

# Atoms to Minerals

Milk, air, and hornblende—the mineral pictured here—are all forms of matter. The photograph, an enlargement, shows something of hornblende's crystal structure.

How does the arrangement of atoms determine a mineral's properties?



PREVIEW

► **FOCUS QUESTIONS** In this chapter you will study atoms and minerals and learn more about the key questions below.

Section 1 What is the relationship of atoms to matter?

Section 2 What are minerals and how do they form?

Section 3 How can minerals be identified?

Section 4 What are common minerals and how are they classified?

► **REVIEW TOPICS** As you investigate atoms and minerals, you will need to use information from earlier chapters.

- geosphere (p. 9)
- Earth's structure (p. 72)
- crust (p. 73)
- lithosphere (p. 73)
- Earth's heat (p. 73)

► **READING STRATEGY**

**QUESTION**

Before you begin reading, scan the chapter, noting the photographs, illustrations, and headings. Develop a list of three or four questions that you would like to answer through your reading.



At our Web site, you will find the following Internet support for this chapter.

**DATA CENTER**

**EARTH NEWS**

**VISUALIZATIONS**

- Common Molecules
- Buckminsterfullerene
- Common Objects Made of Minerals

**LOCAL RESOURCES**

**INVESTIGATIONS**

- How Many Protons, Neutrons, and Electrons Are in Common Elements?
- How Do Crystals Grow?

# 5.1

## KEY IDEA

Ordinary matter is composed of elements, which are made up of tiny particles called atoms.

## KEY VOCABULARY

- element
- atomic number
- isotope
- mass number
- compound
- molecule
- ion
- metal
- nonmetal

## Matter and Atoms

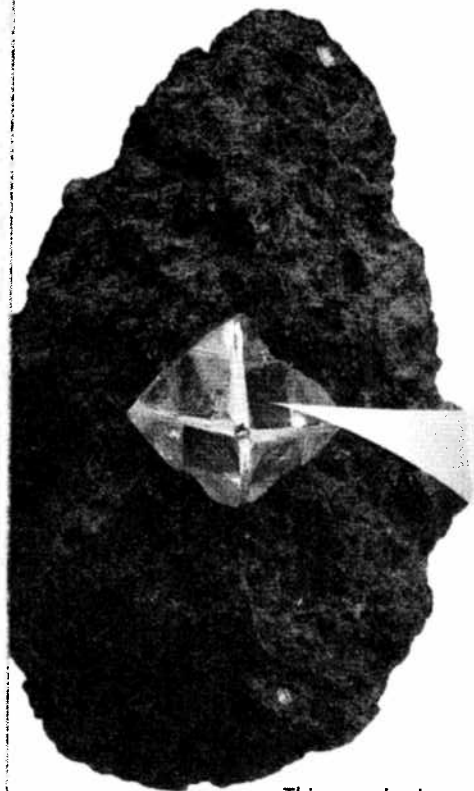
Telling the difference between sand, water, and diamonds is fairly simple. Each of these substances, like the thousands of other materials that occur naturally on Earth, has distinctive characteristics. Yet as different as they may seem, these materials have much in common. Each is a kind of matter.

## Matter

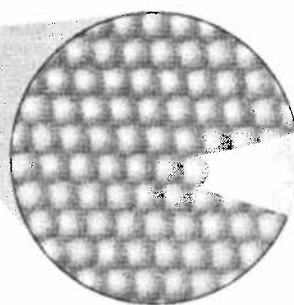
What is matter? Matter is anything that has mass and volume. Mass is a measure of the amount of material in an object or a substance. Mass is often discussed in terms of weight, but mass and weight are not the same. Weight is a measure of the force of gravity acting on an object or substance. Where the force of gravity is very weak, as in outer space, an object may be virtually weightless, but its mass remains the same. Volume is the amount of space taken up by an object or a substance. All the materials found on Earth—rocks and minerals, for example—have mass and volume and therefore are matter.

Ordinary matter is composed of elements. An **element** is a substance that cannot be broken into simpler substances by ordinary chemical means. You may already be familiar with the names of many elements. Oxygen and nitrogen are elements in the atmosphere; gold, silver, and iron are familiar metallic elements. Each element has a symbol as well as a name. In some cases, the symbol is the first letter or two of the element's name. For example, the symbol for hydrogen is H, and the symbol for helium is He. A few elements' symbols are based on their Latin names. For example, the symbol for gold is Au, from the Latin word for gold, *aurum*.

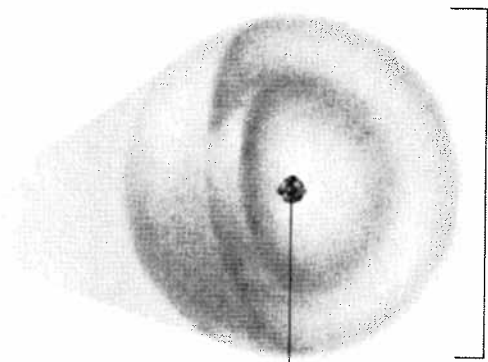
Of what do elements consist? About 200 years ago, the English chemist John Dalton formulated the modern particle model—the concept that each element is made up of tiny particles, all alike, called atoms. Dalton described an atom as the smallest part of an element that has all the element's properties. Today, scientists know that atoms are very complex and consist of still smaller particles.



This sample shows a "rough," or uncut, diamond in its rock matrix.



A diamond is made up of uniformly arranged carbon atoms.



Nucleus

Electron cloud

A carbon atom is made up of a nucleus surrounded by an electron cloud. The nucleus, in which most of the atom's mass is concentrated, consists of protons and neutrons.

## Structure of an Atom

An atom is essentially composed of negatively charged particles moving at high speed about a central nucleus (plural *nuclei*). Each negatively charged particle is called an electron. The moving electrons create a “cloud” of negative charge around the nucleus. To make atomic structure easier to understand, however, diagrams of atoms often show electrons orbiting nuclei like planets orbiting the sun.

### The Nucleus

The nucleus of an atom contains protons and neutrons. Each proton carries a positive charge that is exactly equal to an electron’s negative charge. A neutron (NOO-TRAHN) carries no charge. In its normal state, a neutral atom has an equal number of electrons and protons. The number of protons in the nucleus is the atom’s **atomic number** and is equal to the number of electrons in the atom’s electron cloud. The number of protons and electrons in an atom determines the atom’s properties.

Atoms are tiny and consist mainly of empty space. An atom of iron, for example, is about 25 ten-millionths of a meter in diameter. Most of an iron atom, however, is empty space between the nucleus and its surrounding electrons.

Although the nucleus is small, it contains the more massive atomic particles. A proton is 1836 times more massive than an electron, and a neutron is slightly more massive than a proton. More than 99.9 percent of the mass of an atom is in its nucleus.

The simplest and lightest of all atoms is that of hydrogen (H). The nucleus of the most common form of hydrogen has one proton and no neutrons. One electron circles the nucleus.

The next lightest element is helium (He). The nucleus of a typical helium atom contains two protons and two neutrons. The two electrons in its electron cloud balance the two positively charged protons in the nucleus.

One of the most important elements found on Earth is carbon (C). The most common form of the carbon atom has six protons and six neutrons in its nucleus. The electron cloud contains six electrons. In atoms that have more than two electrons, the electron cloud is divided into energy levels, as described below.

### Electrons and Energy Levels

As the number of electrons in atoms increases, more energy levels are needed to hold them. The greatest number of energy levels in any atom is seven. Each level can hold only a specific number of electrons. For example, the innermost level never holds more than 2 electrons. Other levels hold as many as 32 electrons. Atoms of uranium (U), the heaviest of the natural elements, have 92 electrons distributed in seven energy levels. Going from the innermost level to the outermost, the levels contain 2, 8, 18, 32, 21, 9, and 2 electrons, respectively.



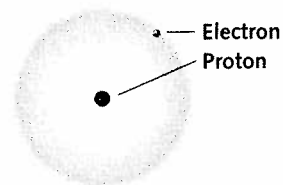
### How Many Protons, Neutrons, and Electrons Are in Common Elements?

Build model atoms, ions, and isotopes from subatomic particles.

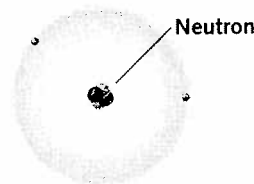
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### VOCABULARY STRATEGY

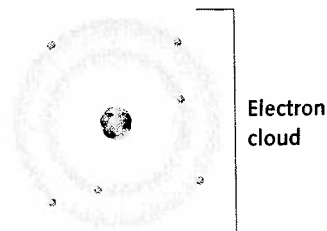
The word *nucleus* is from a Latin word meaning “kernel.”



**HYDROGEN (H)**



**HELIUM (He)**



**CARBON (C)**

## Classifying Atoms

The periodic table, a tool used to organize information about the elements, appears on pages 698–699 of the Appendix. Of the more than 100 known elements listed there, 92 occur naturally on Earth in significant amounts. The rest are synthetic elements produced by scientists. In each row of the periodic table, elements are listed from left to right in order of increasing numbers of protons. The vertical columns, called groups, comprise elements that have similar chemical properties. The location of an element in the table allows you to predict how it will react with other elements.

