CHAPTER 4

Minerals

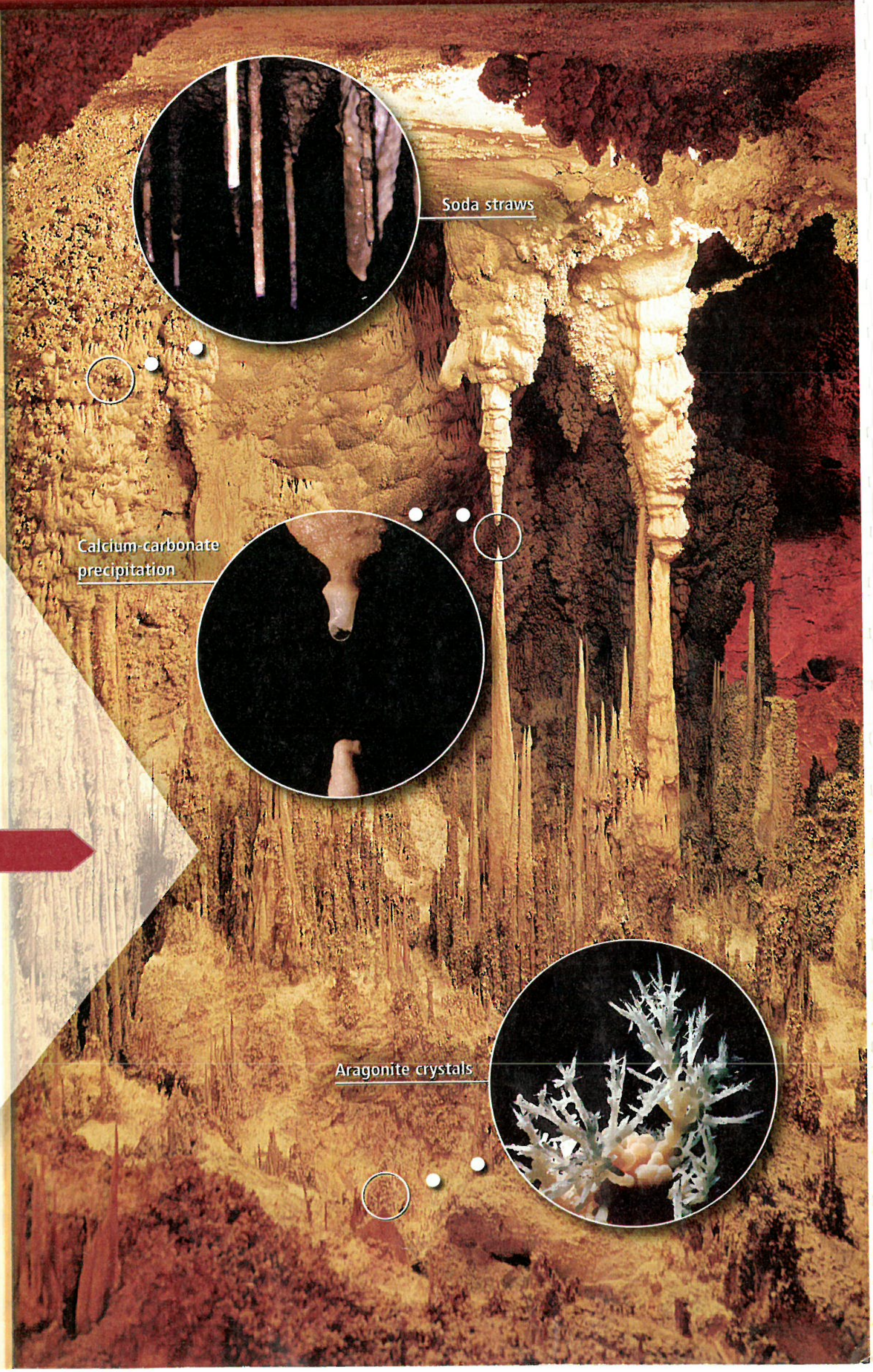
BIG Idea **Minerals are an integral part of daily life.**

4.1 What is a mineral?

MAIN Idea Minerals are naturally occurring, solid, inorganic compounds or elements.

