extract or lose its profitability. If the demand for a metal increases and its value rises sufficiently, the status of a previously unprofitable deposit can be upgraded from a mineral to an ore. Technological advances that allow a resource to be extracted more efficiently and, thus, more profitably than before may also trigger a change of status.

Conversely, changing economic factors can turn what was once a profitable ore deposit into an unprofitable mineral deposit. This situation was illustrated at the copper mining operation located at Bingham Canyon, Utah, one of the largest open-pit mines on Earth (**Figure 2.35**). Mining was halted there in 1985 because outmoded equipment had driven the cost of extracting the copper beyond the current selling price. In 1989 new owners responded by replacing an antiquated 1000-car railroad with modern conveyor belts and large dump trucks for efficiently transporting the ore and waste. The new equipment reduced extraction costs by nearly 30 percent, ultimately returning the copper mine operation to profitability. Today the Bingham Canyon mine produces nearly 18 percent of the refined copper in the United States. In addition to producing about 300,000 metric tons of copper, the Bingham Canyon mine produces about 400,000 troy ounces of gold, 4 million troy ounces of silver, and 25 million pounds of molybdenum.

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 CHECKS 2.6

1. List three examples of renewable resources and three examples of nonrenewable resources.
2. Compare and contrast a *mineral resource* and an *ore deposit*.
3. Explain how a mineral deposit that previously could not be mined profitably might be upgraded to an ore deposit.

▼ **Figure 2.35 Aerial view of Bingham Canyon copper mine near Salt Lake City, Utah** Although the amount of copper in the rock is less than 0.5 percent, the huge volume of material removed and processed each day (over 400,000 metric tons) yields enough metal to be profitable. In addition to copper, this mine produces gold, silver, and molybdenum.
(Photo by Michael Collier)

GEOGRAPHICS 2.2

Gemstones

Precious stones have been prized since antiquity. Although most gemstones are varieties of a particular mineral, misinformation abounds regarding gems and their mineral makeup.

Important Gemstones

Gemstones are classified in one of two categories: precious or semiprecious. Precious gems are rare and generally have hardnesses that exceed 9 on the Mohs scale. Therefore, they are more valuable and thus more expensive than semiprecious gems.

GEM	MINERAL NAME	PRIZED HUES
PRECIOUS		
Diamond	Diamond	Colorless, pinks, blues
Emerald	Beryl	Greens
Ruby	Corundum	Reds
Sapphire	Corundum	Blues
Opal	Opal	Brilliant hues
SEMIPRECIOUS		
Alexandrite	Chrysoberyl	Variable
Amethyst	Quartz	Purples
Cat's-eye	Chrysoberyl	Yellows
Chalcedony	Quartz (agate)	Banded
Citrine	Quartz	Yellows
Garnet	Garnet	Red, greens
Jade	Jadeite or nephrite	Greens
Moonstone	Feldspar	Transparent blues
Peridot	Olivine	Olive greens
Smoky quartz	Quartz	Browns
Spinel	Spinel	Reds
Topaz	Topaz	Purples, reds
Tourmaline	Tourmaline	Reds, blue-greens
Turquoise	Turquoise	Blues
Zircon	Zircon	Reds

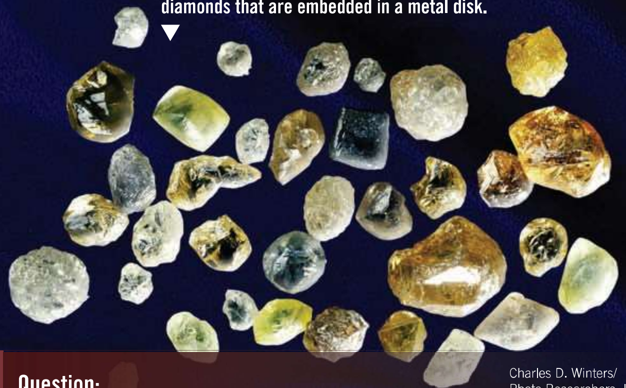
Reuters

The Famous Hope Diamond

The deep-blue Hope Diamond is a 45.52-carat gem that is thought to have been cut from a much larger 115-carat stone discovered in India in the mid-1600s. The original 115-carat stone was cut into a smaller gem that became part of the crown jewels of France and was in the possession of King Louis XVI and Marie Antoinette before they attempted to escape France. Stolen during the French Revolution in 1792, the gem is thought to have been recut to its present size and shape. In the 1800s, it became part of the collection of Henry Hope (hence its name) and is on display at the Smithsonian in Washington, DC.

