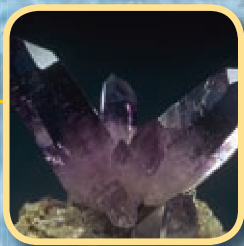
Chapter 5

Minerals of Earth's Crust

Chapter Outline



Why It Matters

Understanding the properties of minerals is important for being able to identify and use them. Minerals are used to make millions of products, from airplanes to zippers.

Inquiry Lab

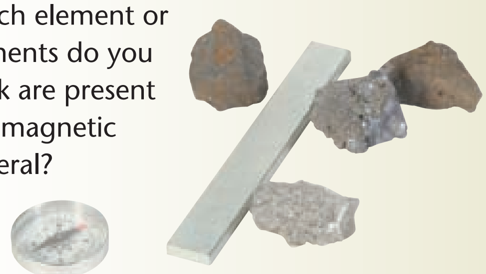
30 min

Magnetic Minerals

Use a **bar magnet** to decide which of the **mineral samples** given to you have magnetic properties. Then, test the magnetic minerals using a **directional compass.** Use your observations of their effect on the compass needle to arrange the minerals in order of increasing magnetic strength.

Questions to Get You Started

1. How can a bar magnet help you to distinguish certain types of minerals from others?
2. How can a directional compass be used to compare magnetic strength?
3. Which element or elements do you think are present in a magnetic mineral?



READING TOOLBOX

These reading tools will help you learn the material in this chapter.

Classification

Kinds of Minerals Classification is a tool for organizing objects and ideas by grouping them into categories. Groups are classified by defining characteristics. One of the ways that minerals can be classified is on the basis of their composition. For example, some minerals contain the element silicon and others do not. Based on this fact, minerals can be classified into two major groups.

Your Turn In Section 1, you will learn about two major groups of minerals. As you learn about these groups, make a table with three columns. In the first column, list each of the kinds of minerals. In the second column, describe the basis for classifying minerals as one of these kinds. In the third column, list examples and descriptions of each kind of mineral.

Note Taking

Two-Column Notes Two-column notes can help you learn the key ideas from each section.

- Write the key ideas in the left column.
- In your own words, record notes and examples in the right column.

Your Turn Complete the two-column notes for Section 1, adding another row for each key idea.

KEY IDEA #1	A mineral is a solid that meets all four of these criteria:
Define mineral.	• It is inorganic. • It occurs naturally. • It is crystalline. • It has a consistent chemical composition.

FoldNotes

Key-Term Fold The key-term fold can help you learn key terms from this chapter, such as the physical properties that help distinguish one mineral from another.

Your Turn Create a key-term fold, as described in **Appendix A.**

1. Write one of the physical properties of minerals on the front of each tab.
2. Write a definition or description for each term under its tab.
3. Use this FoldNote to help you study the key terms in this chapter.

For more information on how to use these and other tools, see **Appendix A.**

SECTION 1

What Is a Mineral?

Key Ideas	Key Terms	Why It Matters
❯ Define *mineral.* ❯ Compare the two main groups of minerals. ❯ Identify the six types of silicate crystalline structures. ❯ Describe three common nonsilicate crystalline structures.	**mineral** **silicate mineral** **nonsilicate mineral** **crystal** **silicon-oxygen tetrahedron**	Almost everything you do each day—from brushing your teeth in the morning to setting your alarm clock at night—involves minerals in some way.

A ruby, a gold nugget, and a grain of salt look very different from one another, but they have one thing in common. They are minerals, the basic materials of Earth's crust. A **mineral** is a natural, usually inorganic solid that has a characteristic chemical composition, an orderly internal structure, and a characteristic set of physical properties.

Characteristics of Minerals

To determine whether a substance is a mineral or a nonmineral, scientists ask four basic questions, as shown in **Table 1.** If the answer to all four questions is yes, the substance is a mineral.

First, is the substance inorganic? An inorganic substance is one that is not made up of living things or the remains of living things. Coal, for example, is organic—it is composed of the remains of ancient plants. Thus, coal is not a mineral.

Second, does the substance occur naturally? Minerals form and exist in nature. Thus, a manufactured substance, such as steel or brass, is not a mineral.

Third, is the substance a solid in crystalline form? The volcanic glass obsidian is a naturally occurring substance. However, the atoms in obsidian are not arranged in a regularly repeating crystalline structure. Thus, obsidian is not a mineral.

Finally, does the substance have a consistent chemical composition? The mineral fluorite has a consistent chemical composition of one calcium ion for every two fluoride ions. Granite, however, can have a variety of substances. The ratio of these substances commonly varies in each sample of granite.

mineral a natural, usually inorganic solid that has a characteristic chemical composition, an orderly internal structure, and a characteristic set of physical properties

SCILINKS.
www.scilinks.org
Topic: Minerals
Code: **HQX0966**

Table 1 Four Criteria for Minerals

Questions to Identify a Mineral	Coal	Brass	Obsidian	Basalt	Fluorite
Is it inorganic?	No	Yes	Yes	Yes	Yes
Does it occur naturally?		No	Yes	Yes	Yes
Is it a crystalline solid?			No	Yes	Yes
Does it have a consistent chemical composition?				No	Yes

Figure 1 Plagioclase feldspar (left), muscovite mica (center), and orthoclase feldspar (right) are 3 of the 20 common rock-forming minerals.

Kinds of Minerals

Earth scientists have identified more than 4,000 minerals, but fewer than 20 of the minerals are common. The common minerals are called *rock-forming minerals* because they form the rocks that make up Earth's crust. Three of these minerals are shown in **Figure 1.** Of the 20 rock-forming minerals, about half are so common that they make up 90% of the mass of Earth's crust. These include quartz, orthoclase, plagioclase, muscovite, biotite, calcite, dolomite, halite, gypsum, and ferromagnesian minerals. All minerals, however, can be classified into two main groups—silicate minerals and nonsilicate minerals—based on the chemical compositions of the minerals.

Silicate Minerals

silicate mineral a mineral that contains a combination of silicon and oxygen and that may also contain one or more metals