4.2 Types of Minerals

MAIN Idea Minerals are classified based on their chemical properties and characteristics.



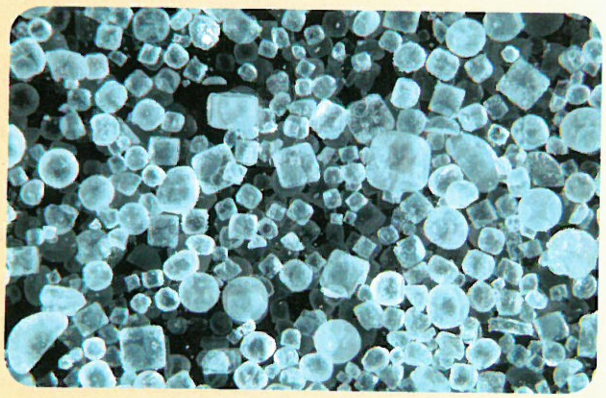
GeoFacts

- Stalactites and other cave formations take thousands of years to form. One estimate is that a stalactite will grow only 10 cm in 1000 years. That is equal to 0.1 mm each year!
- The diameter of a soda straw is equal to the droplets of water that form them.
- The longest soda straws discovered measure more than 9 m long.

LAUNCH Lab

What shapes do minerals form?

Although there are thousands of minerals in Earth's crust, each type of mineral has unique characteristics. These characteristics are clues to a mineral's composition and to the way it formed. Physical properties can also be used to distinguish one type of mineral from another.



Procedure

1. Read and complete the lab safety form.
2. Place a few grains of **table salt** (the mineral halite) on a **microscope slide.** Place the slide on the **microscope** stage. Or, observe the grains with a **magnifying lens.**
3. Focus on one grain at a time. Count the number of sides of each grain. Make sketches of the grains.
4. Next, examine a **quartz crystal** with the microscope or magnifying lens. Count the number of sides of the quartz crystal. Sketch the shape of the quartz crystal.

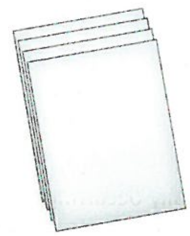
Analysis

1. **Compare and contrast** the shapes of the samples of halite and quartz.
2. **Describe** some other properties of your mineral samples.
3. **Infer** what might account for the differences you observed.

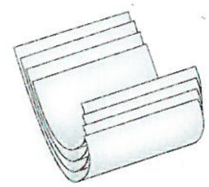
FOLDABLES™ Study Organizer

Mineral Identification Make the following Foldable to explain the tests used to identify minerals.

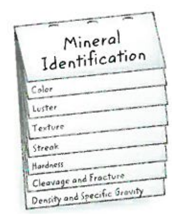
STEP 1 Collect ~~four~~ 5 sheets of paper and layer them 2 cm apart vertically. Keep the left and right edges even.



STEP 2 Fold up the bottom edges of the sheets to form seven equal tabs. Crease the fold to hold the tabs in place.



STEP 3 Staple along the fold. Label the tabs with the names of the tests used to identify minerals.



FOLDABLES **Use this Foldable with Section 4.1.** As you read this section, describe the chemical or physical properties of minerals that are used in each test.

Earth Science Online

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- **access Web Links for more information, projects, and activities;**
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Section 4.1

Objectives

- **Define** a mineral.
- **Describe** how minerals form.
- **Classify** minerals according to their physical and chemical properties.

Review Vocabulary

element: a pure substance that cannot be broken down into simpler substances by chemical or physical means

New Vocabulary

mineral
crystal
luster
hardness
cleavage
fracture
streak
specific gravity

What is a mineral?

MAIN Idea Minerals are naturally occurring, solid, inorganic compounds or elements.

Real-World Reading Link Look around your classroom. The metal in your desk, the graphite in your pencil, and the glass in the windows are just three examples of how modern humans use products made from minerals.

Mineral Characteristics

Earth's crust is composed of about 3000 minerals. Minerals play important roles in forming rocks and in shaping Earth's surface. A select few have helped shape civilization. For example, great progress in prehistory was made when early humans began making tools from iron.

