2 Minerals

Big idea

Earth's Materials and Systems

Q: What are minerals and why are they important?

VIRGINIA SCIENCE STANDARDS OF LEARNING

ES.1.a, ES.4.a, ES.4.b. **See lessons for details.**

The structures in this cave are giant natural crystals of the mineral gypsum. They formed about 300 meters below the desert in northern Mexico. The geologist is wearing a suit that protects against the high temperature (50°C) of the cave.

INQUIRY
TRY IT!

HOW ARE A GROUP OF MINERALS ALIKE AND DIFFERENT?

Procedure

1. Obtain several mineral samples from your teacher. Examine them closely.
2. Design a data table in which you can record your observations.
3. Record at least three ways that the samples are alike. Also record three ways that the samples are different.
4. Classify the minerals into two groups based on your observations. Give reasons for your classification scheme.
5. Put on safety goggles. Gently strike each sample with a hammer and observe the pieces of each sample. If necessary, use these results to reclassify the minerals into two groups.

Think About It

1. **Observe** What kinds of characteristics did you observe in all of the samples?
2. **Compare and Contrast** How did the samples differ?
3. **Classify** Each of the minerals you just observed belongs to a different group. Design a scheme for how these minerals might be classified into four different groups.

2.1 Matter

Key Questions

What is an element?

What particles make up atoms?

What are isotopes?

What are compounds and why do they form?

How do chemical bonds differ?

Vocabulary

- element • atomic number
- energy level • isotope
- mass number • compound
- chemical bond • ion
- ionic bond • covalent bond
- metallic bond

Reading Strategy

Compare and Contrast
Copy the graphic organizer. As you read, complete the organizer to compare and contrast protons, neutrons, and electrons.

Protons	Electrons	Neutrons
Differences		
Similarities		

YOU AND EVERYTHING else in the universe are made of matter. *Matter* is anything that has volume and mass. On Earth, matter usually exists in one of three states—solid, liquid, or gas. A solid is a type of matter that has a definite shape and a definite volume. Rocks are examples of solids. A liquid is matter that has a definite volume, but not a definite shape. Earth's oceans, rivers, and lakes are liquids. A gas is matter that has neither a definite shape nor a definite volume. Earth's atmosphere contains gases.

Elements and the Periodic Table

You may already know the names of several elements. For example, carbon, oxygen, and gold. **An element is a substance that cannot be broken down into simpler substances by chemical or physical means.** There are more than 100 known elements, and new elements continue to be discovered. Of these, about 90 occur naturally; the others are produced in laboratories.

The elements have been organized by their properties in a table called the periodic table, which is shown in **Figure 2** later in this lesson. You see from the table that the name of each element is represented by a symbol consisting of one, two, or three letters. Symbols provide a shorthand way of representing an element. Each element is also known by a number called its atomic number, which is shown above each symbol on the table. For example, the atomic number of carbon is 6, oxygen is 8, and gold is 79. You will learn more about atomic number on the next page.

The rows in the periodic table are called periods. The number of elements in a period varies. Period 1, for example, contains only two elements. These elements are hydrogen (H) and helium (He). Period 2 contains the elements lithium (Li) through neon (Ne). Periods 4 and 5 each contain 18 elements while Period 6 includes 32 elements.

The columns in the periodic table are called groups. Note that there are 18 groups. All the elements within a group have similar physical and chemical properties.

The most common elements found on Earth's surface are listed in **Table 1.** Six of these eight elements are classified as metals. Metals have specific properties such as the ability to be shaped and drawn into wire. Metals are also good conductors of heat and electricity. These common elements in Table 1 combine in thousands of ways with other elements to form all the materials found on Earth.

Atoms

All elements are made of atoms. **An *atom* is the smallest particle of an element that retains the characteristics of that element.** An atom is so small it can only be viewed using highly specialized instruments.

Atoms consist of smaller particles called subatomic particles. The major subatomic particles are protons, neutrons, and electrons. The central core of an atom is called the *nucleus*. *Protons* are subatomic particles with a positive charge that are found in the nucleus. *Neutrons* are subatomic particles with no charge that are also found in the nucleus. *Electrons*, which are subatomic particles with negative electrical charges, surround the nucleus of an atom.

Subatomic particles are not unique to any specific element. For example, a proton found in a hydrogen atom is essentially the same as a proton found in an atom of any other element.

Table 1 Most Common Elements on Earth's Surface

Element	Approximate Percentage by Weight
Oxygen (O)	46.6
Silicon (Si)	27.7
Aluminum (Al)	8.1
Iron (Fe)	5.0
Calcium (Ca)	3.6
Sodium (Na)	2.8
Potassium (K)	2.6
Magnesium (Mg)	2.1
All others	1.7

Source: Data from Brian Mason.

Protons and Neutrons

A proton has about the same mass as a neutron. Hydrogen atoms have only a single proton in their nuclei. Some types of atoms contain more than 100 protons. The number of protons in the nucleus of an atom is called the **atomic number.** All atoms with six protons, for example, are carbon atoms. Likewise, every atom with eight protons is an oxygen atom.

The number of neutrons in the nucleus can vary. For example, all atoms of carbon have six protons. However, some carbon atoms have six neutrons, other carbon atoms have seven neutrons, and still others have eight or more neutrons.

Atoms have the same number of protons and electrons. Carbon atoms have six protons and therefore six electrons. Oxygen atoms have eight protons, with eight electrons surrounding the nucleus.

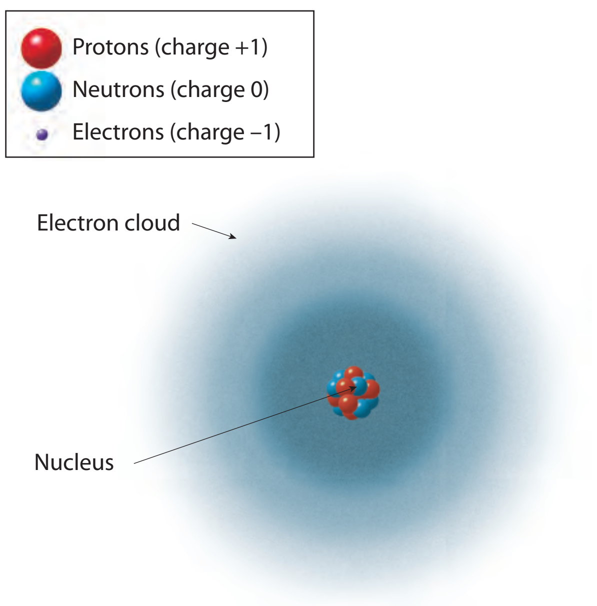
Electrons

An electron is the smallest of the three subatomic particles in an atom. Each electron has a mass of about 1/1840 the mass of a proton or a neutron. Electrons rapidly move about the nucleus in a sphere-shaped negative zone. You can picture moving electrons by imagining a cloud of negative charges surrounding the nucleus, as shown in **Figure 1.** At any one moment in time the electrons will be located somewhere within that cloud.

Electrons occupy regions called **energy levels.** Each energy level contains a certain number of electrons. Interactions among electrons in the highest energy levels explains how atoms chemically combine with other atoms.

Reading Checkpoint *How are electrons, protons, and neutrons alike and how are they different?*

FIGURE 1 Electron Cloud Model of an Atom Electrons can be located anywhere within a cloud-like sphere surrounding the nucleus. Notice that the cloud is denser near the nucleus.
Draw Conclusions ***What do you think this means about the chance of finding electrons near the nucleus compared with the outer edges of the sphere?***



VISUAL SUMMARY

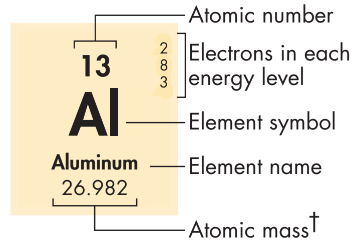
PERIODIC TABLE OF THE ELEMENTS

FIGURE 2 Categories of Elements

Metals—elements that are good conductors of heat and electric current

Nonmetals—elements that are poor conductors of heat and electric current

Metalloids—elements with properties that are somewhat similar to metals and nonmetals



†The atomic masses in parentheses are the mass numbers of the longest-lived isotope of elements for which a standard atomic mass cannot be defined.

Period	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B
1	1 **H** Hydrogen 1.0079 1								
2	3 **Li** Lithium 6.941 2 1	4 **Be** Beryllium 9.0122 2 2							
3	11 **Na** Sodium 22.990 2 8 1	12 **Mg** Magnesium 24.305 2 8 2							
4	19 **K** Potassium 39.098 2 8 8 1	20 **Ca** Calcium 40.08 2 8 8 2	21 **Sc** Scandium 44.956 2 8 9 2	22 **Ti** Titanium 47.90 2 8 10 2	23 **V** Vanadium 50.941 2 8 11 2	24 **Cr** Chromium 51.996 2 8 13 1	25 **Mn** Manganese 54.938 2 8 13 2	26 **Fe** Iron 55.847 2 8 14 2	27 **Co** Cobalt 58.933 2 8 15 2
5	37 **Rb** Rubidium 85.468 2 8 18 8 1	38 **Sr** Strontium 87.62 2 8 18 8 2	39 **Y** Yttrium 88.906 2 8 18 9 2	40 **Zr** Zirconium 91.22 2 8 18 10 2	41 **Nb** Niobium 92.906 2 8 18 12 1	42 **Mo** Molybdenum 95.94 2 8 18 13 1	43 **Tc** Technetium (98) 2 8 18 14 1	44 **Ru** Ruthenium 101.07 2 8 18 15 1	45 **Rh** Rhodium 102.91 2 8 18 16 1
6	55 **Cs** Cesium 132.91 2 8 18 18 8 1	56 **Ba** Barium 137.33 2 8 18 18 8 2	71 **Lu** Lutetium 174.97 2 8 18 32 9 2	72 **Hf** Hafnium 178.49 2 8 18 32 10 2	73 **Ta** Tantalum 180.95 2 8 18 32 11 2	74 **W** Tungsten 183.85 2 8 18 32 12 2	75 **Re** Rhenium 186.21 2 8 18 32 13 2	76 **Os** Osmium 190.2 2 8 18 32 14 2	77 **Ir** Iridium 192.22 2 8 18 32 15 2
7	87 **Fr** Francium (223) 2 8 18 32 18 8 1	88 **Ra** Radium (226) 2 8 18 32 18 8 2	103 **Lr** Lawrencium (262) 2 8 18 32 32 9 2	104 **Rf** Rutherfordium (261) 2 8 18 32 32 10 2	105 **Db** Dubnium (262) 2 8 18 32 32 11 2	106 **Sg** Seaborgium (263) 2 8 18 32 32 12 2	107 **Bh** Bohrium (264) 2 8 18 32 32 13 2	108 **Hs** Hassium (265) 2 8 18 32 32 14 2	109 **Mt** Meitnerium (268) 2 8 18 32 32 15 2

Elements 104–118 are the transactinide elements.

