Chapter 4

Minerals

What You'll Learn

- How minerals form, and which are most common in Earth's crust.
- Which properties can be used to identify and classify minerals.
- Why certain minerals are ores and gems.

Why It's Important

Many products used in daily life are made directly or indirectly from minerals. Minerals also play a vital role in the processes that shape Earth. Some minerals form crystals that are valued for their beauty. The crystals shown here consist of albite, watermelon tourmaline, and smoky quartz.

Earth Science Online

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CONTENTS

Discovery Lab Observing Mineral Shapes

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 chemical composition and to the way it formed. Physical properties can also be used to distinguish one type of mineral from another.

1. Place a few grains of table salt—the mineral halite—on a microscope slide. Place the slide on the microscope stage and separate the grains. Or, simply observe the grains with a magnifying glass.
2. Focus on one grain at a time. Count the number of sides each grain has. Make sketches of the grains.
3. Next, examine a sample of quartz with the microscope or magnifying glass. Count the number of sides in the quartz sample. Sketch the shape of the quartz sample.

Observe Compare and contrast the shapes of the samples of halite and quartz. What might account for the differences you observed? In your science journal, describe some other physical properties of your mineral samples.

SECTION 4.1 *What is a mineral?*

OBJECTIVES

- **Define** *a mineral.*
- **Describe** *how minerals form.*
- **Identify** *the most common elements in Earth's crust.*

VOCABULARY

mineral
crystal
magma
silicate

Earth's crust is composed of about 3000 minerals. Minerals play important roles in forming rocks and in shaping Earth's surface, and a select few have played—and continue to play—a role in shaping civilization. For example, great leaps in prehistory were made when early humans began making tools from iron. Calcite is the mineral that forms the 2 million limestone blocks that make up the Great Pyramid in Egypt. It is also the primary mineral in the marble found in the Parthenon in Greece. Throughout history, wars have been fought and empires have crumbled over minerals such as gold and silver.

MINERAL CHARACTERISTICS

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. But what exactly is a mineral? A **mineral** is a naturally occurring, inorganic solid with a specific chemical composition and a definite crystalline structure. Let's examine each part of this definition in turn.

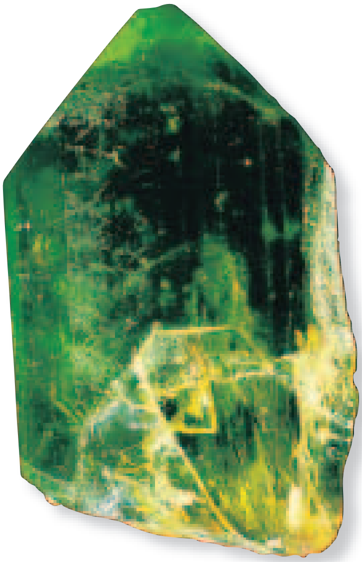
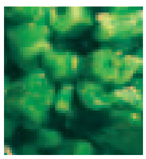
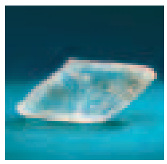
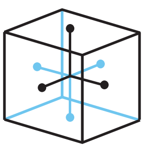
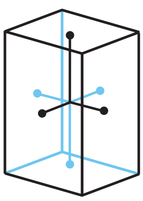
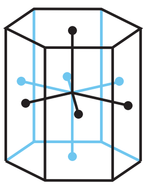
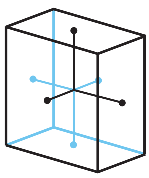
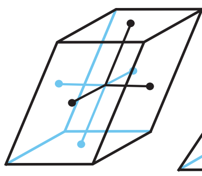
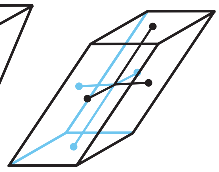


Figure 4-1 The chemical composition of olivine varies within a limited range.

Naturally Occurring and Inorganic To say that minerals are naturally occurring simply means that they are formed by natural processes, which you'll learn about later in this section. Thus, synthetic diamonds and other substances developed in labs are not minerals. Secondly, all minerals are inorganic. That is, they aren't alive and never were alive during any part of their existence. Based on this criterion, 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 hundreds of millions of years ago, it formed from organic processes.

Solids with Specific Compositions The third characteristic of minerals is that they all are solids. Solids have definite shapes and volumes. Liquids and gases do not. Thus, no gas or liquid can be considered a mineral. Next, each type of mineral has a chemical composition unique to that mineral. 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, for instance, is a combination of two atoms of oxygen and one atom of silicon. Although other minerals may contain silicon and oxygen, the arrangement and proportion of these elements in quartz are unique to quartz.

Table 4-1 Crystal Systems

Examples	 Pyrite	 Wulfenite	 Pyromorphite	 Topaz	 Gypsum	 Feldspar
Systems	 Cubic	 Tetragonal	 Hexagonal	 Orthorhombic	 Monoclinic	 Triclinic

In some minerals, such as the one shown in ***Figure 4-1,*** chemical composition may vary within a certain range. For instance, the amount of individual iron and magnesium atoms in the mineral olivine may vary, with some forms of olivine containing more iron than others. But the ratio of the total amount of iron and magnesium atoms to the amount of silicon atoms in olivine is always the same. Thus, the chemical composition of this mineral varies, but only within a well-defined range.

Definite Crystalline Structure The last part of the definition of minerals relates to crystalline structures. The atoms in minerals are arranged in regular geometric patterns that are repeated again and again. A **crystal** is a solid in which the atoms are arranged in repeating patterns. At times, a mineral will form in an open space and grow into one large crystal. The resulting mineral crystal may take the shape of one of the six major crystal systems shown in ***Table 4-1.*** You'll model crystal systems in the *MiniLab* on this page. The well-defined crystal shapes shown in the table are fairly rare. More commonly, the internal atomic arrangement of a mineral is not so readily apparent because the mineral formed in a restricted space. ***Figure 4-2*** compares a crystal that grew in an open space with one that grew in a restricted space.

MiniLab

How can crystal systems be modeled?

Model the six major crystal systems, then classify mineral samples according to these systems.

