6.1 Ionic Bonding

Reading Focus

Key Concepts

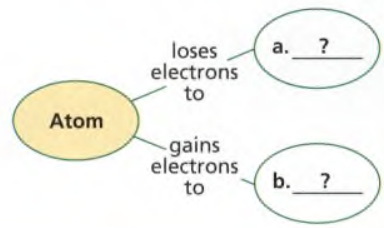
- When is an atom unlikely to react?
- What is one way in which elements can achieve stable electron configurations?
- How does the structure of an ionic compound affect its properties?

Vocabulary

- electron dot diagram
- ion
- anion
- cation
- chemical bond
- ionic bond
- chemical formula
- crystals

Reading Strategy

Sequencing Copy the concept map. As you read, complete the concept map to show what happens to atoms during ionic bonding.



The handle of the titanium mug in Figure 1 was joined to the body by welding. The pieces were heated until their surfaces fused together. The welding of titanium does not take place in air. At the temperature at which welding occurs, titanium becomes hot enough to react with oxygen in the air, forming an oxide. The oxide makes the weld more brittle and likely to break. Because titanium does not react with a noble gas such as argon, the welding of titanium usually takes place in an argon atmosphere.

Argon's name is a reminder of its inactivity. It comes from the Greek word *argos,* which means "idle" or "inert." Why is argon very inactive yet oxygen is highly reactive? Chemical properties, such as reactivity, depend on an element's electron configuration.

Figure 1 The handle and body of this titanium mug were welded together in an argon atmosphere. If titanium is allowed to react with oxygen in air, the compound that forms makes the weld more brittle and more likely to break.

Stable Electron Configurations

The highest occupied energy level of a noble gas atom is filled. **When the highest occupied energy level of an atom is filled with electrons, the atom is stable and not likely to react.** The noble gases have stable electron configurations with eight valence electrons (or two in the case of helium).

The chemical properties of an element depend on the number of valence electrons. Therefore, it is useful to have a model of atoms that focuses only on valence electrons. The models in Figure 2 are electron dot diagrams. An **electron dot diagram** is a model of an atom in which each dot represents a valence electron. The symbol in the center represents the nucleus and all the other electrons in the atom.

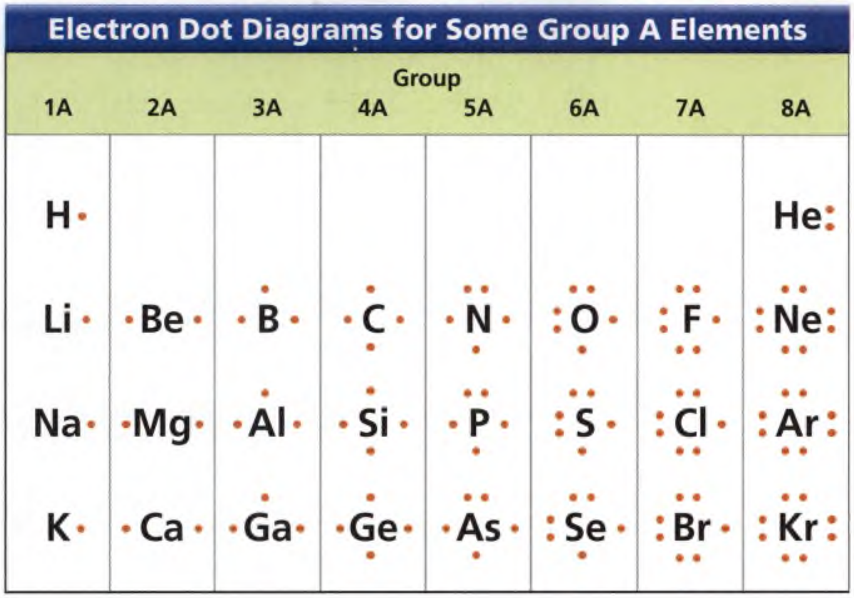


Figure 2 In an electron dot diagram, each dot represents a valence electron. **Observing** ***How many valence electrons do sodium and chlorine have?***