**Understanding the Periodic Table**

<b>Symbol</b> A one- or two-letter abbreviation derived from the element's English or Latin name.	6 <b>C</b>	<b>Atomic Number</b> Equal to the number of protons in the nucleus, as well as the number of electrons in the electron cloud.
<b>Name</b> Element's common name.	<b>Carbon</b> 12.011	<b>Atomic Mass</b> Weighted average of the masses of all the element's isotopes. Rounding the atomic mass to the nearest whole number yields the mass number of the most common isotope.
	14	

**Electron** —

**Protons**  
6

**Neutrons**  
6

**Mass Number**  
The sum of the numbers of protons and neutrons in a specific isotope.

**Carbon Atom**

### VOCABULARY STRATEGY

The word *isotope* is of Greek origin. *Iso-* comes from the word *īsos*, which means "equal," and *tope* comes from *topos*, which means "place."

The identity of an atom depends only on the number of protons, not on the number of neutrons. Many elements have atoms with the same number of protons but different numbers of neutrons. Atoms of an element that have different masses are **isotopes** (EYE-suh-TOHPHS). The **mass number** of any given isotope is the sum of the numbers of protons and neutrons in that isotope. An atomic mass is a proportional average of the naturally occurring masses of an element's isotopes. This is why an atomic mass often includes a fractional part. For example, the average mass of carbon atoms is 12.011 atomic mass units (amu).

By learning how to interpret data in the periodic table, you can determine the number of particles in any element's atoms. For example, potassium's atomic number is 19, and the mass number of its most common isotope is 39. The potassium nucleus, therefore, contains 19 protons. By subtracting 19 from 39, you can find the number of neutrons; potassium has 20. How many

electrons surround the nucleus? Because the number of electrons in a neutral atom equals the number of protons, the answer is 19 electrons.

Hydrogen has three isotopes. The most common has one proton and no neutrons in its nucleus. Its atomic number is 1 and its mass number is also 1. However, hydrogen has a second isotope with one proton and one neutron in its nucleus. Its atomic number is 1, but its mass number is 2. This isotope is known as heavy hydrogen or deuterium (doo-TEER-ee-uhm). It is much less common than ordinary hydrogen. The third isotope of hydrogen is even rarer. Known as tritium (TRIHT-ee-uhm), it has a mass number of 3. Its nucleus contains one proton and two neutrons.

You may have heard of carbon-14, a "heavy" isotope of carbon. Each ordinary atom of carbon-12 has a nucleus consisting of six protons and six neutrons. A carbon-14 atom, with a mass of 14, has a nucleus with six protons and eight neutrons.

Uranium has several isotopes, all of which have 92 protons in the nucleus. The most commonly occurring isotope, uranium-238, has 146 neutrons in its nucleus; uranium-235, however, has only 143 neutrons.

## Bonding of Atoms

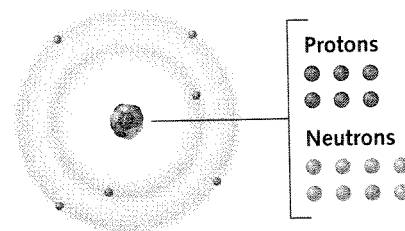
Most substances on Earth are not pure elements but rather compounds. A **compound** is a substance that contains atoms of two or more elements that are chemically combined.

Understanding more about the energy levels in atoms can help you see why elements combine to form compounds. Atoms tend to be most stable when their outermost energy level is filled with electrons. For example, atoms of helium, neon, and the other elements in the right-most column of the periodic table naturally have their outermost energy level filled. For this reason, these elements are very stable and do not readily combine with other elements to form compounds. In contrast, the atoms of most other elements tend to fill their outermost energy level by gaining, losing, or sharing electrons with other atoms. The gain, loss, or sharing of electrons forms a chemical bond that holds atoms together. There are three main types of bonds: (1) covalent bonds, (2) ionic bonds, and (3) metallic bonds.

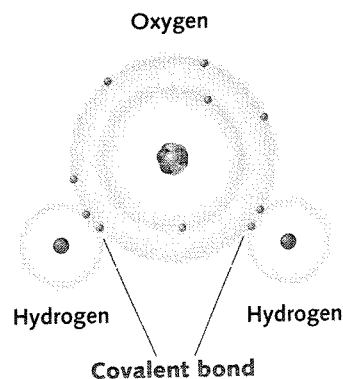
### COVALENT BONDS

Some compounds form when atoms share electrons. The type of bond formed by sharing electrons is called a covalent bond. Two or more atoms held together by covalent bonds form a **molecule**. For example, in a molecule of water, two atoms of hydrogen and one atom of oxygen share electrons. In a molecule of carbon dioxide, one carbon atom and two oxygen atoms share electrons.

In some cases, atoms of the same element also form covalent bonds with each other to form molecules. For example, the two most abundant gases in Earth's atmosphere, nitrogen and oxygen, both form such molecules. Nitrogen naturally occurs as molecules of two atoms each ( $N_2$ ), and oxygen also most commonly exists as molecules of two atoms ( $O_2$ ).



**CARBON 14** is an isotope of carbon, with two more neutrons than ordinary carbon.



**COVALENT BOND** The two hydrogen atoms and one oxygen atom of a water molecule are held together by covalent bonds.

## IONIC BONDS

Other compounds are held together by the force of electrical attraction between atoms that have lost or gained electrons. In the neutral state, atoms have equal numbers of protons and electrons. If an atom gains one or more electrons, it becomes negatively charged. But if an atom loses one or more electrons, it becomes positively charged. Such a charged atom is called an **ion** (EYE-uhn). Groups of atoms may also form ions.

Because opposite charges attract each other, ions of opposite charges bond to form compounds. The force of attraction, or ionic bond, between the oppositely charged ions holds them together. Ionic bonds are common in many minerals. For example, positively charged sodium ions are bonded with negatively charged chlorine ions in the compound sodium chloride, or table salt. Sodium chloride is found in nature as the mineral halite.

How do atoms lose or gain electrons to form ions? Consider the element sodium. You can see from the diagram below that the sodium atom's outer energy level contains only one electron. A stable, or nonreactive, element would have its outer energy level completely filled with electrons. Sodium reacts with many elements that cause it to lose this outer electron. Chlorine is reactive for the opposite reason. Its atom's outer energy level is short one electron, so it reacts with other elements to gain an electron. When sodium and chlorine react, sodium atoms lose their outer electrons to chlorine atoms' outer energy level.

A **metal** is an element that loses electrons easily to form positive ions. Among the metallic elements are aluminum, sodium, potassium, calcium, zinc, gold, silver, iron, copper, and lead. Metals dominate the periodic table. Ionic bonds do not form between metals.

### Sodium Chloride

**Sodium atom (11 electrons)**

**Chlorine atom (17 electrons)**

**REACTION**

**Sodium ion (Na<sup>+</sup>) (a 1<sup>+</sup> charge)**

**Chlorine ion (Cl<sup>-</sup>) (a 1<sup>-</sup> charge)**

**1** During the chemical reaction that forms sodium chloride, ionic bonds form between sodium atoms and chlorine atoms.

**2** Each sodium atom has lost one electron from its outermost energy level. The chlorine atom has gained one electron. The molecule is held together by an ionic bond.

**Sodium (element)**

**Chlorine (element)**

**Sodium chloride (compound)**

An element that gains electrons easily to form a negative ion is classified as a **nonmetal**. Although ionic bonds form most readily between metals and nonmetals, some compounds do form from ions of different nonmetals. Nonmetals include nitrogen, oxygen, fluorine, chlorine, phosphorus, and sulfur. Nonmetals are located on the right side of the periodic table.

### **METALLIC BONDS**

The bonds that form between metal atoms have different characteristics than bonds that form between metal and nonmetal atoms. In pure metallic minerals such as iron, the atoms exist as positively charged ions. Rather than moving distinctly around one nucleus, the outer electrons move freely around all the positive ions. This arrangement of electrons is sometimes described as a sea of electrons. The free movement of electrons around metal ions accounts for some typical properties of pure metals, such as high conductivity.

### **Compounds and Mixtures**

A compound can have properties entirely unlike those of the elements of which it is made. For example, water is certainly different from either hydrogen or oxygen. At room temperature, hydrogen and oxygen are gases, while water is a liquid. Another example is table salt, which is a compound of the elements sodium and chlorine. Both sodium and chlorine are poisonous. Yet when these two elements react chemically, they form table salt, a compound most people can eat safely with their food.

Compounds should not be confused with mixtures. In a mixture, the individual elements or compounds keep their own properties and can be present in any proportion. Most mixtures can be separated by physical means. Salt water is an example of a mixture. It can be separated by evaporating the water. The elements in a compound, however, can be separated only by chemical means. For example, water can be decomposed into hydrogen and oxygen by breaking the chemical bonds with a strong electric current.