Procedure

1. Using ***Table 4-1*** for guidance, cut pieces of foam board into geometric shapes. Your largest geometric shape should be no more than about 8 cm in length. Your group will need about 38 various shapes.
2. Tape or glue the geometric shapes into models of the six major crystal systems. Again, use ***Table 4-1*** for guidance.
3. Use the mineral samples provided by your teacher to classify minerals according to their crystal shapes.

Analyze and Conclude

1. What geometric shapes did you use to model the crystal systems?
2. Was the crystal structure readily apparent in all mineral samples? Infer why or why not.
3. Use *Appendix H* to identify your minerals. Besides crystal shape, what properties did you use for identification purposes?

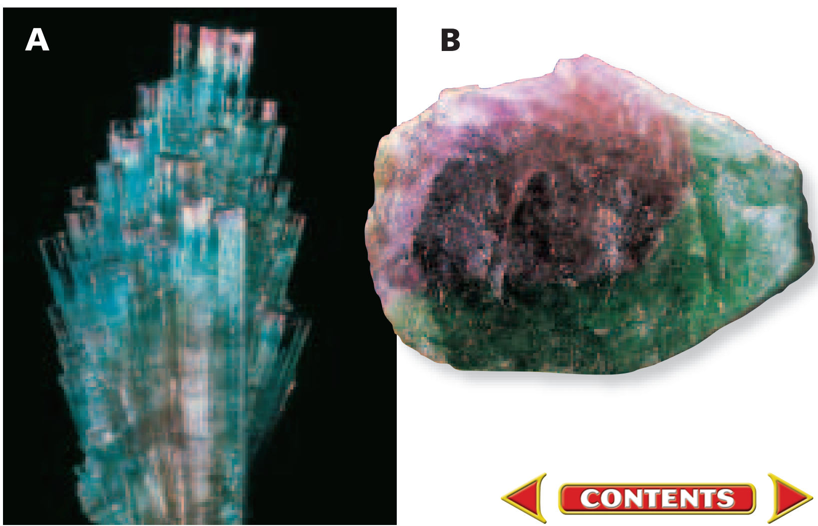


Figure 4-2 The well-shaped crystals of this sample of watermelon tourmaline indicate that it grew in an open space **(A).** This sample of watermelon tourmaline does not have well-defined crystals and thus grew in a restricted space **(B).**

Figure 4-3 Gypsum, shown in the foreground, forms when elements evaporate from a supersaturated solution.

Minerals from Magma

Minerals can form from the cooling of magma. **Magma** is molten material found beneath Earth's surface. Density differences can force magma upward into cooler layers of Earth's interior, where the magma cools. The compounds in the magma no longer move freely in the cooling material, and they may begin to interact chemically to form minerals. The type and amount of elements present in the magma help determine which minerals will form, while 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 don't have time to arrange themselves into large crystals. Thus, small crystals form from rapidly cooling magma and large crystals form from slowly cooling magma. You'll learn more about crystal size in Chapter 5.

Using Math

Using Numbers Of the 3000 known minerals, ten make up about 90 percent of the rocks in Earth's crust. What percentage of the total number of minerals do these ten minerals represent?

Minerals from Solution

A given volume of water in a solution can dissolve only so much of a solid before the water becomes saturated. At that point, the saturated water cannot dissolve any more of the solid. In nature, if a solution becomes supersaturated, or overfilled, with another substance, mineral crystals may begin to precipitate, or drop out of solution. This is one way that minerals can form from a supersaturated solution.

Minerals can also form when elements dissolve in a supersaturated solution. When liquid evaporates from the solution, the elements remain behind and may begin to arrange into crystals. ***Figure 4-3*** shows gypsum deposits that were formed from the evaporation of water. This is the second way that minerals form from a supersaturated solution.

Mineral Groups

Earlier, we said that 3000 minerals are found in Earth's crust. However, only about 30 of these minerals are common. The most common minerals are often referred to as rock-forming minerals

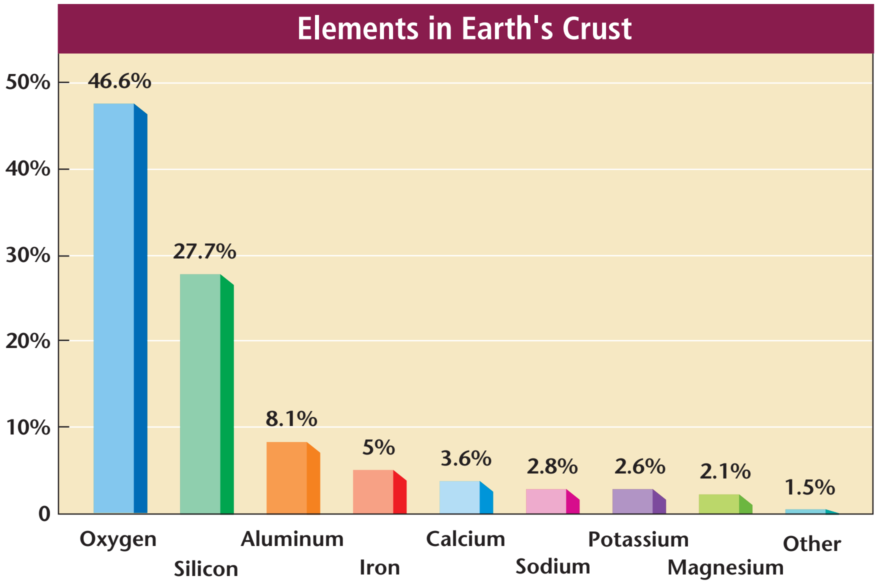


Figure 4-4 Oxygen is the most common element in Earth's crust, followed by silicon. The eight most common elements make up most minerals.

because they make up most of the rocks found in Earth's crust. Elements also are present in Earth's crust. About 90 known elements occur naturally in the crust. The vast majority of minerals are made up of the eight most common elements. ***Figure 4-4*** shows the percentages by weight of the common elements in Earth's crust.

Silicates Oxygen (O) is the most abundant element in Earth's crust, followed by silicon (Si). 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 found in Earth's crust. The most common minerals, feldspar and quartz, are silicates.