Ionic Bonds

Elements that do not have complete sets of valence electrons tend to react. By reacting, they achieve electron configurations similar to those of noble gases. **Some elements achieve stable electron configurations through the transfer of electrons between atoms.**

Transfer of Electrons Look at the electron dot diagram for chlorine in Figure 2. A chlorine atom has one electron fewer than an argon atom. If the chlorine atom were to gain a valence electron, it would have the same stable electron arrangement as argon. Look at the electron dot diagram for sodium. A sodium atom has one more electron than a neon atom. If a sodium atom were to lose this electron, its highest occupied energy level would have eight electrons. It would then have the same stable electron arrangement as neon.

What happens at the atomic level when sodium reacts with chlorine? An electron is transferred from each sodium atom to a chlorine atom. Each atom ends up with a more stable electron arrangement than it had before the transfer.

$$Na\cdot + \cdot\ddot{\underset{\cdot\cdot}{Cl}}: \longrightarrow Na^{+}\ :\ddot{\underset{\cdot\cdot}{Cl}}:^{-}$$

Formation of Ions When an atom gains or loses an electron, the number of protons is no longer equal to the number of electrons. The charge on the atom is not balanced and the atom is not neutral. An atom that has a net positive or negative electric charge is called an **ion.** The charge on an ion is represented by a plus or a minus sign. Notice the plus sign next to the symbol for sodium and the minus sign next to the symbol for chlorine.

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Data Analysis

What Determines the Size of an Atom or Ion?

Scientists use atomic radii to compare the sizes of atoms of different elements. Remember from mathematics that the radius of a sphere is the distance from the center of the sphere to its outer edge. The radius is half the diameter of the sphere. Because atomic radii are extremely small, these distances are expressed in units called picometers (pm). As a comparison, there are one billion (10^9) picometers in a millimeter.

The table shows the atomic radius and ionic radius for six metals and six nonmetals. You will use the data to relate the size of an element's atoms to the element's location on the periodic table. You also will use the data to compare the sizes of atoms and their ions.

Atomic and Ionic Radii

1A	2A	6A	7A
Li 152 1+ 60	Be 112 2+ 31	O 66 2– 140	F 64 1– 136
Na 186 1+ 95	Mg 160 2+ 65	S 103 2– 184	Cl 99 1– 181
K 227 1+ 133	Ca 197 2+ 99	Se 117 2– 198	Br 114 1– 195

Atomic radius (upper number); Ionic radius (lower number)

1. **Using Tables** Within a period, what happens to the atomic radius as the atomic number of the elements increases?
2. **Using Tables** Within Groups 1A, 2A, 6A, and 7A, what happens to the atomic radius of elements as the atomic number increases?
3. **Inferring** How does adding an occupied energy level affect the atomic radius? (*Hint:* Lithium is a Period 2 element and sodium is a Period 3 element.)
4. **Comparing and Contrasting** Compare the atomic and ionic radii for potassium (K), and for bromine (Br).
5. **Making Generalizations** What happens to the radius of an atom when the atom loses electrons? When the atom gains electrons?
6. **Relating Cause and Effect** Explain the difference in size between a metal atom and its cation.

The ion that forms when a chlorine atom gains an electron has 17 protons and 18 electrons. This ion has a charge of 1– because it has one extra electron. The symbol for the ion is written Cl^{1-}, or Cl^{-} for short. An ion with a negative charge is an **anion** (AN eye un). Anions like the Cl^{-} ion are named by using part of the element name plus the suffix *–ide.* Thus, Cl^{-} is called a *chloride* ion.

A sodium ion has 11 protons and 10 electrons. Because it has one extra proton, the sodium ion has a charge of 1+. The symbol for the ion is written Na^{1+}, or Na^{+} for short. An ion with a positive charge is a **cation** (KAT eye un). Naming a cation is easy. You just use the element name, as in the *sodium* ion.