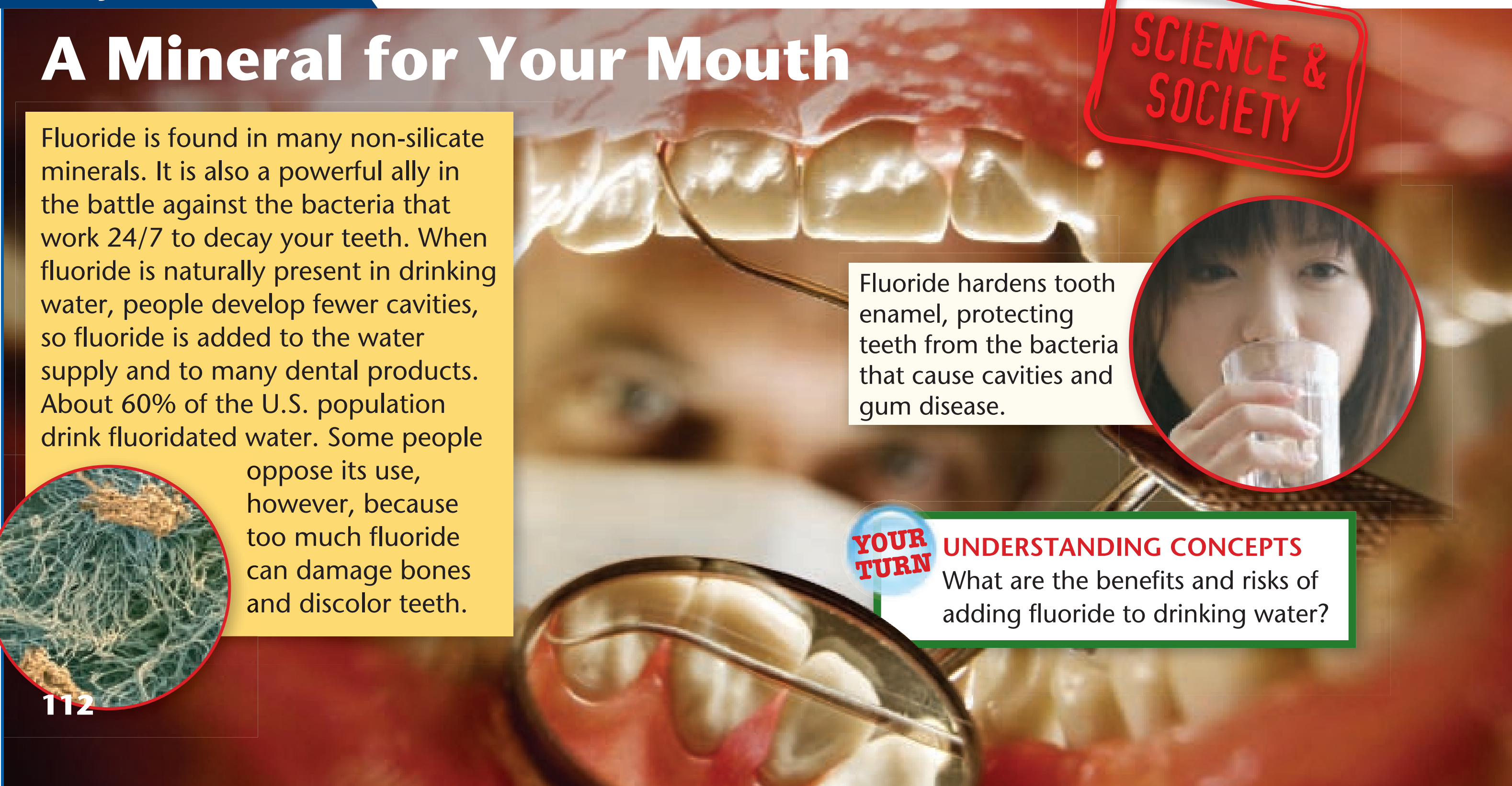
A mineral that contains a combination of silicon, Si, and oxygen, O, is a **silicate mineral.** The mineral quartz has only silicon and oxygen atoms. However, other silicate minerals have one or more additional elements. Feldspars are the most common silicate minerals. The type of feldspar that forms depends on which metal combines with the silicon and oxygen atoms. Orthoclase forms when the metal is potassium, K. Plagioclase forms when the metal is sodium, Na, calcium, Ca, or both.

In addition to quartz and the feldspars, ferromagnesian minerals—which are rich in iron, Fe, and magnesium, Mg—are silicates. These minerals include olivines, pyroxenes, amphiboles, and biotite. Silicate minerals make up 96% of Earth's crust. Feldspars and quartz alone make up more than 50% of the crust.

Why It Matters

A Mineral for Your Mouth

SCIENCE & SOCIETY

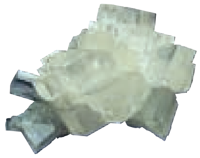
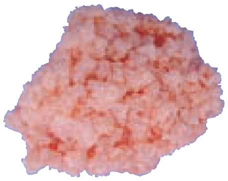
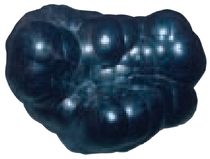


Fluoride is found in many non-silicate minerals. It is also a powerful ally in the battle against the bacteria that work 24/7 to decay your teeth. When fluoride is naturally present in drinking water, people develop fewer cavities, so fluoride is added to the water supply and to many dental products. About 60% of the U.S. population drink fluoridated water. Some people oppose its use, however, because too much fluoride can damage bones and discolor teeth.

Fluoride hardens tooth enamel, protecting teeth from the bacteria that cause cavities and gum disease.

YOUR TURN **UNDERSTANDING CONCEPTS**
What are the benefits and risks of adding fluoride to drinking water?

Table 2 Major Classes of Nonsilicate Minerals

Carbonates compounds that contain a carbonate group (CO_3)	 Dolomite, $CaMg(CO_3)_2$	 Calcite, $CaCO_3$
Halides compounds that consist of chlorine or fluorine combined with sodium, potassium, or calcium	 Halite, NaCl	 Fluorite, CaF_2
Native elements elements uncombined with other elements	 Silver, Ag	 Copper, Cu
Oxides compounds that contain oxygen and an element other than silicon	 Corundum, Al_2O_3	 Hematite, Fe_2O_3
Sulfates compounds that contain a sulfate group (SO_4)	 Gypsum, $CaSO_4 \bullet 2H_2O$	 Anhydrite, $CaSO_4$
Sulfides compounds that consist of one or more elements combined with sulfur	 Galena, PbS	 Pyrite, FeS_2

Nonsilicate Minerals

Approximately 4% of Earth's crust is made up of minerals that do not contain compounds of silicon and oxygen, or **nonsilicate minerals.** **Table 2** organizes the six major groups of nonsilicate minerals by their chemical compositions: carbonates, halides, native elements, oxides, sulfates, and sulfides.

nonsilicate mineral a mineral that does not contain compounds of silicon and oxygen

Reading Check **What compounds will you never find in a nonsilicate mineral?** (See Appendix G for answers to Reading Checks.)

Quick Lab

5 min

Modeling Tetrahedra

Procedure

1. Place **four toothpicks** in a **small marshmallow.** Evenly space the toothpicks as far from each other as possible.
2. Place **four large marshmallows** on the ends of the toothpicks.

Analysis

1. In your model, what do the toothpicks represent?
2. When tetrahedra form chains or rings, they share oxygen atoms. If you wanted to build a chain of tetrahedra, how would you connect two tetrahedra together?

crystal a solid whose atoms, ions, or molecules are arranged in a regular, repeating pattern

silicon-oxygen tetrahedron the basic unit of the structure of silicate minerals; a silicon ion chemically bonded to and surrounded by four oxygen ions

Crystalline Structure

All minerals in Earth's crust have a crystalline structure. Each type of mineral crystal is characterized by a specific geometric arrangement of atoms. A **crystal** is a solid whose atoms, ions, or molecules are arranged in a regular, repeating pattern. A large mineral crystal displays the characteristic geometry of that crystal's internal structure. The conditions under which minerals form, however, often hinder the growth of single, large crystals. As a result, minerals are commonly made up of masses of crystals that are so small you can see them only with a microscope. But, if a crystal forms where the surrounding material is not restrictive, the mineral will develop as a single, large crystal that has one of six basic crystal shapes. Knowing the crystal shapes is helpful in identifying minerals.

One way that scientists study the structure of crystals is by using X rays. X rays that pass through a crystal and strike a photographic plate produce an image that shows the geometric arrangement of the atoms that make up the crystal.

