7.3 Bonding in Metals

Connecting to Your World You have probably seen decorative fences, railings, or weathervanes made of a metal called wrought iron. Wrought iron is a very pure form of iron that contains trace amounts of carbon. It is a tough, malleable, ductile, and corrosion-resistant material that melts at a very high temperature. As you already know, metals often have distinctive, useful properties. In this section, you will learn how metallic properties derive from the way that metal ions form bonds with one another.

Guide for Reading

Key Concepts

- How can you model the valence electrons of metal atoms?
- How are metal atoms arranged?
- Why are alloys important?

Vocabulary

metallic bonds

alloys

Reading Strategy

Using Prior Knowledge Before you read, jot down three things you know about metals. When you have read the section, explain how what you already knew helped you learn something new.

Metallic Bonds and Metallic Properties

Metals are made up of closely packed cations rather than neutral atoms. **The valence electrons of metal atoms can be modeled as a sea of electrons.** That is, the valence electrons are mobile and can drift freely from one part of the metal to another. **Metallic bonds** consist of the attraction of the free-floating valence electrons for the positively charged metal ions. These bonds are the forces of attraction that hold metals together.

The sea-of-electrons model explains many physical properties of metals. For example, metals are good conductors of electrical current because electrons can flow freely in them. As electrons enter one end of a bar of metal, an equal number leave the other end. Metals are ductile—that is, they can be drawn into wires, as shown in Figure 7.12. Metals are also malleable, which means that they can be hammered or forced into shapes.

Interactive Textbook

Animation 9 See how metallic bonding explains some physical properties of metals.

with ChemASAP

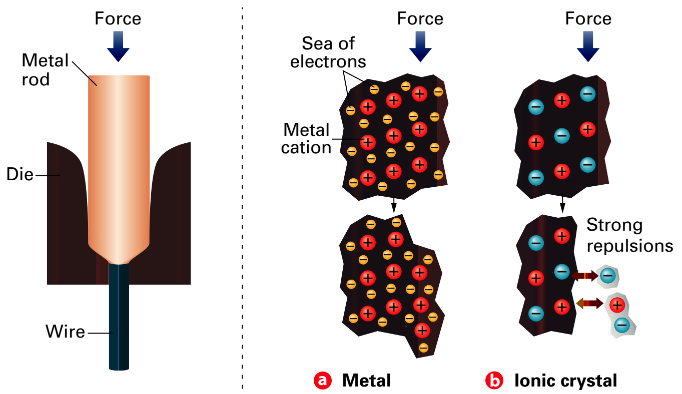


Figure 7.12 A metal rod can be forced through a narrow opening in a die to produce wire. **a** As this occurs, the metal changes shape but remains in one piece. **b** If an ionic crystal were forced through the die, it would shatter. **Interpreting Diagrams** ***What causes the ionic crystal to break apart?***

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 7.3
- **Core Teaching Resources,** Section 7.3 Review
- **Transparencies,** T82–T84
- **Laboratory Manual,** Lab 10

Technology

- **Interactive Textbook with ChemASAP,** Animation 9, Assessment 7.3

7.3

1 FOCUS

Objectives

7.3.1 **Model** the valence electrons of metal atoms.

7.3.2 **Describe** the arrangement of atoms in a metal.

7.3.3 **Explain** the importance of alloys.

Guide for Reading

Build Vocabulary L2

Word Forms From what they know about the terms *metallic* and *bond,* have students infer the meaning of *metallic bond.*

Reading Strategy L2

Relating Cause and Effect Have students describe the cause-and-effect relationship between metallic bonding and the properties of metals.

2 INSTRUCT

Connecting to Your World

Have students read the text that opens the section. Ask, **What property makes metals good electrical conductors?** *(Metal bonding involves highly mobile electrons, which are shared by all of the nuclei in a metallic solid. Electron mobility accounts for the high electrical conductivity of metals.)*

Metallic Bonds and Metallic Properties

Relate L2

To assess students' prior knowledge about metals, ask, **What are the properties of malleable and ductile metals?** *(They can be hammered into different shapes and drawn into wires.)* **What is an alloy? Give an example.** *(An alloy is a mixture of two or more elements, at least one of which is a metal. Examples include steel and brass.)*

Answers to...

