Section 6.4

1 FOCUS

Objectives

6.4.1 **Describe** the structure and strength of bonds in metals.

6.4.2 **Relate** the properties of metals to their structure.

6.4.3 **Define** an alloy and **demonstrate** how the composition of an alloy affects its properties.

Reading Focus

Build Vocabulary L2

Vocabulary Knowledge Rating Chart Have students construct a chart with four columns labeled Term, Can Define It/Use It, Heard It/Seen It, and Don't Know. Have students copy the terms *metallic bond, metal lattice, alloy,* and *metallurgy* into the first column and rate their term knowledge by putting a check in one of the other columns. Ask how many students actually know each term. Have them share their knowledge. To provide a purpose for reading, ask focused questions to help students predict text content based on each term. After students have read the section, have them rate their knowledge again.

Reading Strategy L2

a. and b. Conductivity or malleability

2 INSTRUCT

Metallic Bonds

Integrate Social Studies L2

In the first light bulbs, air was removed from the light bulb to prevent combustion as the filament heated up. This solution was not ideal because atoms can sublime from the hot filament at very low pressures. With almost no air, atoms of the vaporized filament have uninterrupted paths to the inner walls of the bulb where they are deposited. The modern light bulb uses an argon atmosphere and a tungsten filament. This prolongs the life of the bulb because collisions between tungsten atoms and argon atoms can redirect tungsten atoms back toward the filament. Have interested students research the search for an effective filament. Students can present their findings in a poster or other visual display.
Visual

6.4 The Structure of Metals

Reading Focus

Key Concepts

- What are the forces that give a metal its structure as a solid?
- How do metallic bonds produce some of the typical properties of metals?
- How are the properties of alloys controlled?

Vocabulary

- metallic bond
- alloy

Reading Strategy

Relating Cause and Effect Copy the concept map. As you read, complete the map to relate the structure of metals to their properties.

Mobile electrons —produce— a. ? ; b. ?

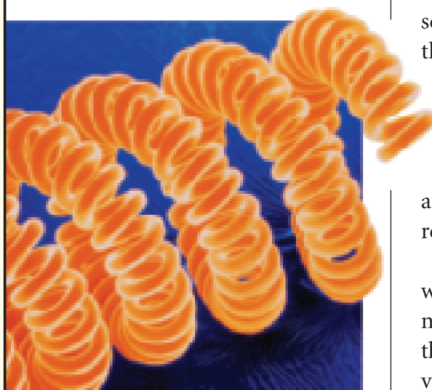

Figure 21 This photograph of the tungsten filament from a light bulb was taken with a scanning electron microscope. Color was added to the photo. The filament is magnified more than 100 times. The diameter of the wire is about 15 μm, or 0.0015 cm.

Light bulbs are easy to ignore unless a bulb burns out and you are searching for a replacement in the dark. But in the decades just before the year 1900, light bulbs were an exciting new technology. One challenge for researchers was to find the best material for the filaments in light bulbs. The substance had to be ductile enough to be drawn into a narrow wire. It could not melt at the temperatures produced when an electric current passes through a narrow wire. It had to have a low vapor pressure so that particles on the surface were not easily removed by sublimation.

The substance the researchers found was tungsten (W), a metal whose name means "heavy stone" in Swedish. Figure 21 shows a magnified view of the narrow coils in a tungsten filament. Tungsten has the highest melting point of any metal—3410°C—and it has the lowest vapor pressure. The properties of a metal are related to bonds within the metal.

Metallic Bonds

Metal atoms achieve stable electron configurations by losing electrons. But what happens if there are no nonmetal atoms available to accept the electrons? There is a way for metal atoms to lose and gain electrons at the same time. In a metal, valence electrons are free to move among the atoms. In effect, the metal atoms become cations surrounded by a pool of shared electrons. A **metallic bond** is the attraction between a metal cation and the shared electrons that surround it.