57 **La** Lanthanum 138.91 2 8 18 18 9 2	58 **Ce** Cerium 140.12 2 8 18 20 8 2	59 **Pr** Praseodymium 140.91 2 8 18 21 8 2	60 **Nd** Neodymium 144.24 2 8 18 22 8 2	61 **Pm** Promethium (145) 2 8 18 23 8 2	62 **Sm** Samarium 150.4 2 8 18 24 8 2

Lanthanide Series

89 **Ac** Actinium (227) 2 8 18 32 18 9 2	90 **Th** Thorium 232.04 2 8 18 32 18 10 2	91 **Pa** Protactinium 231.04 2 8 18 32 20 9 2	92 **U** Uranium 238.03 2 8 18 32 21 9 2	93 **Np** Neptunium (237) 2 8 18 32 22 9 2	94 **Pu** Plutonium (244) 2 8 18 32 24 8 2

Actinide Series

Representative Elements

- Alkali Metals
- Alkaline Earth Metals
- Other Metals
- Metalloids
- Nonmetals
- Noble Gases

Transition Elements

- Transition metals
- Inner transition metals

- C Solid
- Br Liquid
- He Gas
- Tc Not found in nature

10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
								2 He Helium 4.0026 (2)
			5 B Boron 10.81 (2 3)	6 C Carbon 12.011 (2 4)	7 N Nitrogen 14.007 (2 5)	8 O Oxygen 15.999 (2 6)	9 F Fluorine 18.998 (2 7)	10 Ne Neon 20.179 (2 8)
			13 Al Aluminum 26.982 (2 8 3)	14 Si Silicon 28.086 (2 8 4)	15 P Phosphorus 30.974 (2 8 5)	16 S Sulfur 32.06 (2 8 6)	17 Cl Chlorine 35.453 (2 8 7)	18 Ar Argon 39.948 (2 8 8)
28 Ni Nickel 58.71 (2 8 16 2)	29 Cu Copper 63.546 (2 8 18 1)	30 Zn Zinc 65.38 (2 8 18 2)	31 Ga Gallium 69.72 (2 8 18 3)	32 Ge Germanium 72.59 (2 8 18 4)	33 As Arsenic 74.922 (2 8 18 5)	34 Se Selenium 78.96 (2 8 18 6)	35 Br Bromine 79.904 (2 8 18 7)	36 Kr Krypton 83.80 (2 8 18 8)
46 Pd Palladium 106.4 (2 8 18 18)	47 Ag Silver 107.87 (2 8 18 18 1)	48 Cd Cadmium 112.41 (2 8 18 18 2)	49 In Indium 114.82 (2 8 18 18 3)	50 Sn Tin 118.69 (2 8 18 18 4)	51 Sb Antimony 121.75 (2 8 18 18 5)	52 Te Tellurium 127.60 (2 8 18 18 6)	53 I Iodine 126.90 (2 8 18 18 7)	54 Xe Xenon 131.30 (2 8 18 18 8)
78 Pt Platinum 195.09 (2 8 18 32 17 1)	79 Au Gold 196.97 (2 8 18 32 18 1)	80 Hg Mercury 200.59 (2 8 18 32 18 2)	81 Tl Thallium 204.37 (2 8 18 32 18 3)	82 Pb Lead 207.2 (2 8 18 32 18 4)	83 Bi Bismuth 208.98 (2 8 18 32 18 5)	84 Po Polonium (209) (2 8 18 32 18 6)	85 At Astatine (210) (2 8 18 32 18 7)	86 Rn Radon (222) (2 8 18 32 18 8)
110 Ds Darmstadtium (269) (2 8 18 32 32 17 1)	111 Rg Roentgenium (272) (2 8 18 32 32 18 1)	112 Cn Copernicium (277) (2 8 18 32 32 18 2)	113 *Uut Ununtrium (284) (2 8 18 32 32 18 3)	114 *Uuq Ununquadium (289) (2 8 18 32 32 18 4)	115 *Uup Ununpentium (288) (2 8 18 32 32 18 5)	116 *Uuh Ununhexium (293) (2 8 18 32 32 18 6)	117 *Uus Ununseptium Classification pending	118 *Uuo Ununoctium (299) (2 8 18 32 32 18 8)

*Discovery reported but not verified

63 Eu Europium 151.96 (2 8 18 25 8 2)	64 Gd Gadolinium 157.25 (2 8 18 25 9 2)	65 Tb Terbium 158.93 (2 8 18 27 8 2)	66 Dy Dysprosium 162.50 (2 8 18 28 8 2)	67 Ho Holmium 164.93 (2 8 18 29 8 2)	68 Er Erbium 167.26 (2 8 18 30 8 2)	69 Tm Thulium 168.93 (2 8 18 31 8 2)	70 Yb Ytterbium 173.04 (2 8 18 32 8 2)
95 Am Americium (243) (2 8 18 32 25 8 2)	96 Cm Curium (247) (2 8 18 32 25 9 2)	97 Bk Berkelium (247) (2 8 18 32 27 8 2)	98 Cf Californium (251) (2 8 18 32 28 8 2)	99 Es Einsteinium (252) (2 8 18 32 29 8 2)	100 Fm Fermium (257) (2 8 18 32 30 8 2)	101 Md Mendelevium (258) (2 8 18 32 31 8 2)	102 No Nobelium (259) (2 8 18 32 32 8 2)

Isotopes

Atoms of the same element always have the same number of protons. For example, every carbon atom has 6 protons. Carbon is element number 6 on the periodic table. But the number of neutrons for atoms of the same element can vary. **Atoms with the same number of protons but different numbers of neutrons are isotopes of an element.** Isotopes of the same element are labeled using a convention called the mass number and with the element's name or symbol. The **mass number** of an atom is the total mass of the atom expressed in atomic mass units (amu). A proton and a neutron each have a mass of one amu. Recall that the mass of an electron is so small that the number of electrons has no effect on the mass number of an atom. Therefore, an atom's mass number is the sum of the masses of the protons and neutrons in its nucleus.

Carbon has 15 different isotopes. Models for three of these are shown in **Figure 3.** Carbon-12 makes up almost 99 percent of all carbon on Earth. Carbon-12 has 6 protons and 6 neutrons. Carbon-13 makes up much of the remaining naturally occurring carbon atoms on Earth. Carbon-13 has 6 protons and 7 neutrons. Carbon-14, with 6 protons and 8 neutrons, is relatively rare.

The nuclei of most atoms are stable. However, many elements have atoms whose nuclei are unstable. Such atoms disintegrate through a process called *radioactive decay*. During radioactive decay, unstable atoms give off nergy and particles. Carbon-14 is an example of a radioactive isotope.

In nature, radioactive decay occurs at a constant rate. For example, it takes 5730 years for one half of any size sample of carbon-14 to decay. Since the rate of decay is measurable, radioactive atoms can be used to determine the ages of fossils, rocks, and minerals. Since the element carbon is found in living things, carbon-14 is used to determine the age of many fossils.

Reading Checkpoint *What are isotopes?*

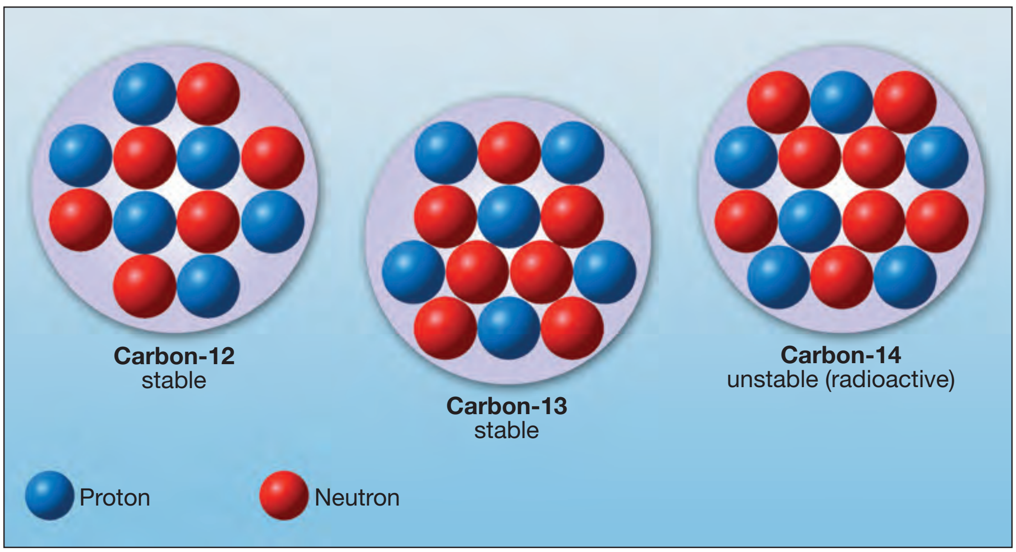


FIGURE 3 Nuclei of Isotopes of Carbon These three isotopes of carbon occur naturally. The remaining dozen isotopes of carbon are manufactured in laboratories.

Compare and Contrast *How are the nuclei of these isotopes the same, and how do they differ?*

Why Atoms Bond

Most matter exists in nature as a chemical combination of two or more elements. Chemical combinations of elements are called compounds. **A compound is a substance that consists of two or more elements that are chemically combined in specific proportions.** For example, the elements sodium and chlorine combine to form a compound called sodium chloride.

The elements in a compound are held together by forces called **chemical bonds.** Chemical bonds involve the interaction between negative electrons and positive nuclei. When two or more elements combine to form compounds, the atoms of the elements gain, lose, or share electrons.

Some elements are more reactive than others. The most reactive elements are found in Groups 1 and 17. The more reactive an element is, the more likely it will combine with another element and form a compound.

The most stable (least reactive) elements are found in Group 18. These elements are stable largely because their highest energy levels contain the maximum number of electrons. Reactive elements form compounds in order to make their electron structures more like the elements in Group 18. **When an atom's highest energy level does not contain the maximum number of electrons, the atom is likely to form a chemical bond with one or more other atoms.**

Look at **Figure 4.** It shows the shorthand way of representing the number of electrons in the highest energy level. Electrons in the highest energy level are sometimes called *valence electrons*. For example, neon has eight valence electrons, which is the maximum number of electrons in the highest energy level. So neon, argon, and krypton are stable elements. Most of the other elements in the table have incomplete highest energy levels. This means these elements are reactive and would be most likely to form chemical bonds. The principal types of chemical bonds are ionic bonds, covalent bonds, and metallic bonds.

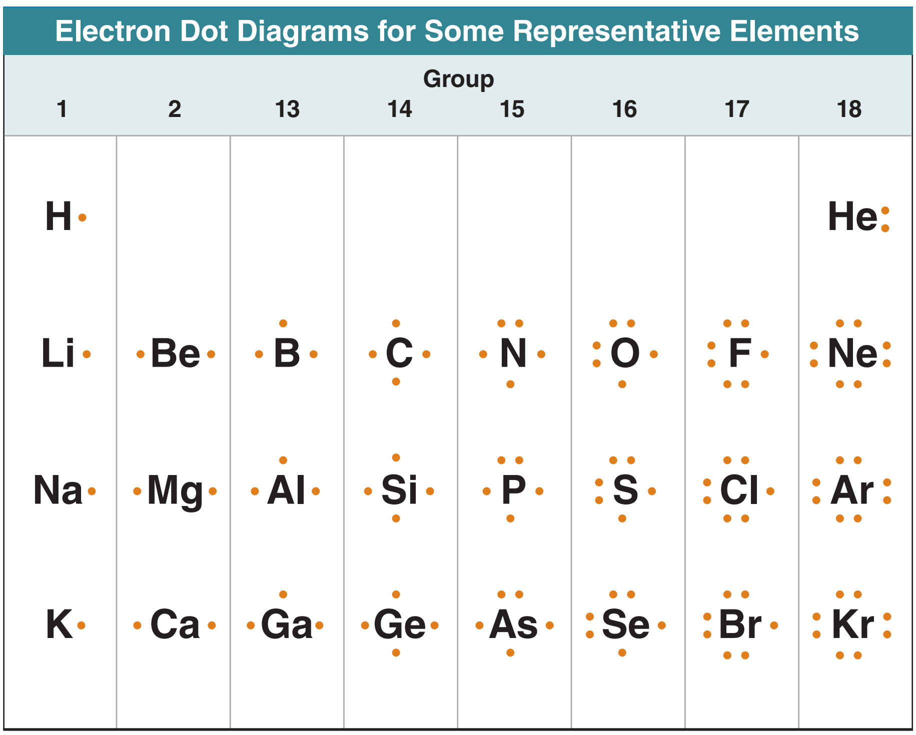


FIGURE 4 Electron Dot Diagrams In an electron dot diagram, each dot represents an electron in the atom's highest energy level. These electrons are sometimes called valence electrons. **Observe** *How many valence electrons do sodium (Na) and chlorine (Cl) have?*

Types of Chemical Bonds

Ionic Bonds If an atom loses an electron, it has more protons than electrons. This results in a positive charge. An atom that gains one or more electrons has more electrons than protons. This results in a negative charge. An atom that possesses an electric charge is called an **ion**. Opposite charges attract. So, ions with positive charges are attracted to ions with negative charges. **Ionic bonds form between positive and negative ions.**

Compounds that contain ionic bonds are called *ionic compounds*. Sodium chloride, or table salt, is an example of an ionic compound. Salt forms when sodium (Na) reacts with chlorine (Cl) as shown in **Figure 5.** Sodium is very unstable and reactive. Sodium atoms lose one electron and become positive ions. Chlorine atoms gain one electron and become negative ions. These oppositely charged ions are attracted to each other and form the compound sodium chloride.