A **mineral** is a naturally occurring, inorganic solid, with a specific chemical composition and a definite crystalline structure. This crystalline structure is often exhibited by the crystal shape itself. Examples of mineral crystal shapes are shown in **Figure 4.1.**

Naturally occurring and inorganic Minerals are naturally occurring, meaning that they are formed by natural processes. Such processes will be discussed later in this section. Thus, synthetic diamonds and other substances developed in labs are not minerals. All minerals are inorganic. They are not alive and never were alive. Based on these criteria, salt is a mineral, but sugar, which is harvested from plants, is not. What about coal? According to the scientific definition of minerals, coal is not a mineral because millions of years ago, it formed from organic materials.

Figure 4.1 The shapes of these mineral crystals reflect the internal arrangement of their atoms.


Pyrite


Calcite

Definite crystalline structure The atoms in minerals are arranged in regular geometric patterns that are repeated. This regular pattern results in the formation of a crystal. A **crystal** is a solid in which the atoms are arranged in repeating patterns. Sometimes, a mineral will form in an open space and grow into one large crystal. The well-defined crystal shapes shown in **Figure 4.1** are rare. More commonly, the internal atomic arrangement of a mineral is not apparent because the mineral formed in a restricted space. **Figure 4.2** shows a sample of quartz that grew in a restricted space.

Reading Check **Describe** the atomic arrangement of a crystal.

Figure 4.2 This piece of quartz most likely formed in a restricted space, such as within a crack in a rock.

Solids with specific compositions The fourth characteristic of minerals is that they are solids. Recall from Chapter 3 that solids have definite shapes and volumes, while liquids and gases do not. Therefore, no gas or liquid can be considered a mineral.

Each type of mineral has a chemical composition unique to that mineral. This composition might be specific, or it might vary within a set range of compositions. A few minerals, such as copper, silver, and sulfur, are composed of single elements. The vast majority, however, are made from compounds. The mineral quartz (SiO_2), for example, is a combination of two atoms of oxygen and one atom of silicon. Although other minerals might contain silicon and oxygen, the arrangement and proportion of these elements in quartz are unique to quartz.

VOCABULARY

ACADEMIC VOCABULARY

Restricted

small space; to have limits

The room was so small that it felt very restricted.

Quartz

Aquamarine

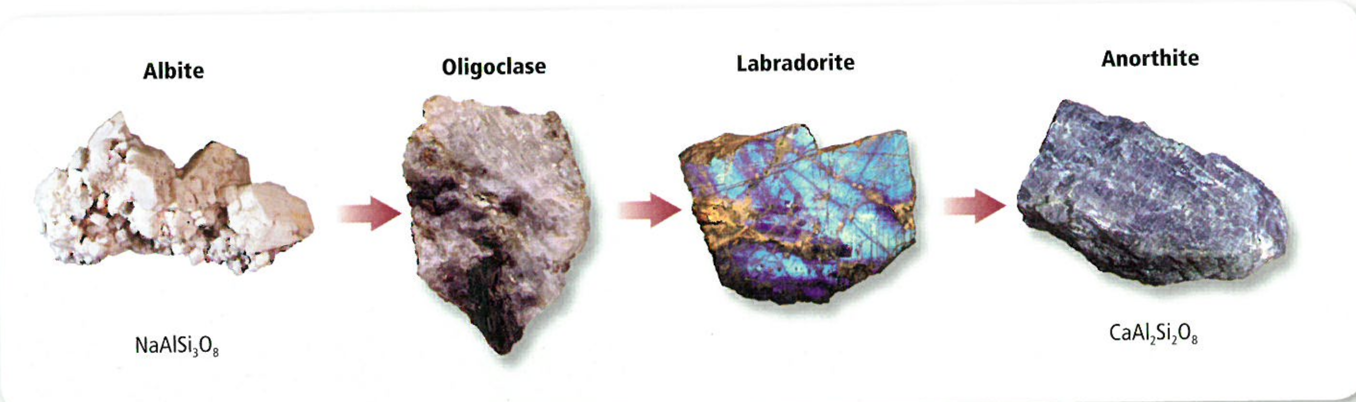

Figure 4.3 The range in composition and resulting appearance is specific enough to identify numerous feldspar varieties accurately.