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Section Resources

Print
- ***Reading and Study Workbook With Math Support***, Section 6.4
- ***Transparencies***, Section 6.4

Technology
- ***Interactive Textbook***, Section 6.4
- ***Presentation Pro CD-ROM***, Section 6.4
- ***Go Online***, *Science News*, Metals

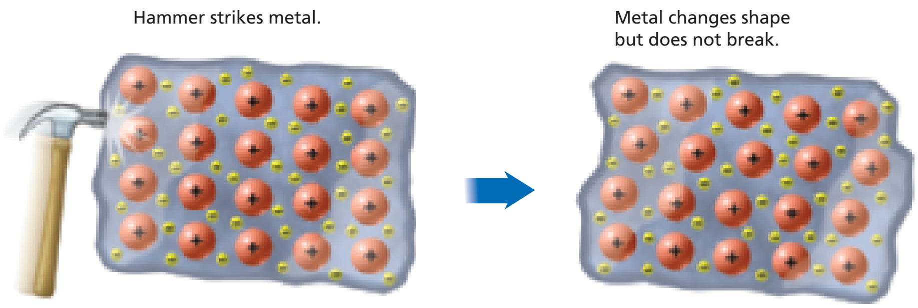


Figure 22 In a metal, cations are surrounded by shared valence electrons. If a metal is struck, the ions move to new positions, but the ions are still surrounded by electrons. **Classifying** ***What property of metals is displayed when a hammer strikes a metal?***

The cations in a metal form a lattice that is held in place by strong metallic bonds between the cations and the surrounding valence electrons. Although the electrons are moving among the atoms, the total number of electrons does not change. So, overall, the metal is neutral.

The metallic bonds in some metals are stronger than in other metals. The more valence electrons an atom can contribute to the shared pool, the stronger the metallic bonds will be. The bonds in an alkali metal are relatively weak because alkali metals contribute only a single valence electron. The result is that alkali metals, such as sodium, are soft enough to cut with a knife and have relatively low melting points. Sodium melts at 97.8°C. Transition metals, such as tungsten, have more valence electrons to contribute and, therefore, are harder and have higher melting points. Recall that tungsten melts at 3410°C.

Explaining Properties of Metals

The structure within a metal affects the properties of metals. **The mobility of electrons within a metal lattice explains some of the properties of metals.** The ability to conduct an electric current and malleability are two important properties of metals.

Recall that a flow of charged particles is an electric current. A metal has a built-in supply of charged particles that can flow from one location to another—the pool of shared electrons. An electric current can be carried through a metal by the free flow of the shared electrons.

The lattice in a metal is flexible compared to the rigid lattice in an ionic compound. Figure 22 is a model of what happens when someone strikes a metal with a hammer. The metal ions shift their positions and the shape of the metal changes. But the metal does not shatter because ions are still held together by the metallic bonds between the ions and the electrons. Metallic bonds also explain why metals, such as tungsten and copper, can be drawn into thin wires without breaking.

Reading Checkpoint ***What two important properties of metals can be explained by their structure?***

Customize for English Language Learners

Use a Cloze Strategy
Use a Cloze strategy for students with very limited English proficiency. Have students fill in the blanks in the following sentences while reading Explaining Properties of Metals. **The ________ of ________ within a metal lattice explains some of the properties of metal. The lattice in a metal is ________ compared to the ________ lattice in an ionic compound.** *(mobility; electrons; flexible; rigid)*

Teacher Demo

Comparing Bond Types **L2**

Purpose Students observe differences in the properties of substances with ionic bonds and metallic bonds.

Materials salt lick (or rock salt), copper wire, hammer, goggles

Procedure Take students outside to an open area. Allow them to examine the samples of rock salt and copper. Have students stand back a safe distance. While wearing goggles, hit each sample with a hammer against a hard surface, such as concrete. Allow students to observe how each sample looks after being pounded with a hammer.

Expected Outcome The rock salt shatters because sodium chloride is an ionic substance. The end of the copper wire can be pounded flat with a hammer because metals are malleable.
Visual

Explaining Properties of Metals

Use Visuals **L1**

Figure 22 Have students examine Figure 22. Ask, **How are the cations affected when the hammer strikes the metal?** *(The cations shift positions.)* **How are the metallic bonds between the cations and electrons affected when the hammer strikes the metal?** *(The metallic bonds are unaffected. Each cation is still surrounded by electrons.)*
Visual

Address Misconceptions **L2**

Many students think that particles in solids cannot move. Challenge this misconception by reminding students that the kinetic theory of matter says that all particles of matter are in constant motion. Ask, **Describe the motion of cations in a metal when the metal is not being struck by a hammer.** *(The cations vibrate, or move repeatedly back and forth, around fixed locations.)*
Logical

Answer to . . .