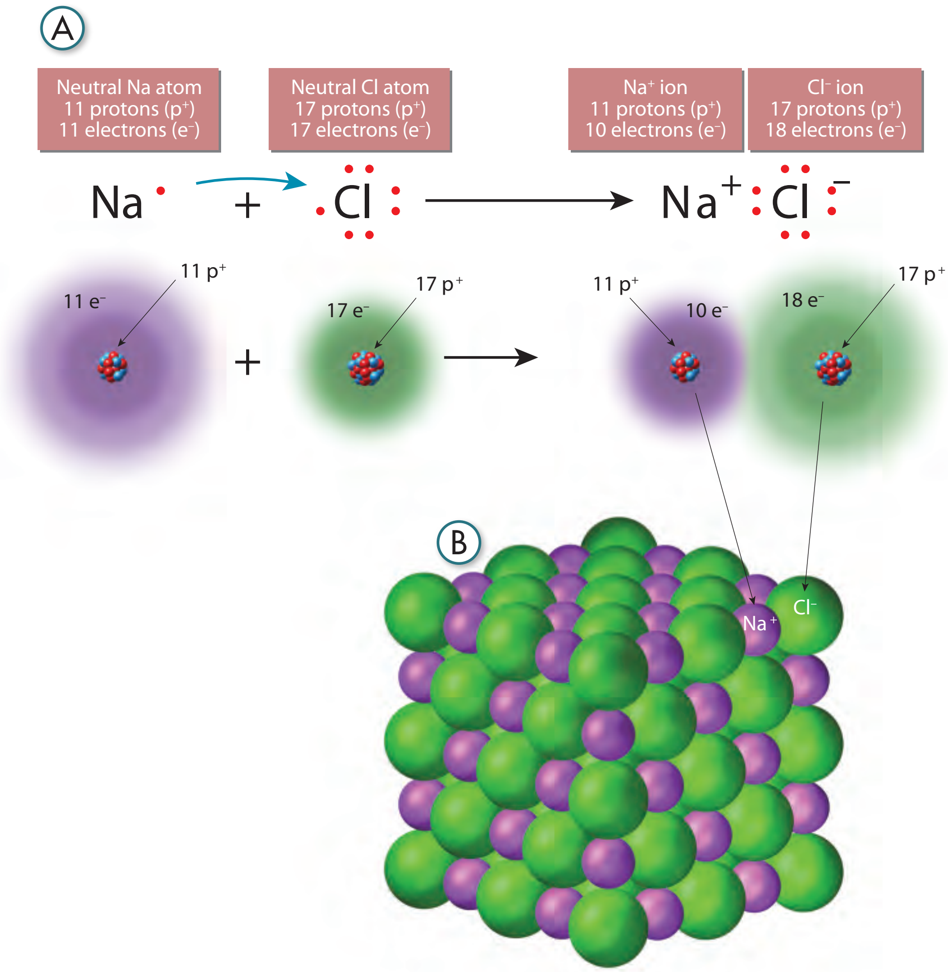
The properties of a compound are different from the properties of the elements in the compound. Sodium is a soft, silvery metal that reacts vigorously with water. If you held it in your hand, sodium could burn your skin. Chlorine is a green poisonous gas. When chemically combined, these atoms produce table salt, the familiar crystalline solid that is used to flavor food.

Reading Checkpoint *What happens when two or more atoms form an ionic bond?*

VISUAL SUMMARY

FORMATION OF SODIUM CHLORIDE

FIGURE 5 **A** Sodium atoms transfer one electron each to the highest energy levels of chlorine atoms. Both ions now have filled highest energy levels. **B** The positive and negative ions attract each other and form a crystalline solid with a rigid structure.



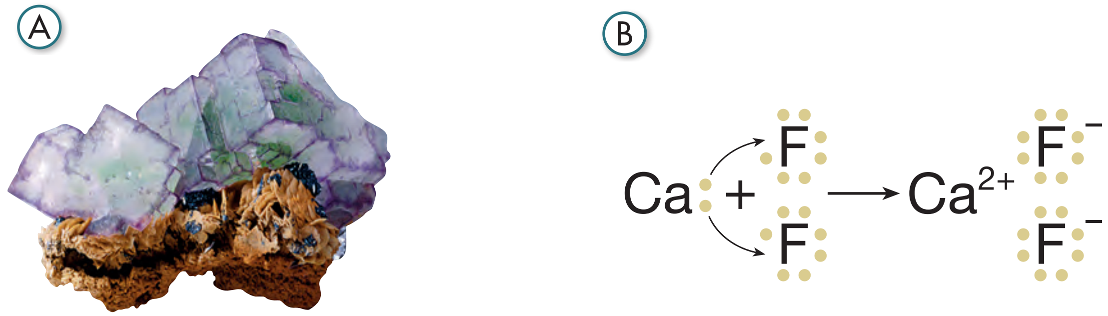


FIGURE 6 Ionic Compound
A Calcium flouride is an ionic compound that forms when calcium reacts with fluorine.
B The dots shown with the element's symbol represent the electrons in the highest energy levels of the ions.

Explain *What happens to the electrons in calcium atoms and fluorine atoms when calcium flouride forms?*

Figure 6 shows calcium fluoride, another common ionic compound. Our model for ionic bonding suggests that one calcium atom transfers two electrons from its highest energy level to two atoms of fluorine. This transfer gives all atoms the right numbers of electrons in their highest energy levels.

Ionic compounds are rigid solids with high melting and boiling points. These compounds are poor conductors of electricity in their solid states. When melted, however, many ionic compounds are good conductors of electricity. Most ionic compounds consist of elements from Groups 1 and 2 on the periodic table reacting with elements from Groups 16 and 17.

☑ **Reading Checkpoint** *What are some properties of ionic compounds?*

Covalent Bonds

Covalent bonds form when atoms share electrons. Compounds with covalent bonds are called *covalent compounds*. **Figure 7A** on the next page shows silicon dioxide (quartz), one of the most common covalent compounds on Earth. Silicon dioxide forms when one silicon atom and two oxygen atoms share electrons in their highest energy levels.

Covalent compounds generally have different properties than ionic compounds. For example, while ionic compounds have high melting and boiling points, many covalent compounds have low melting and boiling points. Sodium chloride, an ionic compound, boils at 1413°C. Water, a covalent compound, boils at 100°C. Covalent compounds also are poor conductors of electricity, even when melted.

The smallest particle of a covalent compound that shows the properties of that compound is a molecule. A *molecule* is a neutral group of atoms joined by one or more covalent bonds. Water, for example, consists of molecules. These molecules are made of two hydrogen atoms covalently bonded to one oxygen atom. The many gases that make up Earth's atmosphere, including hydrogen, oxygen, nitrogen, and carbon dioxide, also consist of molecules.

In a molecule, each atom exerts a pulling force on the electrons that are being shared. When the atoms in a molecule pull equally on the shared electrons, the electrons are shared equally. Molecules of hydrogen (H_2), oxygen (O_2), and chlorine (Cl_2) are examples of covalent bonds with equally shared electrons.

However, in some covalent bonds the electrons are not shared equally. **Figure 7B** shows a model of a molecule of water—one example of covalent bonds with unequal electron sharing. In a water molecule, an oxygen and two hydrogen atoms are pulling on the shared electrons. But the pulling force of oxygen is greater than the pulling force of hydrogen. As a result, the shared electrons are being pulled away from the hydrogen atoms toward the oxygen atom. The hydrogen atoms gain a slight positive charge. And the oxygen atom gains a slight negative charge. The unequal sharing of electrons results in a weak positive side and a weak negative side of the molecule.

Look again at the model of the water molecule below. Notice that the two hydrogen atoms are located on one side of the oxygen atom. So the water molecule can be said to have a hydrogen side and an oxygen side. Since the oxygen atom has a slight negative charge, the oxygen side of the water molecule has a weak negative pole. Conversely, the hydrogen atoms have a slight positive charge so the hydrogen side of the water molecule has a weak positive pole. A covalent bond that produces a molecule with negative and positive poles is called a *polar bond*.

Polar bonds give molecules unique properties. For example, many different kinds of compounds dissolve in water. Water's ability to dissolve compounds is related to the polar bonds in water molecules. Other examples of molecules with polar bonds are hydrogen chloride (HCl) and ammonia (NH_3).

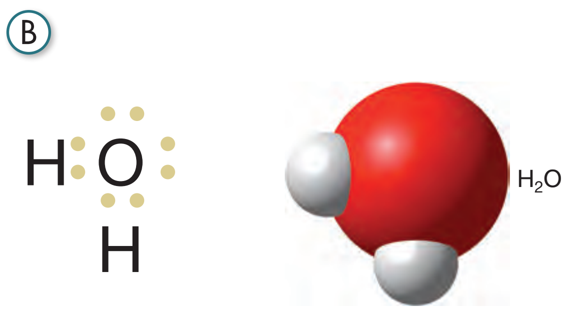


FIGURE 7 Examples of Covalent Bonds—
A Quartz is a covalent compound that forms when oxygen and silicon atoms bond.

B Water forms when hydrogen and oxygen share electrons.

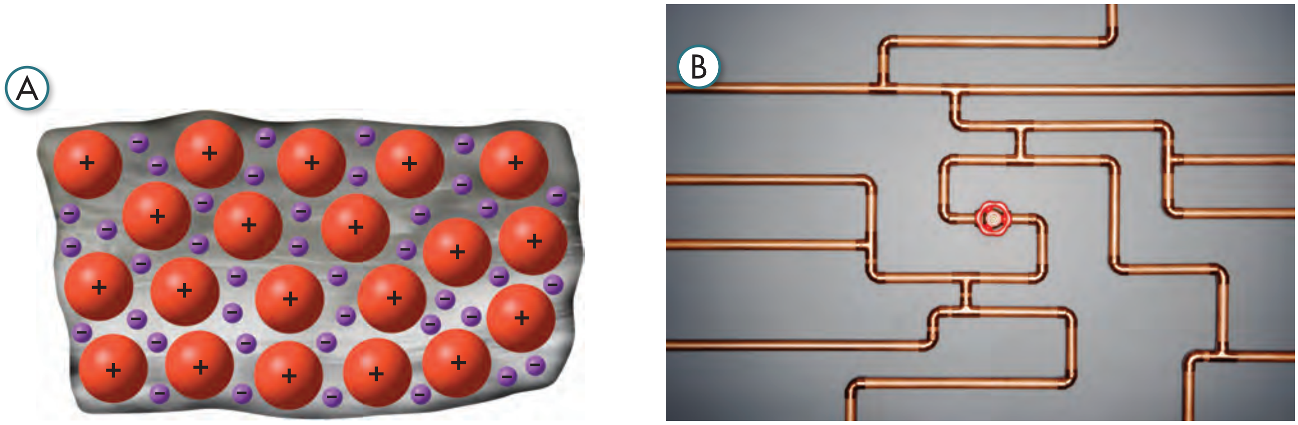


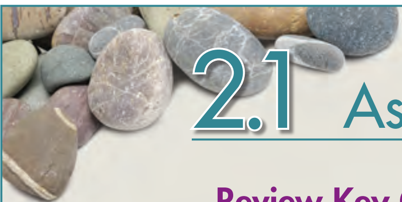
FIGURE 8 Metallic Bonds

A Metals form bonds when metallic atoms share electrons.

B Metallic bonds give metals, such as copper, their characteristic properties. Metals can be easily shaped and pulled into wire.