Variations in Composition In some minerals, chemical composition can vary slightly depending on the temperature at which the mineral crystallizes. The plagioclase feldspar, shown in **Figure 4.3,** ranges from sodium-rich albite (AHL bite) at low temperatures to calcium-rich anorthite (uh NOR thite) at high temperatures. The difference in the mineral's appearance is due to a slight change in the chemical composition and a difference in growth pattern as the temperature changes. At intermediate temperatures, both calcium and sodium are incorporated in the crystal structure, building up alternating layers that allow light to refract or scatter, producing a range of colors, as show in the labradorite in **Figure 4.3.**

Rock-Forming Minerals

Although about 3000 minerals occur in Earth's crust, only about 30 of these are common. Eight to ten of these minerals are referred to as rock-forming minerals because they make up most of the rocks in Earth's crust. They are primarily composed of the eight most common elements in Earth's crust. This is illustrated in **Table 4.1.**

Table 4.1 Most Common Rock-Forming Minerals

Quartz	Feldspar	Mica	Pyroxene*
SiO_2	$NaAlSi_3O_8 - CaAl_2Si_2O_8$ & $KAlSi_3O_8$	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$ $KAl_2(AlSi_3O_{10})(OH)_2$	$MgSiO_3$ $CaMgSi_2O_6$ $NaAlSi_2O_6$
Amphibole*	**Olivine**	**Garnet***	**Calcite**
$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$ $Fe_7Si_8O_{22}(OH)_2$	$(Mg,Fe)_2SiO_4$	$Mg_3Al_2Si_3O_{12}$ $Fe_3Al_2Si_3O_{12}$ $Ca_3Al_2Si_3O_{12}$	$CaCO_3$

*representative mineral compositions

Minerals from magma Molten material that forms and accumulates below Earth's surface is called magma. Magma is less dense than the surrounding solid rock, so it can rise upward into cooler layers of Earth's interior. Here, the magma cools and crystallizes. The type and number of elements present in the magma determine which minerals will form. The rate at which the magma cools determines the size of the mineral crystals. If the magma cools slowly within Earth's heated interior, the atoms have time to arrange themselves into large crystals. If the magma reaches Earth's surface, comes in contact with air or water, and cools quickly, the atoms do not have time to arrange themselves into large crystals. Thus, small crystals form from rapidly cooling magma, and large crystals form from slowly cooling magma. The mineral crystals in the granite shown in **Figure 4.4** are the result of cooling magma. You will learn more about crystal size in Chapter 5.

Reading Check **Explain** how contact with water affects crystal size.

Minerals from solutions Minerals are often dissolved in water. For example, the salts that are dissolved in ocean water make it salty. When a liquid becomes full of a dissolved substance and it can dissolve no more of that substance, the liquid is saturated. If the solution then becomes overfilled, it is called supersaturated and conditions are right for minerals to form. At this point, individual atoms bond together and mineral crystals precipitate, which means that they form into solids from the solution.

Minerals also crystallize when the solution in which they are dissolved evaporates. You might have experienced this if you have ever gone swimming in the ocean. As the water evaporated off your skin, the salts were left behind as mineral crystals. Minerals that form from the evaporation of liquid are called evaporites. The rock salt in **Figure 4.4** was formed from evaporation. **Figure 4.5** shows Mammoth Hot Springs, a large evaporite complex in Yellowstone National Park.

Figure 4.4 The crystals in these two samples formed in different ways. **Describe** *the differences you see in these rock samples.*

Figure 4.5 This large complex of evaporite minerals is in Yellowstone National Park. The variation in color is the result of the variety of elements that are dissolved in the water.

Identifying Minerals

Geologists rely on several simple tests to identify minerals. These tests are based on a mineral's physical and chemical properties, which are crystal form, luster, hardness, cleavage, fracture, streak, color, texture, density, specific gravity, and special properties. As you will learn in the GeoLab at the end of this chapter, it is usually best to use a combination of tests instead of just one to identify minerals.