Formation of Ionic Bonds Remember that a particle with a negative charge will attract a particle with a positive charge. When an anion and a cation are close together, a chemical bond forms between them. A **chemical bond** is the force that holds atoms or ions together as a unit. An **ionic bond** is the force that holds cations and anions together. An ionic bond forms when electrons are transferred from one atom to another.

Ionization Energy An electron can move to a higher energy level when an atom absorbs energy. Cations form when electrons gain enough energy to escape from atoms. The energy allows electrons to overcome the attraction of the protons in the nucleus. The amount of energy used to remove an electron is called ionization energy. It varies from element to element. The lower the ionization energy, the easier it is to remove an electron from an atom.

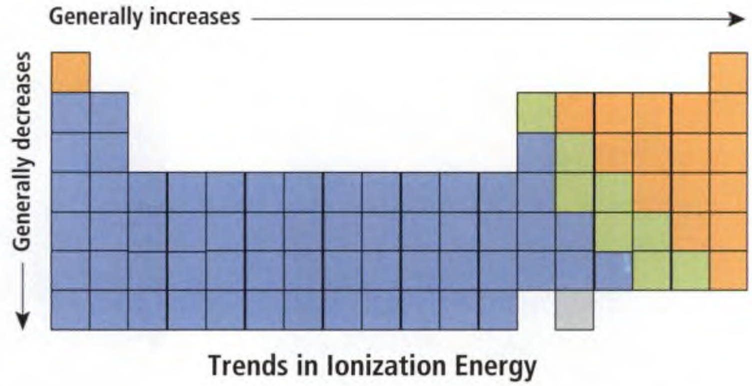


Figure 3 Ionization energies generally increase from left to right across a period. **Interpreting Diagrams** ***What is the trend for ionization energy within a group?***

Figure 3 shows two trends for ionization energy. Ionization energies tend to increase from left to right across a period. It takes more energy to remove an electron from a nonmetal than from a metal in the same period. Ionization energies tend to decrease from the top of a group to the bottom. In Group 1A, potassium has a lower ionization energy than sodium. So it is easier to remove an electron from potassium than from sodium, and potassium is more reactive than sodium.

Reading Checkpoint *What is ionization energy?*

Ionic Compounds

Compounds that contain ionic bonds are ionic compounds, which can be represented by chemical formulas. A **chemical formula** is a notation that shows what elements a compound contains and the ratio of the atoms or ions of these elements in the compound. The chemical formula for sodium chloride is NaCl. From the formula, you can tell that there is one sodium ion for each chloride ion in sodium chloride.

Based on the diagram in Figure 4, what would the formula for magnesium chloride be? A magnesium atom cannot reach a stable electron configuration by reacting with just one chlorine atom. It must transfer electrons to two chlorine atoms. After the transfer, the charge on the magnesium ion is 2+ and its symbol is Mg^{2+}. The formula for the compound is $MgCl_2$. The 2 written to the right and slightly below the symbol for chlorine is a subscript. Subscripts are used to show the relative numbers of atoms of the elements present. If there is only one atom of an element in the formula, no subscript is needed.

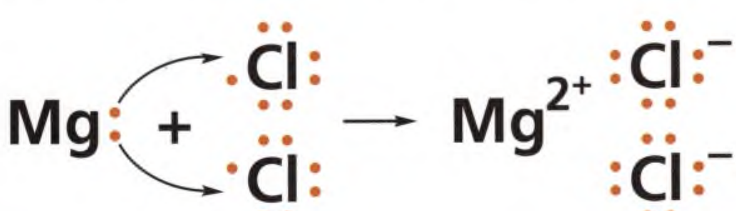


Figure 4 Magnesium chloride forms when magnesium atoms transfer electrons to chlorine atoms. Magnesium chloride is used to control dust that is stirred up by traffic on unpaved roads.