Metallic Bonds **Metallic bonds form when electrons are shared by metal ions.** A model for this kind of bond is shown in **Figure 8A**. Sharing a pool of electrons gives metals their characteristic properties. Using the model you can see how an electrical current is easily carried through the pool of electrons. If electrons were added to one end of a metal, other electrons leave the opposite end.

Metals are malleable, which means that they can be easily shaped. You've observed this property when you wrapped aluminum foil around food or crushed an aluminum can. Metals are also ductile, meaning that they can be drawn into thin wires without breaking. The wiring in your school or home is probably made of the metal copper. Metals are excellent conductors of electricity.



2.1 Assessment

Review Key Concepts

1. What is an element?
2. What kinds of particles make up atoms?
3. What are isotopes?
4. What are compounds and how do they form?
5. Contrast ionic, covalent, and metallic bonds.

Think Critically

6. **Compare and Contrast** Compare and contrast solids, liquids, and gases.
7. **Apply Concepts** Which elements in Table 1 are metals?
8. **Apply Concepts** A magnesium atom has two valence electrons. A chlorine atom needs one electron to fill its highest energy level. If magnesium reacts with chlorine, which type of bond will most likely form? Explain.
9. **Apply Concepts** Which elements in the periodic table might combine with oxygen to form compounds similar to magnesium oxide (MgO)?

MATH PRACTICE

10. **Interpret Data** The isotopes of carbon have 2 to 16 neutrons. Use this information to make a table that shows the 15 isotopes of carbon and the atomic number and mass number of each.

2.2 Minerals

ES.4 The student will investigate and understand how to identify major rock-forming and ore minerals based on physical and chemical properties. Key concepts include **a.** hardness, color and streak, luster, cleavage, fracture, and unique properties; and **b.** uses of minerals.

Key Questions

What are five characteristics of a mineral?

What processes result in the formation of minerals?

How can minerals be classified?

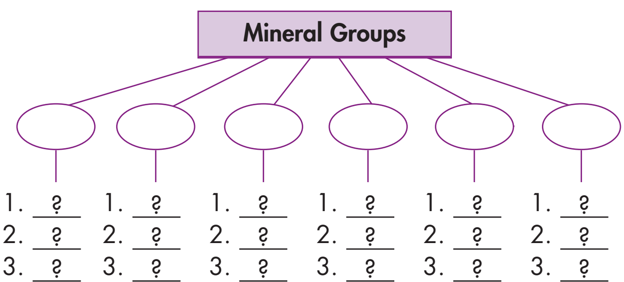
What are some of the major groups of minerals?

Vocabulary

- mineral
- silicate
- silicon-oxygen tetrahedron

Reading Strategy

Preview Copy the organizer below. Skim the material on mineral groups on pages 47 to 49. Place each group name into one of the ovals in the organizer. As you read this section, complete the organizer with characteristics and examples of each major mineral group.



LOOK AT THE SALT shaker in **Figure 9B.** Did you know that each part of the salt shaker, including the salt, is made of elements or compounds that either are minerals or that are obtained from minerals? In fact, practically every manufactured product that you might use in a typical day contains materials obtained from minerals. What minerals do you probably use regularly? The "lead" in your pencils is actually a soft lack mineral called graphite. Most body powders and many kinds of make-up contain fi ely ground bits of the mineral talc. Your dentist's drill bits contain tiny pieces of the mineral diamond. It is hard enough to drill through your tooth enamel. The mineral quartz is the main ingredient in the windows in your school and the drinking glasses in your family's kitchen. What do all of these minerals have in common? How do they differ?

FIGURE 9 Many Objects Are Made From Minerals A Table salt is the mineral halite. **B** Glass is made from the mineral quartz. The aluminum top comes from bauxite.

Minerals

A dictionary provides several defi itions for "mineral." In Earth science, the term has a specific meaning. **A mineral is a naturally occurring, inorganic solid with an orderly crystalline structure and a defin te chemical composition.** All minerals share the following characteristics:

1. **Naturally occurring** A mineral forms by natural geologic processes. Therefore, synthetic gems (made by people), such as synthetic diamonds and rubies, are not considered minerals.
2. **Solid substance** Minerals are solids within the temperature ranges that are normal for Earth's surface.
3. **Orderly crystalline structure** The atoms of minerals are arranged in an orderly and repetitive manner and form crystals. Halite and opal contain the same elements. Halite is a mineral because it has a definite crystal structure. Opal does not have an orderly internal structure, so opal is not a mineral.
4. **Defin te chemical composition** Most minerals are chemical compounds made of two or more elements. For example, halite is a compound containing one sodium atom and one chlorine atom ($NaCl$). A few minerals, such as gold and silver, consist of a single element (native form).
5. **Generally considered inorganic** Most minerals are inorganic crystalline solids found in nature. Halite (table salt) is an example. However, sugar, another crystalline solid, is not a mineral because it is an organic compound. Sugar comes from sugar beets or sugar cane. Many marine animals secrete inorganic compounds, such as calcium carbonate (calcite). The shell of a clam is an example. Calcite is considered a mineral, even though it comes from an animal.

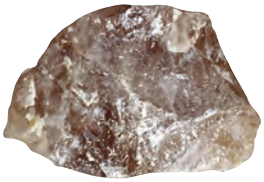
How Minerals Form

Minerals form under a wide variety of conditions. For example, minerals called silicates often form deep under Earth's surface where temperatures and pressures are very high. Most of the minerals known as carbonates form in warm, shallow ocean waters. Most clay minerals form at or near Earth's surface when existing minerals are exposed to weathering. Still other minerals form when rocks are subjected to changes in pressure or temperature. **There are four major processes by which minerals form: crystallization from magma, precipitation, changes in pressure and temperature, and formation from hydrothermal solutions.**

Crystallization From Magma Magma is molten rock that forms deep within Earth. As magma cools, elements combine to form minerals such as those shown in **Figure 10** on the next page. The fi st minerals to crystallize from magma are usually those rich in iron, calcium, and magnesium. As minerals continue to form, the composition of the magma changes. Minerals rich in sodium, potassium, and aluminum then form.

FIGURE 10 Minerals From Magma These minerals can form from crystallization of magma.

Feldspar



Quartz

Muscovite

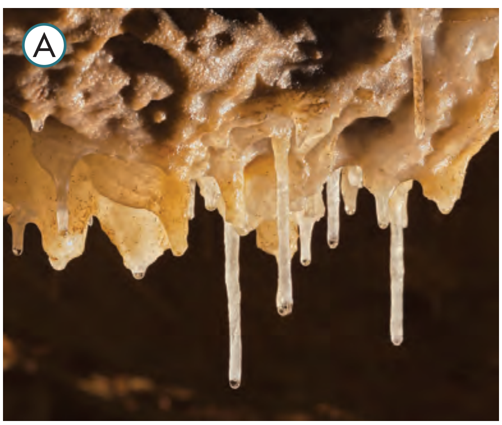
Hornblende

Precipitation The water in Earth's lakes, rivers, ponds, oceans, and beneath its surface contains many dissolved substances. When this water evaporates, some of the dissolved substances can react to form minerals. Changes in water temperature may also cause dissolved material to precipitate out of a body of water. Generally, as water temperature increases, the amount of dissolved material in the water can increase. But when water temperature decreases, the maximum amount of dissolved material in water decreases. As the water cools, the minerals are left ehind, or *precipitated,* out of the water. Two common minerals that form in this way are shown in **Figure 11.**

Pressure and Temperature Some minerals, including talc and muscovite, form when existing minerals are subjected to changes in pressure and temperature. An increase in pressure can cause a mineral to recrystallize while still solid. The atoms are simply rearranged to form more compact minerals. Changes in temperature can also cause certain minerals to become unstable. Under these conditions, new minerals form, which are stable at the new temperature. Before a method for manufacturing sheet glass was invented, sheets of muscovite were mined and used in buildings as window panes. Today, muscovite has many uses, including as windows in wood stoves.

Hydrothermal Solutions A hydrothermal solution is a very hot mixture of water and dissolved substances. Hydrothermal solutions have temperatures between about 100°C and 300°C. When these solutions come into contact with existing minerals, chemical reactions take place that form new minerals. Also, when such solutions cool, some of the elements in them combine to form minerals such as quartz and pyrite. The sulfur minerals in the sample shown in **Figure 12** formed from thermal solutions.

☑ **Reading Checkpoint** *Describe what happens when a mineral is subjected to changes in pressure or temperature.*



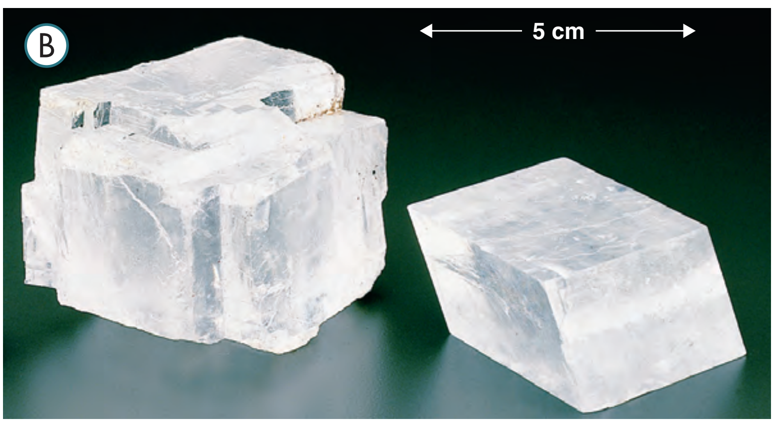


FIGURE 11 Minerals From Precipitation
A This limestone cave formation is an obvious example of precipitation.

B Halite and calcite are also formed by precipitation.

Mineral Groups

Over 4000 minerals have been named, and several new ones are identifi d each year. Only a few dozen, however, are known as common minerals. **Common minerals, together with the thousands of others that form on Earth, can be classified into groups based on their composition.** Some of the more common mineral groups include silicates, carbonates, oxides, sulfates and sulfides, alides, and native elements.

FIGURE 12 Minerals From Hydrothermal Solutions Bornite (blue and purple) and chalcopyrite (gold) are sulfur minerals that form from hydrothermal solutions.

Silicates

Silicon and oxygen are the most abundant elements on Earth's surface. **Silicon and oxygen combine to form a structure called the silicon-oxygen tetrahedron.** The **silicon-oxygen tetrahedron** is a structure composed of four oxygen atoms surrounding a central silicon atom. The structure is shown in **Figure 13A.** **Silicates** are minerals that have the silicon-oxygen tetrahedron as their basic structure. Silicates are the most abundant groups of minerals on Earth. The tetrahedron provides the framework of every silicate mineral. Except for a few silicate minerals, such as pure quartz, most silicates also contain one or more other elements.

Silicon-oxygen tetrahedra can join in a variety of ways, as you can see in **Figure 14** on the next page. Silicon-oxygen bonds are very strong. Some minerals, such as olivine, are made of millions of single tetrahedra. In minerals such as augite, the tetrahedra join to form single chains. Double chains are formed in minerals such as hornblende. Micas are silicates in which the tetrahedra join to form sheets. Three-dimensional structures are found in silicates such as quartz and feldspar. As you will see, the internal structure of a mineral affects its properties.

PLANET DIARY

For links to learn more about **Minerals,** visit PlanetDiary.com/HSES.