Figure 4-5 shows how one silicon atom attaches to four oxygen atoms to form a silica tetrahedron. A tetrahedron is a three-dimensional shape structured like a pyramid. The basic silica tetrahedron has the ability to share oxygen atoms with other tetrahedron molecules. This unique structure allows molecules to combine chemically and

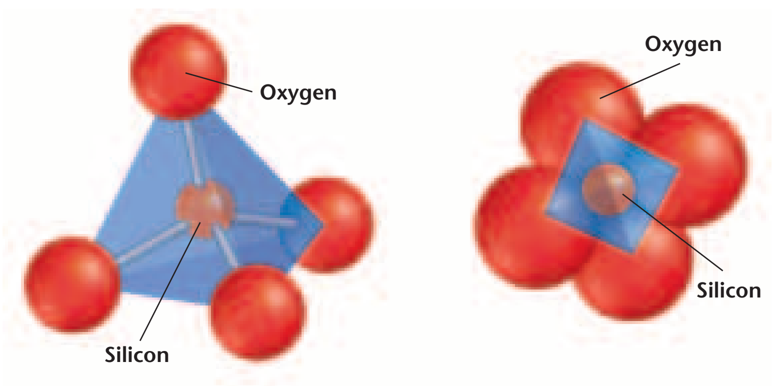


Figure 4-5 A silica tetrahedron is made up of one silicon atom bonded to four oxygen atoms.

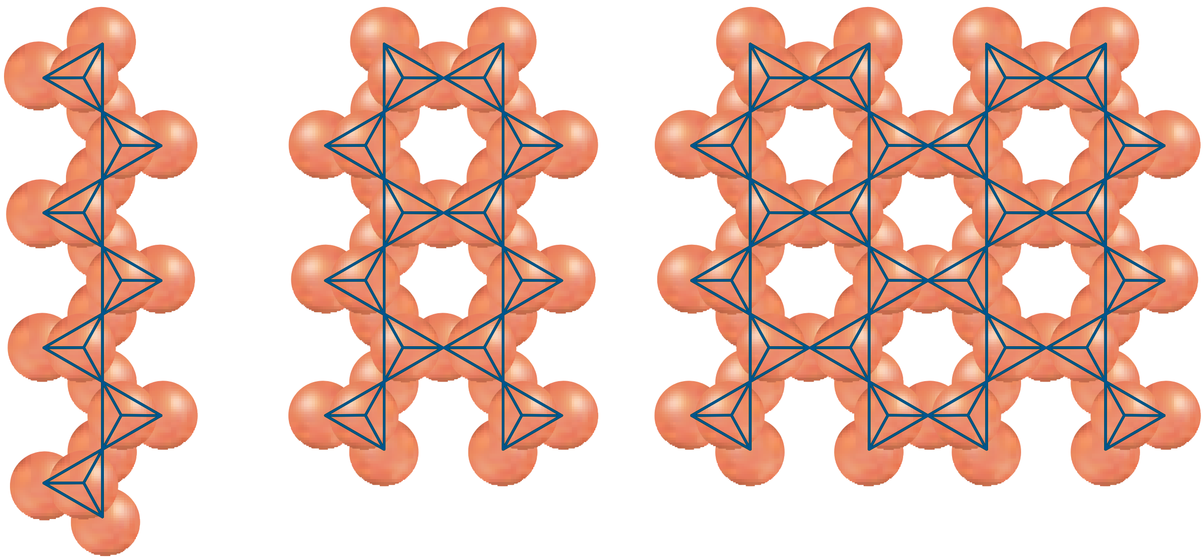


Figure 4-6 Silica tetrahedrons can combine in many ways, including single chains, double chains, and sheets. The different structural combinations account for the diversity of silicates.

structurally in a vast number of ways, which accounts for the diversity of silicates. ***Figure 4-6*** shows some possible arrangements formed by silica tetrahedrons, including single chains, double chains, and sheets. The bonds between the atoms help determine several mineral properties, including the way a mineral splits. Minerals generally split along planes of weak bonds. For instance, mica is an example of a sheet tetrahedron, wherein an atom of aluminum (Al) or potassium (K) bonds sheets together. Mica separates easily into sheets because the attraction between the tetrahedrons and the atom of aluminum or potassium is weak. Quartz, on the other hand, has an intricate network. Quartz is highly resistant to weathering and does not break easily along any planes because its atoms are strongly bonded together.

Table 4-2 Mineral Groups

Group	Example
Native elements	Copper metal (Cu)
Oxides and hydroxides	Hematite (Fe_2O_3) Brucite ($Mg[OH]_2$)
Halides	Halite (NaCl)
Carbonates	Calcite ($CaCO_3$)
Sulfates	Anhydrite ($CaSO_4$)
Silicates	Olivine (Mg_2SiO_4)
Sulfides	Pyrite (FeS_2)

Carbonates Oxygen easily combines with many other elements and thus forms other mineral groups, such as the carbonates and the oxides. Carbonates are minerals composed of one or more metallic elements with the carbonate compound CO_3. Examples of carbonates are calcite, dolomite, and rhodochrosite. Carbonates are the primary minerals found in rocks such as limestone, coquina, and marble. Some carbonates have distinctive colorations, such as the greenish hue of malachite and the blue of azurite, shown in ***Figure 4-7.***

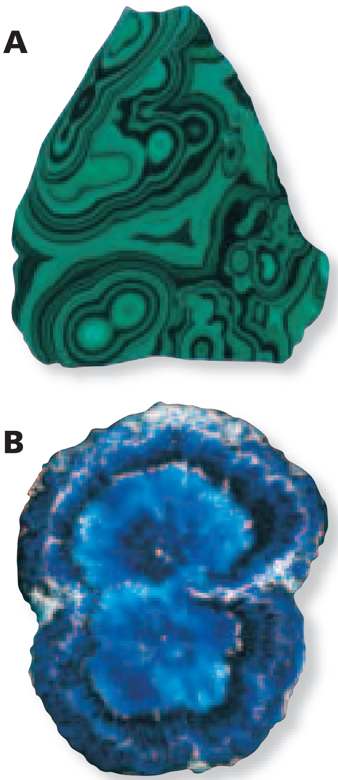


Figure 4-7 The carbonates malachite **(A)** and azurite **(B)** have distinct colorations.