Figure 7.12 repulsions between ions of like charge

TEACHER Demo

Metals vs. Ionic Compounds L2

Purpose Students compare copper metal and a copper compound.

Materials copper metal or alloy, copper-containing ionic compound

Procedure Show the class a small sample of elemental copper or a copper alloy and a sample of a copper-containing crystalline ionic mineral such as chalcocite (Cu_2S). Wearing safety glasses and standing far from the students, smash both samples with a hammer. Discuss why the two substances respond differently to the stress of the hammer blow.

Expected Outcomes The elemental copper will flatten but not break because the cations and electrons are mobile; the crystal will shatter.

Crystalline Structure of Metals

Use Visuals L1

Figure 7.14 Lead a class discussion on the concept of "closest packing" of metal cations in pure metals. Use the three different closest packing arrangements shown in Figure 7.14 as a reference. Emphasize that the concept of closest packing also relates to more than just metal atoms. Have the students describe other examples of closest packing.

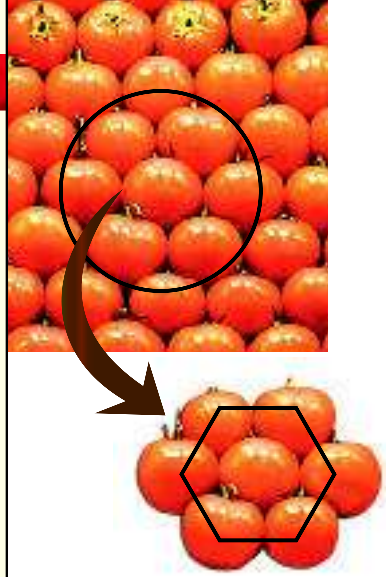


Figure 7.13 These tomatoes illustrate a pattern called a hexagonal close-packed arrangement.

Both the ductility and malleability of metals can be explained in terms of the mobility of valence electrons. A sea of drifting valence electrons insulates the metal cations from one another. When a metal is subjected to pressure, the metal cations easily slide past one another like ball bearings immersed in oil. In contrast, if an ionic crystal is struck with a hammer, the blow tends to push the positive ions close together. They repel, and the crystal shatters.

Crystalline Structure of Metals

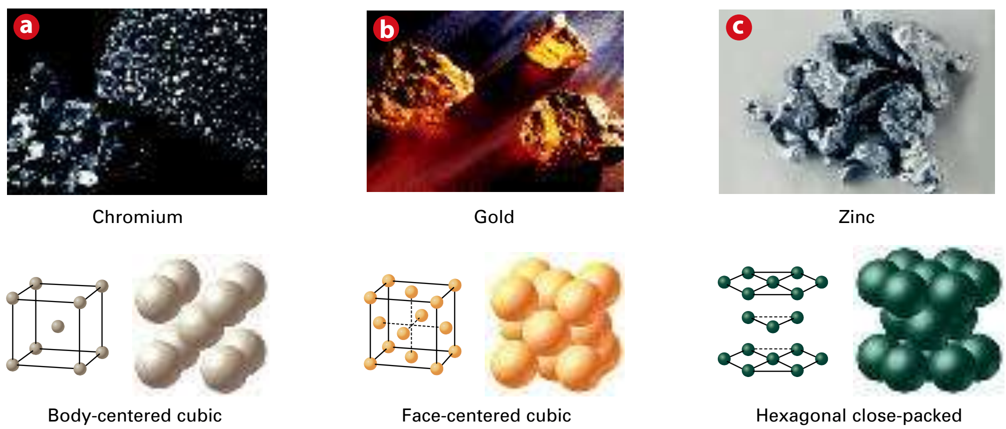
The next time you visit a grocery store, take a look at how the apples or tomatoes are stacked. More than likely, they will have a close-packed arrangement, as shown in Figure 7.13. This arrangement helps save space while allowing as many tomatoes to be stacked as possible.

Similar arrangements can be found in the crystalline structures of metals. You may be surprised to learn that metals are crystalline. In fact, metals that contain just one kind of atom are among the simplest forms of all crystalline solids. **Metal atoms are arranged in very compact and orderly patterns.** For spheres of identical size, such as metal atoms, there are several closely packed arrangements that are possible. Figure 7.14 shows three such arrangements: body-centered cubic, face-centered cubic, and hexagonal close-packed arrangements.