Reading Checkpoint *What is the silicon-oxygen tetrahedron, and in how many ways can it combine?*

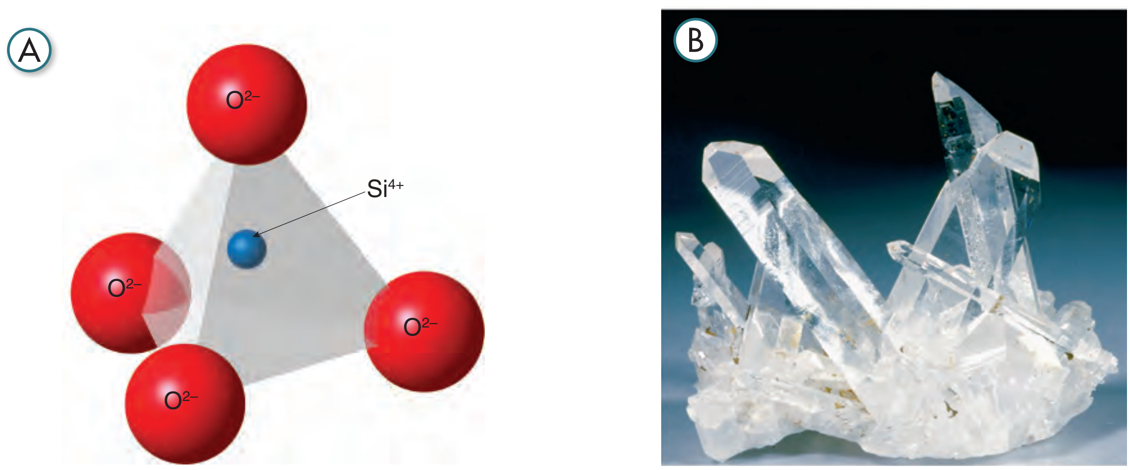
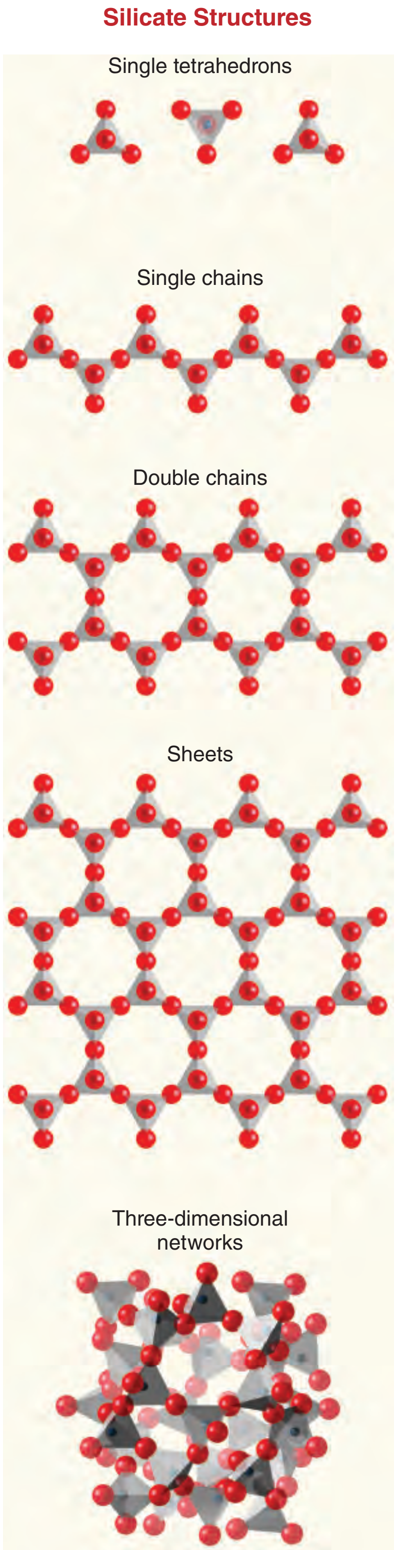


FIGURE 13 The Silicon-Oxygen Tetrahedron
A A tetrahedron is a shape with four triangular faces. The silicon-oxygen tetrahedron has one silicon atom in the middle and an oxygen atom at each of the four corners.

B Quartz is the most common silicate mineral. A typical piece of quartz like this contains millions of silicon-oxygen tetrahedra.

FIGURE 14 Silicate Structures
Silicate structures are chains, sheets, and three-dimensional networks.
Form a Hypothesis ***What type of chemical bond is formed by silicon atoms in an SiO_4 tetrahedron?***



Recall that most silicate minerals crystallize from magma as it cools. This cooling can occur at or near Earth's surface, where temperatures and pressures are relatively low. The formation of silicates can also occur at great depths, where temperatures and pressures are high. The place of formation and the chemical composition of the magma determine which silicate minerals will form. For example, the silicate olivine crystallizes at temperatures of about 1200°C. Quartz crystallizes at about 700°C.

Some silicate minerals form at Earth's surface when existing minerals are exposed to weathering. Clay minerals, which are silicates, form this way. Other silicate minerals form under the extreme pressures that occur with mountain building. Therefore, silicate minerals can often provide scientists with clues about the conditions in which the minerals formed.

To date, more than 800 silicate minerals have been identified and they make up more than 90 percent of Earth's surface. All the remaining minerals are sometimes grouped together and classified as nonsilicates. The nonsilicates include carbonates, oxides, sulfates and sulfides, halides, and the native elements.

Carbonates Carbonates are the second most common mineral group. **Carbonates are minerals that contain the elements carbon, oxygen, and one or more other metallic elements.** Calcite ($CaCO_3$), which contains the metal calcium, is the most common carbonate mineral. Many marine animals secrete the mineral calcite. Dolomite is another carbonate mineral that contains magnesium and calcium. Both limestone and marble are rocks composed of carbonate minerals. Both types of rock are used in building and construction.

Oxides **Oxides are minerals that contain oxygen and one or more other elements, which are usually metals.** Some oxides, including the mineral called rutile (TiO_2), form as magma cools deep beneath Earth's surface. Rutile is titanium oxide. Other oxides, such as corundum (Al_2O_3), form when existing minerals are subjected to changes in temperature and pressure. Corundum is aluminum oxide. Still other oxides, such as hematite (Fe_2O_3), form when existing minerals are exposed to oxygen in the presence of water or moisture in the air. Hematite is one form of iron oxide.

Sulfates and Sulfides **Sulfates and sulfides are minerals that contain the element sulfur.** Sulfates, including anhydrite ($CaSO_4$) and gypsum ($CaSO_4 \bullet 2H_2O$), form when mineral-rich waters evaporate. Sulfides, which include the minerals galena (PbS), sphalerite (ZnS), and pyrite (FeS_2), often form from thermal, or hot-water, solutions. **Figure 15** shows two of these sulfides.

Halides **Halides are minerals that contain a halogen ion plus one or more other elements.** Halogens are elements from Group 17 of the periodic table. This group includes the elements fluorine (F) and chlorine (Cl). The mineral halite (NaCl), table salt, is a common halide. Fluorite (CaF_2) is also a common halide and is used in making steel. It forms when salt water evaporates.

Native Elements **Native elements are minerals that only contain one element or type of atom.** You are probably familiar with some native elements, such as gold (Au), silver (Ag), copper (Cu), sulfur (S), and carbon (C). The reason that native metals are so rare is that most metal atoms readily combine with the abundant element oxygen and form oxides.

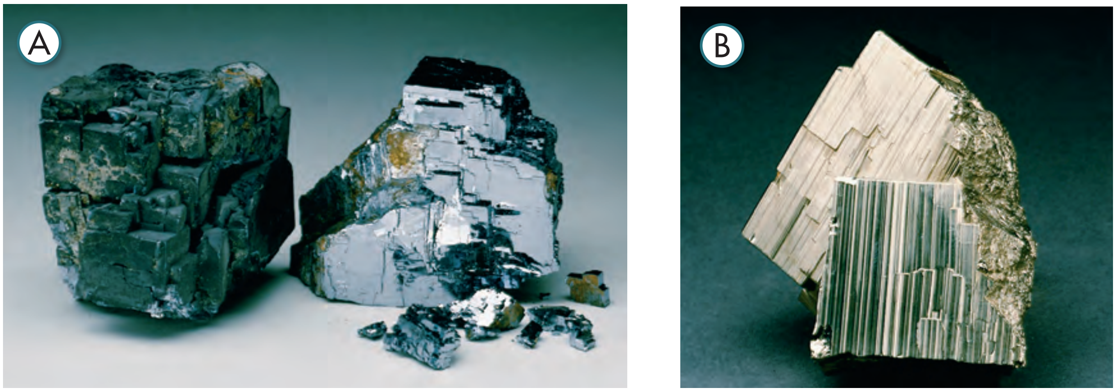
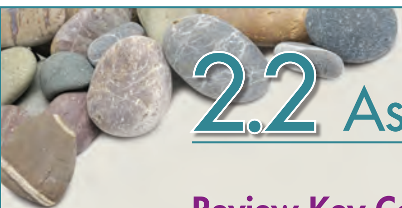


FIGURE 15 Sulfides
A Galena is a sulfide mineral that can be mined for its lead.
B Pyrite, another sulfide, is often called fool's gold.



2.2 Assessment

Review Key Concepts

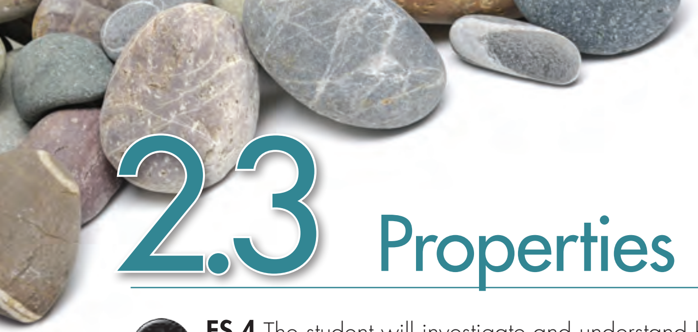
1. What are five characteristics of a mineral?
2. Describe four processes that result in the formation of minerals.
3. How can minerals be classified?
4. Name the major groups of minerals, and give at least two examples of minerals in each group.

Think Critically

5. **Compare and Contrast** Compare and contrast sulfates and sulfides.
6. **Draw Conclusions** When hit with a hammer, quartz shows an uneven breakage pattern. Using Figure 14, what can you suggest about its structure?
7. **Apply Concepts** To which mineral group does each of the following minerals belong: bornite (Cu_5FeS_4), cuprite (Cu_2O), magnesite ($MgCO_3$), and barite ($BaSO_4$)?

BIGIDEA EARTH'S MATERIALS AND SYSTEMS

8. **Explain** Write a paragraph that describes what minerals are. Be sure to include the five characteristics that all minerals share.



2.3 Properties of Minerals

ES.4 The student will investigate and understand how to identify major rock-forming and ore minerals based on physical and chemical properties. Key concepts include **a.** hardness, color and streak, luster, cleavage, fracture, and unique properties; and **b.** uses of minerals.

Key Questions

What properties can be used to identify minerals?

What is the Mohs scale?

What are some distinctive properties of minerals?

Vocabulary

- streak • luster
- crystal form • hardness
- Mohs scale • cleavage
- fracture • density

Reading Strategy

Outline Before you read, make an outline of this section, following the format below. Use the orange headings as the main topics. As you read, add supporting details.

I. Properties of Minerals
   A. Color
      1. ____________
      2. ____________
   B. Streak
      1. ____________
      2. ____________

AS YOU CAN SEE from the photographs in this chapter, minerals occur in different colors and shapes. Minerals also vary in the way they reflect light and in the way in which they break. Some minerals are harder than others and some minerals smell like rotten eggs. Still other minerals attract objects containing iron. All of these characteristics, or properties, of minerals can be used to identify them.

Color

One of the fi st things you might notice about a mineral is its color. While color is unique to some minerals, this property is often not useful in identifying many minerals. **Small amounts of different elements can give the same mineral different colors.** You can see examples of this in **Figure 16.**

FIGURE 16 Color Small amounts of different elements give these sapphires their distinct colors.
Observe *Why is color often not a useful property in mineral identification?*

Streak

Streak is the color of a mineral in its powdered form. Streak is obtained by rubbing a mineral across a streak plate, a piece of unglazed (rough) porcelain. While the color of a mineral may vary from sample to sample, the streak usually doesn't. Therefore, streak can be a good indicator.