#### **5.1 Section Review**

- 1 What are the characteristics of matter?
- 2 Compare and contrast a proton and a neutron. How are they alike? How are they different?
- 3 Name and describe the three types of chemical bonds.
- 4 **APPLICATION** Suppose you are given two liquids and told that one is a compound and the other is a mixture. How might you determine which was which? Describe one method you could use.
- 5 **MATHEMATICS** Use the periodic table on pages 698–699 to determine the numbers of protons, neutrons, and electrons in an atom of silver (Ag).

# 5.2

## Composition and Structure of Minerals

### KEY IDEA

A mineral is a naturally occurring element or compound that is inorganic and crystalline in structure.

### KEY VOCABULARY

- mineral
- crystal
- silicate
- silica tetrahedron
- cleavage

### What Is a Mineral?

All the rocks and minerals of Earth's crust consist of elements. How are minerals different from other forms of matter? A **mineral** has the following characteristics:

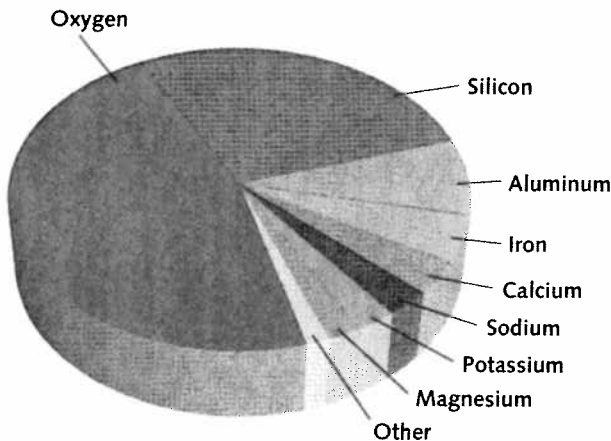
1. It occurs naturally.
2. It is solid.
3. It has a definite chemical composition.
4. Its atoms are arranged in an orderly pattern.
5. It is inorganic (was never alive).

There are about 4000 known minerals, and each satisfies the conditions listed above. You may already be familiar with the minerals quartz, halite (rock salt), gold, and diamond. Many materials found on Earth are not minerals, however. Water at room temperature is not a mineral because it is not a solid. Coal is not a mineral because it is made from plant remains, it lacks a definite composition, and its atoms are not arranged in an orderly way. (Although they are produced by living things, the shells of such marine animals as clams are composed of minerals.)

Of all the elements in Earth's crust, a mere eight make up 98.5 percent of the crust's total mass. These elements, which are the ones most common in minerals, are listed in the table below. More than 90 percent of the minerals in Earth's crust are compounds containing oxygen and silicon, the two most abundant elements.

Most minerals are compounds. Quartz is a compound of silicon and oxygen. The mineral galena is a compound of lead and sulfur. A few minerals, however, consist of single elements and are called native elements. Examples are silver (Ag), copper (Cu), sulfur (S), and diamond (C). Often, different types of minerals (compounds and native elements) are found mixed together. Such mixtures of minerals are called rocks.

**COMMON ELEMENTS** The circle graph (below) and the chart (right) show the eight most common elements in Earth's crust by mass. Compare the amount of oxygen and silicon to the amounts of the other elements.



Name	Element Symbol	Percent by Mass
Oxygen	O	46.6
Silicon	Si	27.7
Aluminum	Al	8.1
Iron	Fe	5.0
Calcium	Ca	3.6
Sodium	Na	2.8
Potassium	K	2.6
Magnesium	Mg	2.1
Other	-	1.5

## How Minerals Form

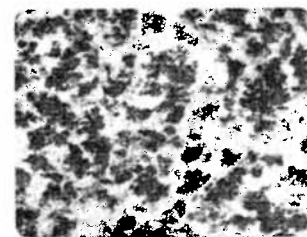
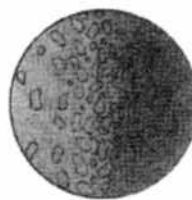
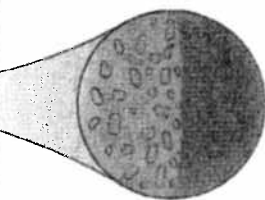
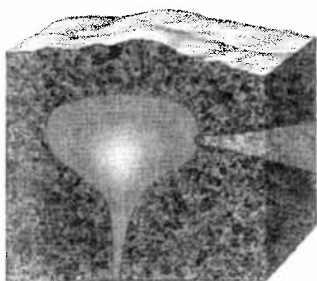
Minerals can form in several ways. Many minerals form out of molten rock, or magma, in which atoms, molecules, and ions can move freely. As magma cools, the atoms, molecules, and ions move closer together and form chemical bonds that create compounds.

Many kinds of minerals can form out of a single magma mass. The types of minerals that form depend in part on the types and amounts of elements that are present in the magma. The rate at which the magma cools determines the size of the mineral grains that form.

Mineral-forming processes can be gradual and lengthy. Some types of minerals form as water containing dissolved ions slowly evaporates. For example, halite forms when water evaporates from a solution of salt and water. As the water molecules evaporate, sodium and chlorine ions bond to form the mineral halite. New minerals also form when existing minerals are transformed by heat, pressure, or chemical action.

### Mineral Formation

#### THE MAGMA PROCESS



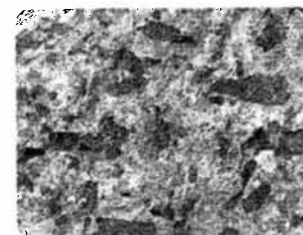
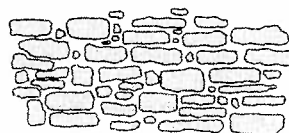
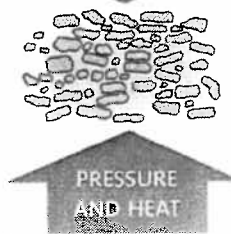
1 Magma rises from deep within Earth. The particles in the hot magma move freely.

2 When the magma begins to cool, atoms, molecules, and ions move closer together and bond to form various compounds.

3 Over time, molecules of the compounds mass together as grains of minerals.

**DIORITE** is formed by the cooling of magma. Large mineral grains give diorite its speckled appearance.

#### THE PRESSURE PROCESS



1 When a rock is subjected to high temperature and pressure, the minerals can begin to break down chemically.

2 The temperature and pressure becomes great enough to change the minerals in a solid state, without melting them.

3 The free atoms, ions, and molecules recombine in new ways, forming new minerals. More growth occurs in directions away from the pressure.

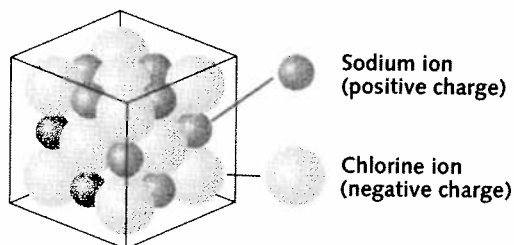
**HORNBLLENDE SCHIST** is formed from minerals changed by high temperature and pressure. The elongated black crystals are aligned in one direction.

## Structure of Minerals

The orderly arrangement of atoms in a mineral is often apparent in the mineral's shape. You may be most familiar with minerals in the form of beautiful crystals. A **crystal** is a regular geometric solid with smooth surfaces called crystal faces. By definition, all minerals have crystalline structures—that is, regular, orderly arrangements of atoms.

### Crystal Structure

What is the crystalline structure of halite, commonly known as rock salt? Recall that halite is composed of positively charged sodium ions bonded ionically to negatively charged chlorine ions. In the resulting pattern, illustrated below, each sodium ion is surrounded by six chlorine ions, and each chlorine ion is surrounded by six sodium ions. This pattern is repeated throughout the mineral. As a result of this arrangement of ions, halite typically occurs in crystals that have a cubic shape.



**CRYSTAL STRUCTURE OF SALT**

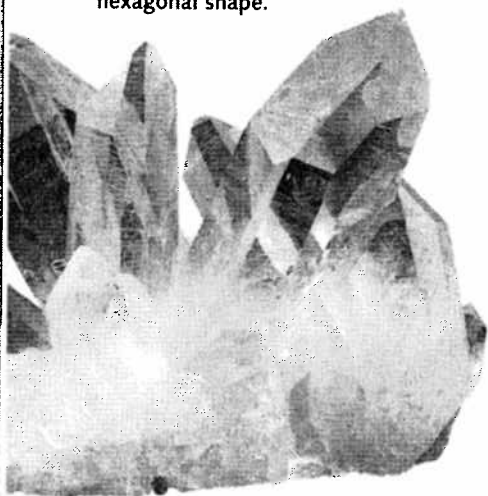
It is the orderly arrangement of ions, molecules, or atoms in any mineral that determines the shape of its crystals. Each type of mineral has its own crystal form. For example, quartz, consisting of silicon and oxygen atoms bonded together, may form long six-sided crystals. All quartz crystals, from microscopic to hand-size or larger, have the same six-sided shape.