In a body-centered cubic structure, every atom (except those on the surface) has eight neighbors. The elements sodium, potassium, iron, chromium, and tungsten crystallize in a body-centered cubic pattern. In a face-centered cubic arrangement, every atom has twelve neighbors. Among the metals that form a face-centered cubic lattice are copper, silver, gold, aluminum, and lead. In a hexagonal close-packed arrangement, every atom also has twelve neighbors. Because of its hexagonal shape, however, the pattern is different from the face-centered cubic arrangement. Metals that have the hexagonal close-packed crystal structure include magnesium, zinc, and cadmium.

Checkpoint *What metals crystallize in a face-centered cubic pattern?*

Figure 7.14 Metal atoms crystallize in characteristic patterns. (a) Chromium atoms have a body-centered cubic arrangement. (b) Gold atoms have a face-centered cubic arrangement. (c) Zinc atoms have a hexagonal close-packed arrangement. **Inferring** ***Which of these arrangements is the most closely packed?***



Differentiated Instruction

Gifted and Talented L3

Have students develop formulas for calculating the density of a metal given the atomic radius of the metal and the cubic unit cell packing arrangement of the metal atoms. Use sodium, potassium, iron, chromium, and tungsten for body-centered cubic metals. Use copper, silver, gold, aluminum, and lead for face-centered cubic metals. The students may need to make models to see geometric relationships more clearly.

Figure 7.15 Bicycle frames are often made of titanium alloys that contain aluminum and vanadium.

Alloys

Although every day you use metallic items, such as spoons, very few of these objects are pure metals. Instead, most of the metals you encounter are alloys. **Alloys** are mixtures composed of two or more elements, at least one of which is a metal. Brass, for example, is an alloy of copper and zinc. **Alloys are important because their properties are often superior to those of their component elements.** Sterling silver (92.5% silver and 7.5% copper) is harder and more durable than pure silver but still soft enough to be made into jewelry and tableware. Bronze is an alloy generally containing seven parts of copper to one part of tin. Bronze is harder than copper and more easily cast. Nonferrous (non-iron) alloys, such as bronze, copper-nickel, and aluminum alloys, are commonly used to make coins.

The most important alloys today are steels. The principal elements in most steel, in addition to iron and carbon, are boron, chromium, manganese, molybdenum, nickel, tungsten, and vanadium. Steels have a wide range of useful properties, such as corrosion resistance, ductility, hardness, and toughness. Table 7.3 lists the composition of some common alloys.

Alloys can form from their component atoms in different ways. If the atoms of the components in an alloy are about the same size, they can replace each other in the crystal. This type of alloy is called a substitutional alloy. If the atomic sizes are quite different, the smaller atoms can fit into the interstices (spaces) between the larger atoms. Such an alloy is called an interstitial alloy. In the various types of steel, for example, carbon atoms occupy the spaces between the iron atoms. Thus, steels are interstitial alloys.

Table 7.3
Composition of Some Common Alloys

Name	Composition (by mass)
Sterling silver	Ag 92.5% Cu 7.5%
Cast iron	Fe 96% C 4%
Stainless steel	Fe 80.6% Cr 18.0% C 0.4% Ni 1.0%
Spring steel	Fe 98.6% Cr 1.0% C 0.4%
Surgical steel	Fe 67% Cr 18% Ni 12% Mo 3%

7.3 Section Assessment

23. **Key Concept** How do chemists model the valence electrons in metal atoms?
24. **Key Concept** How can you describe the arrangement of atoms in metals?
25. **Key Concept** Why are alloys more useful than pure metals?
26. Describe what is meant by ductile and malleable.
27. Why is it possible to bend metals but not ionic crystals?
28. What are three different packing arrangements found in metallic crystals?
29. Describe two widely used alloys.

Writing Activity

Explanatory Paragraph Write a paragraph describing how the sea-of-electrons model is used to explain the physical properties of metals. *Hint:* First write a sentence that summarizes the model. Then discuss how the model applies to specific properties of metals.

Interactive Textbook

Assessment 7.3 Test yourself on the concepts in Section 7.3.

with ChemASAP

Alloys

TEACHER Demo

Types of Alloys L2

Purpose Students compare models of interstitial and substitutional alloys.