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. Cutting and polishing is accomplished using abrasive material, most often tiny fragments of diamonds that are embedded in a metal disk.

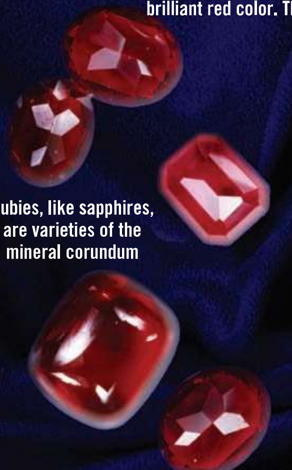


Charles D. Winters/
Photo Researchers, Inc.

? **Question:**
Why are diamonds used as an abrasive material to cut and polish gemstones?

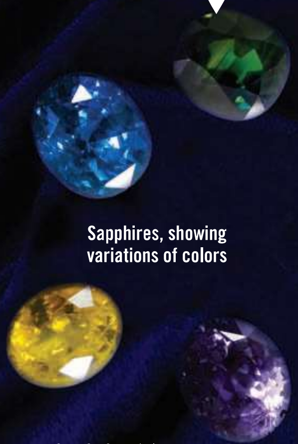
Naming Gemstones

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. 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. This variety of corundum is called ruby.



Rubies, like sapphires, are varieties of the mineral corundum

Dorling Kindersley



Sapphires, showing variations of colors

Greg C. Grace/ Alamy

2 CONCEPTS IN REVIEW

Matter and Minerals

2.1 Minerals: Building Blocks of Rocks

List the main characteristics that an Earth material must possess to be considered a mineral and describe each characteristic.

KEY TERMS: mineralogy, mineral, rock

- In Earth science, the word mineral refers to naturally occurring inorganic solids that possess an orderly crystalline structure and a characteristic chemical composition. The study of minerals is called mineralogy.
- Minerals are the building blocks of rocks. Rocks are naturally occurring masses of minerals or mineral-like matter such as natural glass or organic material.

2.2 Atoms: Building Blocks of Minerals

Compare and contrast the three primary particles contained in atoms.

KEY TERMS: atom, nucleus, proton, neutron, electron, valence electron, atomic number, element, periodic table, chemical compound

- Minerals are composed of atoms of one or more elements. All atoms consist of the same three basic components: protons, neutrons, and electrons.
- The atomic number represents the number of protons found in the nucleus of an atom of a particular element. For example, an oxygen atom has eight protons, so its atomic number is eight. Protons and neutrons have approximately the same size and mass, but protons are positively charged, whereas neutrons have no charge.
- Electrons weigh only about 1/2000 as much as protons or neutrons. They occupy the space around the nucleus, where they form what can be thought of as a cloud that is structured into several distinct energy levels called principal shells. The electrons in the outermost principal shell, called valence electrons, are responsible for the bonds that hold atoms together to form chemical compounds.
- Elements that have the same number of valence electrons tend to behave similarly. The periodic table is organized so that elements with the same number of valence electrons form a column, called a group.

? Use the periodic table (see Figure 2.5) to identify the geologically important elements that have the following numbers of protons: (A) 14, (B) 6, (C) 13, (D) 17, and (E) 26.

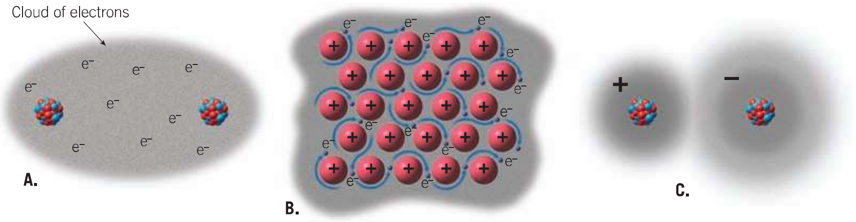
2.3 Why Atoms Bond

Distinguish among ionic bonds, covalent bonds, and metallic bonds.