The angle at which crystal faces meet is characteristic for each type of mineral and can be used to help identify the mineral. Halite's crystal faces meet at right angles. In quartz, the crystal faces meet at angles of  $120^\circ$ . Not all crystalline substances, however, have crystal faces. If space is limited when a mineral is forming, there may not be enough room for crystal faces to develop fully, or "grow." The mineral simply fills the available space. Such a mineral is still crystalline, but crystal faces are not visible.

Although there are thousands of different types of minerals, their crystals have only six basic types of shapes. Imaginary lines called crystallographic axes are used to distinguish the six systems of crystal shapes. Each axis passes through the center of the crystal. In crystals of the cubic system, including halite crystals, three axes equal in length intersect at right angles.

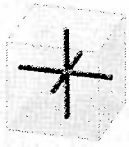
### HEXAGONAL CRYSTALS

Under the right conditions, quartz crystals will exhibit their characteristic hexagonal shape.



## Six Crystal Systems

### Cubic System



Three axes of equal length intersect at  $90^\circ$  angles.

**Examples:**  
sylvite, halite



Sylvite

### Orthorhombic System



Three axes, each of a different length, intersect at  $90^\circ$  angles.

**Examples:**  
topaz, sulfur



Topaz

### Tetragonal System



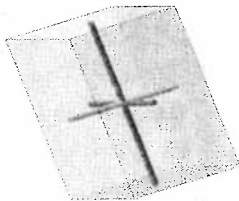
Three axes intersect at  $90^\circ$  angles. Two of the axes are equal in length.

**Examples:**  
wulfenite, zircon



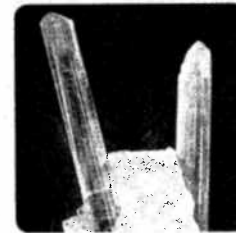
Wulfenite

### Triclinic System



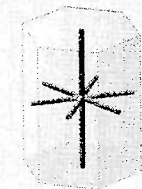
Three axes, each of a different length, intersect at oblique angles.

**Examples:**  
kyanite, turquoise



Kyanite

### Hexagonal System



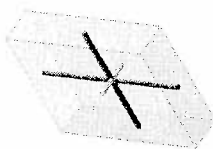
Three axes of equal length intersect at  $60^\circ$  angles. The fourth axis (vertical) can be longer or shorter than the other axes.

**Examples:**  
emerald, graphite



Emerald (a form of beryl)

### Monoclinic System



Three axes, each of a different length, intersect, with two of the intersections at  $90^\circ$  angles and the third at an oblique angle.

**Examples:**  
gypsum, mica



Gypsum

Axes of equal length are shown in the same color.

## VOCABULARY STRATEGY

Prefixes in words that describe geometric shapes can often give you clues to the words' meanings. For example, *mono-* means "one" and *clin* means "incline." Therefore, *monoclinic* means "having one axis at an inclined (oblique) angle." In *tetragonal*, *tetra-* means "four," and *-gon* means "angle." Each face of a tetragonal shape has four angles.



Examine 3-D models of common molecules.

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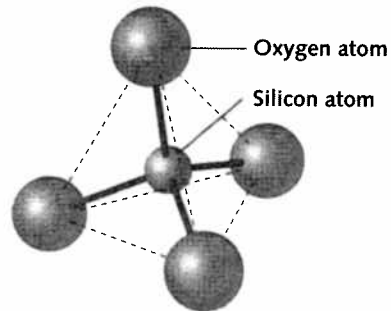
## Silicates

Silicon and oxygen are the two most abundant elements in Earth's crust, so it is not surprising that most minerals contain these elements. Minerals that are compounds including silicon and oxygen are called **silicates**. A silicate may also contain one or more metallic elements, such as aluminum or iron. A few silicates do not contain metal. For example, quartz is composed only of oxygen and silicon. More than 90 percent of the minerals in Earth's crust are silicates.

The basic building block of a silicate is the **silica tetrahedron**, consisting of four oxygen atoms packed closely around a silicon atom. This unit is named for its shape. As shown in the ball-and-stick model below, imaginary lines connecting the four oxygen atoms form a geometric figure called a tetrahedron. A silica tetrahedron is held together by chemical bonds between the silicon atom and the oxygen atoms. All silicates are composed of these tetrahedra, although the tetrahedra may be arranged in various ways. The table on the next page shows how silicates are classified according to the different arrangements of tetrahedral units. Note that the metals contained in silicate compounds are not considered in the classification.

### SILICA TETRAHEDRON

The arrangement of silica tetrahedra determines many properties of silicate minerals, including cleavage. Several arrangements are shown in the table on page 101. For all but the first arrangement, oxygen atoms are shared by adjacent tetrahedra.



BALL-AND-STICK MODEL



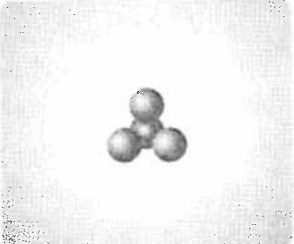
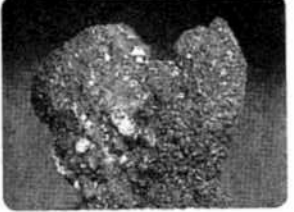
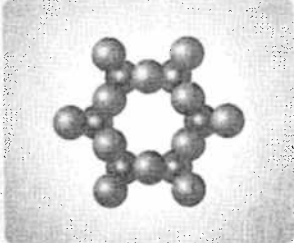

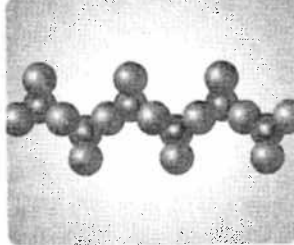

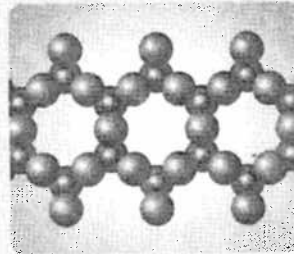

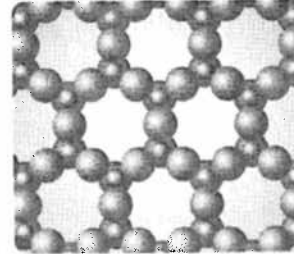


SPACE-FILLED MODEL

## Crystal Structure and Physical Properties

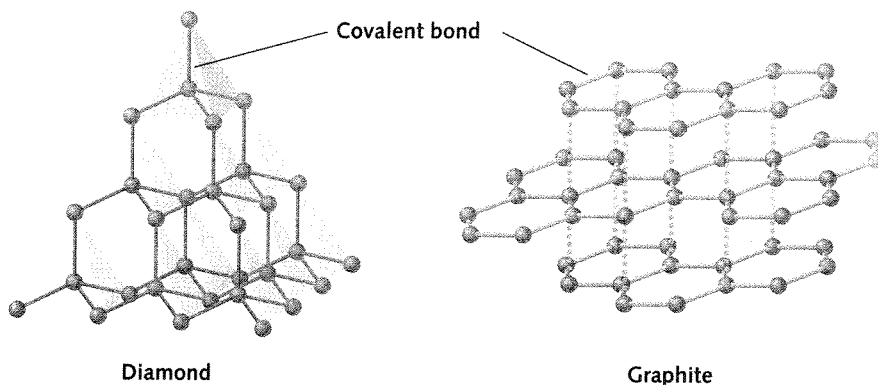
As a result of their crystalline structures, minerals are solid. The atoms, ions, and molecules in minerals are closely packed, bound by strong chemical bonds. An increase in temperature, however, may weaken the bonds between particles. At high temperatures, minerals melt, becoming liquids made up of loose groups of particles. At even higher temperatures, minerals vaporize, becoming gases in which individual particles are far apart. The temperatures at which a mineral melts and vaporizes are characteristic of the mineral and can sometimes be used to differentiate two different minerals of similar appearance.

Crystal structure also determines a mineral's **cleavage**, or tendency to split along definite planes. The planes along which the mineral splits correspond to planes of weak bonds between the atoms, ions, or molecules of the mineral. Halite splits into cubes between layers of ions. Quartz, with its strong network of atoms, does not split along any plane.

## Molecular Structures of Some Common Silicate Minerals

	Structure	Cleavage	Mineral
Olivine Group		Olivine has no cleavage.	 <p>Olivine</p>
Beryl		Beryl has one imperfect cleavage.	 <p>Beryl</p>
Pyroxene Group		Diopside has two perfect cleavages, at close to 90° angles.	 <p>Diopside</p>
Amphibole Group		Tremolite has one perfect and one imperfect cleavage at close to 60° and 120° angles.	 <p>Tremolite</p>
Mica Group		Micas exhibit perfect cleavage in one direction.	 <p>Muscovite Mica</p>
Feldspar Group	Too complex to draw	Microcline feldspar has two good cleavages, at or near 90° angles.	 <p>Microcline Feldspar</p>

The hardness of a mineral also depends on the arrangement of its ions, atoms, or molecules and on the strength of the chemical bonds between them. A good example of the relationship between hardness and crystalline structure is the two minerals that consist of the element carbon. When carbon atoms are arranged in a tetrahedral network, the result is diamond, the hardest natural mineral. Yet when carbon atoms are arranged in sheets of hexagonal networks, the result is graphite, a very soft mineral that flakes easily.