Figure 22 *Malleability*

Reading Checkpoint *The ability to conduct an electric current and malleability*

Alloys

Use Community Resources

L2

Arrange for your class to visit the workshop of a jewelry maker, metalworker, blacksmith, or welder. Have students observe the types of equipment used to work with different metals. Ask questions regarding the artisan's choice of materials for different projects. Ask about the use of different alloys in metallurgy.
Interpersonal

FYI

There are different categories of alloys: true solutions, heterogeneous mixtures with two phases (a pure element and a compound), or intermetallic compounds with definite compositions.

SCIENCE and History

Milestones in Metallurgy

L2

Ask students to choose one of the significant events in metallurgy history described in the time line. Have them do research in the library or on the Internet to find out more about the materials, applications, and people involved in their chosen topic. Have them present their findings to the class. Be sure that part of their presentation focuses on the specific properties of metals and alloys.
Verbal

Writing in Science

Henry Ford saw an automobile part made from vanadium steel when a French racer crashed at a European race meeting in 1905. He was impressed with the strength and low weight of the steel. American foundries did not have furnaces that could achieve the temperature required to produce the alloy. Ford found a small steel company in Ohio that was willing to experiment with the process and produce the alloy exclusively for Ford.
Verbal

Alloys

A friend shows you a beautiful ring that she says is made from pure gold. Your friend is lucky to have such a valuable object. The purity of gold is expressed in units called karats. Gold that is 100 percent pure is labeled 24-karat gold. Gold jewelry that has a 12-karat label is only 50 percent gold. Jewelry that has an 18-karat label is 75 percent gold.

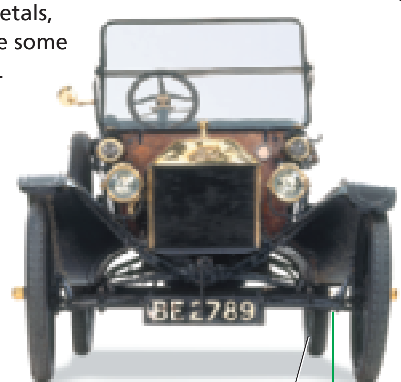
The surface of an object made from pure gold can easily be worn away by contact with other objects or dented because gold is a soft metal. When silver, copper, nickel, or zinc is mixed with gold, the gold is harder and more resistant to wear. These gold mixtures are alloys. An **alloy** is a mixture of two or more elements, at least one of which is a metal. Alloys have the characteristic properties of metals.

SCIENCE and History

Milestones in Metallurgy

The science of metallurgy includes ways to extract metals from ores, refine metals, and use metals. Described here are some advances in metallurgy since 1850.

BESSEMER CONVERTER



Vanadium steel *This alloy becomes popular in car manufacturing because it is lightweight and strong.*

Hot gas flame *The flame from a burning gas melts the surfaces where two metal parts will join.*

Gas torch

GAS WELDING

1856 Henry Bessemer develops an efficient process for producing steel by blowing air through molten iron.

1886 Charles Hall and Paul Héroult independently develop a method for using electricity to obtain aluminum from aluminum oxide.

1908 Henry Ford uses vanadium steel (an alloy of iron with carbon and vanadium) extensively in his Model T Fords.

1914 The start of World War I leads to the wide-scale use of welding techniques, such as gas welding with acetylene, for ship building.

1850 | 1880 | 1910

Copper Alloys The first important alloy was bronze, whose name is associated with an important era in history—the Bronze Age. Metalworkers in Thailand may have been the first to make bronze. But people in other locations probably thought they were the first to make bronze. News didn't travel quickly in that era.

Metalworkers might have noticed that the metal they extracted by heating deposits of copper was not always the same. The difference in properties could be traced to the presence of tin. In its simplest form, bronze contains only copper and tin, which are relatively soft metals. Mixed together in bronze, the metals are much harder and stronger than either metal alone. **Scientists can design alloys with specific properties by varying the types and amounts of elements in an alloy.**

Writing in Science

Cause-Effect Paragraph
Write a paragraph about Henry Ford's decision to use vanadium steel for automobile parts. Where did Ford first see parts made from vanadium steel? What properties of this type of steel impressed Ford? Did Ford need to overcome any problems before going ahead with his plan?

Steel-framed structure *The Empire State Building is supported by a framework of steel columns and beams that weigh 60,000 tons.*

EMPIRE STATE BUILDING

1931 The 102-story Empire State Building in New York City is completed. Skyscrapers would be impossible without steel-framed construction.

