CHAPTER

2 Minerals

CONCEPTS in Action

Exploration Lab
Mineral Identification

Understanding Earth
Gemstones

GEODe Earth Science
Earth Materials
↳ Rock Cycle

Discovery Channel School

Video Field Trip

Gold

Take a trip to Brazil with the Discovery Channel and see how gold on the Rio Medeira River is mined. Answer the following questions after watching the video.

1. In what two parts of Earth is gold found?
2. Describe what happens to gold during the "smelting" process.

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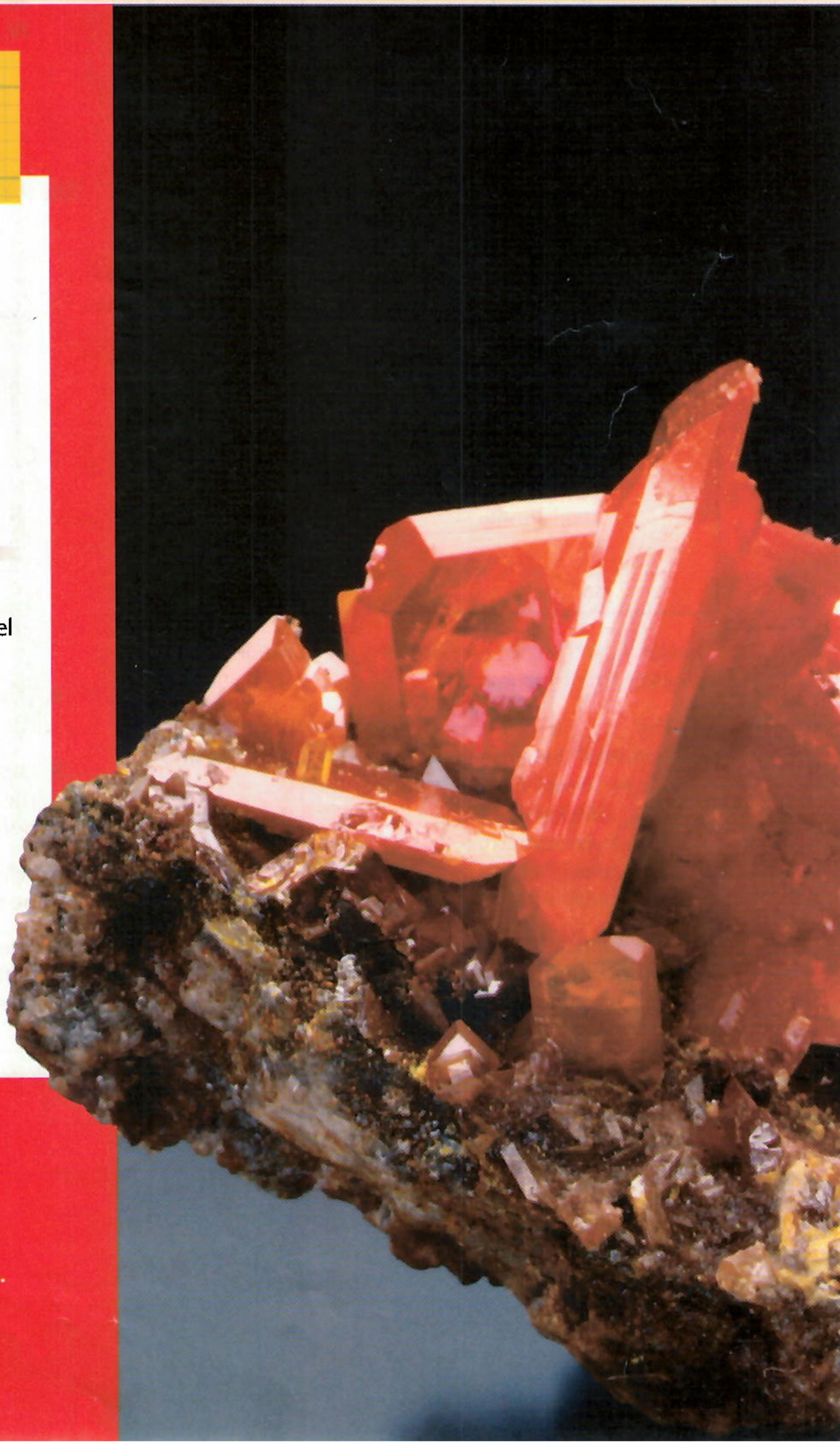

The large reddish-orange crystals are ► crystals of wulfenite. Wulfenite is one of more than 3800 minerals found on Earth.

Chapter Preview

Inquiry Activity

How Are a Group of Minerals Alike and Different?

Procedure

1. Obtain the mineral samples from your teacher. Examine them closely.
2. Make a data table to record at least three ways that the samples are alike.
3. Now record at least three ways that the samples differ.
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. **Observing** What kinds of characteristics did you observe in all of the samples?
2. **Contrasting** How did the samples differ?
3. **Formulating Hypotheses** 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

Reading Focus

Key Concepts

- 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

Comparing and Contrasting 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 and minerals are 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. Most of Earth's atmosphere is composed of the gases nitrogen and oxygen. Though matter can be classified by its physical state: solid, liquid, or gas, it is more useful to look at its chemical composition and structure. Each of Earth's nearly 4000 minerals is a unique substance. The building blocks of minerals are **elements.**

Elements and the Periodic Table

The names of many elements are probably very familiar to you. Many common metals are elements, such as copper, iron, silver, and gold. **An element is a substance that cannot be broken down into simpler substances by chemical or physical means.** There are more than 112 known elements, and new elements continue to be discovered. Of these, 92 occur naturally, the others are produced in laboratories.

The elements have been organized by their properties in a document called the periodic table, which is shown in Figure 1 on pages 36 and 37. 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

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also known by its atomic number, which is shown above each symbol on the table. Look at the block for sulfur, element 16, and gold, element 79. Sulfur and gold are minerals made of one element. Most elements are not stable enough to exist in pure form in nature. Thus, most minerals are combinations of elements.

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 in the periodic table shown on pages 36 and 37. Elements within a group have similar properties.

Of the known elements, only eight make up most of Earth's continental crust. These eight elements are listed in Table 1. Notice that six of the eight elements in Table 1 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. They combine in thousands of ways to form compounds, the building blocks of most Earth materials. To understand how elements form compounds we need to review their building blocks which are atoms.

Table 1 Relative Abundance of the Most Common Elements in Earth's Continental Crust

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.

Atoms

As you might already know, all elements are made of atoms. **An atom is the smallest particle of matter that contains the characteristics of an element.**

The central region of an atom is called the nucleus. The nucleus contains protons and neutrons. Protons are dense particles with positive electrical charges. Neutrons are equally dense particles that have no electrical charge. Electrons, which are small particles with little mass and negative electrical charges, surround an atom's nucleus.

Protons and Neutrons A proton has about the same mass as a neutron. Hydrogen atoms have only a single proton in their nuclei. Other 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. The atomic number of carbon is 6. Likewise, every atom with eight protons is an oxygen atom. The atomic number of oxygen is 8.

Atoms have the same number of protons and electrons. Carbon atoms have six protons and therefore six electrons. Oxygen atoms have eight protons in their nuclei and have eight electrons surrounding the nucleus.