Oxides Oxides are compounds of oxygen and a metal. Hematite (Fe_2O_3) and magnetite (Fe_3O_4) are common iron oxides and good sources of iron. The mineral uraninite is valuable because it is the major source of uranium, which is used to generate nuclear power.

Other major mineral groups are sulfides, sulfates, halides, and native elements. Sulfides such as pyrite (FeS_2) are compounds of sulfur and one or more elements. Sulfates such as anhydrite ($CaSO_4$) are composed of elements with the sulfate compound SO_4. Halides such as halite (NaCl) are made up of chloride or fluoride along with calcium, sodium, or potassium. A native element such as silver (Ag) or copper (Cu) is made up of one element only. ***Table 4-2*** on the previous page summarizes the mineral groups. *Appendix H* contains further information about individual minerals. In the next section, you'll learn how to identify some of the minerals discussed thus far.

SECTION ASSESSMENT

1. Define a mineral. Give two reasons why petroleum is not a mineral.
2. How do minerals form from solution? How do they form from magma?
3. What are the two most abundant elements in Earth's crust? What mineral group do these elements form?
4. Identify the other major mineral groups.
5. Describe a crystal. What determines the size of a mineral crystal formed from magma?
6. **Thinking Critically** Water is an inorganic substance formed by natural processes on Earth. It has a unique chemical composition. Under what conditions, if any, could water be considered a mineral?

SKILL REVIEW

7. **Concept Mapping** Use the following terms and *Appendix H* to construct a concept map of the six major crystal systems. For more help, refer to the *Skill Handbook.*

gypsum, topaz, cubic, pyrite, triclinic, hexagonal, tetragonal, crystal systems, wulfenite, pyromophite, feldspar, orthorhombic, monoclinic

SECTION 4.2 Identifying Minerals

OBJECTIVES

- **Classify** *minerals according to their physical and chemical properties.*
- **Identify** *different types of minerals.*
- **Discuss** *how minerals are used.*

VOCABULARY

luster
streak
hardness
cleavage
fracture
specific gravity
ore
gem

At the beginning of this chapter, we discussed just a few of the many ways in which humans use minerals. Before a mineral can be used, it must first be identified. With more than 3000 minerals in Earth's crust, this presents a problem. How does one go about identifying an unknown mineral?

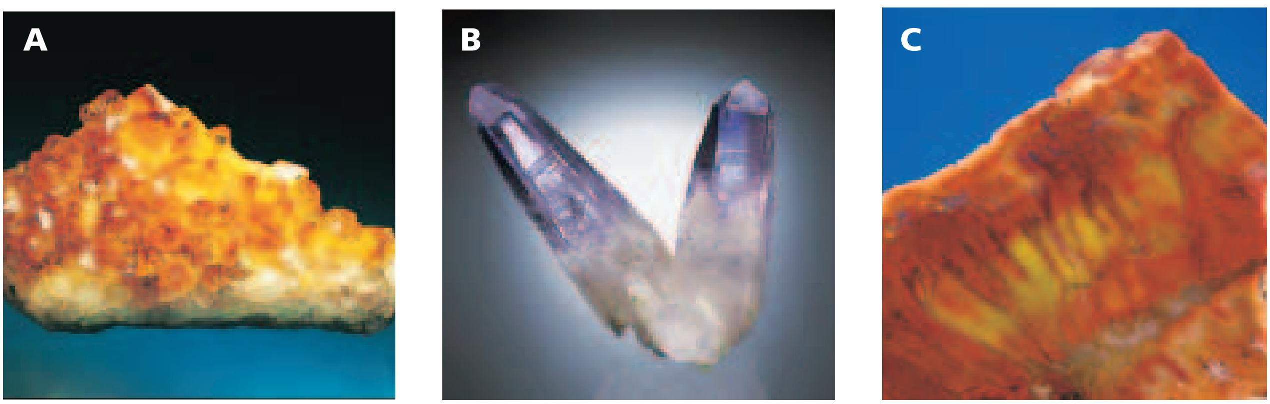
MINERAL IDENTIFICATION

Geologists rely on several relatively simple tests to identify minerals. These tests are based upon a mineral's physical and chemical properties. As you'll see in the *Design Your Own GeoLab* at the end of this chapter, it's usually best to use a combination of tests rather than just one to identify minerals.

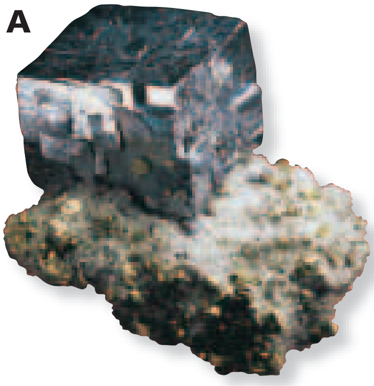
Color One of the most noticeable characteristics of a mineral is its color. Color is sometimes caused by the presence of trace elements or compounds within a mineral. For example, quartz can be found in a variety of colors, as shown in ***Figure 4-8,*** and these different colors are the result of different trace elements in the quartz samples. Red jasper has trace elements of iron oxides, purple amethyst contains ferric iron, orange citrine contains iron hydrates, and rose quartz contains manganese or titanium. The appearance of milky quartz, on the other hand, is caused by the numerous bubbles of gas and liquid trapped within the crystal. In general, color is one of the least reliable clues to a mineral's identity.

Luster The way that a mineral reflects light from its surface is called **luster.** Luster is described as being either metallic or nonmetallic. 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.

Figure 4-8 Orange citrine **(A),** purple amethyst **(B),** and red jasper **(C)** are all varieties of quartz. The different colors are caused by trace elements.



A



B

Figure 4-9 Galena has a metallic luster **(A).** Gypsum has a nonmetallic luster **(B).**

Nonmetallic minerals, such as calcite, gypsum, sulfur, and quartz, do not shine like metals. Their lusters might be described as dull, pearly, waxy, or silky. Differences in luster, shown in ***Figure 4-9,*** are caused by differences in the chemical compositions of minerals.