Metal parts, *such as the gears in this gold watch, are made by applying heat and pressure to powdered metal in a mold.*

METAL PARTS FROM POWDER

1942 Making small, complex parts from metal powders is less wasteful than machining. World War II spurs advances in iron powder metallurgy.

Superalloys containing rhenium are used in jet engines.

1991 New alloys containing rhenium are introduced. These superalloys are capable of retaining their strength at very high temperatures.

1940 | 1970 | 2000

Build Reading Literacy

L1

Compare and Contrast Refer to page **226D** in **Chapter 8**, which provides the guidelines for comparing and contrasting.

Have students read the passage on copper alloys. Then, have students construct a chart that does the following: 1. Identify two copper alloys described in the text. 2. Make a list of properties the alloys have in common. 3. Make a list of properties that differ between the two alloys.
Visual

Facts and Figures

Bronze Bronze jewelry found in graves beneath the town of Ban Chiang in northeast Thailand has been dated to 3600 B.C., but this date is controversial. If correct, the site predates sites in Mesopotamia by several hundred years. Some copper alloys that contain little tin but are similar in color to bronze are labeled as bronzes to take advantage of the reputation of bronze as a hard, durable material.

Teacher Demo

Bronze and Brass Tones L2

Purpose Students observe the difference in tone between a brass bell and a bronze bell.

Materials brass bell, bronze bell

Procedure Allow students to examine each bell to see if they appear different in color or shininess. Ring each bell and allow students to note the difference in tone.

Expected Outcome In general, brass is shinier than bronze. A brass bell will have a duller tone that does not last as long as the clear, loud tone of a bronze bell. (Bell bronze contains about 80% copper and 20% tin, which is just the right composition to produce a hard, resonant material.)
Visual, Musical

Build Science Skills L2

Applying Concepts After students read about copper alloys, present the following problem to the class. **Imagine that you are going to make a wind chime in shop class as a gift. You have two choices of metals to use, brass or bronze. Which do you choose? Explain your answer.** *(Some students may choose brass because it is shinier and easier to shape into forms than bronze. Others may choose bronze because it has a clearer, louder tone and weathers better than brass.)*
Intrapersonal

Go Online SCIENCE NEWS

Science News provides students with current information on metals.

Figure 23 This ancient statue of horses from Venice, Italy, and this modern French horn are both made from copper alloys. The statue is made from bronze, an alloy of copper and tin. The French horn is made from brass, an alloy of copper and zinc.

Bronze is hard and durable enough to be used for propellers on ships and for statues, such as the statue of horses in Figure 23. A bronze bell has a clear, loud tone that lasts for several seconds.

A brass bell has a duller tone that dies away quickly. Brass is another alloy of copper that has been known for centuries. In its simplest form, brass contains only copper and zinc. Although both bronze and brass are alloys of copper, they have distinctly different properties. Brass is softer than bronze and is easier to shape into forms such as the French horn in Figure 23. Brass is shinier than bronze but is likely to weather more quickly.

Steel Alloys The 1900s could be called the Age of Steel because of the skyscrapers, automobiles, and ships that were built from steel during the 1900s. Steel is an alloy of iron that contains small quantities of carbon, ranging from less than 0.2 percent to about 3 percent by mass. The smaller carbon atoms fit in the spaces between the larger iron atoms in the lattice. The carbon atoms form bonds with neighboring iron atoms. These bonds make the lattice harder and stronger than a lattice that contains only iron.

The properties of any particular type of steel depend on which elements other than iron and carbon are used and how much of those elements are included. Stainless steels contain more than 10 percent chromium by mass, but almost no carbon. Stainless steels are durable because chromium forms an oxide that protects the steel from rusting. But stainless steel is more brittle than steels that contain more carbon. The steel cables in the bridge in Figure 24 have to be strong enough to resist forces that might stretch the cables or cause them to break. The steel used contains sulfur, manganese, phosphorus, silicon, and 0.81 percent carbon.

Go Online SCIENCE NEWS

For: Articles on metals
Visit: PHSchool.com
Web Code: cce-1064

Facts and Figures

Bronze Horses The origin of the gilded bronze horses of St. Mark's is unclear. The sculptures are not similar in style to other Greek or Roman sculptures of horses. Nor are they similar in composition. From chemical analyses, art historians know that the bronze is 98% copper, 1% tin, and 1% lead, which is an unusually high percent of copper. Art historians do know that the horses were cast in pieces that were welded together. The pieces were made using the lost wax method described in Chapter 2.