Crystal form Some minerals form such distinct crystal shapes that they are immediately recognizable. Halite—common table salt—always forms perfect cubes. Quartz crystals, with their double-pointed ends and six-sided crystals, are also readily recognized. However, as you learned earlier in this section, perfect crystals are not always formed, so identification based only on crystal form is rare.

CAREERS IN EARTH SCIENCE

Lapidary A lapidary is someone who cuts, polishes, and engraves precious stones. He or she studies minerals and their properties in order to know which minerals are the best for certain projects. To learn more about Earth science careers, visit glencoe.com.

Luster The way that a mineral reflects light from its surface is called **luster.** There are two types of luster—metallic luster and nonmetallic luster. Silver, gold, copper, and galena have shiny surfaces that reflect light, like the chrome trim on cars. Thus, they are said to have a metallic luster. Not all metallic minerals are metals. If their surfaces have shiny appearances like metals, they are considered to have a metallic luster. Sphalerite, for example, is a mineral with a metallic luster that is not a metal.

Minerals with nonmetallic lusters, such as calcite, gypsum, sulfur, and quartz, do not shine like metals. Nonmetallic lusters might be described as dull, pearly, waxy, silky, or earthy. Differences in luster, shown in **Figure 4.6,** are caused by differences in the chemical compositions of minerals. Describing the luster of nonmetallic minerals is a subjective process. For example, a mineral that appears waxy to one person might not appear waxy to another. Using luster to identify a mineral should usually be used in combination with other physical characteristics.

Reading Check **Define** the term *luster.*

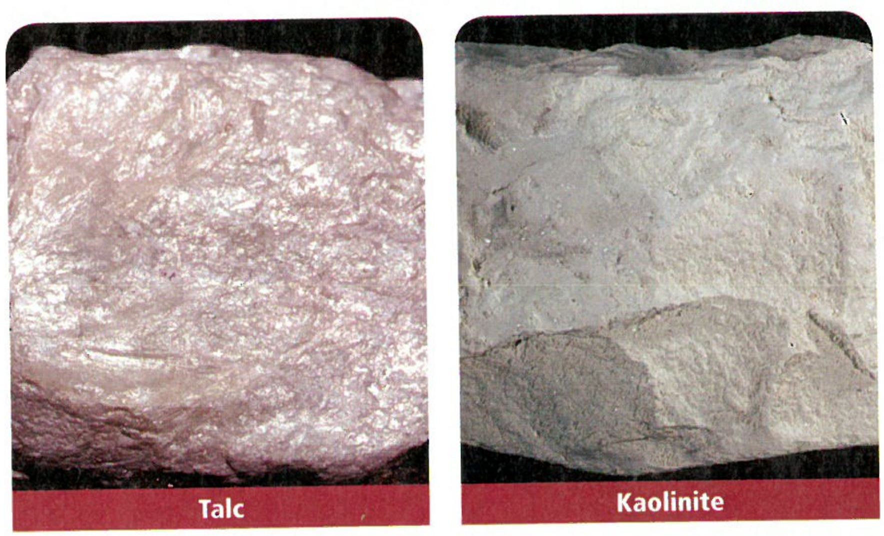

Figure 4.6 The flaky and shiny nature of talc gives it a pearly luster. Another white mineral, kaolinite, contrasts sharply with its dull, earthy luster.

Table 4.2	Mohs Scale of Hardness	
Mineral	**Hardness**	**Hardness of Common Objects**
Diamond	10	
Corundum	9	
Topaz	8	
Quartz	7	streak plate = 7
Feldspar	6	steel file = 6.5
Apatite	5	glass = 5.5
Fluorite	4	iron nail = 4.5
Calcite	3	piece of copper = 3.5
Gypsum	2	fingernail = 2.5
Talc	1	

Concepts In Motion Interactive Table To explore more about Mohs scale of hardness, visit glencoe.com.

Hardness One of the most useful and reliable tests for identifying minerals is hardness. **Hardness** is a measure of how easily a mineral can be scratched. German geologist Friedrich Mohs developed a scale by which an unknown mineral's hardness can be compared to the known hardness of ten minerals. The minerals in the Mohs scale of mineral hardness were selected because they are easily recognized and, with the exception of diamond, readily found in nature.