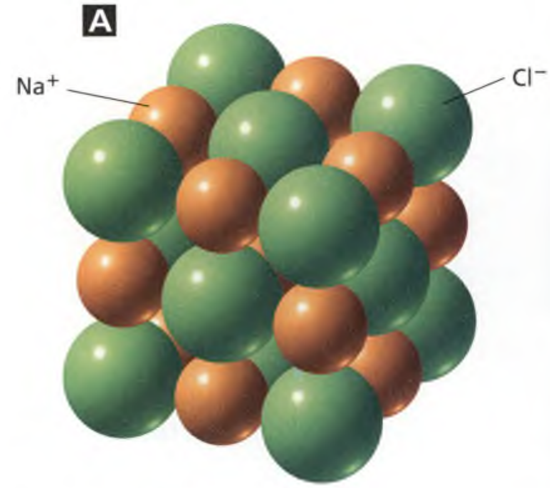


Figure 5 The structure and shape of a crystal are related. **A** In a sodium chloride crystal, each ion is surrounded by six oppositely charged ions. **B** Sodium chloride crystals are shaped like cubes.

Crystal Lattices A chemical formula for an ionic compound tells you the ratio of the ions in the compound. But it does not tell you how the ions are arranged in the compound. If you looked at a sample of sodium chloride with a hand lens or microscope, you would be able to see that the pieces of salt are shaped like cubes. This shape is a clue to how the sodium and chloride ions are arranged in the compound.

Figure 5A shows that the ions in sodium chloride are arranged in an orderly, three-dimensional structure. Each chloride ion is surrounded by six sodium ions and each sodium ion is surrounded by six chloride ions. Each ion is attracted to all the neighboring ions with an opposite charge. This set of attractions keeps the ions in fixed positions in a rigid framework, or lattice. The repeating pattern of ions in the lattice is like the repeating pattern of designs on the wallpaper in Figure 6.

Solids whose particles are arranged in a lattice structure are called **crystals.** Compare the cubic shape of the sodium chloride crystals in Figure 5B to the arrangement of ions in Figure 5A. The shape of an ionic crystal depends on the arrangement of ions in its lattice. In turn, the arrangement of the ions depends on the ratio of ions and their relative sizes. Crystals are classified into groups based on the shape of their crystals. Crystals of ruby have a six-sided, hexagonal shape. The How It Works box on page 163 describes one way to make rubies.