Periodic Table of the Elements

Figure 1

	Nonmetals	Metals	Metalloids
Solid	C	Li	B
Liquid	Br	Hg	
Gas	H		
Not found in nature		Tc	

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

Lanthanide Series

57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.4

Actinide Series

89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)

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

Atomic number	Element symbol	Element name	Atomic mass
6	C	Carbon	12.011

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

*Name not officially assigned.

63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04

95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)

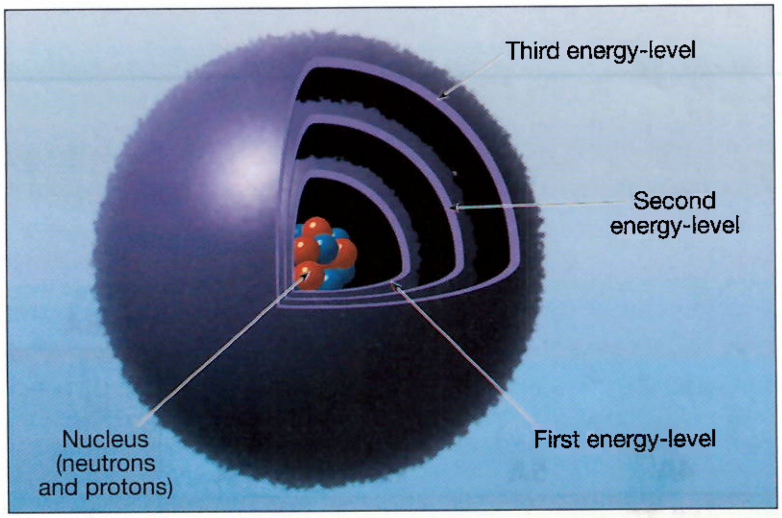


Figure 2 Model of an Atom
The electrons that move about an atom's nucleus occupy distinct regions called energy levels.

Electrons An electron is the smallest of the three fundamental particles in an atom. An electron has a mass of about 1/1836 the mass of a proton or a neutron. Electrons move about the nucleus so rapidly that they create a sphere-shaped negative zone. You can picture moving electrons by imagining a cloud of negative charges surrounding the nucleus, as shown in Figure 2.

Electrons are located in regions called **energy levels.** Each energy level contains a certain number of electrons. Interactions among electrons in the outermost energy levels explains how atoms form compounds, as you will find out later in the chapter.

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

Q&A

Q *Are the minerals in this chapter the same as those in dietary supplements?*

A Not ordinarily. Most minerals found in dietary supplements are compounds made in the laboratory. These dietary minerals often contain elements that are metals, such as calcium, potassium, magnesium, and iron. From the geologist's point of view, a mineral must be a naturally occurring crystalline solid.

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 (protons plus neutrons) expressed in atomic mass units. The proton and the neutron each have a mass that is slightly larger than the atomic mass unit. 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.

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.Though only traces of carbon-14 are found in nature, the presence of this isotope is often used to determine the age of once-living things. Carbon-14 has 6 protons and 8 neutrons

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. Radioactive decay occurs because the forces that hold the nucleus together are not strong enough.

During radioactive decay, unstable atoms radiate energy and particles. Some of this energy powers the movements of Earth's crust and upper mantle. The rates at which unstable atoms decay are measurable. Therefore certain radioactive atoms can be used to determine the ages of fossils, rocks, and minerals.

Reading Checkpoint *What are isotopes?*

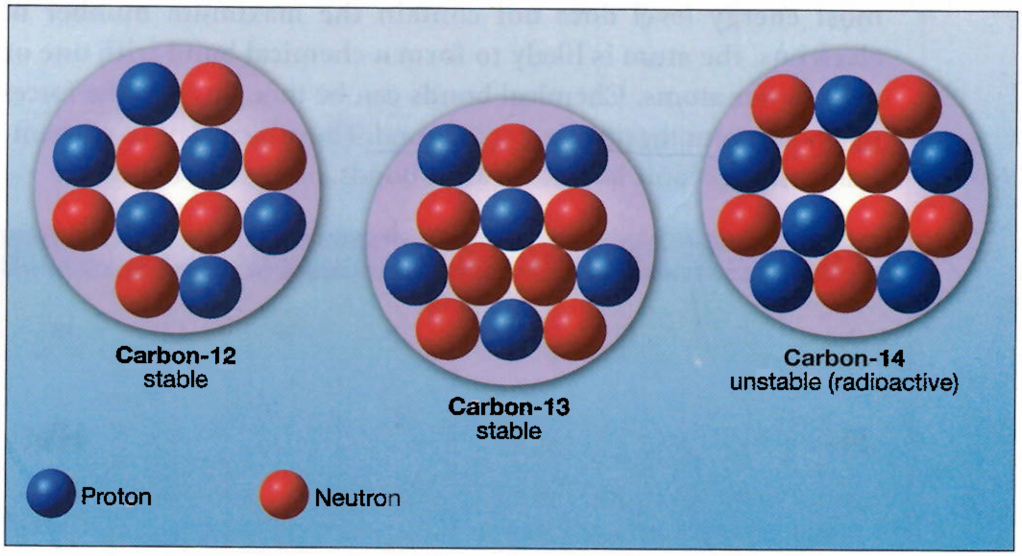


Figure 3 Nuclei of Isotopes of Carbon Carbon has many isotopes. Of these, three occur in nature. **Comparing and Contrasting** ***How are the nuclei of these isotopes the same, and how do they differ?***

Why Atoms Bond

Most elements exist combined with other elements to form substances with properties that are different from the elements themselves. Sodium is often found combined with the element chlorine as the mineral halite. Lead ore is really the mineral galena, which is the element, lead, combined with the element, sulfur. Chemical combinations of the atoms of elements are called **compounds.** **A compound is a substance that consists of two or more elements that are chemically combined in specific proportions.** Compounds form when atoms are more stable (exist at a lower energy state) in a combined form. The chemical process, called bonding, centers around the electron arrangements of atoms. Thus, when atoms combine with others to form compounds, they gain, lose, or share electrons.

Scientists have discovered that the most stable elements are found on the right side of the periodic table in Group 8A (18). These elements have a very low reactivity and exist in nature as single atoms. Scientists explain why atoms form compounds by considering how an atom undergoes changes to its electron structure to be more like atoms in Group 8A.

Look at Figure 4. It shows the shorthand way of representing the number of electrons in the outer energy level. Recall that electrons move about the nucleus of an atom in a region called an electron cloud. Within this cloud, only a certain number of electrons can occupy each energy level. For example, a maximum of two electrons can occupy the first energy level. From Figure 4, you see that helium (He) is shown with two electrons. A maximum of eight electrons can be found in the second energy level. You also see from the figure that neon (Ne) is shown with eight electrons. **When an atom's outermost 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. Chemical bonds** can be thought of as the forces that hold atoms together in a compound. The principal types of chemical bonds are ionic bonds, covalent bonds, or metallic bonds.