Crystalline Structure of Silicate Minerals

Even though there are many kinds of silicate minerals, their crystalline structure is made up of the same basic building blocks. Each building block has four oxygen atoms arranged in a pyramid with one silicon atom in the center. **Figure 2** shows this four-sided structure, which is known as a **silicon-oxygen tetrahedron.**

Silicon-oxygen tetrahedra combine in different arrangements to form different silicate minerals. The various arrangements are the result of the kinds of bonds that form between the oxygen atoms of the tetrahedra and other atoms. The oxygen atoms of tetrahedra may be shared with those of neighboring tetrahedra. Bonds may also form between the oxygen atoms in the tetrahedra and other elements' atoms outside of the tetrahedra.

Reading Check **What is the building block of the silicate crystalline structure?**

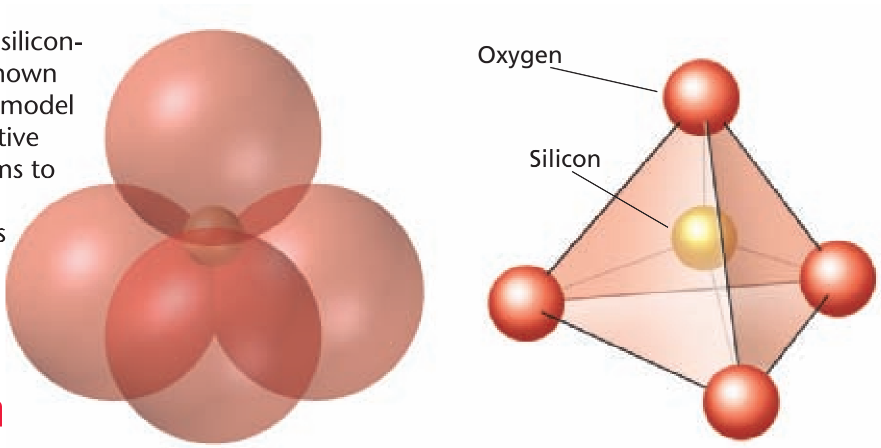


Figure 2 The structure of a silicon-oxygen tetrahedron can be shown by two different models. The model on the left represents the relative size and proximity of the atoms to one another in the molecule. The model on the right shows the tetrahedral shape of the molecule.

THINK central
INTERACT ONLINE
Keyword: HQXMINF2

Isolated Tetrahedral Silicates and Ring Silicates

Six kinds of arrangements that tetrahedra form are shown in **Figure 3.** In minerals that have *isolated tetrahedra,* only atoms other than silicon and oxygen atoms link silicon-oxygen tetrahedra. For example, olivine is a mineral that forms when the oxygen atoms of tetrahedra bond to magnesium, Mg, and iron, Fe, atoms.

Ring silicates form when shared oxygen atoms join the tetrahedra to form three-, four-, or six-sided rings. The rings can align to create channels that can contain a variety of ions, molecules, and neutral atoms. Beryl and tourmaline are minerals that have ring-silicate structures.

Single-Chain Silicates and Double-Chain Silicates

In *single-chain silicates,* each tetrahedron shares corner oxygen atoms with two others. In *double-chain silicates,* two single chains of tetrahedra link to each other by sharing oxygen atoms. Most single-chain silicate minerals are called *pyroxenes,* and those made up of double chains are called *amphiboles.*

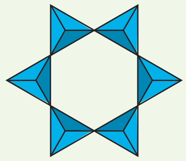
Sheet Silicates and Framework Silicates

In the *sheet silicates,* each tetrahedron shares three oxygen atoms with other tetrahedra. The unshared oxygen atoms bond with aluminum, Al, or magnesium atoms that hold other sheets of silicon-oxygen tetrahedra together. The mica minerals, such as muscovite and biotite, are examples of sheet silicates.

In the *framework silicates,* each tetrahedron shares all of its oxygen atoms with four neighboring tetrahedra to form a three-dimensional network. Frameworks that contain only silicon-oxygen tetrahedra form the mineral quartz. The chemical formula for quartz is SiO_2. Other framework silicates, such as the feldspars, contain some tetrahedra in which atoms of aluminum substitute for some of the silicon atoms.

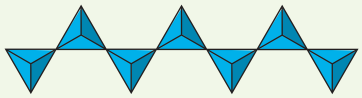
Figure 3 Six Kinds of Silicate-Mineral Arrangements

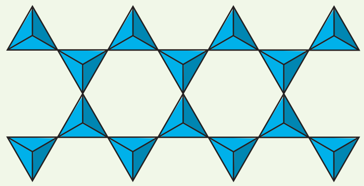
1 Isolated tetrahedra do not link with other silicon or oxygen atoms.



2 Ring silicates form rings by sharing oxygen atoms.

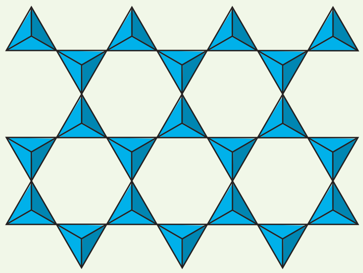
3 Single-chain silicates form a chain by sharing oxygen atoms.

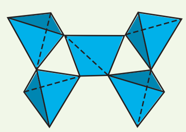




4 Double-chain silicates form when two single chains of tetrahedra link to each other by sharing oxygen atoms.

5 Sheet silicates form when each tetrahedron shares three of its oxygen atoms with other tetrahedra.





6 Framework silicates form when each tetrahedron is bonded to four other tetrahedra.

Figure 4 Gold (left) commonly has a dendritic shape. Halite (center) commonly has cubic crystals. Diamond (right) commonly has an octahedral crystal shape. All three of these minerals are nonsilicates.

Crystalline Structure of Nonsilicate Minerals

Because nonsilicate minerals have diverse chemical compositions, nonsilicate minerals display a vast variety of crystalline structures. Common crystal structures for nonsilicate minerals include cubes, hexagonal prisms, and irregular masses. Some of these structures are shown in **Figure 4.**

Nonsilicates may form tetrahedra that are similar to those in silicates. However, the ions at the center of these tetrahedra are not silicon. Minerals that have the same ion at the center of the tetrahedron commonly share similar crystal structures. Thus, the classes of nonsilicate minerals can be divided into smaller groups based on the structural similarities of the minerals' crystals.

The structure of a nonsilicate crystal determines the nonsilicate's characteristics. For example, the native elements have very high densities because their crystal structures are based on the packing of atoms as close together as possible. This crystal structure is called *closest packing*. In this crystal structure, each metal atom is surrounded by 12 other metal atoms that are as close to each other as the charges of the atomic nuclei will allow.

Academic Vocabulary

similar (SIM uh luhr) alike; almost the same

READING TOOLBOX

Key-Term Fold

Create a key-term fold for the key terms in Section 1. Add other terms that you want to remember, such as the six kinds of silicate crystal structures.

Section 1 Review

Key Ideas

1. **Define** *mineral*.
2. **Summarize** the characteristics that are necessary to classify a substance as a mineral.
3. **Compare** the two main groups of minerals.
4. **Identify** the two elements that are in all silicate minerals.
5. **Name** six types of nonsilicate minerals.
6. **Describe** the six main crystalline structures of silicate minerals.
7. **Explain** why nonsilicate minerals have a wider variety of crystalline structures than silicate minerals do.

Critical Thinking

8. **Predicting Consequences** If silicon bonded with three oxygen atoms, how might the crystalline structures of silicate minerals be different?
9. **Applying Ideas** Gold is an inorganic substance that forms naturally in Earth's crust. Gold is also a solid and has a definite chemical composition. Is gold a mineral? Explain your answer.