Luster

Luster is used to describe how light is reflected from the surface of a mineral. Minerals that have the appearance of metals, regardless of their color, are said to have a metallic luster. The piece of copper shown in **Figure 17A** has a metallic luster. Minerals with a nonmetallic luster are described by many adjectives. These include vitreous or glassy, like the quartz crystals in Figure 13B. Other types of mineral luster include pearly, silky, and earthy. Diamond, shown in **Figure 17B,** has an adamantine, or brilliant, luster. Some minerals appear somewhat metallic and are said to have a sub-metallic luster. Streak can also show the difference between minerals with metallic lusters and minerals with nonmetallic lusters. Metallic minerals generally have a dense, dark streak. Minerals with nonmetallic lusters do not have such streaks.

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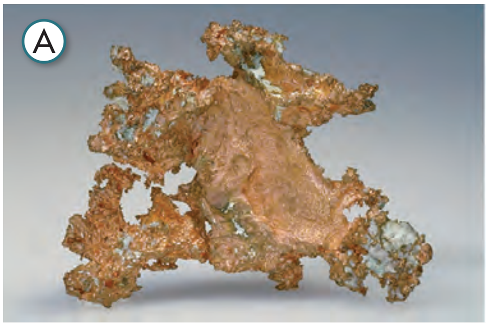


FIGURE 17 Luster
A The mineral copper has a metallic luster. **B** The brilliant luster of diamond is also known as an adamantine luster.

Crystal Form

A *crystal* is a three-dimensional, orderly arrangement of atoms. This arrangement gives minerals their shape. **Crystal form is the visible expression of a mineral's internal arrangement of atoms.** Every mineral has a crystal form based on one of six distinct crystal systems. All the minerals that belong to a given crystal system have crystals of the same shape. For example, fluorite in **Figure 18** belongs to the cubic crystal system. Quartz has hexagonal (six-sided) crystals and belongs to the hexagonal crystal system.

Usually, when a mineral forms slowly and without space restrictions, it will develop into a crystal with well-formed faces—sides, top, and bottom. Most of the time, however, minerals compete for space. This crowding results in an intergrown mass of small crystals. When this happens, the crystal form is not as noticeable.

FIGURE 18 Crystal Form Fluorite often forms cubic crystals.

Reading Checkpoint *What two conditions produce crystals with well-defined faces?*

Hardness

When you think of minerals, you probably imagine substances that are fairly hard. But, did you know that you can scratch some minerals with your fi gernail? The scratch test is one method used to identify minerals. **Hardness** is a measure of the resistance of a mineral to being scratched. You can identify the hardness of a mineral by rubbing it against another object of known hardness. One object will scratch the other, unless both objects have the same hardness.

Geologists use a standard hardness scale called the Mohs scale. **The Mohs scale consists of 10 index minerals arranged from 10 (hardest) to 1 (softest).** The Mohs scale of hardness is illustrated in **Figure 19.** Notice that some of the index minerals are talc, calcite, and quartz. Any mineral of unknown hardness can be rubbed against these index minerals to determine its hardness. Other objects can also be used to determine hardness. Your fi gernail, for example, has a hardness of 2.5. A copper penny has a hardness of 3.5. A piece of glass has a hardness of about 5.5. Look again at Figure 19. The mineral gypsum, which has a Mohs hardness of 2, can be easily scratched by your fi gernail. The mineral calcite, which resembles gypsum, has a hardness of 3. Calcite cannot be scratched by your fi gernail. Calcite, which can resemble the mineral quartz, cannot scratch glass, because its hardness is less than 5.5. Quartz, the hardest of the common minerals with a Mohs hardness of 7, will scratch a glass plate. Diamond, the hardest mineral on Earth, can scratch any other mineral.

Reading Checkpoint *Describe three or four of the most useful properties for identifying unknown minerals.*

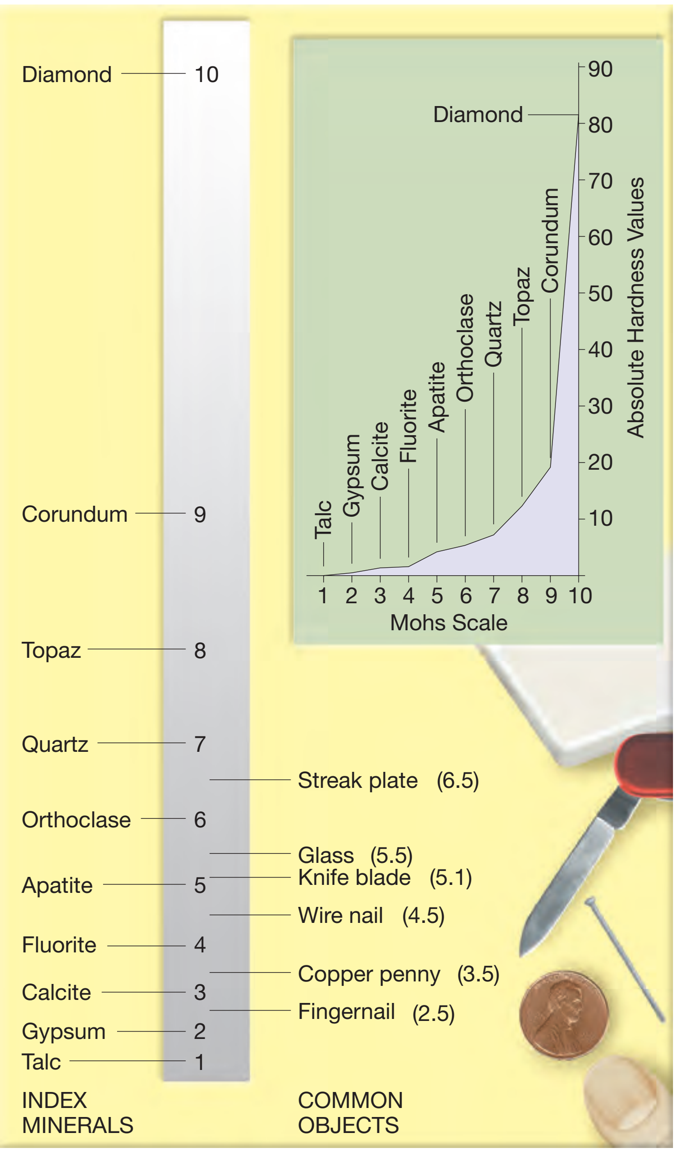


FIGURE 19
Mohs Scale of Hardness
Common objects can be used with the Mohs scale to determine mineral hardness.
Interpret Graphs *A mineral has a hardness of 4.2. Which common items on the chart will that mineral scratch?*

Cleavage

In the atomic structure of a mineral, some bonds are weaker than others. These weak bonds are places where a mineral will break when it is stressed. **Cleavage is the tendency of a mineral to cleave, or break, along flat, even surfaces.**

Minerals called micas show the simplest type of cleavage. Because the micas have weak bonds in one direction, they cleave to form thin, flat sheets, as shown in **Figure 20A.** Look again at Figure 14. Can you see the relationship between mica's internal structure and the cleavage it shows? Mica, and all other silicates, tend to cleave between the silicon-oxygen structures rather than across them. This is because the silicon-oxygen bonds are strong. The sheet structure of mica causes the mineral to cleave into flat plates.

Some minerals have cleavage in more than one direction. Look back at Figure 11. Halite has three directions of cleavage. The cleavage planes of halite meet at 90-degree angles. Calcite also has three directions of cleavage. The cleavage planes of calcite, however, meet at 75-degree angles.

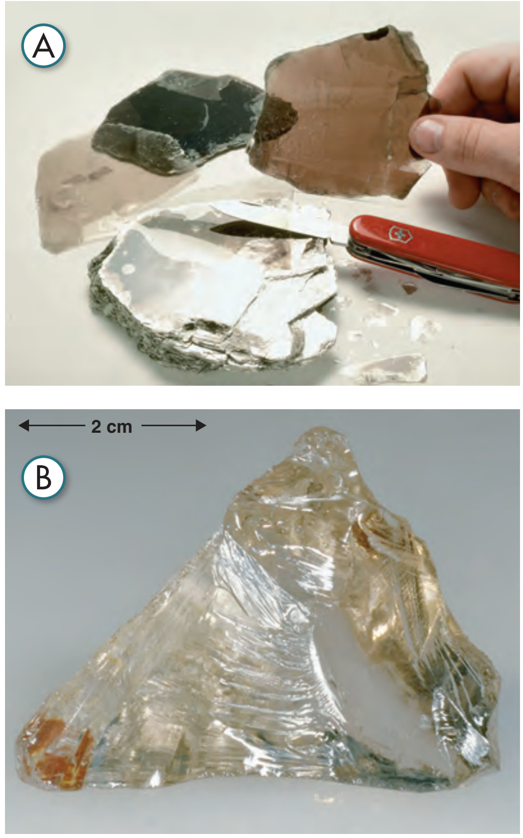


FIGURE 20 Cleavage and Fracture A Mica has cleavage in one direction and therefore cleaves into thin sheets. **B** The bonds in quartz are very strong in all directions, causing quartz to display conchoidal fracture.

Fracture

Minerals that do not show cleavage when broken are said to fracture. Fracture is the uneven breakage of a mineral. Both mica and quartz contain silicon-oxygen bonds. However, quartz has equally strong silicon-oxygen bonds in all directions. Therefore, quartz fractures instead of cleaving like the micas. Like cleavage, there are different kinds of fracture. Minerals that break into smooth, curved surfaces like the quartz in **Figure 20B** have a curved, glassy (conchoidal) fracture. Other minerals, such as asbestos, break into splinters or fibers. Many minerals have an irregular fracture.

Reading Checkpoint *How are cleavage and fracture different?*

Density

Density is a property of all matter and is the ratio of an object's mass to its volume. Density is a ratio and can be expressed using the following equation.

$$\frac{mass\ (m)}{Volume\ (V)} = Density\ (D)$$

Suppose a sample of lead, for example, has a mass of 113 grams and a volume of 10 cubic centimeters. You can calculate the density of lead by dividing its mass by its volume—113 grams divided by 10 cubic centimeters equals 11.3 grams per cubic centimeter. Several different samples of the same pure mineral will have the same density. So, density can be used to help identify minerals. For example, suppose you had an unknown sample and you determined its density was 7.5 g/cm^3. You could use the chart on the next page to determine which mineral this sample might be.

Table 2 Some Common Minerals and Their Properties					
Name	**Chemical Formula and Mineral Group**	**Common Color(s)**	**Density (g/cm^3)**	**Hardness**	**Comments**
Quartz	SiO_2 silicates	colorless, milky white, pink, brown	2.65	7	glassy luster; conchoidal fractures
Orthoclase feldspar	$KAlSi_3O_8$ silicates	white to pink	2.57	6	cleaves in two directions at 90°
Plagioclase feldspar	$(Na,Ca)AlSi_3O_8$ silicates	white to gray	2.69*	6	cleaves in two directions at 90°; striations common
Galena	PbS sulfides	metallic silver	7.5*	2.5	cleaves in three directions at 90°; lead gray streak
Pyrite	FeS_2 sulfides	brassy yellow	5.02	6–6.5	fractures; forms cubic crystals; greenish-black streak
Sulfur	S native elements	yellow	2.07*	1.5–2.5	fractures; yellow streak smells like rotten eggs
Fluorite	CaF_2 halides	colorless, purple	3.18	4	perfect cleavage in three directions; glassy luster
Olivine	$(Mg,Fe)_2SiO_4$ silicates	green, yellowish-green	3.82*	6.5–7	fractures; glassy luster; often has granular texture
Calcite	$CaCO_3$ carbonates	colorless, gray	2.71	3	bubbles with HCl; cleaves in three directions
Talc	$Mg_3Si_4O_{10}(OH)_2$ silicates	pale green, gray, white	2.75*	1	pearly luster; feels greasy; cleaves in one direction
Gypsum	$CaSO_4 \cdot 2H_2O$ sulfates	colorless, white, gray	2.32	2	glassy or pearly luster; cleaves in three directions
Muscovite mica	$KAl_3Si_3O_{10}(OH)_2$ silicates	colorless in thin sheets to brown	2.82*	2–2.5	silky to pearly luster; cleaves in one direction to form flexible sheets

* Average density of the mineral

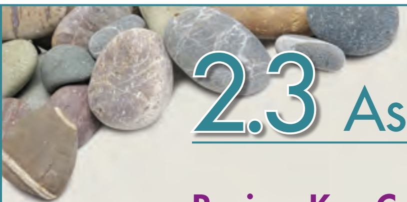
FIGURE 21 An Example of Distinctive Properties
Calcite shows the property of double refraction.