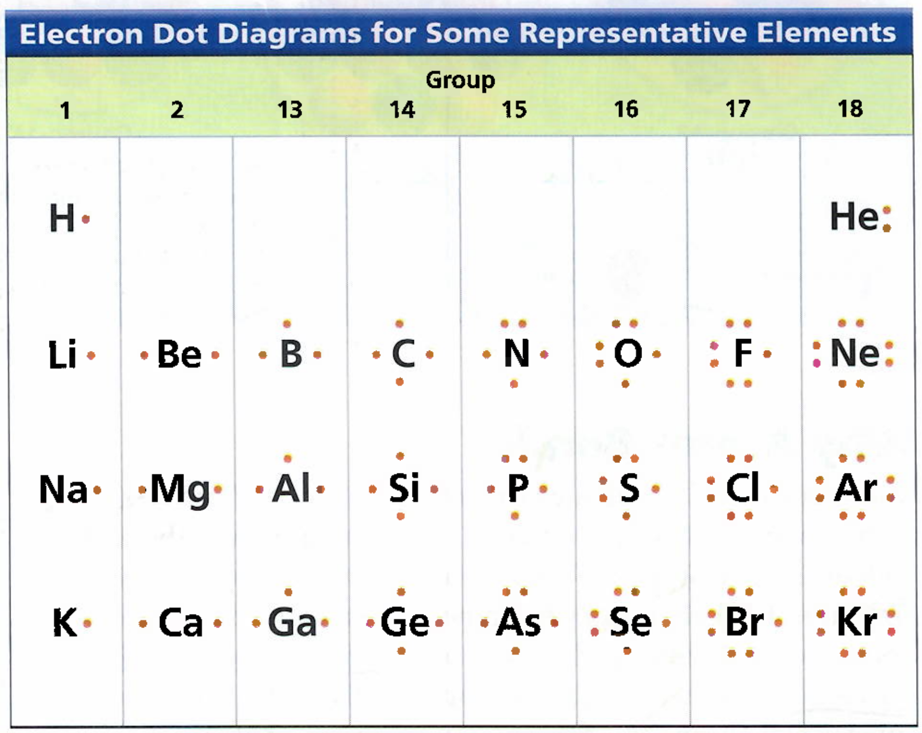


Figure 4 In an electron dot diagram, each dot represents an electron in the atom's outer energy level. These electrons are sometimes called valence electrons.
Observing ***How many electrons do sodium and chlorine have in their outer energy levels?***

Types of Chemical Bonds

Ionic Bonds An atom that gains electrons becomes negatively charged. This happens because the atom now has more electrons than protons. An atom that loses electrons becomes positively charged. This happens because the atom now has more protons than electrons. An atom that has an electrical charge because of a gain or loss of one or more electrons is called an **ion.** Oppositely charged ions attract each other to form crystalline compounds. **Ionic bonds form between positive and negative ions.**

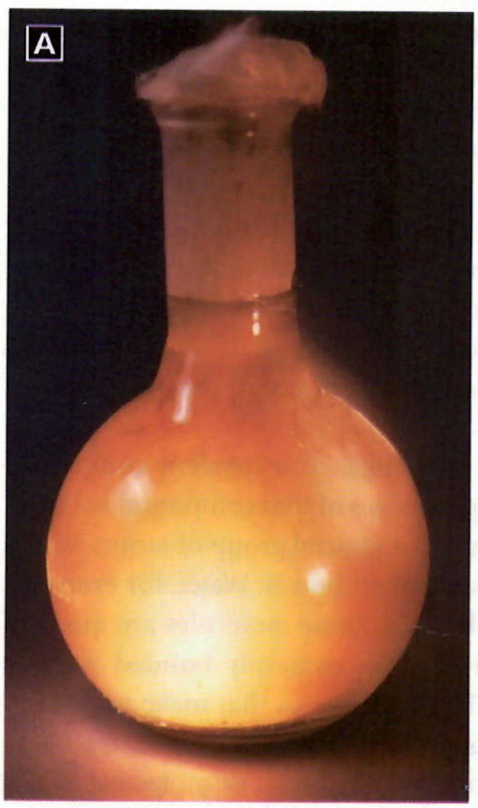
Some common compounds on Earth have both a chemical name and a mineral name. For example, table salt has a chemical name, sodium chloride, and a mineral name, halite. Salt forms when sodium (Na) reacts with chlorine (Cl) as shown in Figure 5A. Sodium is very unstable and reactive. Sodium atoms lose one 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 called sodium chloride.

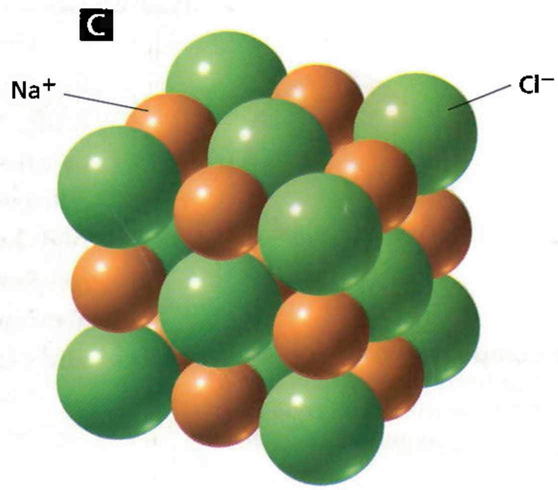
The properties of a compound are different from the properties of the elements in the compound. Sodium is a soft, silvery metal that reacts vigorously with water. If you held it in your hand, sodium could burn your skin. Chlorine is a green poisonous gas. Chemically combined these atoms produce table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

Reading Checkpoint ***What happens when two or more atoms react?***

Formation of Sodium Chloride

Figure 5 **A** When sodium metal comes in contact with chlorine gas, a violent reaction occurs. **B** Sodium atoms transfer one electron to the outer energy levels of chlorine atoms. Both ions now have filled outer energy levels **C** The positive and negative ions formed attract each other to form a crystalline solid with a rigid structure.





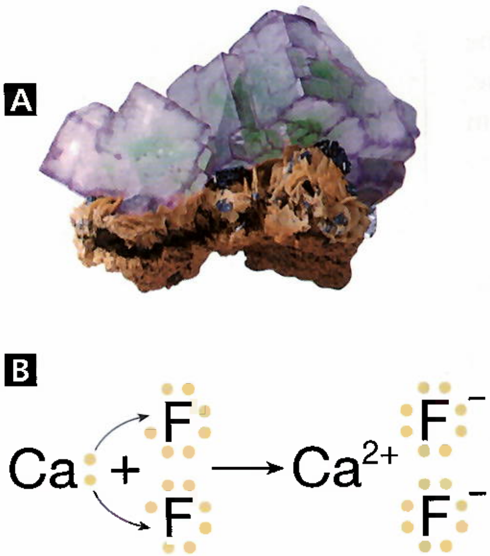


Figure 6 Ionic Compound A Fluorite is an ionic compound that forms when calcium reacts with fluorine. **B** The dots shown with the element's symbol represent the electrons in the outermost levels of the ions. **Explaining** ***Explain what happens to the electrons in calcium atoms and fluorine atoms when fluorite forms.***

Compounds that contain ionic bonds are called ionic compounds. Figure 6 shows calcium fluoride, a common ionic compound. Our model for ionic bonding suggests that one calcium atom transfers two electrons from its outermost energy level to two atoms of fluorine. This transfer gives all atoms the right numbers of electrons in their outer energy levels. The compound that forms is known as the mineral fluorite.

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 of the table.

Reading Checkpoint ***How do ionic bonds form, and 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 7 shows silicon dioxide, one of the most common covalent compounds on Earth. Silicon dioxide forms when one silicon atom and two oxygen atoms share electrons in their outermost energy levels. Silicon dioxide is also known as the mineral quartz.