Concept Mapping

10. Use the following terms to create a concept map: *mineral, crystal, silicate mineral, nonsilicate mineral, ring silicate, framework silicate, single-chain silicate,* and *silicon-oxygen tetrahedron.*

SECTION 2

Identifying Minerals

Key Ideas	Key Terms		Why It Matters
❯ Describe seven physical properties that help to distinguish one mineral from another. ❯ List five special properties that may help to identify certain minerals.	**mineralogist** **streak** **luster** **cleavage**	**fracture** **Mohs hardness scale** **density**	Some minerals glow in the dark; others are magnetic. The properties of minerals help people to identify and use them.

Earth scientists called **mineralogists** examine, analyze, and classify minerals. To identify minerals, mineralogists study the properties of the minerals. Some properties are simple to study, while special equipment may be needed to study other properties.

Physical Properties of Minerals

Each mineral has specific properties that are a result of its chemical composition and crystalline structure. These properties provide useful clues for identifying minerals. Many of these properties can be identified by simply looking at a sample of the mineral. Other properties can be identified through simple tests.

Color

One property of a mineral that is easy to observe is the mineral's color. Some minerals have very distinct colors. For example, sulfur is bright yellow, and azurite is deep blue. Color alone, however, is generally not a reliable clue for identifying a mineral sample. Many minerals are similar in color, and very small amounts of certain elements may greatly affect the color of a mineral. For example, corundum is a colorless mineral composed of aluminum and oxygen atoms. However, corundum that has traces of chromium, Cr, forms the red gem called *ruby*. Sapphire, which is a type of corundum, gets its blue color from traces of iron, Fe, and titanium, Ti. **Figure 1** compares colorless, pure quartz with purple amethyst. Amethyst is quartz that has manganese, Mn, and iron, Fe, which cause the purple color.

mineralogist a person who examines, analyzes, and classifies minerals

Color is also an unreliable identification clue because weathered surfaces may hide the color of minerals. For example, the golden color of iron pyrite ranges from dark yellow to black when iron pyrite is weathered. When examining a mineral for color, you should inspect only the mineral's freshly exposed surfaces.

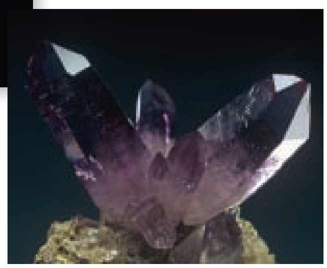


Figure 1 Pure quartz (above) is colorless. Amethyst (right) is a variety of quartz that is purple because of the presence of small amounts of manganese and iron.

Figure 2 All minerals have either a metallic luster, as platinum does (top), or a nonmetallic luster, as talc does (bottom).

Streak

A more reliable clue to the identity of a mineral is the color of the mineral in powdered form, which is called the mineral's **streak.** The easiest way to observe the streak of a mineral is to rub some of the mineral against a piece of unglazed ceramic tile called a *streak plate*. The streak's color may differ from the color of the solid form of the mineral. Metallic minerals generally have a dark streak. For example, the streak of gold-colored pyrite is black. For most non-metallic minerals, however, the streak is either colorless or a very light shade of the mineral's standard color. Minerals that are harder than the ceramic plate will leave no streak.

Luster

Light that is reflected from a mineral's surface is called **luster.** A mineral is said to have a *metallic luster* if the mineral reflects light as polished metal does, as shown in **Figure 2.** All other minerals have a *nonmetallic luster*. Mineralogists distinguish several types of nonmetallic luster. Transparent quartz and other minerals that look like glass have a glassy luster. Minerals that have the appearance of candle wax have a waxy luster. Some minerals, such as the mica minerals, have a pearly luster. Diamond is an example of a mineral that has a brilliant luster. A mineral that lacks any shiny appearance has a dull or earthy luster.

streak the color of a mineral in powdered form

luster the way in which a mineral reflects light

cleavage the tendency of a mineral to split along specific planes of weakness to form smooth, flat surfaces

fracture the manner in which a mineral breaks along either curved or irregular surfaces

Academic Vocabulary

specific (spuh SIF ik) unique; peculiar to or characteristic of; exact

Cleavage and Fracture

The tendency of a mineral to split along specific planes of weakness to form smooth, flat surfaces is called **cleavage.** When a mineral has cleavage, as shown in **Figure 3,** it breaks along flat surfaces that generally run parallel to planes of weakness in the crystal structure. For example, the mica minerals, which are sheet silicates, tend to split into parallel sheets.

Many minerals, however, do not break along cleavage planes. Instead, they **fracture,** or break unevenly, into pieces that have curved or irregular surfaces. Mineralogists describe a fracture according to the appearance of the broken surface. For example, a rough surface has an *uneven* or *irregular fracture*. A broken surface that looks like a piece of broken wood has a *splintery* or *fibrous fracture*. Curved surfaces are *conchoidal fractures* (kahng KOYD uhl FRAK chuhr), as shown in **Figure 3.**

Figure 3 Calcite is a mineral that cleaves in three directions. Quartz (right) tends to have a conchoidal fracture.

Table 1 Mohs Hardness Scale

Mineral	Hardness	Common test	Mineral	Hardness	Common test
Talc	1	easily scratched by fingernail	Feldspar	6	scratches glass, but does not scratch steel
Gypsum	2	can be scratched by fingernail	Quartz	7	easily scratches both glass and steel
Calcite	3	barely can be scratched by copper penny	Topaz	8	scratches quartz
Fluorite	4	easily scratched with steel file or glass	Corundum	9	scratches topaz
Apatite	5	can be scratched by steel file or glass	Diamond	10	scratches everything

Hardness

The measure of the ability of a mineral to resist scratching is called *hardness*. Hardness does not mean "resistance to cleavage or fracture." A diamond, for example, is extremely hard but can be split along cleavage planes more easily than calcite, a softer mineral, can be split.

To determine the hardness of an unknown mineral, you can scratch the mineral against those on the **Mohs hardness scale,** which is shown in **Table 1.** This scale lists 10 minerals in order of increasing hardness. The softest mineral, talc, has a hardness of 1. The hardest mineral, diamond, has a hardness of 10. The difference in hardness between two consecutive minerals is about the same throughout the scale except for the difference between the two hardest minerals. Diamond (10) is much harder than corundum (9), which is listed on the scale before diamond.

To test an unknown mineral for hardness, you must determine the hardest mineral on the scale that the unknown mineral can scratch. For example, galena can scratch gypsum but not calcite. Thus, galena has a hardness that ranges between 2 and 3 on the Mohs hardness scale. If neither of two minerals scratches the other, the minerals have the same hardness.

The strength of the bonds between the atoms that make up a mineral's internal structure determines the hardness of that mineral. Both diamond and graphite consist only of carbon atoms. However, diamond has a hardness of 10, while the hardness of graphite is between 1 and 2. A diamond's hardness results from a strong crystalline structure in which each carbon atom is firmly bonded to four other carbon atoms. In contrast, the carbon atoms in graphite are arranged in layers that are held together by much weaker chemical bonds.

Reading Check **What determines the hardness of a mineral?**

SCILINKS.
www.scilinks.org
Topic: Mineral Identification
Code: **HQX0965**

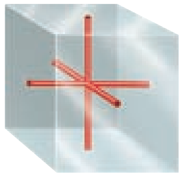
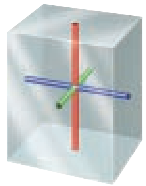
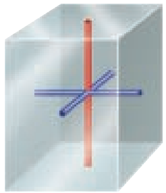
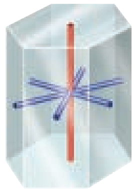
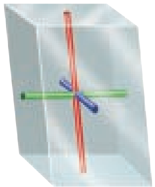
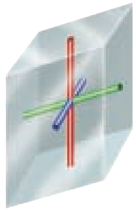
Mohs hardness scale the standard scale against which the hardness of minerals is rated

READING TOOLBOX

Two-Column Notes

Create two-column notes to outline all the physical properties of minerals, including special properties, that mineralogists can use to help them identify minerals. Put the physical properties in the first column, and add notes and examples in the second column.