Distinctive Properties of Minerals

Some minerals can be recognized by other distinctive properties. Talc and graphite, for example, both have distinctive feels. Talc feels soapy. Graphite feels greasy. Metallic minerals, such as gold, silver, and copper, are easily shaped. Some minerals, such as magnetite and hematite, are magnetic. Magnetite will attract paper clips and small nails. When a piece of transparent calcite is placed over printed material, the lines appear doubled, as **Figure 21** shows. This property is called double refraction. Streaks of a few minerals that contain sulfur smell like rotten eggs. A droplet of hydrochloric acid will cause carbonate minerals, such as calcite, to fizz.

A mineral's properties depend on the elements that make up the mineral (its composition) and how the atoms are arranged (its structure). **Table 2** lists some of the more common minerals and their properties.

Table 2 Some Common Minerals and Their Properties, *continued*					
Name	**Chemical Formula and Mineral Group**	**Common Color(s)**	**Density (g/cm^3)**	**Hardness**	**Comments**
Biotite mica	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$ silicates	dark green to brown to black	3.0*	2.5–3	perfect cleavage in one direction to form flexible sheets
Halite	$NaCl$ halides	colorless, white	2.16	2.5	has a salty taste; dissolves in water; cleaves in three directions
Augite	$(Ca, Na)(Mg, Fe, Al)(Si, Al)_2O_6$ silicates	dark green to black	3.3*	5–6	glassy luster; cleaves in two directions; crystals have 8-sided cross section
Hornblende	$(Ca, Na)_{2\text{-}3}(Mg, Fe, Al)_5Si_6(Si, Al)_2O_{22}(OH)_2$ silicates	dark green to black	3.2*	5–6	glassy luster; cleaves in two directions; crystals have 6-sided cross section
Hematite	Fe_2O_3 oxides	reddish brown to black	5.26	5.5–6.5	metallic luster in crystals; dull luster in earthy variety; dark red streak; weakly magnetic
Dolomite	$CaMg(CO_3)_2$ carbonates	pink, colorless, white, gray	2.85	3.5–4	does not react to HCl as quickly as calcite; cleaves in three directions
Magnetite	Fe_3O_4 oxides	black	5.18	6	metallic luster; black streak; strongly magnetic
Copper	Cu native elements	copper-red on fresh surface	8.9	2.5–3	metallic luster; fractures; can be easily shaped
Graphite	C native elements	black to gray	2.3	1–2	black to gray streak; marks paper; feels slippery



2.3 Assessment

Review Key Concepts

1. Describe five common properties of minerals that can be used to identify them.
2. How is the Mohs scale used?
3. What are some unique properties that can be used to identify minerals?

Think Critically

4. **Apply Concepts** What kind of luster do the minerals shown in Figure 15 have? Explain your choice.
5. **Apply Concepts** Hornblende is a double-chain silicate. How many planes of cleavage do you think hornblende has when it breaks? Explain your answer.
6. **Apply Concepts** A mineral scratches a piece of fluorite but cannot be scratched by a piece of glass. What is this mineral's hardness?

CONNECTING CONCEPTS

7. **Classify** Choose one of the minerals pictured in this chapter. Find out to which mineral system it belongs as well as its luster, streak, hardness, density, and whether it cleaves or fractures. Also note any unique properties of the mineral.

EARTH & ITS RESOURCES

Gemstones

Precious stones have been prized by people since ancient times. Unfortunately, much misinformation exists about the nature of gems and the minerals of which they are composed. Part of the misinformation stems from the ancient practice of grouping precious stones by color rather than mineral makeup. For example, the more common red spinels were often passed off to royalty as rubies, which are more valuable gems. Even today, when modern techniques of mineral identification are commonplace, yellow quartz is frequently sold as topaz.

What's In a Name?

Compounding the confusion is the fact that many gems have names that are different from their mineral names. For example, diamond is composed of the mineral of the same name, whereas sapphire is a form of corundum, an aluminum oxide-rich mineral. Although pure aluminum oxide is colorless, a tiny amount of a foreign element can produce a vividly colored gemstone. Therefore, depending on the impurity, sapphires of nearly every color exist. Pure aluminum oxide with trace amounts of titanium and iron produce the most prized blue sapphires. If the mineral corundum contains enough chromium, it exhibits a brilliant red color, and the gem is called ruby. Large gem-quality rubies are much rarer than diamonds and thus command a very high price.

If the specimen is not suitable as a gem, it simply goes by the mineral name corundum. Although common corundum is not a gemstone, it does have value as an abrasive material. Whereas two gems—rubies and sapphires—are composed of the mineral corundum, quartz is the parent mineral of more than a dozen gems. **Table 3** lists some well-known gemstones and their mineral names.

Precious or Semiprecious?

What makes a gem a gem instead of just another mineral? Basically, certain mineral specimens, when cut and polished, possess beauty of such quality that they can command a price that makes the process of producing the gem profitable. Gemstones can be divided into two categories: precious and semiprecious. A *precious* gem has beauty, durability, size, and rarity, whereas a *semiprecious* gem usually has only one or two of these qualities. The gems that have traditionally enjoyed the highest esteem are diamonds, rubies, sapphires, emeralds, and some varieties of opal. All other gemstones are classified as semiprecious. It should be noted, however, that large, high-quality specimens of semiprecious stones can often command a very high price.

FIGURE 22 Two Forms of the Mineral Beryl Emerald is the dark green variety of the mineral beryl. More common blue-green beryl is aquamarine.

FIGURE 23 Two Examples of Diamond A diamond in the rough looks very different from the brilliant, multi-faceted gem it can become.

Obviously, beauty is the most valuable quality that a gem can possess. Today we prefer translucent stones with evenly tinted colors. The most favored hues appear to be red, blue, green, purple, rose, and yellow. The most prized stones are deep red rubies, blue sapphires, grass-green emeralds, and canary-yellow diamonds. Colorless gems are generally less than desirable except in the case of diamonds that display "flashes of color" known as brilliance.

Notice in **Figure 23** that gemstones in the "rough" are dull and would be passed over by most people as "just another mineral." Gemstones must be cut and polished by experienced artisans before their true beauty can be displayed.

The durability of a gem depends on its hardness—that is, its resistance to abrasion by objects normally encountered in everyday living. For good durability, gems should be as hard or harder than quartz, as defined by the Mohs scale of hardness. One notable exception is opal, which is comparatively soft (hardness 5 to 6.5) and brittle. Opal's esteem comes from its fire, which is a display of a variety of brilliant colors including greens, blues, and reds.

It seems to be human nature to treasure that which is rare. In the case of gemstones, large, high-quality specimens are much rarer than smaller stones. Thus, large rubies, diamonds, and emeralds, which are rare in addition to being beautiful and durable, command the very highest prices.

Table 3 Some Important Gemstones

Gem	Mineral Name	Prized Hues
Precious		
Diamond	Diamond	Colorless, yellows
Emerald	Beryl	Greens
Opal	Nonmineral	Brilliant hues
Ruby	Corundum	Reds
Sapphire	Corundum	Blues
Semiprecious		
Alexandrite	Chrysoberyl	Variable
Amethyst	Quartz	Purples
Aquamarine	Beryl	Blue-greens
Cat's-eye	Chrysoberyl	Yellows
Chalcedony	Quartz (agate)	Banded
Citrine	Quartz	Yellows
Garnet	Garnet	Reds, greens
Jade	Jadeite or nephrite	Greens
Moonstone	Feldspar	Transparent blues
Peridot	Olivine	Olive greens
Smoky quartz	Quartz	Browns
Spinel	Spinel	Reds
Topaz	Topaz	Purples, reds
Tourmaline	Tourmaline	Reds, blue-greens
Turquoise	Turquoise	Blues
Zircon	Zircon	Reds

INQUIRY
EXPLORATION LAB

Mineral Identification

Problem How can you use simple tests and tools to identify common minerals?

Materials mineral samples, hand lens, streak plate, copper penny, steel knife blade, glass plate, piece of quartz, dilute hydrochloric acid, magnet, hammer, 50 mL graduated cylinder, tap water, balance, thin thread, scissors, paper or cloth towels, Table 2 in the chapter.

Skills Observing, Comparing and Contrasting, Measuring

Connect to the Big idea Most minerals can be identified by using the properties discussed in this chapter. In this lab, you will use what you have learned about mineral properties and the information in Table 2 (pages 54 and 55) to identify some common rock-forming minerals. In the next chapter, you will learn about rocks, which are mixtures of one or more minerals. Being able to identify minerals will enable you to understand more about the processes that form and change the rocks at and beneath Earth's surface.

Procedure

Part A: Color and Luster

1. Examine each mineral sample with and without the hand lens. Examine both the central part of each mineral as well as the edges of the samples.

2. Record the color and luster of each sample in a data table like the one shown on the next page.

Part B: Streak and Hardness

3. To determine the streak of a mineral, gently drag it across the streak plate and observe the color of the powdered mineral. If a mineral is harder than the streak plate ($H = 7$), it will not produce a streak.
4. Record the streak color for each mineral in your data table.
5. Use your fi gernail, the penny, the glass plate, the knife blade, and the piece of quartz to test the hardness of each mineral. Remember that if a mineral scratches an object, the mineral is harder than the object. If an object scratches a mineral, the mineral is softer than the object.
6. Record the hardness values for each sample in your data table.

Part C: Cleavage and Fracture

7. Cover one of the mineral samples with two layers of paper towel. With your goggles on and everyone out of your way, gently strike the sample with a hammer.
8. Observe the broken mineral pieces. Does the mineral cleave or fracture? *Cleavage* is even surfaces and *fracture* is uneven breakage. Record your observations in your data table.
9. Repeat Steps 7 and 8 for the other minerals.

Part D: Density

10. Using a balance, determine the mass of your mineral sample. Record the mass in the fi st column under Density.
11. Cut a piece of thread about 20 cm long. Tie a small piece of your mineral sample to one end of the thread.
12. Securely tie the other end of the thread to a pencil or pen.
13. Fill the graduated cylinder about half full with water. Record the volume of the water in the second column under Density.

Data Table										
Mineral Number	Color	Luster	Streak	Relative Hardness	Cleavage/ Fracture	Density				Other Properties
						m	V_1	V_2	d	
1										
2										
3										
4										
5										
6										
7										
8										

14. Lower the mineral into the graduated cylinder. Read the volume of the water now. Record the volume in the third column under Density.

15. Calculate the density of the mineral using the following equation:

$$\frac{\text{mass}_1}{\text{volume}_2 - \text{volume}_1}$$

Record this value in the fourth column.

Part E: Other Properties

16. Use the magnet to determine if any of the minerals are magnetic. Record your observations in the data table.

17. Place the transparent minerals over a word on this page to see if any have the property of double refraction. If a mineral has this property, you will see two sets of the word. Record your observations.

18. Compare the feel of the minerals. In the data table, note any differences.

19. Carefully place one or two drops of dilute hydrochloric acid on each mineral. Record your observations. When you are fi ished with this test, wash the minerals well with tap water to rinse away the acid.

Analyze and Conclude

1. Identify Use your data and Table 2 to identify each of the minerals tested.

2. Evaluate Which of the properties did you fi d most useful? Least useful? Give reasons for your answers.

3. Compare and Contrast In general, how did the minerals with metallic luster differ from those with non-metallic luster?

4. Classify Classify your minerals into at least three groups based on your observations. How does your classification scheme differ from those of at least two other students?

GO FURTHER Obtain some rock samples from your teacher or collect some of your own. Use the hand lens to try to identify the minerals in each rock. Make a table in which to record your observations. Compare your table to the information presented in the Rocks chapter.