The bonding in covalent compounds results in properties that differ from those of ionic compounds. Unlike ionic compounds, many covalent compounds have low melting and boiling points. For example, water, a covalent compound, boils at 100°C at standard pressure. Sodium chloride, an ionic compound, boils at 1413°C at standard pressure. 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.

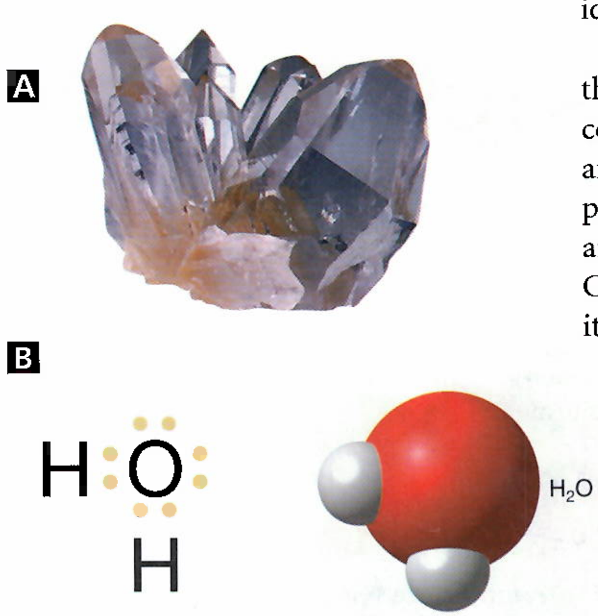
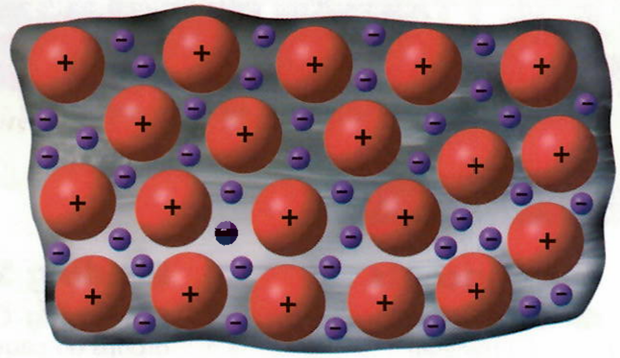


Figure 7 Covalent Compounds A Quartz is a covalent compound that forms when silicon and oxygen atoms bond. **B** Water consists of molecules formed when hydrogen and oxygen share electrons.

Metallic Bonds 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.

Metallic bonds form when electrons are shared by metal ions. Figure 8 shows a model for this kind of bond. The sharing of an electron pool gives metals their characteristic properties. Using the model you can see how an electrical current is easily carried through the pool of electrons. Later in this chapter, you will learn about some metals that are classified as minerals.

A



B

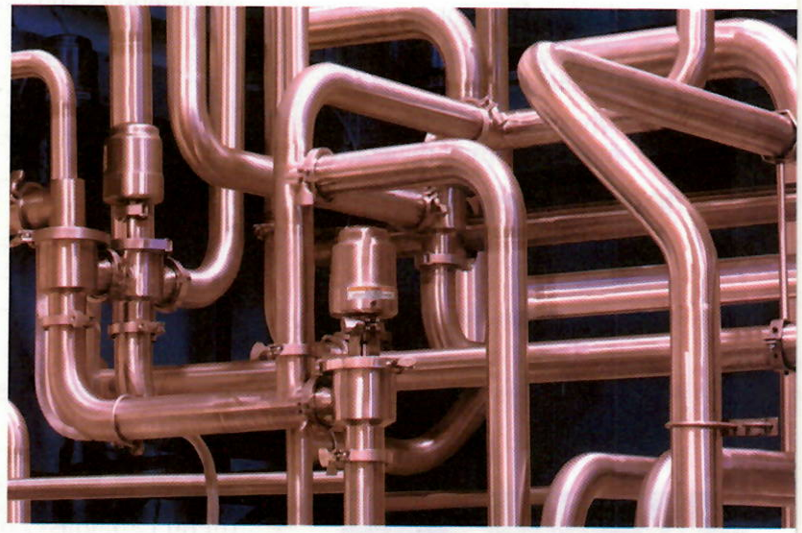


Figure 8 Metallic Bonds A Metals form bonds with one another by sharing electrons. **B** Such bonds give metals, such as this copper, their characteristic properties. Metals can be easily formed and shaped.

Section 2.1 Assessment

Reviewing Concepts

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

Critical Thinking

6. **Comparing and Contrasting** Compare and contrast solids, liquids, and gases.
7. **Applying Concepts** What elements in Table 1 are metals?
8. **Applying Concepts** A magnesium atom needs two electrons to fill its outermost energy level. A chlorine atom needs one electron to fill its outermost shell. If magnesium reacts with chlorine, what type of bond will most likely form? Explain.
9. **Applying Concepts** Which elements in the periodic table might combine with oxygen to form compounds similar to magnesium dioxide (MgO_2)?

Math Practice

10. The isotopes of carbon have from 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

Reading Focus

Key Concepts

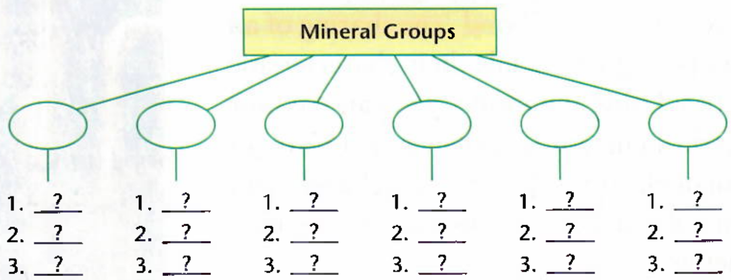
- What are five characteristics of a mineral?
- What processes result in the formation of minerals?
- How can minerals be classified?
- What are some of the major groups of minerals?

Vocabulary

- mineral
- silicate
- silicon-oxygen tetrahedron

Reading Strategy

Previewing 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. This system is made up of the metal cap, glass container, and salt grains. Each component 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 other minerals do you probably use regularly? The lead in your pencils actually contains a soft black mineral called graphite. Most body powders and many kinds of make-up contain finely 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?


A

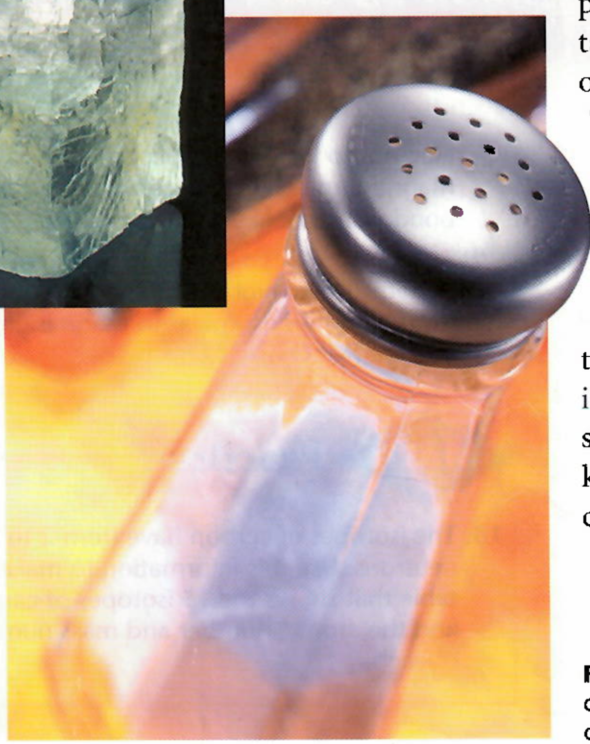

B

Figure 9 A Table salt is the mineral halite. **B** The glass container is made from the mineral quartz. Bauxite is one of the minerals that provides aluminum for the cap.