### CARBON STRUCTURES

Recall that the density of a material is the ratio of its mass to its volume. Density depends not only on the masses of the atoms in the mineral but also on how they are arranged. For example, although both graphite and diamond are made of carbon atoms, the density of graphite is about  $2.2 \text{ g/cm}^3$ , whereas that of diamond is  $3.5 \text{ g/cm}^3$ .

## 5.2 Section Review

- 1 List the five characteristics of a mineral.
- 2 Describe two ways in which minerals are formed. Include an example of each process.
- 3 List three physical characteristics of a mineral that are influenced by its crystalline structure.
- 4 Both diamond and graphite are composed purely of carbon atoms. Explain why diamond is so much harder than graphite.
- 5 **CRITICAL THINKING** Silicate minerals have a variety of crystalline structures, even though they are made from the same building blocks—silica tetrahedra. What factors do you think affect the structures of silicate minerals as they are forming?
- 6 **GEOGRAPHY** What types of minerals are common in the region where you live? Speculate on the processes by which they might have formed.

## SCIENCE & Technology

### A New Form of Carbon Creates a New Ball Game for Scientists

*Until recently, scientists knew of only two forms of pure carbon: graphite and diamond. In 1985, however, a form of carbon with molecules resembling soccer balls bounced onto the scene. This new form of carbon didn't look like or behave like graphite or diamond.*

Why do such discoveries excite scientists? In what ways can research on the unseen—atoms and molecules, for example—affect our daily lives?

Sometimes scientists make discoveries that surprise even themselves. Researchers trying to reproduce some unusual deep-space carbon chains placed graphite in a helium-filled chamber and then vaporized it with a laser. The result was a collection of sphere-shaped molecules of pure carbon. Most of these molecules were made up of 60 atoms of carbon. Each resembled a soccer ball, having 20 hexagonal sides and 12 pentagonal sides. Scientists named the substance buckminsterfullerene—and called its molecules buckyballs, in honor of R. Buckminster Fuller. A buckyball resembles one of the geodesic domes designed by this American architect.

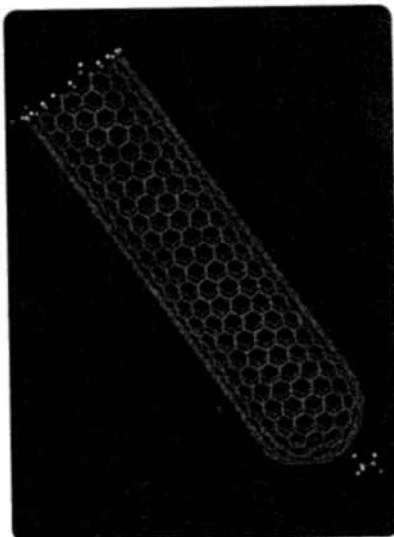
The unusual electrical, structural, and chemical properties of buckminsterfullerene excited scientists. In the first years after its discovery, scientists proposed using it as an ingredient in substances ranging from photocopier toner to rocket fuel. But in tests it didn't always produce the desired results. Furthermore, buckminsterfullerene isn't cheap to produce. In October 2000 it cost more than \$200 per ounce.

A more important breakthrough may have come in 1991, when a scientist manufacturing buckyballs instead produced "buckytubes," or

nanotubes. Measuring one fifty-thousandth the width of a human hair, a nanotube consists of a layer of rolled-up graphite, usually sealed at each end with half a buckyball.

Nanotubes have remarkable electrical properties and are 100 times stronger than steel. These attributes, combined with their microscopic size, make nanotubes ideal for new technology. They can be used as the muscles of tiny robotic machines, and they can store energy generated by ocean waves or fuel cells. Nanotubes

**NANOTUBES**, another form of carbon, are 100 times stronger than steel.



**GEODESIC DOMES** like this one, which buckyballs resemble, were designed by architect R. Buckminster Fuller.

can transmit the photons for high-resolution, ultra-thin display screens and lead to the production of smaller and more powerful transistors for future computers. ■

#### Extension

##### SCIENCE NOTEBOOK

Do some additional research on the current studies and uses of buckyballs and nanotubes. Since their discovery, what are some ways scientists have used them? Try to think of some practical applications on your own and write them in your science notebook.



Examine a model of a buckminsterfullerene.  
Keycode: ES0504

# 5.3

## Identifying Minerals

### KEY IDEA

Minerals can be identified by physical and chemical properties that include color, luster, crystal shape, streak, cleavage, fracture, hardness, specific gravity, and reaction to an acid.

### KEY VOCABULARY

- mineralogy
- rock-forming mineral
- luster
- streak
- fracture
- specific gravity

**Mineralogy** is the study of minerals and their properties. Many minerals can be identified and classified by inspecting them visually and performing simple tests to determine their properties.





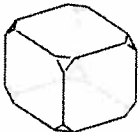


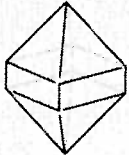
### Rock-Forming Minerals

Of the nearly 4000 known minerals, only about 30 are at all common. Most minerals, including gold and diamond, are rare. Among the most commonly found minerals are quartz, feldspar, mica, and calcite. These and the other minerals that make up most of the rocks in Earth's crust are called **rock-forming minerals**. Most rock-forming minerals are silicates.

Identifying rock-forming minerals can be difficult. A rock often consists of several minerals, some of which may be present in small amounts or well-mixed with other minerals. Sometimes a rock must be broken up in order to retrieve a mineral sample for identification. Although even very small mineral grains can usually be identified, identification is easier with a hand specimen, a sample that is large enough to be readily observed and manipulated. The method commonly used to identify a hand specimen of a mineral is the examination of the mineral's physical properties. Tests may also be performed to identify chemical properties of the mineral. However, the simplest way to identify a mineral is by means of physical tests and inspection.

### Identifying Minerals by Inspection

A field guide to minerals is a useful tool, because it lists properties such as color, luster, and crystal shape, as shown below. Visual inspection of a mineral may reveal such properties, but they must be considered together. Rarely is a mineral identified by a single property.

Characteristics of Some Common Minerals				
Mineral	Galena	Sulfur	Hornblende	Zircon
				
Crystal shape				
Color	lead or silver-gray; may have bluish tint	bright yellow as crystals; pale yellow as powder	black to dark green	brown, red, yellow, green, blue, black, or colorless
Luster	metallic to dull	glassy to earthy	glassy to dull	adamantine

Color is the most easily observed mineral property. Some minerals have distinctive colors that help identify them. For example, cinnabar, an ore of mercury, is red. Malachite (MAL-uh-KYT), an ore of copper, is green. Color, however, is the least useful property for mineral identification. One reason is that many minerals have similar colors. Also, impurities can turn colorless minerals into colored minerals. Although pure quartz is colorless or white, a small amount of iron gives quartz a purple color, and trace amounts of titanium produce pink quartz. Another reason not to rely on color alone is that some minerals can change color in various circumstances. For example, brown-bronze bornite, a copper ore, turns purple when exposed to air.

The **luster** of a mineral is the way the mineral shines in light. Luster can be described as either metallic or nonmetallic. Minerals with metallic luster, such as galena and pyrite, shine like polished metal. A mineral that does not shine like a metal has a nonmetallic luster. There are several categories of nonmetallic lusters. For example, quartz has a vitreous (VIHT-ree-uhs) luster, like shiny glass. Mica has a pearly luster. The hard, brilliant luster of diamond is called adamantine (AD-uh-MAN-TEEN). Other terms that are used to describe luster are *greasy*, *oily*, *dull*, and *earthy*.

Although a mineral's crystal shape can help one identify it, recall from Section 5.2 that crystal faces do not form if space is limited during mineral formation. The mineral grains in most rocks are so small and imperfect that flat-faced, regularly shaped crystals are difficult to find.

## Testing Mineral Specimens

Some mineral properties are not revealed by inspection and must be determined by simple physical tests. The streak, cleavage, hardness, and specific gravity of a mineral can be tested with a hand specimen.

The **streak** of a mineral is the color of its powder. The streak is obtained by rubbing the mineral on an unglazed white tile, called a streak plate. In many cases, the streak will not be the same color as the mineral. For example, iron-containing pyrite is brass yellow, yet its streak is always greenish black. Hematite, another iron-containing mineral, can be brown, red, or silver. Its streak, however, is always reddish brown. Although the color of a mineral may vary, the color of its streak rarely does. As a rule, the streak of a metallic mineral is at least as dark as the specimen. The streaks of nonmetallic minerals are usually colorless or white.

You may recall from Section 5.2 that the cleavage of a mineral is its tendency to split easily along flat surfaces. Mica splits very easily in one direction, into thin sheets. Mica is said to have one perfect cleavage. Feldspar splits readily in two directions, always at or near right angles. Feldspar is therefore said to have two good cleavages. Cleavage is useful for identifying minerals because cleavage surfaces can be observed even on tiny mineral grains.