Reading Checkpoint ***What shape are sodium chloride crystals?***

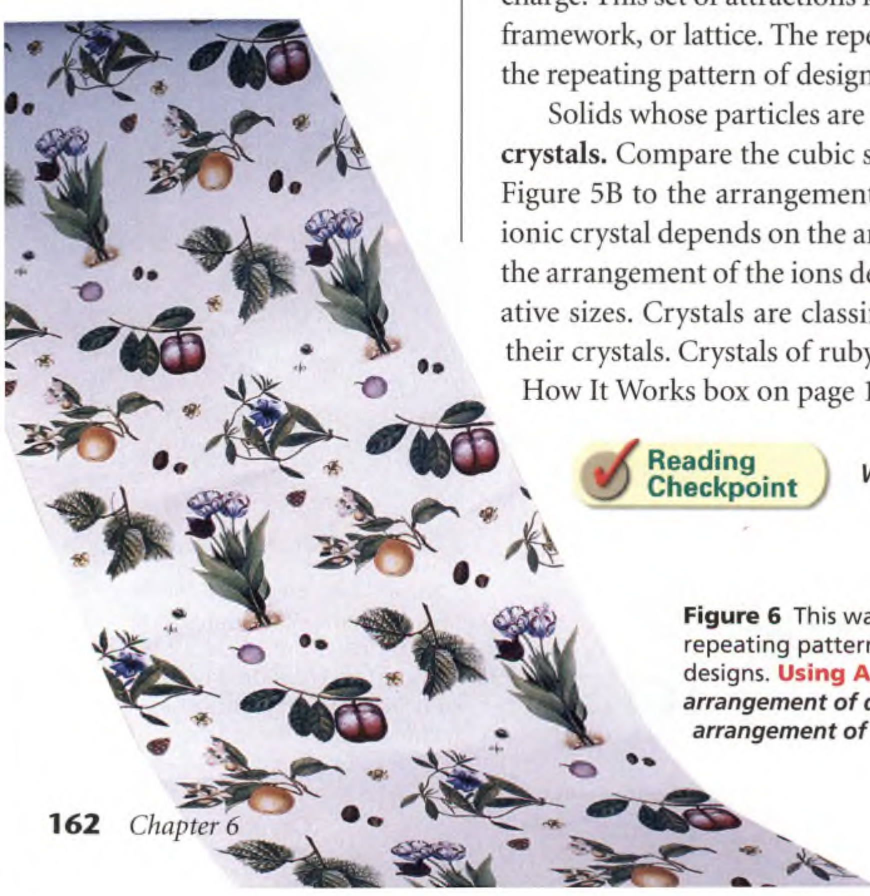


Figure 6 This wallpaper displays a repeating pattern of flower and fruit designs. **Using Analogies** ***How is this arrangement of designs similar to the arrangement of ions in a crystal?***