Table 2 **The Six Basic Crystal Systems**

Isometric or Cubic System Three axes of equal length intersect at 90° angles. 	**Orthorhombic System** Three axes of unequal length intersect at 90° angles. 
Tetragonal System Three axes intersect at 90° angles. The two horizontal axes are of equal length. The vertical axis is longer or shorter than the horizontal axes. 	**Hexagonal System** Three horizontal axes of the same length intersect at 120° angles. The vertical axis is longer or shorter than the horizontal axes. 
Monoclinic System Two of the three axes of unequal length intersect at 90° angles. The third axis is oblique to the others. 	**Triclinic System** Three axes of unequal length are oblique to one another. 

Math Skills

Calculating Density A mineral sample has a mass (*m*) of 85 g and a volume (*V*) of 34 cm^3. Use the equation below to calculate the sample's density (*D*).

$$D = \frac{m}{V}$$

density the ratio of the mass of a substance to the volume of the substance; commonly expressed as grams per cubic centimeter for solids and liquids and as grams per liter for gases

Crystal Shape

A mineral crystal forms in one of six basic shapes, as shown in **Table 2.** A certain mineral always has the same basic crystal system because the atoms that form its crystals always combine in the same geometric pattern. But the six basic shapes can become more complex as a result of environmental conditions during crystal growth, such as temperature and pressure.

Density

When handling equal-sized specimens of various minerals, you may notice that some feel heavier than others do. For example, a piece of galena feels heavier than a piece of quartz of the same size does. However, a more precise comparison can be made by measuring the density of a sample. **Density** is the ratio of the mass of a substance to the volume of the substance.

The density of a mineral depends on the kinds of atoms that the mineral has and on how closely the atoms are packed. Most of the common minerals in Earth's crust have densities between 2 and 3 g/cm^3. However, the densities of minerals that contain heavy metals, such as lead, uranium, gold, and silver, range from 7 to 20 g/cm^3. Thus, density helps identify heavier minerals more readily than it helps identify lighter ones.

Special Properties of Minerals

All minerals exhibit the properties that were described earlier in this section. However, a few minerals have some additional, special properties that can help identify those minerals.

Fluorescence and Phosphorescence

The mineral calcite is usually white in ordinary light, but in ultraviolet light, calcite often appears red. This ability to glow under ultraviolet light is called *fluorescence*. Fluorescent minerals absorb ultraviolet light and then produce visible light of various colors, as shown in **Figure 4.**

When subjected to ultraviolet light, some minerals will continue to glow after the ultraviolet light is turned off. This property is called *phosphorescence*. It is useful in the mining of phosphorescent minerals such as eucryptite, which is an ore of lithium.

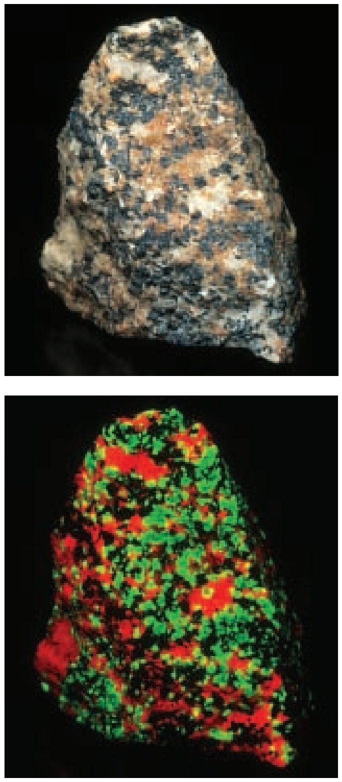


Figure 4 The fluorescent minerals calcite and willemite within this rock change colors as they are exposed to ordinary light (top) and ultraviolet light (bottom).

Chatoyancy and Asterism

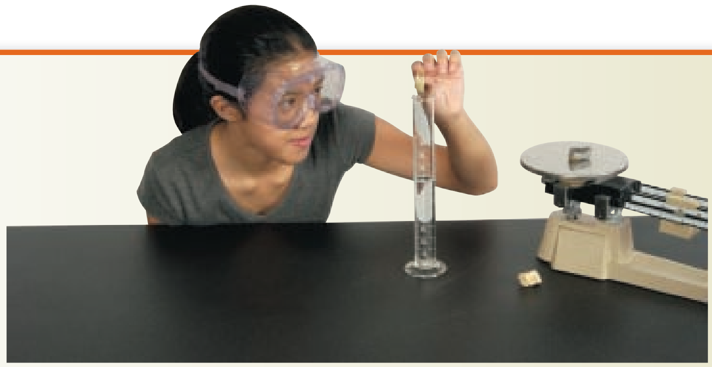
In reflected light, some minerals display a silky appearance that is called *chatoyancy* (shuh TOY uhn see). This effect is also called the *cat's-eye effect*. The word *chatoyancy* comes from the French word *chat*, which means "cat," and from *oeil*, which means "eye." Chatoyancy is the result of closely packed parallel fibers within the mineral. A similar effect called *asterism* is the phenomenon in which a six-sided star shape appears when a mineral reflects light.

Reading Check **What is the difference between chatoyancy and asterism?**

Quick Lab

15 min

Determining Density



Procedure

1. Use a **triple-beam balance** to determine the mass of three similarly sized **mineral samples** that have different masses. Record the mass of each mineral sample.
2. Fill a **graduated cylinder** with **70 mL of water.**
3. Add one mineral sample to the water in the graduated cylinder. Record the new volume after the mineral sample is added to the water.
4. Calculate the volume of the mineral sample by subtracting 70 mL from the new volume.
5. Repeat steps 3 and 4 for the other two mineral samples.
6. Convert the volume of the mineral samples that you calculated in step 4 from milliliters to cubic centimeters by using the conversion: 1 mL=1 cm^3.

Analysis

1. Calculate the density of each mineral sample by using the following equation:

   density = mass/volume

2. Compare the density of each mineral sample with the density of common minerals in Earth's crust. Compare the density of each mineral sample with minerals that contain a high percentage of heavy metals.
3. Do any of the mineral samples contain a high percentage of heavy metals? Explain your answer.

Figure 5 Some forms of the mineral calcite exhibit double refraction when light rays enter the crystal and split.

Double Refraction

Light rays bend as they pass through transparent minerals. This bending of light rays as they pass from one substance, such as air, to another, such as a mineral, is called *refraction*. Crystals of calcite and some other transparent minerals bend light in such a way that they produce a double image of any object viewed through them, as shown in **Figure 5.** This property is called *double refraction*. Double refraction takes place because light rays are split into two parts as they enter the crystal.

Magnetism

Magnets may attract small particles of some minerals that contain iron. Those minerals are also sometimes magnetic. In general, nonsilicate minerals that contain iron, such as magnetite, are more likely to be magnetic than other nonsilicate minerals are. Lodestone is a form of magnetite. Like a bar magnet, some pieces of lodestone have a north pole at one end and a south pole at the other. The needles of the first magnetic compasses were made of tiny slivers of lodestone.