Reading Check **Explain** what hardness measures.

Talc is one of the softest minerals and can be scratched by a fingernail; therefore, talc represents 1 on the Mohs scale of hardness. In contrast, diamond is so hard that it can be used as a sharpener and cutting tool, so diamond represents 10 on the Mohs scale of hardness. The scale, shown in **Table 4.2,** is used in the following way: a mineral that can be scratched by your fingernail has a hardness equal to or less than 2. A mineral that cannot be scratched by your fingernail and cannot scratch glass has a hardness value between 5.5 and 2.5. Finally, a mineral that scratches glass has a hardness greater than 5.5. Using other common objects, such as those listed in the table, can help you determine a more precise hardness and provide you with more information with which to identify an unknown mineral. Sometimes more than one mineral is present in a sample. If this is the case, it is a good idea to test more than one area of the sample. This way, you can be sure that you are testing the hardness of the mineral you are studying. **Figure 4.7** shows two minerals that have different hardness values.

Figure 4.7 The mineral on top can be scratched with a fingernail. The mineral on the bottom easily scratches glass.
Determine ***Which mineral has greater hardness?***

Figure 4.8 Halite has perfect cleavage in three directions; it breaks apart into pieces that have 90° angles. The strong bonds in quartz prevent cleavage from forming. Conchoidal fractures are characteristic of microcrystalline minerals such as flint.

Cleavage and fracture Atomic arrangement also determines how a mineral will break. Minerals break along planes where atomic bonding is weak. A mineral that splits relatively easily and evenly along one or more flat planes is said to have **cleavage.** To identify a mineral according to its cleavage, geologists count the number of cleaved planes and study the angle or angles between them. For example, mica has perfect cleavage in one direction. It breaks in sheets because of weak atomic bonds. Halite, shown in **Figure 4.8,** has cubic cleavage, which means that it breaks in three directions along planes of weak atomic attraction.

MiniLab

Recognize Cleavage and Fracture

How is cleavage used? Cleavage forms when a mineral breaks along a plane of weakly bonded atoms. If a mineral has no cleavage, it exhibits fracture. Recognizing the presence or absence of cleavage and determining the number of cleavage planes is a reliable method of identifying minerals.

Procedure

Part 1

1. Read and complete the lab safety form.
2. Obtain five **mineral samples** from your teacher. Separate them into two sets—those with cleavage and those without cleavage.
3. Arrange the minerals that have cleavage in order from fewest to most cleavage planes. How many cleavage planes does each sample have? Identify these minerals if you can.
4. Examine the samples that have no cleavage. Describe their surfaces. Identify these minerals if you can.

Part 2

5. Obtain two more samples from your teacher. Are these the same mineral? How can you tell?
6. Use a **protractor** to measure the cleavage plane angles of both minerals. Record your measurements.

Analysis

1. **Record** the number of cleavage planes or presence of fracture for all seven samples.
2. **Compare** the cleavage plane angles for Samples 6 and 7. What do they tell you about the mineral samples?
3. **Predict** the shape each mineral would exhibit if you were to hit each one with a hammer.

Quartz, shown in **Figure 4.8,** breaks unevenly along jagged edges because of its tightly bonded atoms. Minerals that break with rough or jagged edges are said to have **fracture.** Flint, jasper, and chalcedony (kal SEH duh nee) (microcrystalline forms of quartz) exhibit a unique fracture with arclike patterns resembling clamshells, also shown in **Figure 4.8.** This fracture is called conchoidal (kahn KOY duhl) fracture and is diagnostic in identifying the rocks and minerals that exhibit it.

Streak A mineral rubbed across an unglazed porcelain plate will sometimes leave a colored powdered streak on the surface of the plate. **Streak** is the color of a mineral when it is broken up and powdered. The streak of a nonmetallic mineral is usually white. Streak is most useful in identifying metallic minerals.

Sometimes, a metallic mineral's streak does not match its external color, as shown in **Figure 4.9.** For example, the mineral hematite occurs in two different forms, resulting in two distinctly different appearances. Hematite that forms from weathering and exposure to air and water is a rusty red color and has an earthy feel. Hematite that forms from crystallization of magma is silver and metallic in appearance. However, both forms make a reddish-brown streak when tested. The streak test can be used only on minerals that are softer than a porcelain plate. This is another reason why streak cannot be used to identify all minerals.