Minerals

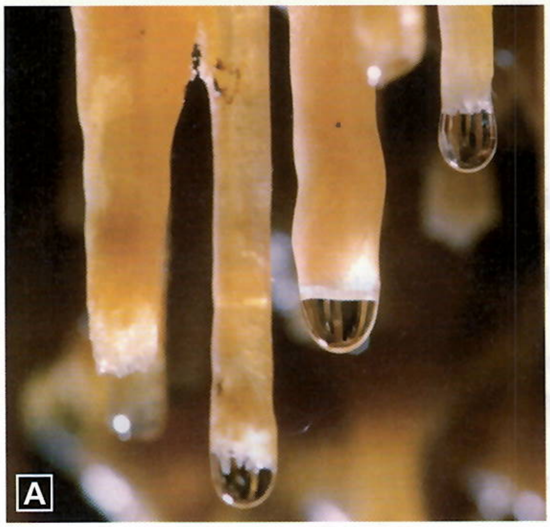
A mineral in Earth science is different from the minerals in foods. **A mineral is a naturally occurring, inorganic solid with an orderly crystalline structure and a definite chemical composition.** For an Earth material to be considered a mineral, it must have the following characteristics:

1. **Naturally occurring** A mineral forms by natural geologic processes. Therefore, synthetic gems, 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** Minerals are crystalline substances which means that their atoms or ions are arranged in an orderly and repetitive manner. You saw this orderly type of packing in Figure 5 for halite (NaCl). The gemstone opal is not a mineral even though it contains the same elements as quartz. Opal does not have an orderly internal structure.
4. **Definite chemical composition** Most minerals are chemical compounds made of two or more elements. A few, such as gold and silver, consist of only a single element (native form). The common mineral quartz consists of two oxygen atoms for every silicon atom. Thus the chemical formula for quartz would be SiO_2.
5. **Generally considered inorganic** Most minerals are inorganic crystalline solids found in nature. Table salt (halite) is one such mineral. However, sugar, another crystalline solid is not considered a mineral because it is classified as an organic compound. Sugar comes from sugar beets or sugar cane. We say "generally inorganic" because many marine animals secrete inorganic compounds, such as calcium carbonate (calcite). This compound is found in their shells and in coral reefs. Most geologists consider this form of calcium carbonate a mineral.

Figure 10 These minerals often form as the result of crystallization from magma.

How Minerals Form

Minerals form nearly everywhere on Earth under different conditions. For example, minerals called silicates often form deep in the crust or mantle 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.**



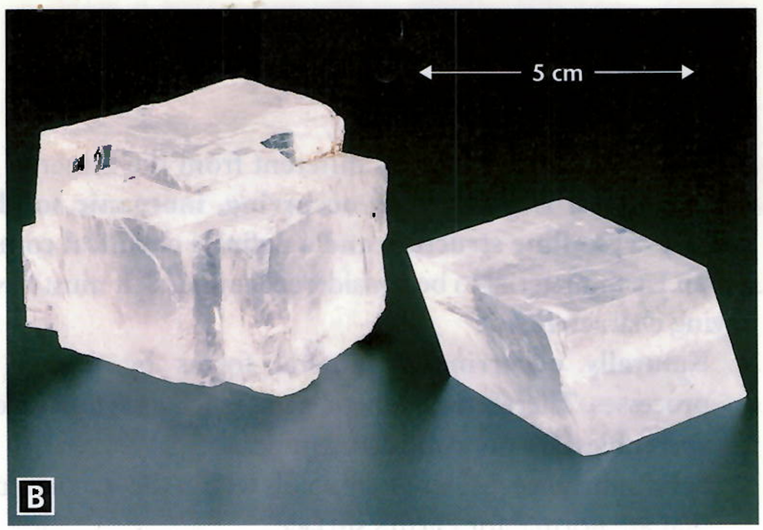


Figure 11 **A** This limestone cave formation is an obvious example of precipitation. **B** Halite and calcite are also formed by precipitation.

Crystallization from Magma Magma is molten rock. It forms deep within Earth. As magma cools, elements combine to form minerals such as those shown in Figure 10 on page 45. The first 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.

Precipitation The water in Earth's lakes, rivers, ponds, oceans, and beneath its surface contains many dissolved substances. If 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. The minerals are left behind, 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.

Figure 12 Bornite (blue and purple) and chalcopyrite (gold) are sulfur minerals that form from thermal solutions.

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 to 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.***

Mineral Groups

Over 3800 minerals have been named, and several new ones are identified each year. You will be studying only the most abundant 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 the silicates, the carbonates, the oxides, the sulfates and sulfides, the halides, and the native elements. First, you will learn about the most common groups of minerals on Earth—the **silicates.**

Silicates If you look again at Table 1, you can see that the two most abundant elements in Earth's crust are silicon and oxygen. **Silicon and oxygen combine to form a structure called the silicon-oxygen tetrahedron.** This structure is shown in Figure 13. The tetrahedron, which consists of one silicon atom and four oxygen atoms, provides the framework of every silicate mineral. Except for a few silicate minerals, such as pure quartz (SiO_2), 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. The 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 network structures are found in silicates such as quartz and feldspar. As you will see, the internal structure of a mineral affects its properties.

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

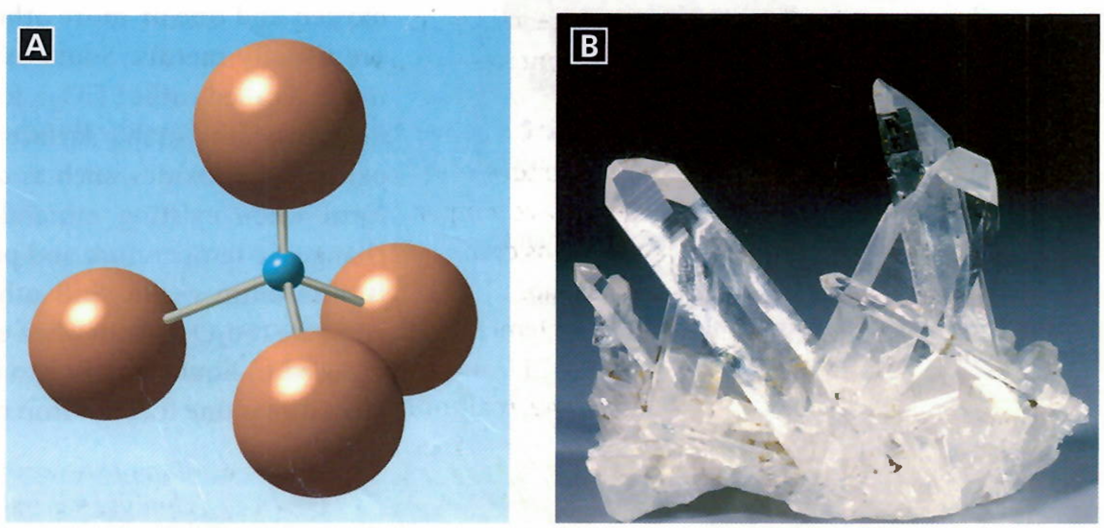


Figure 13 **A** The silicon-oxygen tetrahedron is made of one silicon atom and four oxygen atoms. The rods represent chemical bonds between silicon and the oxygen atoms. **B** Quartz is the most common silicate mineral. A typical piece of quartz like this contains millions of silicon-oxygen tetrahedra.