Radioactivity

Some minerals have a property known as *radioactivity*. The arrangement of protons and neutrons in the nuclei of some atoms is unstable. Radioactivity results as unstable nuclei decay over time into stable nuclei by releasing particles and energy. A *Geiger counter* can be used to detect the released particles and, thus, to identify minerals that are radioactive. Uranium, U, and radium, Ra, are examples of radioactive elements. Pitchblende is the most common mineral that contains uranium. Other uranium-bearing minerals are carnotite and autunite.

Section 2 Review

Key Ideas

1. **Describe** seven physical properties that help distinguish one mineral from another.
2. **Identify** the two main types of luster.
3. **Summarize** how you would determine the hardness of an unidentified mineral sample.
4. **Explain** why color is an unreliable clue to the identity of a mineral.
5. **List** five special properties that may help to identify certain minerals.
6. **Explain** how magnetism can be useful for identifying minerals.

Critical Thinking

7. **Evaluating Data** An unknown mineral has a black streak and a density of 18 g/cm^3. Is the mineral more likely to be metallic or nonmetallic?
8. **Analyzing Methods** Explain how phosphorescence is helpful in mining eucryptite. Describe other ways in which phosphorescent minerals might be used.

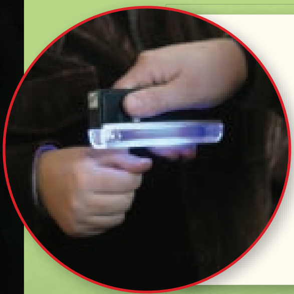
Concept Mapping

9. Use the following terms to create a concept map: *luster, streak, fracture, hardness, Mohs hardness scale, streak plate, nonmetallic luster, metallic luster,* and *conchoidal fracture.*

FORENSIC SCIENCE

Know by the Glow

Fluorescence is one of the special properties of some minerals. This same property is used for identification and authentication purposes. Invisible fluorescent inks are used on checks and important documents. These inks cannot be copied by scanners or reproduced by color printers, but they are seen when exposed to ultraviolet light (also called black light). Many plant and animal tissues fluoresce under black light. Crime investigators can use fluorescent chemicals to reveal traces of blood that otherwise would be invisible.



Fluorescent inks are used in hand stamps at amusement parks to allow re-entry privileges. The stamp does not leave a visible mark, but it easily identifies paying customers.

Fingerprints glow when illuminated by black light. Fluorescent dyes of different colors may be used to give better contrast.

Highlighter pens are available in a variety of colors. When used on paper or fabric with similar color, you can write or create designs only visible in black light.

Real amber, especially if it contains an insect, is expensive. Fake amber is easily made using colored plastic. A black light can detect a fake, because only real amber fluoresces.

U.S. currency is the most counterfeited money in the world. Security features on a $20 bill include a plastic strip to the left of President Jackson's portrait. The strip fluoresces green in ultraviolet light.

YOUR TURN

CRITICAL THINKING

Explain how a service technician could use fluorescent dye to find a leak in an air conditioner.

ONLINE RESEARCH

The fluorescent strip in paper money is one of many security features used in bills. Find out about special inks, watermarks, and fine printing details that help foil counterfeiters.

Mineral Identification

A mineral identification key can be used to compare the properties of minerals so that unknown mineral samples can be identified. Mineral properties that are often used in mineral identification keys are color, hardness, streak, luster, cleavage, and fracture. Hardness is determined by a scratch test. The Mohs hardness scale classifies minerals from 1 (soft) to 10 (hard). Streak is the color of a mineral in a finely powdered form. The streak shows less variation than the color of a sample does and thus is more useful in identification. The luster of a mineral is either metallic (having an appearance of metals) or nonmetallic. Cleavage is the tendency of a mineral to split along a plane. Planes may be in several directions. Other minerals break into irregular fragments in a process called *fracture*. In this lab, you will use these properties to classify several mineral samples.

What You'll Do

- **Identify** several unknown mineral samples.
- **Evaluate** which properties of minerals are most useful in identifying mineral samples.

What You'll Need

file, steel
Guide to Common Minerals (in the Reference Tables section of the Appendix)
hand lens
mineral samples (5)
penny, copper
square, glass
streak plate

Safety

Procedure

1. Make a table with columns for sample number, color/luster, hardness, streak, cleavage/fracture, and mineral name.
2. Observe and record in your table the color of each mineral sample. Note whether the luster of each mineral is metallic or nonmetallic.
3. Rub each mineral against the streak plate, and determine the color of the mineral's streak. Record your observations.

Step 4

Sample number	Color/ luster	Hardness	Streak	Cleavage/ fracture	Mineral name
1					
2					
3					
4					
5					

4. Using a fingernail, copper penny, glass square, and steel file, test each mineral to determine its hardness based on the Mohs hardness scale. Arrange the minerals in order of hardness. Record your observations in your table.

5. Determine whether the surface of each mineral displays cleavage and/or fracture. Record your observations.

6. Use the Guide to Common Minerals in the Reference Tables section of the Appendix to help you identify the mineral samples. Remember that samples of the same mineral will vary somewhat.

Analysis

1. **Analyzing Results** For each mineral, compare the streak with the color of the mineral. Which minerals have the same color as their streak? Which do not?

2. **Classifying Information** Of the mineral samples you identified, how many were silicate minerals? How many were nonsilicate minerals?

3. **Analyzing Methods** Did you find any properties that were especially useful or especially not useful in identifying each sample? Identify these properties, and explain why they were or were not useful.

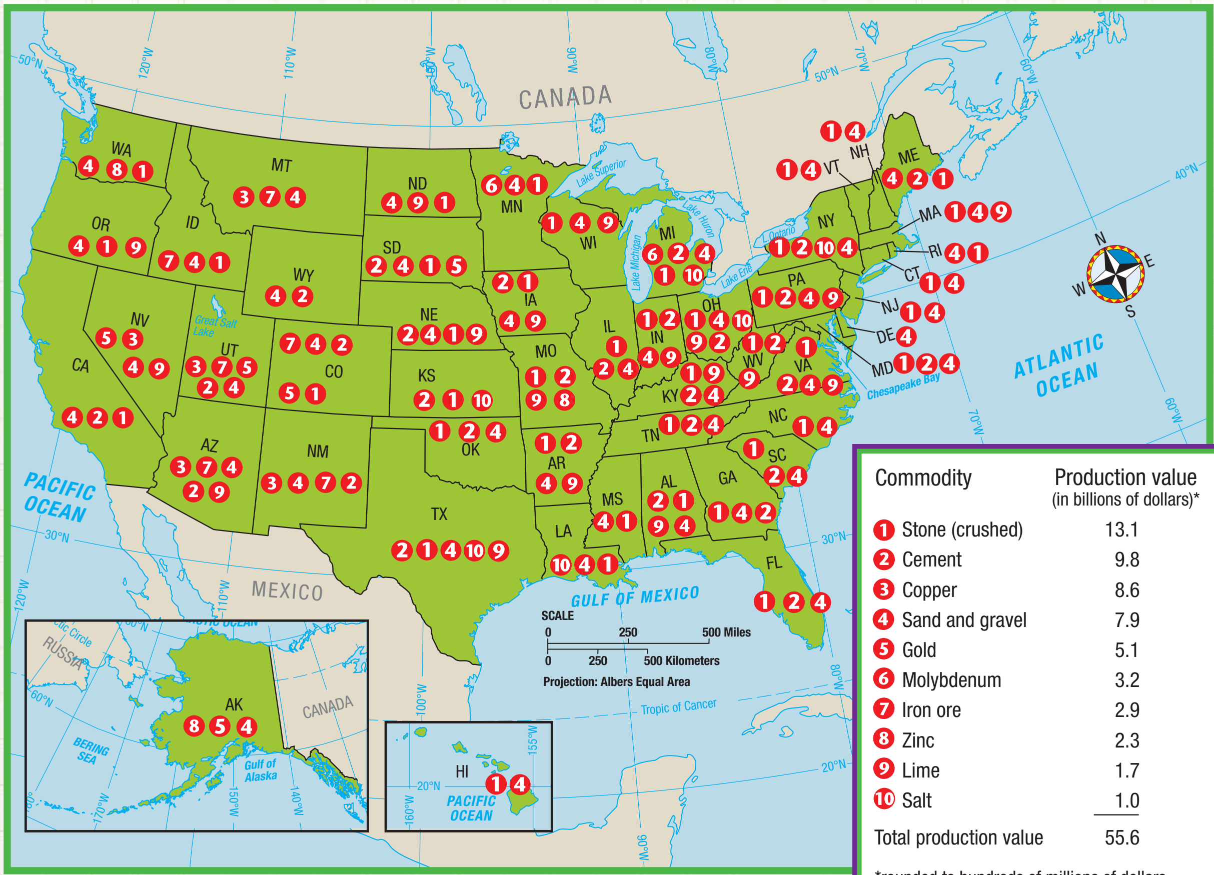
4. **Evaluating Methods** If you had to write a manual to explain, step by step, how to identify minerals, in what order would you test different properties? Explain your reasoning.