KEY TERMS: octet rule, chemical bond, ionic bond, ion, covalent bond, metallic bond

- When atoms are attracted to other atoms, they can form chemical bonds, which generally involve the transfer or sharing of valence electrons. The most stable arrangement for most atoms is to have eight electrons in the outermost principal shell. This concept is called the octet rule.
- To form ionic bonds, atoms of one element give up one or more valence electrons to atoms of another element, forming positively and negatively charged atoms called ions. The ionic bond results from the attraction between oppositely charged ions.
- Covalent bonds form when adjacent atoms share valence electrons.
- In metallic bonds, the sharing is more extensive: The shared valence electrons can move freely through the substance.

? Which of the accompanying diagrams (A, B, or C) best illustrates ionic bonding? What are the distinguishing characteristics of ionic bonding and of covalent bonding?



2.4 Properties of Minerals

List and describe the properties used in mineral identification.

KEY TERMS: diagnostic property, ambiguous property, luster, color, streak, crystal shape (habit), hardness, Mohs scale, cleavage, fracture, tenacity, density, specific gravity

- The composition and internal crystalline structure of a mineral give it specific physical properties. Mineral properties useful in identifying minerals are termed *diagnostic properties.*
- Luster is a mineral's ability to reflect light. The terms transparent, translucent, and opaque describe the degree to which a mineral can transmit light. Color can be unreliable for mineral identification, as impurities can "stain" minerals with diverse colors. A more reliable identifier is streak, the color of the powder generated by scraping a mineral against a porcelain streak plate.
- Crystal shape, also called crystal habit, is often useful for mineral identification.

- Variations in the strength of chemical bonds give minerals properties such as hardness (resistance to being scratched) and tenacity (response to deforming stress, such as whether the mineral tends to undergo brittle breakage like quartz, bend elastically like mica, or deform malleably like gold). Cleavage, the preferential breakage of a mineral along planes of weakly bonded atoms, is very useful in identifying minerals.
- The amount of matter packed into a given volume determines a mineral's density. To compare the densities of minerals, mineralogists use a related quantity, known as specific gravity, which is the ratio between a mineral's density and the density of water.
- Other properties are diagnostic for certain minerals but rare in most others; examples include smell, taste, feel, reaction to hydrochloric acid, magnetism, and double refraction.

? Determine which of these specimens exhibit a metallic luster and which have a nonmetallic luster.

A. Dennis Tasa

B. Dennis Tasa

C. Dennis Tasa

D. Dennis Tasa

E. Dennis Tasa

2.5 Mineral Groups

List the common silicate and nonsilicate minerals and describe what characterizes each group.

KEY TERMS: rock-forming mineral, economic mineral, silicate, nonsilicate, silicon–oxygen tetrahedron, light silicate mineral, potassium feldspar, plagioclase feldspar, quartz, muscovite, clay, dark silicate mineral, olivine, augite, hornblende, biotite, garnet, calcite, dolomite, halite, gypsum

- Silicate minerals have a basic building block in common: a small pyramid-shaped structure called the silicon–oxygen tetrahedron, which consists of one silicon atom surrounded by four oxygen atoms. Neighboring tetrahedra can share some of their oxygen atoms, causing them to develop long chains, sheet structures, and three-dimensional networks.
- Silicate minerals are the most common mineral class on Earth. They are subdivided into minerals that contain iron and/or magnesium (dark silicates) and those that do not (light silicates). The light silicate minerals are generally light in color and have relatively low specific gravities. Feldspar, quartz, muscovite, and clay minerals are examples. The dark silicate minerals are generally dark in color and relatively dense. Olivine, pyroxene, amphibole, biotite, and garnet are examples.
- Nonsilicate minerals include oxides, which contain oxygen ions that bond to other elements (usually metals); carbonates, which have CO_3^{2-} as a critical part of their crystal structure; sulfates, which have SO_4^{2-} as their basic building block; and halides, which contain a nonmetal ion such as chlorine, bromine, or fluorine that bonds to a metal ion such as sodium or calcium.
- Nonsilicate minerals are often economically important. Hematite is an important source of industrial iron, while calcite is an essential component of cement.

2.6 Minerals: A Nonrenewable Resource

Discuss Earth's mineral resources in terms of renewability. Differentiate between mineral resources and ore deposits.

KEY TERMS: renewable, nonrenewable, mineral resource, ore deposit

- Resources are classified as renewable when they can be replenished over short time spans and nonrenewable when they can't.
- Ore deposits are naturally occurring concentrations of one or more metallic minerals that can be extracted economically using current technology. A mineral resource can be upgraded to an ore deposit if the price of the commodity increases sufficiently or if the cost of extraction decreases. The reverse can also happen.