Texture Texture describes how a mineral feels to the touch. Like luster and color, 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, soapy, or glassy. For example, fluorite has a smooth texture, while the texture of talc is greasy.

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. Sometimes, a mineral's streak does not match the mineral's external color, as shown in ***Figure 4-10.*** For example, pyrite, which is also known as fool's gold because it looks like gold, leaves a greenish-black streak. Gold, on the other hand, leaves a yellow streak. Thus, streak is one of the main tests used to distinguish pyrite from gold.

A mineral's streak rarely changes, even if it is weathered or its external color varies slightly. For example, fluorite can be purple, yellow, green, or blue, but its streak is always white. The streak test can be used only on minerals that are softer than a porcelain plate. Thus, this test cannot be used to identify all minerals.

Figure 4-10 Both gray and black samples of hematite leave rust-colored streaks on a porcelain plate.

Earth Science Online

Topic: Minerals
To find out more about mineral identification, visit the Earth Science Web Site at earthgeu.com

Activity: Choose three minerals. Describe their color, luster, texture, and hardness.

Hardness One of the most useful 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 in which an unknown mineral's hardness can be compared to the known hardnesses 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. Talc is one of the softest minerals and can be scratched by a fingernail; thus, 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; diamond represents 10 on the Mohs scale of hardness. The scale, shown in ***Table 4-3,*** works like this: any mineral with a greater hardness than another mineral will scratch that softer mineral. For example, topaz will scratch quartz but not corundum. Hardness, which is one of the most reliable tests of mineral identification, is determined by the arrangement of a mineral's atoms.

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 by cleavage, geologists count the number of cleaved planes and study the angle or angles between them. For instance, mica, shown in ***Figure 4-11A,*** has perfect cleavage in one direction. It breaks in sheets because of weak atomic bonds, as you learned in the earlier discussion about silica tetrahedrons. Halite has a cubic cleavage,

Table 4-3 Mohs Hardness Scale

	Hardness		Hardness of Common Objects
Talc	1	(softest)	
Gypsum	2		fingernail (2.5)
Calcite	3		piece of copper (3.5)
Fluorite	4		iron nail (4.5)
Apatite	5		glass (5.5)
Feldspar	6		steel file (6.5)
Quartz	7		streak plate (7)
Topaz	8		scratches quartz
Corundum	9		scratches topaz
Diamond	10	(hardest)	scratches all common materials

C

Figure 4-11 Mica has perfect cleavage in one direction **(A).** Quartz breaks along rough or jagged edges **(B).** The rock obsidian fractures into arc-like patterns **(C).**

which means that it breaks in three directions along planes of weak atomic attraction. Quartz, shown in ***Figure 4-11B,*** 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, chalcedony, and the rock obsidian share a unique fracture with arc-like patterns resembling clam shells, as shown in ***Figure 4-11C.*** This is called conchoidal fracture.

Density and Specific Gravity Sometimes, two minerals of the same size may feel quite different when they are lifted—one is much heavier than the other. Differences in weight are the result of differences in density, which is defined as mass per unit of volume. Density is expressed as a ratio of the mass of a substance divided by its volume, or $D = M/V$. Pyrite, for instance, has a density of 5.2 g/cm^3, and gold has a density of 19.0 g/cm^3.

Density reflects the atomic weight and structure of a mineral. Because density is not dependent on the size or shape of a mineral, it is a particularly useful identification tool. Often, however, differences in density are too small to be distinguished by simply lifting different minerals and estimating their perceived weights. 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 weight of a substance to the weight

Figure 4-12 Light is bent in two directions when it passes through a sample of Iceland spar. The refraction creates the appearance of two images.

of an equal volume of water at 4°C. Do the *Problem-Solving Lab* to learn how specific gravity and other mineral properties are used to identify minerals.

Special Properties

Several special properties of minerals also can be used for identification purposes. For instance, the arrangement of atoms in a type of calcite called Iceland spar 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, as shown in ***Figure 4-12.*** This process is known as double refraction. Double refraction is also a property of the mineral zircon.

Calcite exhibits another special property as a result of its chemical composition. Calcite ($CaCO_3$) fizzes when it comes into contact with hydrochloric acid (HCl). HCl reacts with calcite to release CO_2 in the form of bubbling gas. In this reaction, shown below, calcium chloride ($CaCl_2$) also forms.

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

Problem-Solving Lab

Making and Using Tables

Complete a mineral identification table Minerals can be identified by their physical and chemical properties. Common properties include color, streak, hardness, specific gravity, and crystalline structure.

Analysis

1. Copy the data table shown here. Use *Appendix H* to complete the table.
2. Expand the table to include the names of the minerals, information about breakage patterns, and mineral uses.

Thinking Critically

3. Which of these minerals will scratch quartz? How do you know?
4. Which of these minerals might be found in a painting? Which might be found in your desk?
5. What other information could you have included in the table?

Mineral Identification Chart

Mineral Color	Streak	Hardness	Specific Gravity	Crystal System
copper red		3	8.5–9	cubic
	red or reddish brown	6	5.3	hexagonal
pale to golden yellow	yellow			cubic
	colorless	7.5	3.5	
gray, green or white			2.5	triclinic
	colorless		4.0	hexagonal

Other special properties are exhibited by magnetite, an iron ore. Magnetite is naturally magnetic. Lodestone, a form of magnetite, will pick up nails like a magnet, as shown in ***Figure 4-13.*** The mineral sphalerite produces a distinctive rotten-egg odor when it is rubbed vigorously across a streak plate. The smell is the result of the presence of sulfide in the mineral.

Figure 4-13 Magnetite can pick up iron nails because it is naturally magnetic.