Extension

Understanding Relationships Corundum, rubies, and sapphires have different colors but are considered to be the same mineral. Diamonds and graphite are made of the element carbon but are not considered to be the same mineral. Research these minerals, and explain why they are classified in this way.

MAPS *in Action*

Rock and Mineral Production in the United States



Commodity	Production value (in billions of dollars)*
1 Stone (crushed)	13.1
2 Cement	9.8
3 Copper	8.6
4 Sand and gravel	7.9
5 Gold	5.1
6 Molybdenum	3.2
7 Iron ore	2.9
8 Zinc	2.3
9 Lime	1.7
10 Salt	1.0
Total production value	55.6

*rounded to hundreds of millions of dollars

Map Skills Activity

This map shows the distribution of the top 10 rock and mineral commodities produced in the United States. The key provides production values for these commodities. Use the map to answer the questions below.

1. **Using a Key** According to the map, which commodity has the highest production value?
2. **Evaluating Data** Gold, copper, iron ore, and zinc are metals in the top 10 mineral commodities produced. What percentage of the total production value do these metals represent? Which of the states produce these metals?
3. **Using a Key** Find your state on the map. Which of the top 10 mineral commodities are produced in your state?
4. **Evaluating Data** Stone, sand, and gravel are collectively known as *aggregates*. What percentage of the total production value of the 10 commodities listed do aggregates represent?
5. **Analyzing Relationships** According to the map, the states that produce enough iron ore to make the top-10 list are located in the western part of the United States. What geologic feature do most of these states share?

Summary

THINK central SUPER SUMMARY Keyword: HQXMINS

Key Ideas

Section 1

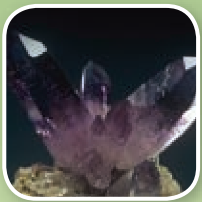
What Is a Mineral?

- A mineral is a natural, usually inorganic solid that has a characteristic chemical composition, an orderly internal structure, and a characteristic set of physical properties.
- The two main types of minerals, silicates and nonsilicates, are classified based on differences in their composition. Silicates contain compounds of silicon and oxygen; nonsilicates do not.
- Six types of silicate crystalline structures are isolated tetrahedral, ring, single-chain, double-chain, sheet, and framework.
- The three common nonsilicate crystalline structures commonly include cubes, hexagonal prisms, and irregular masses, but may also include tetrahedrons.

Key Terms

mineral, p. 111
silicate mineral, p. 112
nonsilicate mineral, p. 113
crystal, p. 114
silicon-oxygen tetrahedron, p. 114

Section 2



Identifying Minerals

- Seven physical properties that help distinguish one mineral from another are color, streak, luster, cleavage and fracture, hardness, crystal shape, and density.
- Special properties that can aid in identifying certain minerals include fluorescence and phosphorescence, chatoyancy and asterism, double refraction, magnetism, and radioactivity.

Key Terms

mineralogist, p. 117
streak, p. 118
luster, p. 118
cleavage, p. 118
fracture, p. 118
Mohs hardness scale, p. 119
density, p. 120

Chapter 5 Review

1. Two-Column Notes You already have two-column notes for the Key Ideas of Section 1. Complete your notes for the whole chapter by creating two-column notes for the Key Ideas of Section 2.

READING TOOLBOX

USING KEY TERMS

Use each of the following terms in a separate sentence.

2. *silicon-oxygen tetrahedron*
3. *mineral*
4. *Mohs hardness scale*
5. *cleavage*

For each pair of terms, explain how the meanings of the terms differ.

6. *mineral* and *crystal*
7. *silicate mineral* and *nonsilicate mineral*
8. *luster* and *streak*
9. *fluorescence* and *phosphorescence*

UNDERSTANDING KEY IDEAS

10. The most common silicate minerals are the
    a. feldspars. **c.** carbonates.
    b. halides. **d.** sulfates.
11. Ninety-six percent of Earth's crust is made up of
    a. sulfur and lead.
    b. silicate minerals.
    c. copper and aluminum.
    d. nonsilicate minerals.
12. An example of a mineral that has a basic structure consisting of isolated tetrahedra linked by atoms of other elements is
    a. mica. **c.** quartz.
    b. olivine. **d.** feldspar.
13. When two single chains of tetrahedra bond to each other, the result is called a
    a. single-chain silicate.
    b. sheet silicate.
    c. framework silicate.
    d. double-chain silicate.
14. The words *waxy, pearly,* and *dull* describe a mineral's
    a. luster. **c.** streak.
    b. hardness. **d.** fluorescence.
15. The words *uneven* and *splintery* describe a mineral's
    a. cleavage. **c.** hardness.
    b. fracture. **d.** luster.
16. The ratio of a mineral's mass to its volume is the mineral's
    a. atomic weight. **c.** mass.
    b. density. **d.** weight.
17. Double refraction is a property of some crystals of
    a. mica. **c.** calcite.
    b. feldspar. **d.** galena.

SHORT ANSWER

18. List six major classes of nonsilicate minerals.
19. List eight of the most common rock-forming minerals.
20. Why do minerals that have the nonsilicate crystalline structure called *closest packing* have high density?
21. Which of the two main groups of minerals is more abundant in Earth's crust?
22. Which of the following mineral groups, if any, contain silicon: carbonates, halides, or sulfides?
23. Describe the tetrahedral arrangement of olivine.
24. Summarize the characteristics that a substance must have to be classified as a mineral.
25. How many oxygen ions and silicon ions are in a silicon-oxygen tetrahedron?

CRITICAL THINKING

26. **Classifying Information** Natural gas is a substance that occurs naturally in Earth's crust. Is it a mineral? Explain your answer.
27. **Making Comparisons** Which of the following are you more likely to find in Earth's crust: the silicates feldspar and quartz or the nonsilicates copper and iron? Explain your answer.

28. Applying Ideas Iron pyrite, FeS_2, is called *fool's gold* because it looks a lot like gold. What simple test could you use to determine whether a mineral sample is gold or pyrite? Explain what the test would show.