GIVE IT SOME THOUGHT

1 Using the geologic definition of *mineral* as your guide, determine which of the items in this list are minerals and which are not. If something in this list is not a mineral, explain.

- **a.** Gold nugget
- **b.** Seawater
- **c.** Quartz
- **d.** Cubic zirconia
- **e.** Obsidian
- **f.** Ruby
- **g.** Glacial ice
- **h.** Amber

2 Assume that the number of protons in a neutral atom is 92 and the atomic mass is 238.02. (*Hint:* Refer to the periodic table in Figure 2.5 to answer this question.)

- **a.** What is the name of the element?
- **b.** How many electrons does it have?

3 Research the minerals *quartz* and *calcite*. List five physical characteristics that may be used to distinguish one from another.

Dennis Tasa

Quartz

Dennis Tasa

Calcite

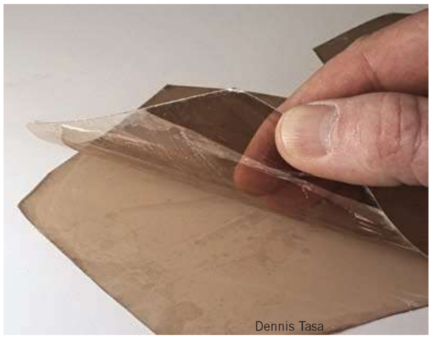
4 Gold has a specific gravity of almost 20. A 5-gallon bucket of water weighs 40 pounds. How much would a 5-gallon bucket of gold weigh?


E. J. Tarbuck

Cleaved sample

5 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?

6 Each of the following statements describes a silicate mineral or mineral group. In each case, provide the appropriate name:
  a. The most common member of the amphibole group
  b. The most common light-colored member of the mica family
  c. The only common silicate mineral made entirely of silicon and oxygen
  d. A silicate mineral with a name based on its color
  e. A silicate mineral characterized by striations
  f. Silicate minerals that originate as a product of chemical weathering


Dennis Tasa

7 What mineral property is illustrated in the accompanying photo?

8 Do an Internet search to determine which minerals are used to manufacture the following products:
  a. Stainless steel utensils
  b. Cat litter
  c. Tums brand antacid tablets
  d. Lithium batteries
  e. Aluminum beverage cans

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 the U.S. Geological Survey [USGS] website: http://minerals.er.usgs.gov/minerals/pubs/state/.) 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, geosphere, 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 in Question 1, in your opinion does the environmental impact of extracting this mineral outweigh the benefits derived from its products?

DATA ANALYSIS

Global Mineral Resources

Mineral resources are important for the global economy. Some minerals are found only in a few locations, while others are more evenly distributed around the globe. The United States Geological Survey maintains a mineral resource database that can help us explore the distribution of major mineral deposits worldwide.

ACTIVITIES

Go to the Mineral Resource On-Line Spatial Data interactive map at http://mrdata.usgs.gov and click Global. Check the box next to Major Deposits. The following questions relate to the contiguous United States.

1 Return to the map and click on the legend. Scroll down to display the Major Deposits symbology. PGE stands for *platinum-group elements*. What are the two most numerous major mineral deposits? Consult the Internet and list one economic use for each mineral.

2 What are the two least numerous major mineral deposits? List one economic use for each mineral.

3 Which minerals do not have major deposits? List one economic use for each.

4 Where are most of the major gold deposits located? Clay deposits? Iron deposits?

5 According to Figure 1.21 (page 25), what continental feature contains most of the major gold deposits? Clay deposits? Iron deposits?

6 Click on the Map Layers icon and then click on the words Major Deposits for information on this category. What important type of natural resource is not included on this map?

Go to http://mrdata.usgs.gov, select the Mineral Resources tab, and click on the map next to Mineral Resources Data System (MRDS).

7 What information is displayed on this map?

8 Notice that Missouri and Iowa have many mineral resources, but Kansas and Nebraska have few. Why might the mining of mineral deposits change so abruptly at state boundaries?

Zoom in to your region on the map and click on one mineral resource site closest to your location. Underneath Find Features by Clicking the Map Above, click the name of the site to open a new page with site information.

9 Which commodities are available from this site?