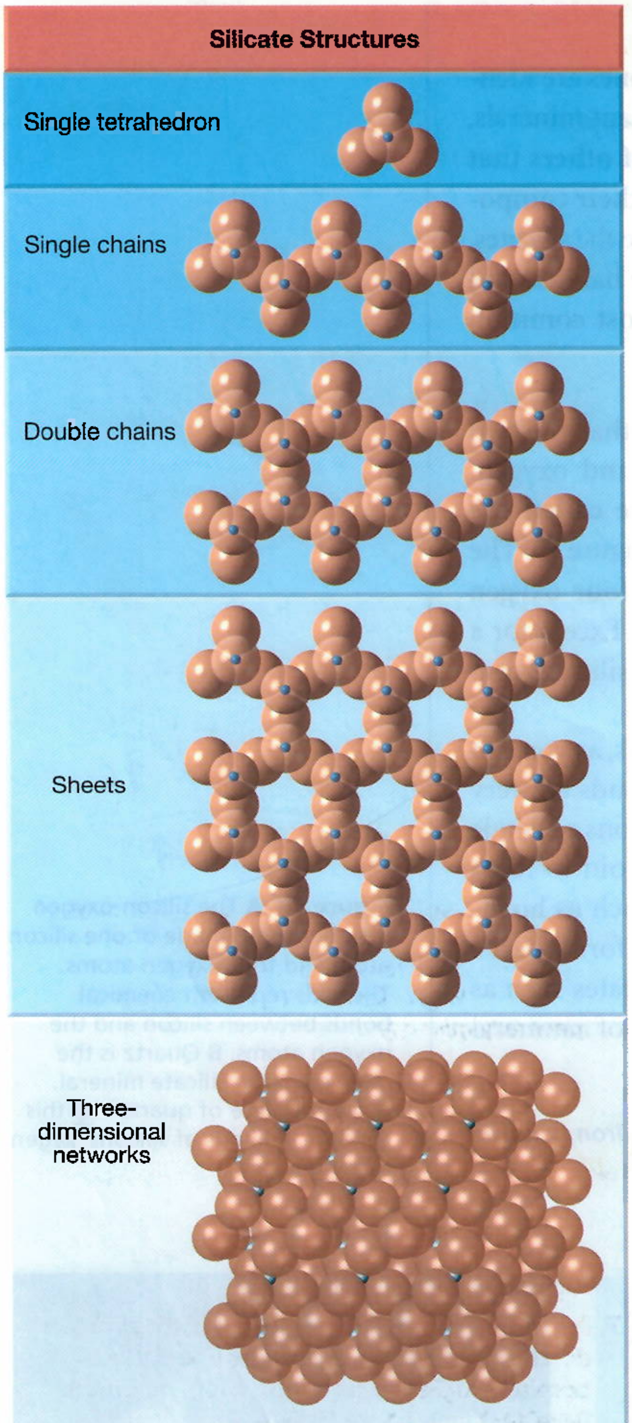


Figure 14 Silicon-oxygen tetrahedra can form chains, sheets, and three-dimensional networks.
Formulating Hypotheses ***What type of chemical bond is formed by silicon atoms in an SiO_4 tetrahedron?***

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.

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 ($CaCO_3$) is the most common carbonate mineral. 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 liquid water or to 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 ($CaSO_4 \cdot 2H_2O$), 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 7A 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 a group of minerals that exist in relatively pure form. You are probably familiar with many native elements, such as gold (Au), silver (Ag), copper (Cu), sulfur (S), and carbon (C). Native forms of carbon are diamond and graphite. Some native elements form from hydrothermal solutions.

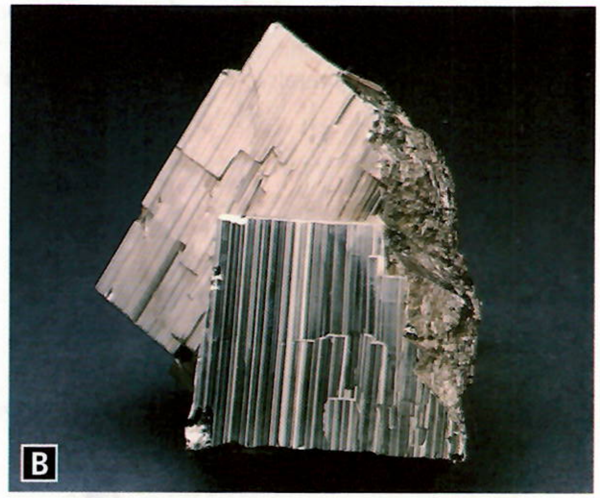


Figure 15 Sulfides A Galena is a sulfide mineral that can be mined for its lead. **B** Pyrite is another sulfide that is often called fool's gold.
Inferring ***What element do you think pyrite is generally mined for?***

Section 2.2 Assessment

Reviewing 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.

Critical Thinking

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

Writing in Science

Explanatory Paragraph Coal forms from ancient plant matter that has been compressed over time. Do you think coal is a mineral? Write a paragraph that explains your reasoning.

2.3 Properties of Minerals

Reading Focus

Key Concepts

- 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

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

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

As you can see from the photographs in this chapter, minerals occur in different colors and shapes. Now you will learn that minerals vary in the way they reflect light and in the way in which they break. You will also find out that some minerals are harder than others and that some minerals smell like rotten eggs. All of these characteristics, or properties, of minerals can be used to identify them.

Color

One of the first 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 Small amounts of different elements give these sapphires their distinct colors. **Observing** ***Why is color often not a useful property in mineral identification?***

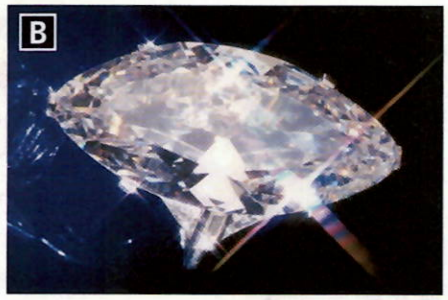


Figure 17 **A** The mineral copper has a metallic luster. **B** The brilliant luster of diamond is also known as an adamantine luster.

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 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. Streak can also help to see 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.

Figure 18 Crystal Form **A** This quartz sample shows hexagonal (six-sided) crystals. The ends of the crystals have a pyramid shape. **B** Fluorite often forms cubic crystals.

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 18A. Other lusters include pearly, silky, and earthy. Diamond has an adamantine, or brilliant luster. Some minerals appear *somewhat* metallic and are said to have a sub-metallic luster.