Materials styrofoam balls of different sizes and colors, toothpicks

Procedure Use styrofoam balls to illustrate the crystal structures of interstitial and substitutional alloys. Use toothpicks to hold the "atoms" together. Point out that brass is a substitutional alloy in which copper atoms are replaced by similarly sized zinc atoms. Steel is an interstitial alloy in which relatively small carbon atoms occupy the interstices between closely packed iron atoms.

Expected Outcome Students should be able to distinguish between the two types of alloys.

3 ASSESS

Evaluate Understanding L2

Ask, **How can the conductivity of metals be explained?** *(Electrons can flow in and out of a metal because the valence electrons are not fixed.)*

Reteach L1

Compare chemical bonding in ionic compounds and pure metals.

Writing Activity

Metal cations are surrounded by free-floating electrons. When metals are hammered, the cations move past each other. Conductivity results from mobile electrons.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 7.3.

with ChemASAP

Answers to...

Figure 7.14 face-centered cubic

Checkpoint copper, silver, gold, aluminum, and lead

Section 7.3 Assessment

23. metal cations surrounded by a sea of mobile valence electrons
24. Atoms in metals are arranged in a compact and orderly manner.
25. The properties of alloys are often superior to their component elements.
26. ductile: can be drawn into wires; malleable: can be hammered into different shapes
27. Under pressure, the cations in a metal slide past each other. The ions in ionic crystals are forced into each other by the rigid structure.
28. body-centered cubic; face-centered cubic; hexagonal close-packed
29. Sterling silver used in jewelry is 92.5% silver and 7.5% copper; bronze used in casting is 7 parts copper and 1 part tin.

Technology & Society

Building With Alloys

Explain that materials for a building must be able to withstand the stresses that a building undergoes. Discuss with students several different types of stress. Tensile stress can be observed when a building beam sags. The bottom of the beam undergoes tensile stress as it is slightly stretched. The top of the beam undergoes compression stress, which results when two forces push toward each other through a solid. The top of the beam is compressed as it is slightly shortened. A building undergoes shear stress in a strong wind. In shear stress, forces are applied from different directions, and the building might twist or break. Ask, **Which of these buildings are most likely to undergo shear stress?** *(The Atomium, the Chrysler Building)*

Metals are used as building materials because of strength and durability, but other properties might determine the use of a metal in a building. Ask, **What property of a metal might make it useful on the outside of a building?** *(Answers might include luster when a shiny appearance is desired, malleability when the metal covers another material, or the ability of a certain metal to form a compound that protects the rest of the metal or other materials under it.)* **What metal was chosen for each these buildings? Why do you think that alloy was used?** *(possible answers: the Atomium—aluminum alloy; shiny, corrosion resistant, light, malleable; the Chrysler Building—steel; shiny, malleable, corrosion-resistant; the Jewish Museum Berlin—zinc-titanium alloy: corrosion resistant, light)*