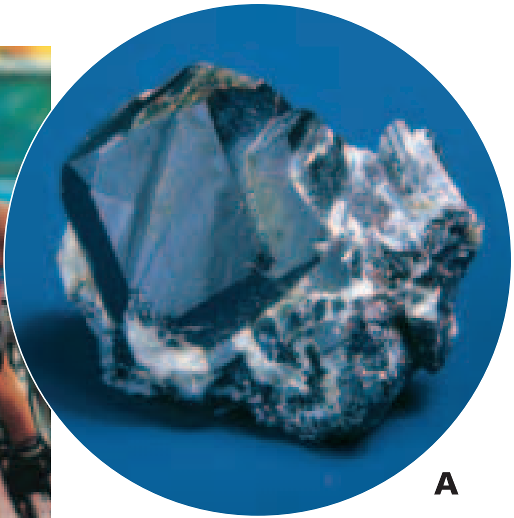
Mineral Uses

There's a good chance that as you read these words, you're sitting on minerals, wearing minerals, and perhaps even eating minerals. Minerals are virtually everywhere. They are used to make computers, cars, televisions, desks, roads, buildings, jewelry, beds, paints, sports equipment, and medicines. This list is by no means exhaustive. In fact, it barely touches upon the many ways in which people use minerals.

Environmental Connection

Ores Many of the items mentioned above are made from ores. A mineral is an **ore** if it contains a useful substance that can be mined at a profit. Hematite, for instance, is a useful ore that contains the element iron. Look around the room. Are any items made of iron? If so, their original source may have been the mineral hematite. Are any items in the room made of aluminum? The element aluminum is found in the ore bauxite. Another mineral and its use are shown in ***Figure 4-14.***

B



A

Figure 4-14 The ore rutile **(A)** contains the element titanium, a durable, lightweight metal often used in sports equipment **(B).**

Figure 4-15 The open-pit mine in the background, located in Carajas, Brazil, is the world's largest iron mine.

Mines Ores that are located deep within Earth's crust are removed by underground mining. Ores that are near Earth's surface are obtained from large, open-pit mines, such as the one shown in ***Figure 4-15.*** When a mine is excavated, unwanted rock and dirt, known as waste material, are dug up along with the valuable ore. The waste material must be separated from the ore before the ore can be used. Removing the waste material can be expensive and, in some cases, harmful to the environment, as you'll learn in later chapters. If the cost of removing the waste material becomes higher than the value of the ore itself, then the mineral will no longer be classified as an ore. It would no longer be economical to mine it.

The classification of a mineral as an ore may also change if the supply of or demand for that mineral changes. Consider a mineral that is used to make computers. Engineers might develop a more efficient design or a less costly alternative material. In either of these cases, the mineral would no longer be used in computers. Demand for the mineral would drop substantially, and the mineral would no longer be considered an ore.

GEMS

What makes a ruby more valuable than mica? Rubies are much rarer and more visually pleasing than mica. Rubies are thus considered gems. **Gems** are valuable minerals that are prized for their rarity and beauty. Gems such as rubies, emeralds, and diamonds are cut, polished, and used for jewelry. ***Figure 4-16*** shows a raw

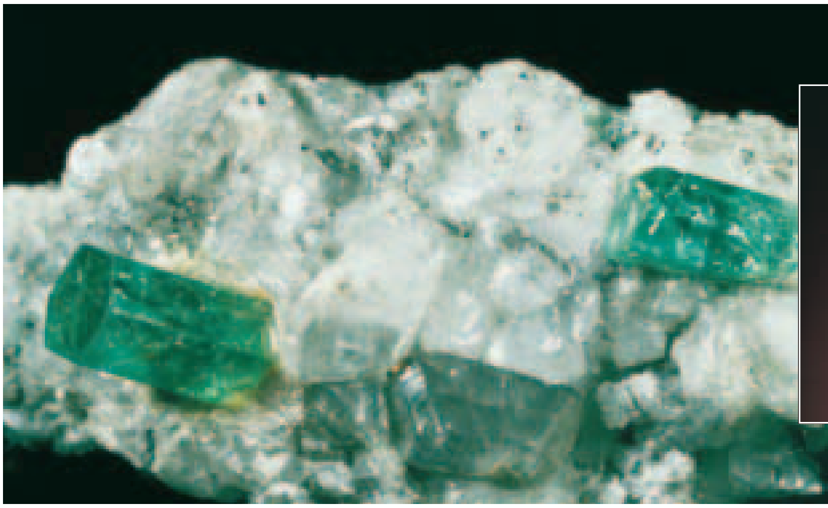



Figure 4-16 A raw emerald can be cut, polished, and used in jewelry. This emerald ring is in the Smithsonian Museum collection.

emerald and a polished emerald. Because of their rareness, rubies and emeralds are actually more valuable than diamonds. You'll learn more about diamonds in the *Science and Math* feature at the end of this chapter.

In some cases, the presence of trace elements can make one variety of a mineral more colorful and thus more prized than other varieties of the same mineral. Amethyst, for instance, is the gem form of quartz. Amethyst contains trace minerals, which give the gem a lovely purple color. The mineral corundum, which is often used as an abrasive, also can be found as rubies and sapphires. Rubies contain trace amounts of chromium; sapphires contain trace amounts of cobalt or titanium.

SECTION ASSESSMENT

1. Explain why color is not a good test for distinguishing between pyrite and gold. What test is most reliable for identifying these two minerals?
2. What is a mineral's texture? List several words that are used to describe texture.
3. Compare and contrast cleavage and fracture. Give an example of a mineral with cleavage and a mineral with fracture.
4. Describe the chemical reaction that takes place when hydrochloric acid comes in contact with calcite.
5. What is the hardness of a mineral if it scratches a penny but will not scratch glass?
6. What is an ore?
7. Why are some minerals classified as gems? List several gems.
8. **Critical Thinking** The mineral fluorite can be found in a variety of colors, yet its streak is always white. Why?

SKILL REVIEW

9. **Making and Using Tables** Use *Appendix H* and reference materials to make a data table that includes examples of minerals with the following special properties: magnetism, double refraction, reaction to acid, and smell. For more help, refer to the *Skill Handbook.*

DESIGN YOUR OWN GeoLab

Making a Field Guide to Minerals

Have you ever used a field guide to identify a bird, flower, rock, or insect? If so, you know that field guides include far more than simply photographs. A typical field guide for minerals might include background information about minerals in general, plus specific information about the formation, properties, and uses of each mineral. In this activity, you'll create a field guide to minerals.

Preparation

Problem

How would you go about identifying minerals? What physical and chemical properties would you test? Which of these properties should be included in a field guide to help others to identify unknown minerals?