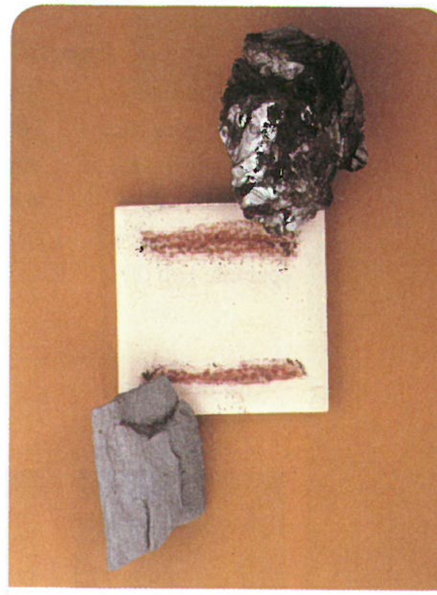

Figure 4.9 Despite the fact that these pieces of hematite appear remarkably different, their chemical compositions are the same. Thus, the streak that each makes is the same color.

Reading Check **Explain** which type of mineral can be identified using streak.

Color One of the most noticeable characteristics of a mineral is its color. Color is sometimes caused by the presence of trace elements or compounds within a mineral. For example, quartz occurs in a variety of colors, as shown in **Figure 4.10.** These different colors are the result of different trace elements in the quartz samples. Red jasper, purple amethyst, and orange citrine contain different amounts and forms of iron. Rose quartz contains manganese or titanium. However, the appearance of milky quartz is caused by the numerous bubbles of gas and liquid trapped within the crystal. In general, color is one of the least reliable clues of a mineral's identity.

FOLDABLES

Incorporate information from this section into your Foldable.

Figure 4.10 These varieties of quartz all contain silicon and oxygen. Trace elements determine their colors.

Concepts In Motion **Interactive Table** To explore more about the special properties of minerals, visit glencoe.com.

Table 4.3 Special Properties of Minerals

Property	**Double refraction** occurs when a ray of light passes through the mineral and is split into two rays.	**Effervescence** occurs when reaction with hydrochloric acid causes calcite to fizz.	**Magnetism** occurs between minerals that contain iron; only magnetite and pyrrhotite are strongly magnetic.	**Iridescence**—a play of colors, caused by the bending of light rays.	**Fluorescence** occurs when some minerals are exposed to ultraviolet light, which causes them to glow in the dark.
Mineral	Calcite—Variety Iceland Spar	Calcite	Magnetite Pyrrhotite	Labradorite	Fluorite Calcite
Example					

Special properties Several special properties of minerals can also be used for identification purposes. Some of these properties are magnetism, striations, double refraction, effervescence with hydrochloric acid, and fluorescence, shown in **Table 4.3**. For example, Iceland spar is a form of calcite that exhibits double refraction. The arrangement of atoms in this type of calcite causes light to be bent in two directions when it passes through the mineral. The refraction of the single ray of light into two rays creates the appearance of two images.

DATA ANALYSIS LAB

Based on Real Data*

Make and Use a Table

What information should you include in a mineral identification chart?

Mineral Identification Chart

Mineral Color	Streak	Hardness	Breakage Pattern
copper red		3	hackly, fracture
	red or reddish brown	6	irregular fracture
pale to golden yellow	yellow		
	colorless	7.5	conchoidal fracture
gray, green or white			two cleavage planes

Analysis

1. Copy the data table and use the *Reference Handbook* to complete the table.
2. Expand the table to include the names of the minerals, other properties, and uses.

Think Critically

3. **Determine** which of these minerals will scratch glass? Explain.
4. **Identify** which of these minerals might be present in both a painting and your desk.
5. **Identify** any other information you could include in the table.

*Data obtained from: Klein, C. 2002. *The Manual of Mineral Science.*

Texture Texture describes how a mineral feels to the touch. This, like luster, is subjective. Therefore, texture is often used in combination with other tests to identify a mineral. The texture of a mineral might be described as smooth, rough, ragged, greasy, or soapy. For example, fluorite, shown in **Figure 4.11,** has a smooth texture, while the texture of talc, shown in **Figure 4.6,** is greasy.