Technology & Society

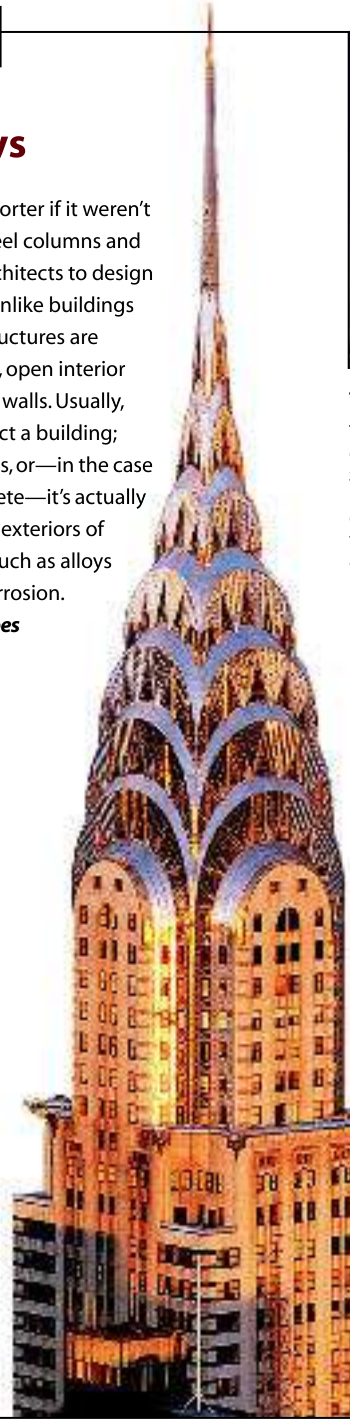
Building with Alloys

Modern architecture would be a lot shorter if it weren't for steel. Since the late 1800s, using steel columns and girders in construction has allowed architects to design taller, stronger, and lighter buildings. Unlike buildings made of wood, brick, or stone, steel structures are strong enough to accommodate large, open interior spaces that do not require supporting walls. Usually, you can't see the steel used to construct a building; either it's hidden by the floors and walls, or—in the case of a building made of reinforced concrete—it's actually embedded in the floors and walls. The exteriors of buildings often feature lighter alloys, such as alloys of aluminum or titanium that resist corrosion.

Comparing and Contrasting ***How does steel-frame construction differ from reinforced-concrete construction?***

Jewish Museum Berlin
Berlin, Germany
This angular building is covered in thin sheets of zinc-titanium alloy. The untreated alloy will slowly oxidize and change color from exposure to the air and weather.

The Atomium
Brussels, Belgium
Designed to resemble a crystal of iron magnified 165 billion times, the Atomium consists of nine spheres made of aluminum-alloy panels and connected by steel tubes. The top sphere contains an observation deck 92 meters above ground.



Chrysler Building
New York City
Completed in 1930, this steel-frame high-rise stands 319 m tall and features a distinctive spire sheathed in shiny stainless steel.

Facts and Figures

A Good Foundation

Concrete itself is not strong enough to be a good framing material. Reinforcing the concrete by pouring it over steel rods that have been laid out in a grid adds a considerable amount of strength to the concrete. When exceptionally strong concrete is needed, it is poured over steel cables that are stretched. After the concrete dries, the rods are released, and the concrete is compressed as the rods return to their original length. This exceptionally strong concrete is called prestressed concrete.

Steel-frame construction The most common method to build a high-rise is to use a steel framework. Steel frames can be assembled quickly and allow for flexible interior spaces.

Reinforced-concrete construction Another method for building high-rises is to use reinforced concrete. Concrete is more rigid than steel and holds up better structurally in fires. In addition, a concrete frame takes up less vertical space than a steel frame, meaning that a concrete-frame building can contain more floors than a steel-frame building of the same height.

TEACHER Demo

Making an Alloy L2

Purpose Students observe how to make an alloy from copper and zinc.

Materials penny, fine sandpaper, granulated zinc, dilute NaOH solution, evaporating dish, tongs, hot plate, teaspoon

Safety Be sure to use adequate ventilation and have no skin contact with the NaOH solution. Do not touch hot objects.

Procedure Use the sandpaper to clean any tarnish from the penny. Add a teaspoon of zinc to the evaporating dish, and cover the zinc with NaOH solution. Place the penny on the zinc, being sure the penny is also covered by the solution. Heat the dish until the penny changes to a silvery color. Using the tongs, remove and rinse the penny. Place the penny on the hot plate, which should be set to medium heat. When the penny turns a gold color, use tongs to remove it from the hot plate.

Expected Outcome A gold-colored alloy forms from copper and zinc. Ask, **Why did the penny turn a silver color?** *(Zinc was deposited on the penny.)* **At what point was an alloy formed?** *(An alloy was formed when the copper and zinc on the penny were heated to a golden color.)* **Why was the penny heated to form the alloy?** *(Heat increases the kinetic energy of the atoms, allowing them to mix more freely.)*

Differentiated Instruction

Less Proficient Readers L1

Have students create a list of the building materials they find in their school building. If the material is a metal, have them try to determine whether the metal is an alloy or not. Point out to students that most of the metals will be alloys, such as steel, because alloys can be made to have the properties desired in a building material.

Answers to...

Comparing and Contrasting Steel frames allow for more flexible interior spaces. Reinforced-concrete construction takes up less vertical space, so more floors can be contained in a building of a certain height if reinforced concrete is used instead of steel.