Not all minerals exhibit cleavage. When minerals break in directions other than along cleavage surfaces, they are said to exhibit **fracture**. The mineral quartz and the rock obsidian show conchoidal (kahng-KOYD-uhl), or shell-like, fracture. The fracture surface is smooth and curved like the inside of a clam shell. Splintery fracture leaves a jagged surface with sharp

**CLEAVAGE TEST** Mica splits well in only one direction.



edges, as in native copper. Uneven or irregular fracture leaves a generally rough surface. The garnets show this type of fracture.

The hardness of a mineral is its resistance to being scratched. Diamond is the hardest of all minerals. It will scratch any other mineral against which it is rubbed. Talc is the softest of all minerals. All other minerals scratch talc.

The mineralogist Friedrich Mohs devised a numeric scale that is used to express the hardness of minerals. In this scale, ten well-known minerals are assigned numbers from 1 to 10. They range from the softest mineral, talc, to the hardest mineral, diamond. One limitation of the Mohs scale is that the increase in hardness at each successive step is not uniform. For example, diamond, number 10, is several times harder than corundum, number 9.

You can determine the approximate hardness of any common mineral by using your fingernail, a copper penny, a small glass plate, and a steel file. Just see whether the mineral scratches or is scratched by each item. If, for example, the mineral scratches the glass plate but is scratched by the steel file, its hardness is between 5.5 and 6.5.

Rating	Reference Mineral	Reference Tool (approximate value)	
1	talc		
2	gypsum	fingernail (2.5)	
3	calcite	copper penny (3.5)	
4	fluorite		
5	apatite	glass plate (5.5)	
6	potassium feldspar	steel file (6.5)	
7	quartz		
8	topaz		
9	corundum		
10	diamond		

Remember that hardness and brittleness are different properties. Glass is a brittle substance that breaks easily when dropped. Glass, however, is harder (more resistant to scratching) than copper and many other metals.

Specific gravity is another property that is helpful in identifying a mineral. A mineral's **specific gravity** is the ratio of its mass to the mass of an equal volume of water. In other words, the specific gravity of a mineral tells you how many times denser the mineral is than water. Recall that density is the ratio between a substance's mass and its volume.

Because minerals are denser than water, their specific gravities are greater than 1. Nonmetallic minerals, such as quartz, have specific gravities less than those of ore minerals and native metals. Some metallic minerals, such as hematite and magnetite, have specific gravities of about 5. Other metallic minerals are much denser. For example, gold has a specific gravity of about 19.3.

To understand how specific gravity is determined, it is important to be familiar with the concept of buoyancy. Buoyancy is the tendency of an object to float in water, due to the difference in densities between the water and the object. Archimedes' Principle states that an object will weigh less when it is in water than when it is in air and that this difference is equal to the weight of the displaced water. Because a mineral is solid, a mineral sample will displace an amount of water equal to its own volume. By weighing the sample in air and again underwater, you can determine the weight of a volume of water that is equal to the volume of the mineral sample.

In addition to physical tests, some minerals can be identified by means of chemical tests. Calcite, the principal mineral in limestone and marble, is calcium carbonate,  $\text{CaCO}_3$ . When a drop of hydrochloric acid is placed on calcite, the drop of acid fizzes. The released bubbles are carbon dioxide gas. Other minerals also react with acid but not as readily.

## Special Properties of Minerals

Some minerals have unusual characteristics that can be confirmed by inspection. For example, a variety of the mineral calcite, Iceland spar, splits light rays that pass through it. This property, called double refraction, causes a single object to appear as two when it is viewed through a transparent specimen of Iceland spar. Other minerals, such as fluorite and calcite, are fluorescent, appearing to glow when viewed under ultraviolet light. Some samples of the minerals willemite and sphalerite continue to glow after the ultraviolet light is turned off. They are phosphorescent.

Minerals that have unique properties are often easy to identify. For example, halite (rock salt) can be identified by its salty taste. Magnetite, an iron ore, is attracted by a magnet.

Some rare minerals, such as the uranium minerals carnotite and uraninite (yu-RAY-nuh-NYT), are radioactive. They give off subatomic particles that can be detected by a Geiger (GY-guhr) counter. Exposure to radioactive minerals can be dangerous to living organisms, including human beings.

### 5.3 Section Review

- 1 What type of compounds are most rock-forming minerals?
- 2 Explain why streak is a useful property for identifying minerals.
- 3 The hardness of a mineral is found to be between 9 and 10 on the Mohs scale. Can you accurately state that the mineral's hardness is 9.5? Why or why not?
- 4 **CRITICAL THINKING** You are given a sample of an unknown mineral. You determine that the mineral's streak is white and its specific gravity is 2.8. Is the mineral most likely to be a metallic mineral or a nonmetallic mineral? Explain your answer.
- 5 **PHYSICS** What is the difference between a mineral's density and its specific gravity?

25-Minute

Mini LAB

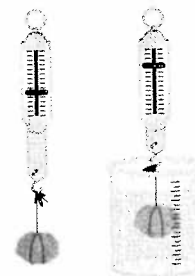
## Measuring Specific Gravity

### Materials

- beaker
- water
- string
- mineral sample
- spring scale

### Procedure

- 1 Fill the beaker  $\frac{3}{4}$  full of water. Tie one end of the string around the mineral. Tie the other end to the scale's hook.



- 2 Hold the scale so that the sample hangs freely. Measure and record the mass in grams ( $M_1$ ).
- 3 Lower the mineral into the beaker so that it is completely covered by water. Do not let the sample touch the bottom or sides of the beaker. Record the mass ( $M_2$ ).
- 4  $(M_1 - M_2)$  is the mass of the water displaced by the mineral. Calculate the specific gravity using the equation  $\frac{M_1}{M_1 - M_2}$ .

### Analysis

How might a larger sample change your results? The specific gravity of water is 1. Pure gold has a specific gravity of about 19. Higher numbers indicate higher densities. Compare the density of your sample with those of water and gold.

# 5.4

## KEY IDEA

The most common minerals in Earth's crust are silicates and carbonates.

## KEY VOCABULARY

- carbonate
- oxide
- sulfide

## Mineral Groups

You can find minerals virtually everywhere. In fact, it is possible that you walk on or pass by samples of common minerals every day. Some minerals are abundant, and many also have important uses.

## Major Silicates

More than 90 percent of the minerals in Earth's crust are members of the silicate family. A silicate is a compound of silicon, oxygen, and usually one or more metallic elements, such as aluminum or iron. In all silicates, the basic building block is the silica tetrahedron, consisting of four oxygen atoms bonded to a central silicon atom. Silicates are classified by the ways the tetrahedra are linked together—in chains, for example, or in single sheets. A common example of a mineral containing these silica tetrahedra is quartz.

## Quartz

Quartz is made entirely of tightly bound silica tetrahedra. Quartz has the chemical formula  $\text{SiO}_2$ . Its chemical name, silicon dioxide, indicates that in quartz there are two oxygen atoms for each silicon atom.

Inspection of a quartz sample reveals a glassy or greasy luster. Pure quartz is colorless or white; colored varieties include rose quartz, amethyst and smoky quartz. All varieties of quartz exhibit either conchoidal or irregular fracture. Quartz's hardness of 7 on the Mohs scale is a common property used for identifying it, since it is the hardest of the common minerals.

The hardness and optical properties of quartz make it ideal for certain industrial uses. It is commonly used in watch movements, prisms, heat lamps, lenses, glass, and paints. The crystal quartz is a semiprecious gemstone often worn as jewelry.

Quartz is found in granite and is a significant component of many other types of rocks. For example, quartzite consists almost entirely of quartz. Most sands consist mainly of grains of quartz.

Although the silica tetrahedra that make up quartz consist of Earth's two most common elements—oxygen and silicon—quartz is only the second most abundant mineral in Earth's crust. The most abundant family of minerals is the feldspars.



**QUARTZ**, such as the amethyst shown here, is often used in jewelry.



**SMOKY QUARTZ**



**CITRINE**

## Feldspars

The feldspar family of minerals makes up about 60 percent of Earth's crust. Despite notable differences, all feldspars share three features: two directions of cleavage, a hardness of 6, and a pearly luster.

How does the molecular structure of feldspar differ from that of quartz? In feldspar, aluminum atoms replace some of the silicon atoms in the silica tetrahedra. This replacement creates a net electrical charge in these tetrahedra, which is balanced by the addition of other metals, such as potassium, sodium, or calcium. On the basis of the types of additional metal elements, feldspars are classified into two major groups—the potassium feldspars and the sodium-calcium feldspars.

The most common potassium feldspar is orthoclase (AWR-thuh-KLAYS). Typically, orthoclase is light-colored—pink or salmon. The two cleavage surfaces meet at right angles. Like quartz, orthoclase is most commonly found in granite.