Figure 4.11 Textures are interpreted differently by different people. The texture of this fluorite is usually described as smooth.

Density and specific gravity Sometimes, two minerals of the same size have different weights. Differences in weight are the result of differences in density, which is defined as mass per unit of volume. Density is expressed as follows.

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

In this equation, D = density, M = mass and V = volume. For example, pyrite has a density of 5.2 g/cm^3, and gold has a density of 19.3 g/cm^3. If you had a sample of gold and a sample of pyrite of the same size, the gold would have greater weight because it is denser.

Density reflects the atomic mass and structure of a mineral. Because density is not dependent on the size or shape of a mineral, it is a useful identification tool. Often, however, differences in density are too small to be distinguished by lifting different minerals. Thus, for accurate mineral identification, density must be measured. The most common measure of density used by geologists is **specific gravity,** which is the ratio of the mass of a substance to the mass of an equal volume of water at 4°C. For example, the specific gravity of pyrite is 5.2. The specific gravity of pure gold is 19.3.

Section 4.1 Assessment

Section Summary

- A mineral is a naturally occurring, inorganic solid with a specific chemical composition and a definite crystalline structure.
- A crystal is a solid in which the atoms are arranged in repeating patterns.
- Minerals form from magma or from supersaturated solutions.
- Minerals can be identified based on their physical and chemical properties.
- The most reliable way to identify a mineral is by using a combination of several tests.

Understand Main Ideas

1. MAIN Idea **List** two reasons why petroleum is not a mineral.
2. **Define** *naturally occurring* in terms of mineral formation.
3. **Contrast** the formation of minerals from magma and their formation from solution.
4. **Differentiate** between subjective and objective mineral properties.

Think Critically

5. **Develop** a plan to test the hardness of a sample of feldspar using the following items: glass plate, copper penny, and streak plate.
6. **Predict** the success of a lab test in which students plan to compare the streak colors of fluorite, quartz, and feldspar.

MATH in Earth Science

7. Calculate the volume of a 5-g sample of pure gold.

Section 4.2

Objectives

- **Identify** different groups of minerals.
- **Illustrate** the silica tetrahedron.
- **Discuss** how minerals are used.

Review Vocabulary

chemical bond: the force that holds two atoms together

New Vocabulary

silicate
tetrahedron
ore
gem

Types of Minerals

MAIN Idea Minerals are classified based on their chemical properties and characteristics.

Real-World Reading Link Everything on Earth is classified into various categories. Food, animals, and music are all classified according to certain properties or features. Minerals are no different; they, too, are classified into groups.

Mineral Groups

You have learned that elements combine in many different ways and proportions. One result is the thousands of different minerals present on Earth. In order to study these minerals and understand their properties, geologists have classified them into groups. Each group has a distinct chemical nature and specific characteristics.

Silicates Oxygen is the most abundant element in Earth's crust, followed by silicon. Minerals that contain silicon and oxygen, and usually one or more other elements, are known as **silicates.** Silicates make up approximately 96 percent of the minerals present in Earth's crust. The two most common minerals, feldspar and quartz, are silicates. The basic building block of the silicates is the silica tetrahedron, shown in **Figure 4.12.** A **tetrahedron** (plural, tetrahedra) is a geometric solid having four sides that are equilateral triangles, resembling a pyramid. Recall from Chapter 3 that the electrons in the outermost energy level of an atom are called valence electrons. The number of valence electrons determines the type and number of chemical bonds an atom will form. Because silicon atoms have four valence electrons, silicon has the ability to bond with four oxygen atoms. As shown in **Figure 4.13,** silica tetrahedra can share oxygen atoms. This structure allows tetrahedra to combine in a number of ways, which accounts for the large diversity of structures and properties of silicate minerals.

Figure 4.12 The silicate polyatomic ion SiO_4^{2-} forms a tetrahedron in which a central silicon atom is covalently bonded to oxygen ions.
Specify *How many atoms are in one tetrahedron?*