Crystal Form

Crystal form is the visible expression of a mineral's internal arrangement of atoms. Every mineral has a distinct crystal form.

Usually, when a mineral forms slowly and without space restrictions, it will develop into a crystal with well-formed faces—sides, top, and bottom—as shown in Figure 18. Most of the time, however, minerals compete for space. This crowding results in an intergrown mass of small crystals. None of these crystals shows its crystal form.

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

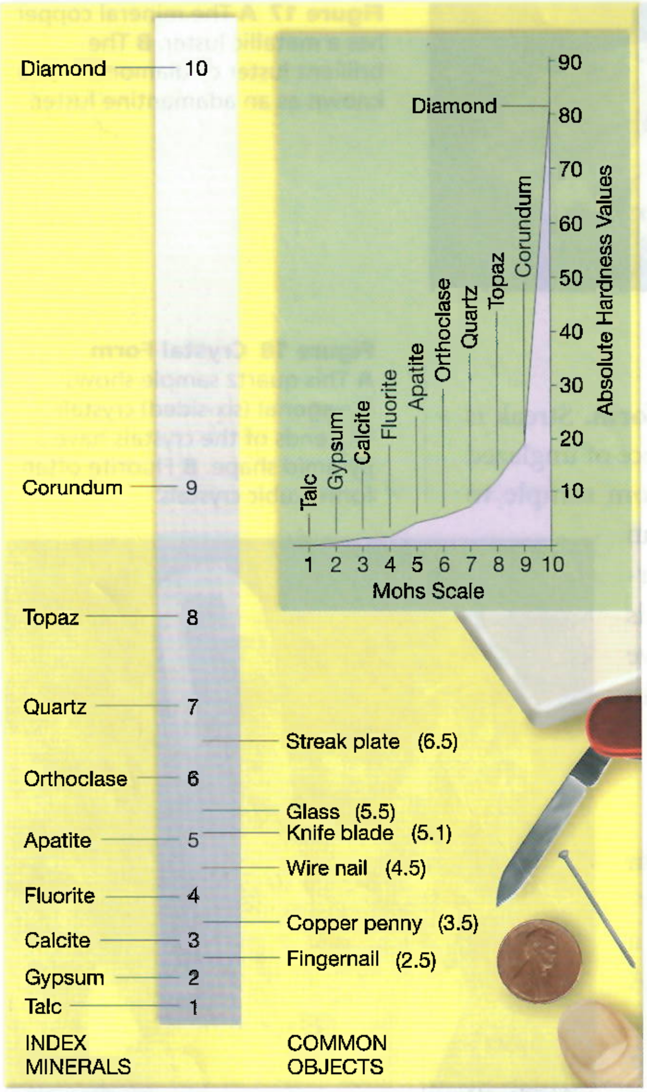


Figure 19 Mohs Scale of Hardness Common objects can be used with the Mohs scale to determine mineral hardness. **Using Tables and Graphs** ***A mineral has a hardness of 4.2. Which common items on the chart will that mineral scratch?***

Hardness

One of the most useful properties to identify a mineral is hardness. **Hardness** is a measure of the resistance of a mineral to being scratched. You can find this property by rubbing the mineral against another mineral of known hardness. One will scratch the other, unless they have the same hardness.

Geologists use a standard hardness scale called the Mohs scale. **The Mohs scale consists of 10 minerals arranged from 10 (hardest) to 1 (softest).** See Figure 19. Any mineral of unknown hardness can be rubbed against these to determine its hardness. Other objects can also be used to determine hardness. Your fingernail, 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 fingernail. The mineral calcite, which resembles gypsum, has a hardness of 3. Calcite cannot be scratched by your fingernail. 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 anything.

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

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 micas' sheet structure causes them to cleave into flat plates. Quartz has equally strong silicon-oxygen bonds in all directions. Therefore, quartz has no cleavage but fractures instead.

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

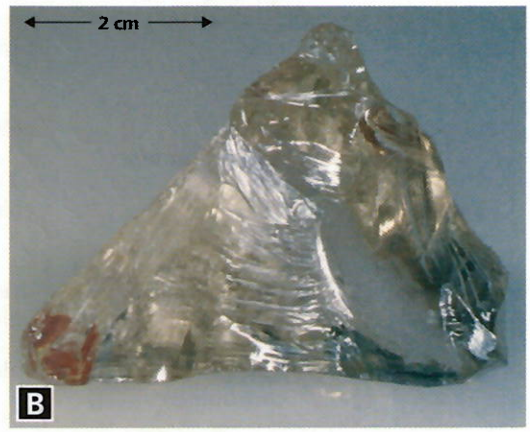


Figure 20 **A** Mica has cleavage in one direction and therefore cleaves into thin sheets. **B** The bonds in quartz are very strong in all directions, causing quartz to display conchoidal fracture.

Fracture

Minerals that do not show cleavage when broken are said to fracture. Fracture is the uneven breakage of a mineral. For example, quartz shows a curvy and glassy fracture. Like cleavage, there are different kinds of fracture. Minerals that break into smooth, curved surfaces like the quartz in Figure 20B have a 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 that is the ratio of an object's mass to its volume. Density is a ratio and can be expressed using the following equation.

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

Density is expressed using derived units with a unit of mass over a unit of volume. For example, the density of copper is 8.96 g/cm^3 (grams per cubic centimeter). Therefore, any sample of pure copper with a volume of one cubic centimeter will have a mass of 8.96 grams.

Many common minerals have densities between 2 and 5 g/cm^3. Some metallic minerals have densities that are often greater than rock-forming minerals. Galena, the ore of lead, has a density around 7.5 g/cm^3. The density of gold is 19.3 g/cm^3. The density of a pure mineral is a constant value. Thus, density can be used to determine the purity or identity of some minerals.

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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	$CaSO_4 \bullet 2H_2O$ 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

Table 2 Some Common Minerals and Their Properties

* Average density of the mineral

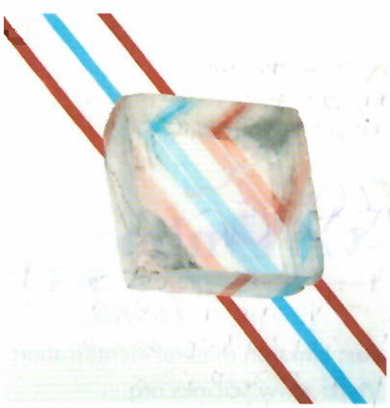


Figure 21 Calcite shows the property of double refraction.

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 types of magnetite are magnetic and can be used to pick up paper clips and small nails. When a piece of transparent calcite is placed over printed material, the letters appear doubled as Figure 21 shows. This property is called double refraction. Streaks of a few minerals that contain sulfur smell like rotten eggs. Carbonate minerals, such as calcite, will fizz when they come into contact with hydrochloric acid.

A mineral's properties depend on the elements that compose the mineral (its composition) and its structure (how its atoms are arranged). Table 2 lists some of the more common minerals and their properties. You will use this table to identify minerals in the lab on pages 58 and 59.

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
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

Section 2.3 Assessment

Reviewing 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?

Critical Thinking

4. **Applying Concepts** What kind of luster do the minerals shown in Figure 15 have? Explain your choice.
5. **Applying Concepts** Hornblende is a double-chain silicate. How many planes of cleavage do you think hornblende has when it breaks? Explain your answer.
6. **Applying 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

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

understanding **EARTH**

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.