29. Drawing Conclusions Can you determine conclusively that an unknown substance contains magnetite by using only a magnet? Explain your answer.

CONCEPT MAPPING

30. Use the following terms to create a concept map: *mineral, silicate mineral, nonsilicate mineral, silicon-oxygen tetrahedron, color, density, crystal shape, magnetism, native element, sulfate,* and *phosphorescence.*

MATH SKILLS

Math Skills

31. Applying Quantities Hematite, Fe_2O_3, has three atoms of oxygen and two atoms of iron in each molecule. What percentage of the atoms in a hematite molecule are oxygen atoms?

32. Making Calculations A sample of olivine contains 3.4 billion silicon-oxygen tetrahedra. How many oxygen atoms are in the sample?

33. Applying Quantities A mineral sample has a mass of 51 g and a volume of 15 cm^3. What is the density of the mineral sample?

WRITING SKILLS

34. Writing from Research Use the Internet or your school library to find a mineral map of the United States. Write a brief report that outlines how the minerals in your state are discovered and mined.

35. Communicating Main Ideas Write and illustrate an essay that explains how six different crystal structures form from silicon-oxygen tetrahedra.

INTERPRETING GRAPHICS

This table provides information about the eight most abundant elements in Earth's crust. Use the table to answer the questions that follow.

The Eight Most Abundant Chemicals in Earth's Crust

Element	Chemical symbol	Weight (% of Earth's crust)	Volume (% of Earth's crust)*
Oxygen	O	46.60	93.8
Silicon	Si	27.72	0.9
Aluminum	Al	8.13	0.5
Iron	Fe	5.00	0.4
Calcium	Ca	3.63	1.0
Sodium	Na	2.83	1.3
Potassium	K	2.59	1.8
Magnesium	Mg	2.09	0.3
	Total	98.59	100.0

*The volume of Earth's crust comprised by all other elements is so small that it is essentially 0% when the numbers are rounded to the nearest tenth of a percent.

36. What percentage of the weight of Earth's crust is made of silicon?

37. Oxygen makes up 93.8% of Earth's crust by volume, but oxygen is only 46.60% of Earth's crust by weight. How is this possible?

38. By comparing the volume and weight percentages of aluminum and calcium, determine which element has the higher density.

Chapter 5 Standardized Test Prep

Understanding Concepts

Directions (1–5): For each question, write on a separate sheet of paper the letter of the correct answer.

1. Coal is
- **A.** organic and a mineral.
- **B.** inorganic and a mineral.
- **C.** organic and not a mineral.
- **D.** inorganic and not a mineral.

2. Which of the following is one of the rock-forming minerals that make up 90% of the mass of Earth's crust?
- **F.** quartz
- **G.** fluorite
- **H.** copper
- **I.** talc

3. In many cases, minerals can be identified by all of the following properties *except*
- **A.** specimen color.
- **B.** specimen streak.
- **C.** specimen hardness.
- **D.** specimen luster.

4. All minerals in Earth's crust
- **F.** have a crystalline structure.
- **G.** are classified as ring silicates.
- **H.** are classified as pyroxenes or amphiboles.
- **I.** have no silicon in their tetrahedral structure.

5. Which mineral can be scratched by a fingernail, which has a hardness of 2.5 on the Mohs scale?
- **A.** diamond
- **B.** quartz
- **C.** topaz
- **D.** talc

Directions (6–8): For each question, write a short response.

6. Carbonates, halides, native elements, oxides, sulfates, and sulfides are classes of what mineral group?

7. What mineral is made up of *only* the elements oxygen and silicon?

8. What property is a mineral said to have when a person is able to view double images through it?

Reading Skills

Directions (9–11): Read the passage below. Then, answer the questions.

Native American Copper

In North America, copper was mined at least 6,700 years ago by the Native Americans who lived on Michigan's upper peninsula. Much of this mining took place on Isle Royale, an island located in the waters of Lake Superior.

These ancient people removed copper from the rock by using stone hammers and wedges. The rock was sometimes heated to make breaking it easier. Copper that was mined was used to make a wide variety of items for the Native Americans including jewelry, tools, weapons, fish hooks, and other objects. These objects were often marked with intricate designs. The copper mined at the Lake Superior site was traded over long distances along ancient trade routes. Copper objects from the region have been found in Ohio, Florida, the Southwest, and the Northwest.

9. According to the passage, Native Americans who mined copper
- **F.** used the mineral as a form of currency when buying goods from other tribes.
- **G.** traded copper objects with other Native American tribes over a large area.
- **H.** used the mineral to produce vastly superior weapons and armor.
- **I.** sold it to the Native Americans living around Lake Superior.

10. Which of the following statements can be inferred from the information in the passage?
- **A.** Copper is a very strong metal and can be forged into extremely strong items.
- **B.** Copper mining in the ancient world was only common in North America.
- **C.** Copper is a useful metal that can be forged into a wide variety of goods.
- **D.** Copper is a weak metal, and no items made by the ancient Native Americans remain.

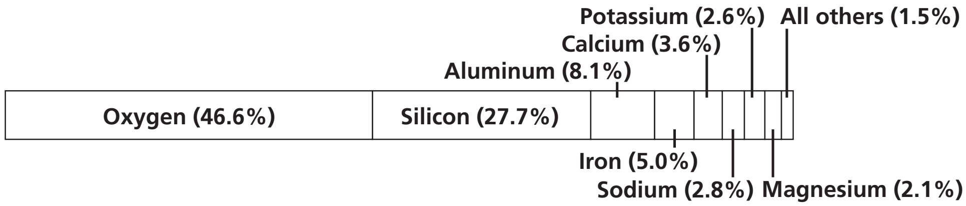
11. What are some properties of copper that might have made the metal useful to Native Americans?

Interpreting Graphics

Directions (12–15): For each question below, record the correct answer on a separate sheet of paper.

Base your answers to questions 12 and 13 on the figure below, which shows the abundance of various elements in Earth's crust.

Elements in Earth's Crust



12. Which of these elements combines with oxygen to form hematite?
- **F.** calcium
- **G.** aluminum
- **H.** sodium
- **I.** iron

13. Silicate minerals make up about 95% of Earth's crust. However, the elements present in all minerals in this group, oxygen and silicon, make up a significantly smaller percentage of the weight of Earth's crust. How can this discrepancy be explained?

Base your answers to questions 14 and 15 on the table below, which provides information about silicate minerals.

Common Silicates

Mineral	Idealized formula	Cleavage
Olivine	$(Mg,Fe)_2SiO_4$	none
Pyroxene group	$(Mg,Fe)SiO_3$	two planes at right angles
Amphibole group	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	two planes at 60° and 120°
Micas, biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	one plane
Micas, muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	one plane
Feldspars, orthoclase	$KAlSi_3O_8$	two planes at 90°
Feldspars, plagioclase	$(Ca,Na)AlSi_3O_8$	two planes at 90°
Quartz	SiO_2	none

14. How is the cleavage of amphibole minerals similar to that of feldspar minerals?
- **A.** Both have two planes.
- **B.** Both have one plane.
- **C.** Both cleave at 60°.
- **D.** Both cleave at 90°.

15. Which minerals are ferromagnesian? How can you identify these minerals? Predict how the chemical composition of ferromagnesian minerals affects the minerals' density and magnetic properties.

Test Tip

If a question or an answer choice contains an unfamiliar term, try to break the word into parts to determine its meaning.