Possible Materials

mineral samples
hand lens
glass plate
streak plate
Mohs scale of mineral hardness
5 percent hydrochloric acid (HCl) with dropper
Appendix H
steel file or nail
piece of copper
paper clip
magnet

Hypothesis

As a group, form a hypothesis about which property or properties might be most useful in identifying minerals.

Objectives

In this GeoLab, you will:

- **Conduct** tests on unknown minerals to determine their physical and chemical properties.
- **Identify** minerals based on the results of your tests.
- **Design** a field guide for minerals.

Safety Precautions

Review the safe use of acids. HCl may cause burns. If a spill occurs, rinse your skin with water and notify your teacher immediately.

CONTENTS

Plan the Experiment

1. As a group, list the steps that you will take to test your hypothesis. Keep the available materials in mind as you plan your procedure. Be specific, describing exactly what you will do at each step. Properties that you may want to test include luster, color, reaction to HCl, magnetism, cleavage, fracture, texture, hardness, streak, double refraction, and density.
2. Should you test any of the properties more than once for any of the minerals? How will you determine whether certain properties indicate a specific mineral?
3. Design a data table to summarize your results. You can use this table as the basis for your field guide.
4. Read over your entire experiment to make sure that all steps are in a logical order.
5. Have you included a step for additional research? You may have to use the library or the Earth Science Web Site to gather all the necessary information for your field guide.
6. What information will be included in the field guide? Possible data include how each mineral formed, its uses, its chemical formula, and a labeled photograph or drawing of the mineral.
7. Make sure your teacher approves your plan before you proceed with your experiment.

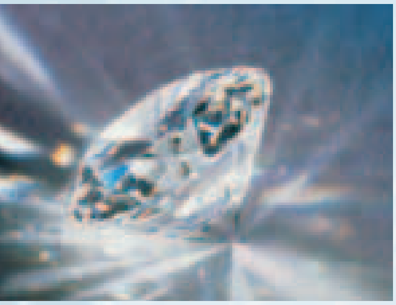
Analyze

1. **Interpreting Results** Which properties were most reliable for identifying minerals? Which properties were least reliable? Discuss reasons why one property is more useful than others.
2. **Defending Your Hypothesis** Was your hypothesis supported? Why or why not?
3. **Thinking Critically** How could you use a piece of paper, a steel knife, and a glass bottle to distinguish between Iceland spar and quartz?
4. **Observing and Inferring** What mineral reacted with the HCl? Why did the mineral bubble? Write the balanced equation that describes the chemical reaction that took place between the mineral and the acid.
5. **Conducting Research** What information did you include in the field guide? What resources did you use to gather your data? Describe the layout of your field guide.

Conclude & Apply

1. Compare and contrast your field guide with those of other groups. How could you improve your field guide?
2. What are the advantages and disadvantages of field guides?
3. Based on your results, is there any one definitive test that can always be used to identify a mineral? Explain.

Science & Math



The Price of Diamonds

For centuries people have valued diamonds for their beauty, sparkle, and hardness. The cost of a diamond in a jewelry store depends mainly on four things, often called the four Cs.

Color and Cut

Diamonds come in many colors. Colorless diamonds cost more than those with a slight yellowish tinge, but stones with a deep, rich color, such as the famous blue Hope Diamond, are the most valued of all. The different colors are caused by minor impurities.

Diamonds are cut into many shapes. Some of the most common shapes are the round brilliant; the rose, which is round with a flat-bottom and pointed top; the marquis, which is an oval with pointed ends; and the emerald cut, which is rectangular with rounded corners. The cut of a diamond affects how it reflects light and thus how much it sparkles. An uncut diamond crystal looks like a greasy piece of glass.

Clarity and Carat Weight

Clarity refers to the presence or absence of visible flaws and impurities in the diamond. A diamond is considered flawless if no such defects are visible under a magnification power of ten. Dozens of minerals occur in diamonds, the most common being olivine, garnet, and clinopyroxene. Bubbles of liquid or gas are also found within diamond crystals.

The weight of a diamond is represented by an ancient unit of measurement called the carat. A carat is 1/5 of a gram, or 1/142 of an ounce. The name probably came from the tropical carob tree, which has quite uniform seeds.

Comparing the Costs

Because the combination of the four *Cs* varies among diamonds, there is no set price for a diamond. A 1-carat diamond may cost $7500. How does that compare with the cost of other items you buy?

Procedure

1. The data table lists some items you may frequently buy, along with their estimated price and mass. Copy the table, then calculate and record the weight in carats of each item.

Challenge

1. Calculate and record the cost per carat of each item in the data table.
2. The price of a 1-carat diamond may be $7500. How much would the items in the data table cost if they were priced at $7500 per carat?

Cost Comparison

Item	Price	Mass (g)	Weight (carats)	Cost/ Carat	Cost at $7500/ carat
music CD	$14.00	16	80	17.5¢	$600,000
magazine	$3.99	148	740	0.5¢	$5.55 million
can of soda	.75¢	355	1775	0.04¢	$13.3 million
gallon of milk	$1.89	3629	18144	0.01¢	$136 million

CONTENTS

CHAPTER 4 Study Guide

Summary

SECTION 4.1

What is a mineral?

Main Ideas

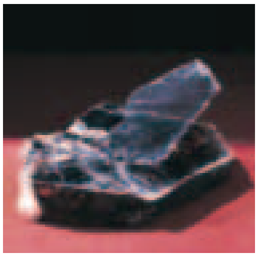
- A mineral is a naturally occurring, inorganic solid with a specific chemical composition and a definite crystalline structure. There are at least 3000 known minerals in Earth's crust.
- A crystal is a solid in which the atoms are arranged in repeating patterns. The six main crystal systems are cubic, tetragonal, hexagonal, orthorhombic, monoclinic, and triclinic.
- Minerals form from magma or from supersaturated solution. Most minerals are formed from the eight most common elements in Earth's crust.
- Oxygen readily combines with other elements to form a diverse group of minerals, including silicates, carbonates, and oxides. A silica tetrahedron is a three-dimensional shape structured like a pyramid. In a silica tetrahedron one silicon atom attaches to four oxygen atoms.
- Other major mineral groups include sulfides, sulfates, halides, and native elements. Native elements such as silver or copper are made of one element only.