The sodium-calcium feldspars are called plagioclase (PLAY-jee-uh-KLAYS) feldspars. Two examples are albite and labradorite. The plagioclase feldspars range in color from white to gray. The two cleavage surfaces meet at slightly less than a right angle. One cleavage surface is often marked by fine parallel lines, called striations (stry-AY-shuhnz).

Feldspars are important rock-forming minerals. Feldspars are also important economically. Minerals in this family are used in the manufacture of such everyday products as glass and ceramics.



**ORTHOCLASE FELDSPAR**



**PLAGIOCLASE FELDSPAR**

## Other Silicates

Minerals in the pyroxene (py-RAHK-SEEN) family occur widely. Pyroxenes have cleavage surfaces that meet nearly at right angles. Augite (AW-JYT) is the most common member of the pyroxene family. Augite is also an example of a ferromagnesian silicate. These silicates can belong to almost any of the silicate families, but they all contain iron and magnesium. Ferromagnesian silicates are always dark in color. Augite has two good cleavages and a hardness between 5 and 6.

Minerals in the mica (MY-kuh) family are soft silicates. With a hardness of 2.5 and perfect cleavage, they can be easily picked out of rocks such as granite and gneiss. All micas form flat crystals that cleave in only one direction to form thin sheets or flakes. Muscovite, also known as white mica, is silvery white. Biotite is a dark brown or black mica.

Observe common objects made of minerals.

Keycode: ES0505

### VOCABULARY STRATEGY

The prefix *ferro-* in the word *ferromagnesian* comes from the Latin word for iron, *ferrum*.

Micas are useful in both sheet and powdered forms. Among their many applications, they are used in electronic insulators, paints, plastics, rubber, and roofing.

The amphibole (AM-fuh-BOHL) minerals are complex silicates that form long, needlelike crystals. The most common amphibole is hornblende. A ferromagnesian silicate, hornblende can be shiny dark green, brown, or black. Its hardness ranges from 5 to 6. Hornblende has two good cleavages that meet at oblique angles. It is found in igneous and metamorphic rocks.

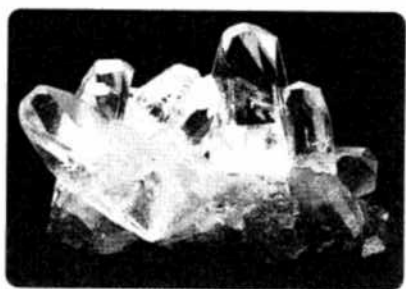
Although the minerals mentioned above are the most common silicates, two others—kaolinite and the olivine group—have important practical uses. Named for its olive-green color, olivine is a ferromagnesian silicate. It has a hardness of 6.5 and a glassy, shell-like fracture. Gem-quality olivine used to make jewelry is called peridot (PEHR-ih-DAHT). Some meteorites contain olivine.

Kaolinite is an aluminum silicate formed by the weathering of feldspars and other silicates. Pure kaolinite is white and has a hardness of about 2 and perfect cleavage in one direction. Kaolin, a clay composed primarily of kaolinite, is sometimes called china clay and is commonly used in ceramics, paints, and fiberglass products.

## Carbonates

Although the most widely found minerals are silicates, several nonsilicate minerals are also common. One nonsilicate group is the carbonates. A **carbonate** is a mineral made of negatively charged carbonate ions bonded to positive metal ions. Each carbonate ion is made up of one carbon atom covalently bonded to three oxygen atoms.

The rocks limestone and marble, often used in construction, consist almost entirely of carbonate minerals. Limestone is also used in the manufacture of everyday products ranging from paper to medicines.



**CALCITE**

**CALCITE** Calcium carbonate, or calcite (KAL-SYT), is the most common carbonate mineral. Usually colorless or white, calcite has a hardness of 3 and can be scratched with a knife. Calcite has three perfect cleavages that meet at oblique angles. Its cleavages give it a very strong tendency to break into flat-sided rhombohedra when dropped or struck. You can use an acid test to identify calcite easily. The chemical formula of calcite is  $\text{CaCO}_3$ .



**DOLOMITE**

**DOLOMITE** Calcium magnesium carbonate, or dolomite (DOH-luh-MYT), has a hardness of 3.5 to 4. Its chemical formula is  $\text{CaMg}(\text{CO}_3)_2$ . Like calcite, it cleaves into rhombohedra. Dolomite does not readily bubble when hydrochloric acid is dropped on it. Dolomite occurs as coarse or fine grains in dolomitic limestones.

## Oxides and Sulfides

Some minerals contain significant amounts of the element iron. Although these minerals are not as common as the silicates or carbonates, they have economic importance. Iron-containing minerals are used in industry to make steel, magnets, and car parts. They are also used in such consumer goods as medicines, cosmetics, plastics, and paints.

In these iron minerals, the iron is usually combined with either oxygen or sulfur. An **oxide** (AHK-SYD) is a mineral consisting of a metal element combined with oxygen. A **sulfide** (SUHL-FYD) is a mineral consisting of a metal element combined with sulfur.

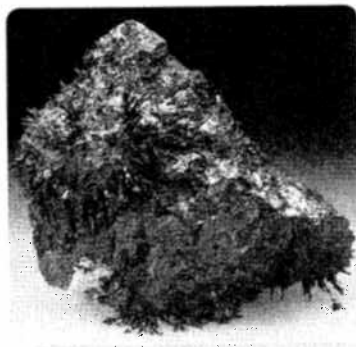
**HEMATITE** Hematite, the most common iron oxide, is usually red. Its properties include an earthy luster and uneven fracture. Some hematite samples have a silvery metallic luster that makes them attractive as gemstones. However, all hematite samples, regardless of their apparent color, leave a red-brown streak on a streak plate. Hematite has a hardness of 5 to 6 on the Mohs scale.

**MAGNETITE** Magnetite is a black iron oxide. Its name refers to the fact that it is attracted to a magnet. Lodestone is a variety of magnetite that is itself a natural magnet. Because of this unique property, the first compass needles were made from lodestone. Magnetite has a hardness of 5.5 to 6.5.

**PYRITE** Pyrite, an iron sulfide, is the most common sulfide mineral. Its color ranges from pale brass to golden yellow. Its hardness is about 6. Pyrite often occurs in 6- or 12-sided crystals. Because it is sometimes mistaken for gold, pyrite is commonly referred to as fool's gold.



HEMATITE



MAGNETITE



PYRITE

#### 5.4 Section Review

- 1 Name one example of a silicate mineral and one example of an oxide mineral. Describe the distinguishing characteristics of each mineral.
- 2 How can you use cleavage to distinguish between orthoclase and plagioclase feldspars?
- 3 **CRITICAL THINKING** Suppose that you are given hand specimens of the carbonates calcite and dolomite. Describe two tests that would allow you to identify the samples.
- 4 **ECONOMICS** According to the principle of supply and demand, the price you pay for a product is determined both by its availability and by consumer demand for the product. On the basis of this principle, which minerals do you think have a higher value, iron-containing minerals or feldspars? Explain your reasoning.

## Specific Gravity and Mineral Identification

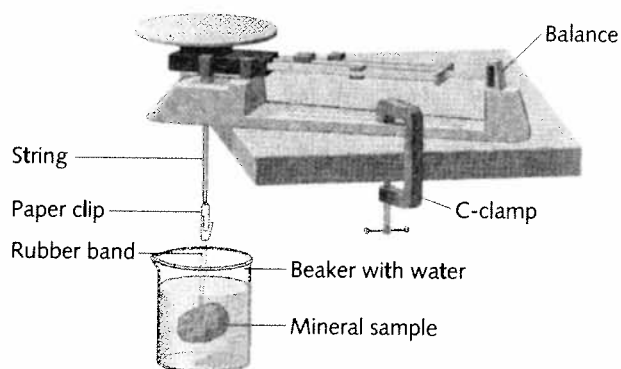
### SKILLS AND OBJECTIVES

- **Measure** data and **calculate** the specific gravity of several minerals.
- **Identify** minerals using their specific gravities.

### MATERIALS

- mineral kit containing 3 unnamed minerals
- triple-beam balance
- C-clamp
- 250-mL beaker
- water
- string
- paper clip
- rubber band
- calculator

It is often quite difficult to distinguish one mineral from another. For example albite and oligoclase, both plagioclase feldspars, are similar in appearance and in most other properties. One property that does slightly differ between these two minerals is specific gravity: 2.62 for albite and 2.65 for oligoclase. Careful measurements of the specific gravity of each mineral make it possible to tell the two apart. In this activity, you will determine the specific gravities of three unnamed minerals and then use these values to identify each mineral.



### Procedure

- 1 Construct a table like Table 1 for recording your data. Add two more columns for Minerals 2 and 3.
- 2 Set the balance on the lab table so that the pan hangs over the edge of the table. Attach the balance to the tabletop with a C-clamp.
- 3 Look under the balance pan and locate the metal bar that hangs down from the pan. Attach a loop of string to this metal bar. Tie the string securely so that the loop of string hangs below the balance.
- 4 Securely wrap a rubber band around one of the mineral samples so that you can suspend the sample by holding onto one of the rubber band's loops without the sample falling out.
- 5 Make a hook out of a paper clip by unbending it as shown in the diagram above. Attach one end to the free loop of the rubber band. Hook the other end to the loop of string suspended from the balance pan. Your mineral sample should now hang freely from the bottom of the pan.
- 6 Find the mass of the sample by adjusting the sliding masses on the balance. Record the result under "Mineral 1" in the row "Mass in air."