ES.1 The student will plan and conduct investigations in which **a.** volume, area, mass, elapsed time, direction, temperature, pressure, distance, density, and changes in elevation/depth are calculated utilizing the most appropriate tools. **ES.4** The student will investigate and understand how to identify major rock-forming and ore minerals based on physical and chemical properties. Key concepts include **a.** hardness, color and streak, luster, cleavage, fracture, and unique properties; and **b.** uses of minerals.

2 Study Guide

Big idea Earth's Materials and Systems

2.1 Matter

An element contains only one type of atom. Therefore, an element cannot be broken down, chemically or physically, into a simpler substance.

An atom is the smallest particle of an element that retains the characteristics of that element.

Atoms with the same number of protons but different numbers of neutrons are isotopes of an element.

A compound is a substance that consists of two or more elements that are chemically combined in specific proportions.

When an atom's highest energy level does not contain the maximum number of electrons, the atom is likely to form a chemical bond with one or more other atoms.

Ionic bonds form between positive and negative ions. Covalent bonds form when atoms share electrons. Metallic bonds form when electrons are shared by metal ions.

element (34)
atomic number (35)
energy level (35)
isotope (38)
mass number (38)
compound (39)
chemical bond (39)
ion (40)
ionic bond (40)
covalent bond (41)
metallic bond (43)

2.2 Minerals

A mineral is a naturally occurring, inorganic solid with an orderly crystalline structure and a definite chemical composition.

There are four major processes by which minerals form: crystallization from magma, precipitation, changes in pressure and temperature, and formation from hydrothermal solutions.

Common minerals, together with the thousands of others that form on Earth, can be classified into groups based on their composition.

Silicates are the most common minerals on Earth and are made of millions of silicon-oxygen tetrahedra. Carbonates contain carbon, oxygen, and one or more other elements. Oxides contain oxygen and one or more other elements, usually metals. Sulfates and sulfides are minerals that contain sulfur. Halides contain a halogen ion plus one or more other elements. Native elements are minerals that only contain one element or type of atom.

mineral (45)
silicon-oxygen tetrahedron (47)
silicate (47)

2.3 Properties of Minerals

Small amounts of different elements can give the same mineral many different colors.

Streak is the color of a mineral in its powdered form.

Luster describes how light is reflected from the surface of a mineral.

Crystal form is the visual expression of a mineral's internal arrangement of atoms.

The Mohs scale consists of 10 index minerals arranged from 10 (hardest) to 1 (softest).

Cleavage is the tendency of a mineral to cleave, or break along flat, even surfaces; fracture is uneven breakage.

Density is a property of all matter and is the ratio of an object's mass to its volume.

Some minerals can be recognized by other distinctive properties, such as feel and magnetism.

streak (50)
luster (51)
crystal form (51)
hardness (52)
Mohs scale (52)
cleavage (53)
fracture (53)
density (53)

Think Visually

Observe Use what you have learned about minerals and Table 2 to list as many properties as possible of the mineral below.

2 Assessment

Review Content

Choose the letter that best answers the question or completes the statement.

1. Which of the following is neutrally charged?
   a. an ion
   b. a compound
   c. an electron
   d. a proton

2. Atoms combine when
   a. their highest electron levels are filled.
   b. their electrons are shared or transferred.
   c. the number of protons and neutrons is the same.
   d. the number of electrons and protons is the same.

3. Compounds with low boiling points have
   a. metallic bonds.
   b. ionic bonds.
   c. covalent bonds.
   d. no chemical bonds.

4. Minerals that form from magma form as the result of
   a. crystallization.
   b. evaporation.
   c. precipitation.
   d. condensation.

5. The mineral barite ($BaSO_4$) is a(n)
   a. oxide.
   b. silicate.
   c. carbonate.
   d. sulfate.

6. Color is often not a useful identification property because
   a. some minerals are colorless.
   b. the same mineral can be different colors.
   c. different minerals can be different colors.
   d. some minerals are single elements.

7. What is a mineral's streak?
   a. the resistance to being scratched
   b. the color of the mineral in powder form
   c. the way in which the mineral reflects light
   d. the way the mineral reacts to hydrochloric acid

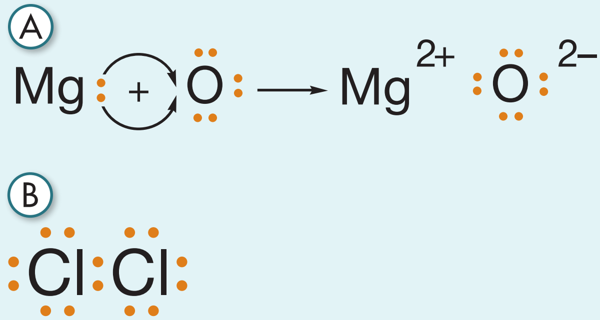
8. A particular mineral breaks like a piece of glass does. Which of these describes the breakage?
   a. cleavage
   b. hardness
   c. metallic luster
   d. fracture

9. Mineral properties depend on composition and
   a. structure.
   b. luster.
   c. cleavage.
   d. streak.

Understand Concepts

10. Name the three types of particles found in an atom and explain how they differ.
11. Compare and contrast ionic and covalent bonds.
12. What are five characteristics of a mineral?
13. Explain three ways in which new minerals can form from existing minerals.
14. Contrast the composition of minerals in each of the mineral groups discussed in the chapter.
15. How is cleavage related to a mineral's atomic structure?
16. Give examples of four minerals that can be identified by unique properties. Describe each property.

Use this diagram to answer Questions 17–21.

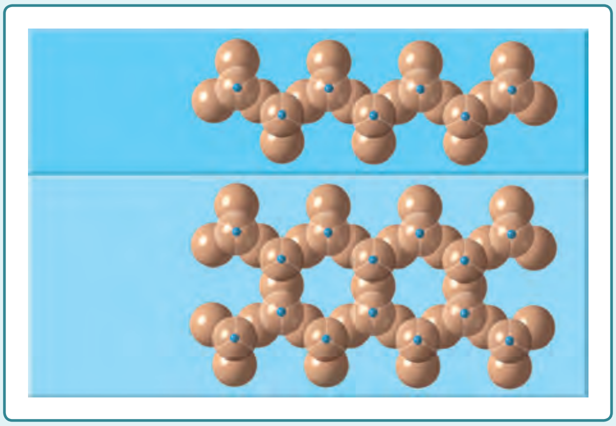


17. Briefly describe the kind of bond that is formed when two atoms shown in **A** bond.
18. Describe the kind of bond that forms when the atoms shown in **B** bond.
19. Is the atom on the left in **A** an ion? Explain your answer.
20. Use the periodic table to determine the atomic number of the atom on the left ide of **A**. What group is this element in?
21. The atoms in **B** contain 17 protons. Are these atoms ions when they bond with each other? Can these atoms form ions when they react with other elements? Explain your answers.

Think Critically

22. **Compare and Contrast** Three atoms have the same atomic number but different mass numbers. What can you say about the atoms?
23. **Predict** Potassium metal in Group 1 of the periodic table is very reactive. When placed in chlorine gas, potassium reacts to form a halide compound. Using Figure 4 and the periodic table propose the formula and name for the compound.
24. **Form a Hypothesis** Why do you think metals can easily be rolled into thin sheets and drawn into wires? (*Hint:* Think about the arrangement of electrons in metals.)
25. **Explain** Explain the processes that result in the formation of silicate minerals.
26. **Form a Hypothesis** A mineral forms deep beneath the surface. It reaches Earth's surface during mountain building. Describe two things that might happen to this mineral at the surface.
27. **Apply Concepts** Classify the following minerals based on their chemical formulas.
    a. $NaCO_3$
    b. PbS
    c. $FeCr_2O_4$
    d. CaF_2

Use the diagrams to answer Questions 28–31.



28. **Identify** What is the basic structural unit in these two diagrams?
29. **Classify** What are the names given to these two silicate structures?
30. **Apply Concepts** How do these two structures affect mineral breakage?
31. **Form a Hypothesis** Which of the two structures is more complex? Explain your choice.

Concepts in Action

32. **Apply Concepts** Your friend shows you a crystal that he thinks is a diamond. Without asking an expert, how could you tell if the crystal is really a diamond?
33. **Apply Concepts** Which two minerals discussed in this chapter would be useful as abrasives? Which could be used as a lubricant? Which might be used in sparkly eye shadows?
34. **Calculate** Gold has a density of 19.3 g/cm^3. What would be the mass of a gold brick that is 30 cm long, 8 cm wide, and 4 cm tall?

Performance-Based Assessment

Apply Concepts Go on a scavenger hunt around your school or home to find at least 20 items that are minerals, that contain minerals, or that were obtained from minerals. Make a poster that shows what you found and display it for the class.

Virginia SOL Test Prep

Tips for Success

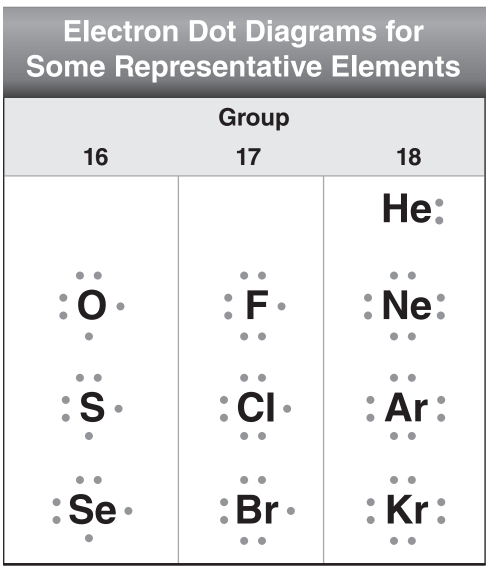
Evaluate Sometimes an answer to a test question contains accurate information, but does not actually answer the question being asked. When this happens, follow the suggestions given below.

- Reread the question several times if necessary.
- Check to see that the information in each answer choice is accurate.
- Eliminate answers you know are incorrect.
- Check to see that your answer choice answers the question being asked.

Choose the letter that *best* answers the question or completes the statement.

1 **Which of the following pairs of minerals and a common usage of the mineral is *not* correct?**
A graphite - pencil lead
B diamond - dentist drill bit
C quartz - drinking glasses
D talc - windows
ES.4.b

Use the table below to answer Question 2.



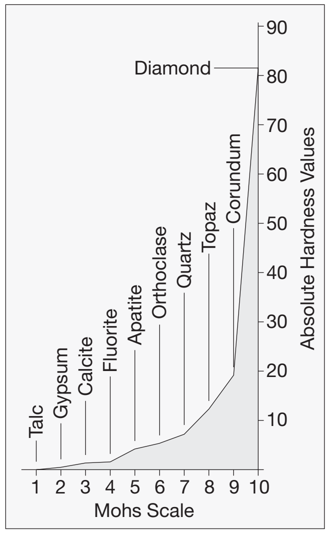
2 **How many electrons are in the outer energy level of oxygen?**
F 5
G 6
H 7
J 8
ES.1.c

If You Have Trouble With . . .

Question	1	2	3	4	5
See Lesson	2.2	2.1	2.2	2.3	2.3

3 **Which of the following *best* describes a mineral?**
A a naturally occurring, inorganic solid, with an orderly crystalline structure
B a naturally occurring, organic solid with an orderly crystalline structure
C the smallest fundamental particle in nature
D the smallest particle of matter that contains the characteristic of an element
ES.4.a

Use the graph to answer Question 4.



4 How does talc's hardness on the Mohs scale compare with its absolute hardness?
F Talc's hardness value on the Mohs scale is less than the absolute hardness value.
G Talc's hardness value on the Mohs scale is about the same as the absolute hardness value.
H Talc's hardness value on the Mohs scale is greater than the absolute hardness value.
J Talc's hardness value on the Mohs scale cannot be compared to the absolute hardness value.
ES.4.a

5 **Which of the following *best* describes the cleavage of a mineral?**
A the uneven breakage of a mineral
B a measure of the resistance of a mineral to being scratched
C the reflection of light from the surface of a mineral
D the tendency of a mineral to break along flat, even surfaces
ES.4.a