Vocabulary

crystal (p. 79)
magma (p. 80)
mineral (p. 77)
silicate (p. 81)

SECTION 4.2

Identifying Minerals



Main Ideas

- 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.
- A mineral's color is generally the result of trace elements within the mineral. Texture describes how a mineral feels, and luster describes how a mineral reflects light. Cleavage and fracture describe how minerals break.
- A mineral's streak, hardness, and density are reliable methods of identification. Special properties of minerals such as magnetism also can be used for identification purposes.
- An ore contains a useful substance that can be mined at a profit. If the cost of mining the ore becomes higher than the value of the ore, then the mineral is no longer classified as an ore. The classification of a mineral as an ore may also change if the supply of or demand for the mineral changes.
- Gems are valuable minerals that are prized for their rarity and beauty. Trace elements can make one variety of a mineral more valuable than other varieties of the same mineral.

Vocabulary

cleavage (p. 86)
fracture (p. 87)
gem (p. 90)
hardness (p. 86)
luster (p. 84)
ore (p. 89)
specific gravity (p. 87)
streak (p. 85)

earthgeu.com/vocabulary_puzzlemaker

CHAPTER 4

Assessment

Understanding Main Ideas

1. How many minerals are found in Earth's crust?
   - **a.** 1000
   - **b.** 2000
   - **c.** 3000
   - **d.** 4000

2. Which of the following is part of the definition of a mineral?
   - **a.** liquid
   - **b.** organic
   - **c.** synthetic
   - **d.** inorganic

3. What element is the most abundant in Earth's crust?
   - **a.** oxygen
   - **b.** aluminum
   - **c.** silicon
   - **d.** potassium

4. What property causes the mineral galena to break into tiny cubes?
   - **a.** its density
   - **b.** the internal arrangement of its atoms
   - **c.** its hardness
   - **d.** its luster

5. What mineral fizzes when it comes in contact with hydrochloric acid?
   - **a.** quartz
   - **b.** calcite
   - **c.** gypsum
   - **d.** fluorite

6. A student rubs a mineral across an unglazed porcelain plate. What mineral property is the student testing?
   - **a.** hardness
   - **b.** luster
   - **c.** color
   - **d.** streak

7. A mineral has a mass of 100 g and a volume of 50 cm^3. What is its density?
   - **a.** 5000 g
   - **b.** 2 g/cm^3
   - **c.** 5 g/cm^3
   - **d.** 150 g/cm^3

8. *Dull, silky, waxy,* and *pearly* are descriptive terms that best describe which property of minerals?
   - **a.** color
   - **b.** luster
   - **c.** streak
   - **d.** cleavage

9. What would you use the Mohs scale of hardness for?
   - **a.** to identify a mineral
   - **b.** to find the mass of a mineral
   - **c.** to calculate the density of a mineral
   - **d.** to determine a mineral's fracture

10. The streak of which mineral is different from its external color?
    - **a.** pyrite
    - **b.** gold
    - **c.** copper
    - **d.** magnetite

11. What is an ore?
    - **a.** a mineral that contains a useful substance
    - **b.** a mineral found in food
    - **c.** a mineral that has streak, but no color
    - **d.** a mineral for which there is no demand

12. Why do some minerals attract magnets? What are some other special properties of minerals?

13. What property do the minerals copper, galena, magnetite, and pyrite have in common? Use *Appendix H* for help.

14. Why do minerals have different crystal shapes? Give examples of minerals that exhibit each of the six main crystal systems.

15. Sapphires and rubies are both forms of the mineral corundum, but they are different colors. Why?

Test-Taking Tip

STOCK UP ON SUPPLIES Bring all your test-taking tools: pencils, pens, erasers, correction fluid, a sharpener, a ruler, a calculator, and a protractor. Bring munchies, too. You might not be able to eat in the testing room, but healthy snacks come in handy during outside breaks.

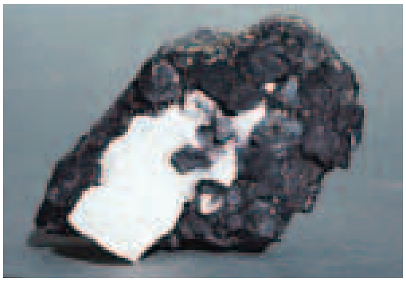
earthgeu.com/chapter_test

Assessment

Applying Main Ideas

16. A student places a clean, transparent sample of Iceland spar on top of the word *geology* in a textbook. How will the word *geology* appear to the student? Explain.

17. Use *Appendix H* to identify the mineral in the photo below. It contains iron, has a metallic luster, and has a streak that is the same color as the mineral itself.



18. Make a data table that compares and contrasts the chemical and physical properties of graphite and diamond. Use *Appendix H* and reference materials for help.

19. Calculate the density of copper if the volume of a sample is 30 cm^3 and the mass is 267 g.

Thinking Critically

20. Topaz will not leave a streak on an unglazed porcelain plate. Why? What method could you use to observe the streak of topaz?

21. Other than diamond, what mineral would be best for making a sandpaper product? Why? Use *Appendix H* for help.

22. Infer how early prospectors used density to determine whether they had found gold or pyrite.

23. When would a mineral no longer be an ore? Explain.

Standardized Test Practice

1. What is the second most abundant element in Earth's crust?
a. magma **c.** silicon
b. oxygen **d.** carbon

Use the table below to answer questions 2–3.

Mineral Characteristics

Mineral	Hardness	Specific Gravity	Luster/ Color
Feldspar	6–6.5	2.5–2.8	nonmetallic/ colorless or white
Fluorite	4	3–3.3	nonmetallic/ yellow, blue, purple, rose, green, or brown
Galena	2.5–2.75	7.4–7.6	metallic/ grayish black
Quartz	7	2.65	nonmetallic/ colorless in pure form

2. What is the hardest mineral in the table?
a. feldspar **c.** galena
b. fluorite **d.** quartz

3. Which mineral most likely has a shiny appearance?
a. feldspar **c.** galena
b. fluorite **d.** quartz

4. Which is the most reliable clue to a mineral's identity?
a. color **c.** hardness
b. streak **d.** luster