Table 1

Property	Mineral 1
Mass in air (g)	
Mass in water (g)	
Loss of mass in water (g)	
Specific gravity (calculated)	
Name of mineral	
Specific gravity (accepted value)	

- 7 Fill a 250-mL beaker with about 150 mL of water. With the mineral attached to the balance, raise the beaker of water under the mineral until the mineral is totally submerged in the water. Do not allow the mineral to rest on the bottom of the beaker. Measure the mass and record the measurement in the row "Mass in water."
- 8 Find the difference between the mass of the mineral in air and the mass in water. Record your result as "Loss of mass in water." Use the formula on the right to calculate the specific gravity of your sample.
- 9 Repeat Steps 3–8 for the other two minerals in your kit.
- 10 Use the accepted values for specific gravity in Table 2 to identify each of your mineral samples. Record the mineral names and actual values for specific gravity in your table.

$$\text{SpG} = \frac{\text{Specific Gravity (SpG)}}{\text{Loss of mass in water}} = \frac{\text{Mass in air}}{\text{Loss of mass in water}}$$

## Analysis and Conclusions

1. Were you able to identify any of the minerals in your mineral kit by inspection prior to determining their specific gravities? If so, describe which tests you used.
2. Were you able to use specific gravity alone in identifying the minerals in your kit?
3. What sources of error in the experiment might account for any differences from the accepted value of specific gravity for each mineral?
4. If you held a sample of sulfur in one hand and an equal-sized sample of galena in the other hand, which would feel heavier? Be sure to use the words *specific gravity* in your response.
5. Why does the mass determined by the scale change when you suspend the mineral in water?
6. When identifying a valuable gemstone, why is specific gravity more likely to be used than mineral tests such as streak or hardness?
7. Why would the procedure for this investigation not be useful in trying to determine the specific gravity of halite?
8. Explain how a liquid with a specific gravity of 5.1 can be used to distinguish pyrite from magnetite.

Table 2

Specific Gravities of Selected Minerals

Mineral	Specific Gravity
Sulfur	2.1
Gypsum	2.3
Calcite	2.7
Chalcopyrite	4.2
Pyrite	5.0
Magnetite	5.2
Galena	7.5



Learn more about minerals and their properties.  
Keycode: ES0507

# CHAPTER 5

## REVIEW

### Summary of Key Ideas

**5.1** Matter is made up of atoms. An atom is the smallest part of an element that has all the element's properties. Two or more chemically bound elements may form a compound. A metal is an element that easily loses electrons to form positive ions. A nonmetal easily gains electrons, forming negative ions.

**5.2** A mineral is a naturally occurring, inorganic solid with a definite chemical composition and an orderly atomic arrangement. Minerals may be either elements or compounds. Atomic structure determines a mineral's properties. Most of Earth's crust consists of silicate minerals.

**5.3** A mineral is identified by its properties. Simple inspection reveals a mineral's color, luster, and crystal shape. Simple tests reveal a mineral's streak, cleavage, fracture, and hardness.

**5.4** Silicates and carbonates are the most common minerals in Earth's crust. Less common but economically important minerals include iron-rich oxides and sulfides.

### KEY VOCABULARY

atomic number (p. 91)	mineral (p. 96)
carbonate (p. 110)	mineralogy (p. 104)
cleavage (p. 100)	molecule (p. 93)
compound (p. 93)	nonmetal (p. 95)
crystal (p. 98)	oxides (p. 111)
element (p. 90)	rock-forming mineral (p. 104)
fracture (p. 105)	silica tetrahedron (p. 100)
ions (p. 94)	silicates (p. 100)
isotopes (p. 92)	specific gravity (p. 106)
luster (p. 105)	streak (p. 105)
mass number (p. 92)	sulfides (p. 111)
metal (p. 94)	

### Vocabulary Review

Explain the difference between the terms in each pair.

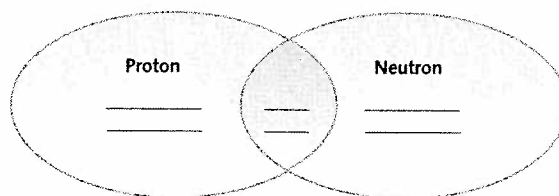
1. atomic number, mass number
2. mineral, element
3. cleavage, fracture
4. compound, molecule
5. metal, nonmetal

Write the term from the key vocabulary list that best completes the sentence.

6. Atoms that have lost or gained electrons and are in a charged condition are \_\_\_\_?\_\_\_\_.
7. Atoms of the same element having different sums of protons and neutrons are called \_\_\_\_?\_\_\_\_.
8. A regular geometric solid with smooth surfaces is called a \_\_\_\_?\_\_\_\_.
9. Compound minerals made up of oxygen and silicon are called \_\_\_\_?\_\_\_\_.
10. Types of minerals that contain large amounts of the element iron are \_\_\_\_?\_\_\_\_ and \_\_\_\_?\_\_\_\_.

### Concept Review

11. How does knowing about ions help with the classification of elements?
12. List three ways minerals can form.
13. What physical properties are determined by a mineral's crystal structure?
14. List the methods you would use to identify a mineral. Describe the method that you would use first.
15. **Graphic Organizer** Copy the Venn diagram below. Organize the following items in the diagram: atomic particle; located in nucleus; has no charge; has positive charge; determines atom's atomic number; most massive atomic particle.



## Critical Thinking

16. **Draw Conclusions** The element mercury (Hg) is a metal. It is solid at temperatures of about  $-39^{\circ}\text{C}$  ( $-38^{\circ}\text{F}$ ), has a definite composition, is inorganic, and lacks a crystalline structure. Ice ( $\text{H}_2\text{O}$ ), on the other hand, is often considered a mineral. Based on the information given, do you think mercury is a mineral? Why or why not?
17. **Hypothesize** Perfect, naturally formed crystals are relatively hard to find. If you were to manufacture perfectly shaped synthetic crystals, in what type of environment would you expect to produce them?
18. **Infer** Graphite and diamond are both made of the element carbon. They are, however, structurally very different. What do these structural differences suggest about the conditions under which each forms? Take into consideration that graphite is more commonly found than diamond.

## Interpreting Charts

The chart at right graphically depicts a range of seven rock-forming minerals that typically make up igneous rocks. Four such rocks are identified at the top of the chart. Copy the 0–100% scale on the left of the chart onto the edge of a piece of paper. Use your scale to read the percent of a given mineral in the particular rocks marked by the red vertical lines.

For example, to find the percent of quartz in tonalite, slide your scale to the vertical line marked *tonalite*. Place the zero of your scale at the line between quartz and plagioclase feldspar. Read the percent of quartz at the line between quartz and potassium feldspar. About 35% of the tonalite's volume is quartz.

19. Which rock contains pyroxene?
20. Find the percent of potassium feldspar in the tonalite.

## Internet Extension



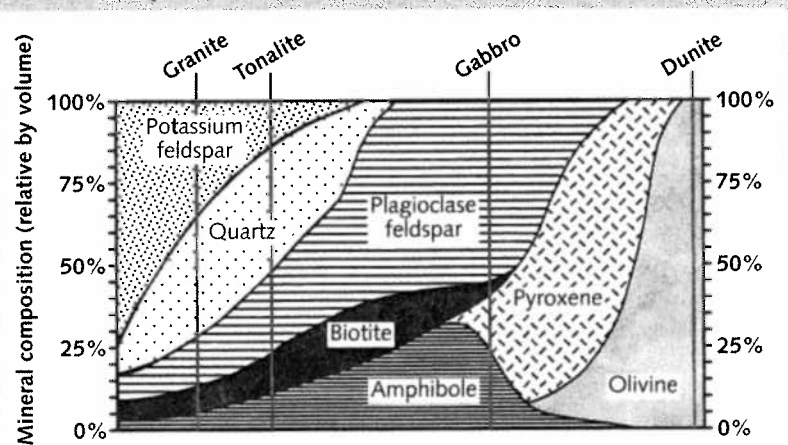
**How Do Crystals Grow?** Select conditions such as temperature and pressure and see their effects on crystal growth.

Keycode: ES0506

## Writing About the Earth System

**SCIENCE NOTEBOOK** While minerals are commonly associated with Earth's crust, they are an essential part of hydrological and biological cycles. For example, dissolved minerals are used by plants and animals to carry out life processes. Investigate two minerals that are used by plants or animals. Determine how plants or animals obtain the minerals. Describe the roles of the minerals in biological functions.

Mineral Composition



21. Identify the rock containing 40% potassium feldspar, 35% quartz, 12% plagioclase feldspar, 8% biotite, and 5% amphibole.
22. Describe the composition of the gabbro.