The horses can be traced from a triumphal arch in Rome to one in Constantinople. They were taken from Constantinople to Venice in 1204 (where they were placed on a balcony of the cathedral), then to Paris in 1797, and then back to Venice in 1815. For protection from air pollution, the horses are now stored inside the cathedral. A copy appears on the balcony.

Figure 24 The Golden Gate Bridge is a landmark in San Francisco, California. Its cables, towers, and deck contain steel. The steel in the cables needs to resist forces that pull on the cables. The steel in the towers needs to resist the compression forces caused by the weight of the cables, the deck, and the vehicles that travel across the bridge.
Drawing Conclusions ***Would the steel used for the cables and the steel used for the towers have the same composition? Give a reason for your answer.***

Other Alloys Airplane parts are made of many different alloys that are suited to particular purposes. The body of a plane is large and needs to be made from a lightweight material. Pure aluminum is lighter than most metals, but it bends and dents too easily. If a small amount of copper or manganese is added to aluminum, the result is a stronger material that is still lighter than steel.

For certain aircraft parts, even lighter materials are needed. Alloys of aluminum and magnesium are used for these parts. Magnesium is much less dense than most metals used to build structures. However, pure magnesium is soft enough to cut with a knife, and it burns in air. An aluminum-magnesium alloy keeps the advantages of magnesium without the disadvantages.

Section 6.4 Assessment

Reviewing Concepts

1. What holds metal ions together in a metal lattice?
2. What characteristic of a metallic bond explains some of the properties of metals?
3. How can scientists design alloys with specific properties?
4. Explain why the metallic bonds in some metals are stronger than the bonds in other metals.
5. Why are metals good conductors of electric current?
6. How does adding carbon to steel make the steel harder and stronger?

Critical Thinking

7. **Predicting** Which element has a higher melting point, potassium in Group 1A or calcium in Group 1B? Give a reason for your answer.
8. **Applying Concepts** Can two different elements form a metallic bond together?

Writing in Science

Compare-Contrast Paragraph Write a paragraph comparing the properties of ionic compounds and alloys. Relate their properties to the structure of their lattices.

Integrate Materials Science L2

The properties of an alloy that are determined by its composition include malleability, ductility, hardness, corrosion resistance, tensile strength (the ability to resist being pulled apart), shear strength (the ability to resist opposing forces that are not acting in a straight line), compressive strength (the ability to withstand pressures acting on a given plane), and elasticity (the ability to return to its original size and shape). Ask, **What properties of steel make it useful for the cables and towers of the Golden Gate Bridge?** *(Its high tensile strength makes steel a useful material for the cables, and its high compressive strength makes it a useful material for the towers.)* **Logical**

3 ASSESS

Evaluate Understanding L2

Have students write the names of the following elements on index cards: copper, gold, silver, nickel, zinc, tin, iron, carbon, and aluminum. On the other side of the cards, have students write common uses for these elements. (For example, alloys of aluminum and copper are used to make airplane parts.)

Reteach L1

Use Figure 22 to review how the structure within a metal affects the properties of a metal.

Writing in Science

In the rigid network of a crystal lattice, the charged particles are not free to flow unless the solid melts. When struck, the crystal shatters because ions with the same charge shift position in the lattice and repel. Thus, ionic solids are brittle and are poor conductors. In a metal lattice, the electrons are free to move and conduct a current. The lattice is malleable when struck because if a cation moves it is still surrounded by particles with an opposite charge.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 6.4.

Answer to . . .

Figure 24 *The compositions would probably be different because the forces acting on the cables and towers are different—tensile versus compressive, respectively.*

Section 6.4 Assessment

1. Metal ions are held together by the strong metallic bonds between the cations and the surrounding valence electrons.
2. The mobility of electrons within a metal lattice explains some of the properties of metals.
3. Scientists can design alloys with specific properties by varying the types and amounts of elements in an alloy.
4. The more valence electrons a metal can contribute, the stronger the bonds will be.
5. The valence electrons are free to move because they are not attached to a specific metal ion.
6. The smaller carbon atoms fit into spaces between the iron atoms and form bonds with neighboring iron atoms, which makes the lattice harder and stronger.
7. Calcium has a higher melting point because it contributes twice as many electrons to the metallic bonds.
8. Yes, alloys usually are mixtures of elements with metallic bonds.