Obviously, beauty is the most important 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,

Figure 22 Emerald is the dark green variety of the mineral beryl. More common blue-green beryl is aquamarine.

Figure 23 A diamond in the rough looks very different from the brilliant, multi-faceted gem it can become.

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	Opal	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

Exploration Lab

Mineral Identification

Most minerals can be easily identified by using the properties discussed in this chapter. In this lab, you will use what you have learned about mineral properties and the table on 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.

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 on pages 54–55

Skills Observing, Comparing and Contrasting, Measuring

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 fingernail, 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. With your goggles on and everyone out of your way, gently strike one of the mineral samples with a hammer.
8. Observe the broken mineral pieces. Does the mineral cleave or fracture? Remember that cleavage is breakage along flat, even surfaces and fracture is uneven breakage. Record your observations in your data table.
9. Repeat Steps 7 and 8 for the other minerals.

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										

Part D: Density

10. Using a balance, determine the mass of your mineral sample. Record the mass in the first 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.

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 finished with this test, wash the minerals well with tap water to rinse away the acid.

Analyze and Conclude

1. **Identifying** Use your data and Table 2 to identify each of the minerals tested.
2. **Evaluating** Which of the properties did you find most useful? Least useful? Give reasons for your answers.
3. **Comparing and Contrasting** In general, how did the minerals with metallic luster differ from those with non-metallic luster?
4. **Classifying** 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 Chapter 3.

CHAPTER 2

Study Guide

2.1 Matter

Key Concepts

- 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 a submicroscopic particle made of even smaller components called protons, neutrons, and electrons.
- 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. Compounds form when electrons are transferred or shared to form bonds.
- When an atom's outermost 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.

Vocabulary

element, *p. 34*; atomic number, *p. 35*; energy level, *p. 38*; isotope, *p. 38*; mass number, *p. 38*; compound, *p. 39*; chemical bond, *p. 40*; ion, *p. 40*; ionic bond, *p. 40*; covalent bond, *p. 42*; metallic bond, *p. 43*

2.2 Minerals

Key Concepts

- A mineral is a naturally occurring, inorganic solid with an orderly internal 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 exist in relatively pure form.

Vocabulary

mineral, *p. 45*; silicate, *p. 47*; silicon-oxygen tetrahedron, *p. 47*

2.3 Properties of Minerals

Key Concepts

- 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 is a scale that can be used to determine a mineral's hardness.
- 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 that is the ratio of an object's mass to its volume.
- Some minerals can be recognized by other distinctive properties.

Vocabulary

streak, *p. 51*; luster, *p. 51*; crystal form, *p. 51*; hardness, *p. 52*; Mohs scale, *p. 52*; cleavage, *p. 52*; fracture, *p. 53*; density, *p. 53*

Thinking Visually

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

CHAPTER 2

Assessment

Reviewing 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 outer electron shells 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

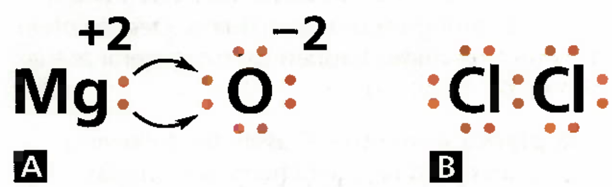
8. A particular mineral breaks like a piece of glass does. Which of these describes the breakage?
   a. cleavage **b.** hardness
   c. metallic luster **d.** fracture

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

Understanding 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 side 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.

CHAPTER 2

Assessment *continued*

Critical Thinking

22. **Comparing and Contrasting** Three atoms have the same atomic number but different mass numbers. What can you say about the atoms?

23. **Predicting** 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.

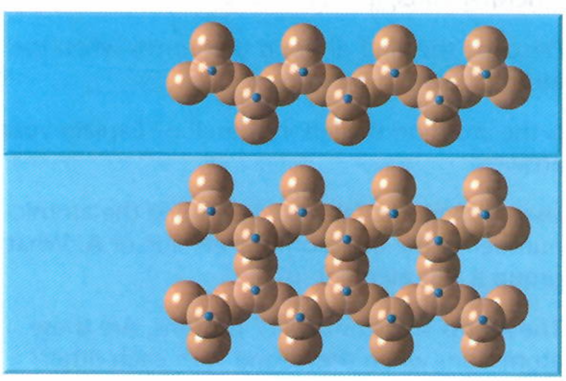
24. **Formulating Hypotheses** Why do you think metals can easily be rolled into thin sheets and drawn into wires? (*Hint:* Think about the arrangement of electrons in metals.)

25. **Explaining** Explain the processes that result in the formation of silicate minerals.

26. **Formulating Hypotheses** 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. **Applying Concepts** Classify the following minerals based on their chemical formulas.

a. $NaCO_3$	b. PbS
c. $FeCr_2O_4$	c. CaF_2



Use the diagrams to answer Questions 28–31.

28. **Identifying** What is the basic structural unit in these two diagrams?

29. **Classifying** What are the names given to these two silicate structures?

30. **Applying Concepts** How do these two structures affect mineral breakage?

31. **Formulating Hypotheses** Which of the two structures is more complex? Explain your choice.

Concepts in Action

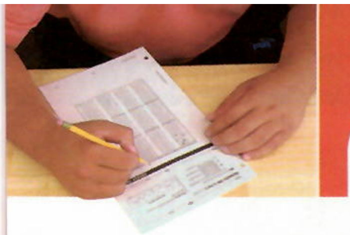
32. **Applying Concepts** Your friend shows you a crystal that he thinks is a diamond. Without asking an expert, how could you tell if the crystal is really a diamond?

33. **Hypothesizing** 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. **Calculating** 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

Applying 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.



Standardized Test Prep

Test-Taking Tip

Evaluating
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. Use this test-taking tip to answer Questions 1–3 on this page.

- 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.

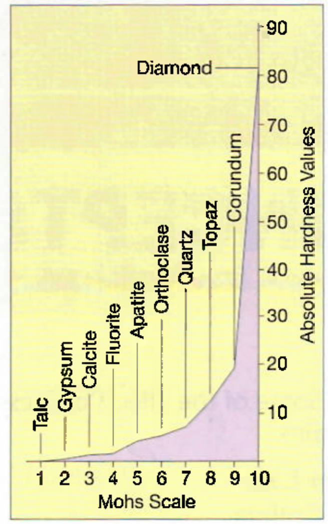
Choose the letter that best answers the question or completes the statement.

1. The central region of an atom includes
   (A) only neutrons.
   (B) only electrons.
   (C) electrons and protons.
   (D) neutrons and protons.

2. Protons in an atom
   (A) make up the atom's electron cloud.
   (B) are equal in number to the atom's neutrons.
   (C) determine the kind of element.
   (D) are NOT used to determine atomic mass.

3. If the atomic number of an element is 6 and its mass number is 14, how many neutrons are in the atom's nucleus?
   (A) 0 (B) 6
   (C) 8 (D) 20

Use the graph to answer Questions 4–6.



4. What does this graph show?

5. How does talc's hardness on the Mohs scale compare with its absolute hardness?

6. Describe the relationship between Mohs hardness and absolute hardness.

Answer the following questions in complete sentences.

7. How do the isotopes of an element differ?

8. Define a mineral.