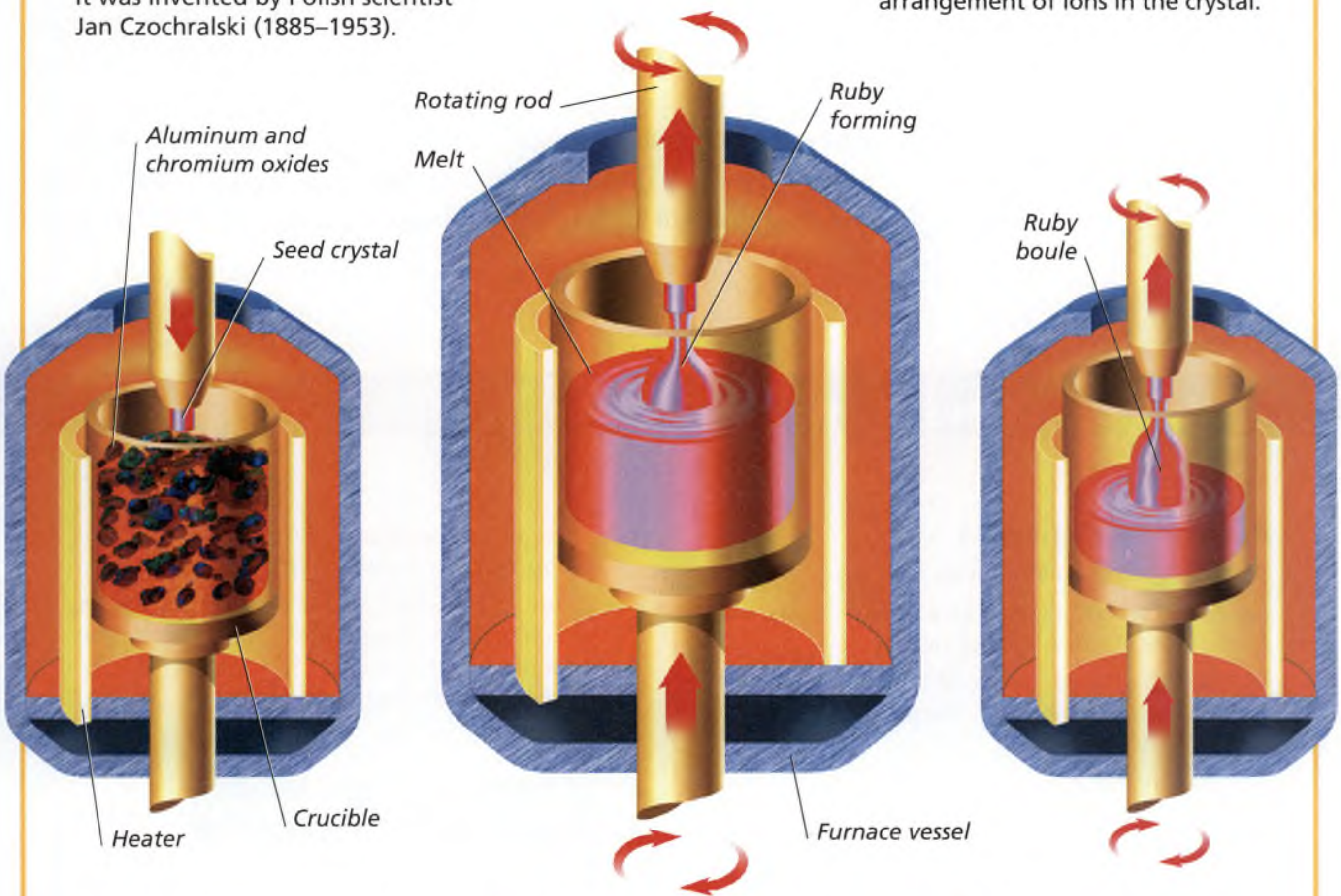
DK HOW It Works

Synthetic Rubies

Rubies are mainly aluminum oxide, which is white. The substitution of a small percentage of chromium ions for aluminum ions gives rubies their distinctive red color. Because natural rubies are rare, rubies are often manufactured. **Interpreting Diagrams** ***What substances are in the mixture used to make rubies?***

Synthetic ruby
A synthetic ruby boule has a hexagonal crystal structure identical to the natural ruby gemstone. Its shape is determined by the arrangement of ions in the crystal.

Making synthetic rubies
One way of making synthetic rubies is called the pulled-growth method. It was invented by Polish scientist Jan Czochralski (1885–1953).



1 **Seed crystal** Aluminum oxide and chromium(VI) oxide are melted. A tiny piece of ruby, called a seed crystal, is attached to a rod and placed above the molten mixture (melt).

2 **Lowering into the melt** The rod is lowered until the seed crystal touches the melt. The rod is slowly lifted, and ions in the melt begin to attach themselves to the seed crystal to form a ruby.

3 **Forming a boule** As the rod is lifted higher, an oblong-shaped crystal called a boule grows from the end. Once cooled, the boule can be cut into different shapes.

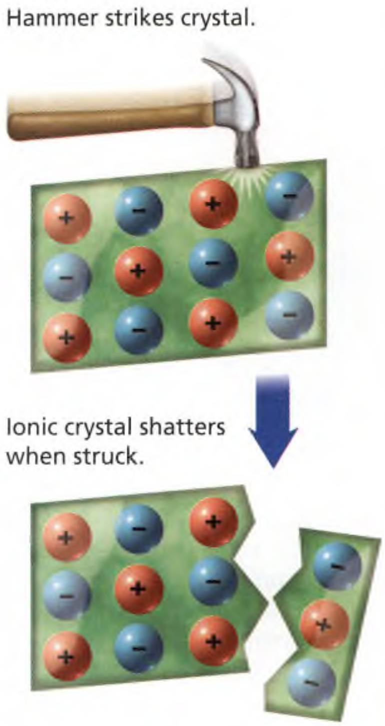


Figure 7 When an ionic crystal is struck, ions are moved from their fixed positions. Ions with the same charge repel one another and the crystal shatters.

Properties of Ionic Compounds The properties of sodium chloride are typical of an ionic compound. It has a high melting point (801°C). In its solid state, sodium chloride is a poor conductor of electric current. But when melted, it is a good conductor of electric current. Sodium chloride crystals shatter when struck with a hammer. **The properties of an ionic compound can be explained by the strong attractions among ions within a crystal lattice.**

Recall that the arrangement of particles in a substance is the result of two opposing factors. The first factor is the attractions among particles in the substance. The second factor is the kinetic energy of the particles. The stronger the attractions among the particles, the more kinetic energy the particles must have before they can separate.

For an electric current to flow, charged particles must be able to move from one location to another. The ions in a solid crystal lattice have fixed positions. However, when the solid melts, the lattice breaks apart and the ions are free to flow. Melted, or molten, sodium chloride is an excellent conductor of electric current.

Rock salt contains large crystals of sodium chloride. If you tapped a crystal of rock salt sharply with a hammer, it would shatter into many smaller crystals. Figure 7 shows what happens to the positions of the ions when the crystal is struck. Negative ions are pushed into positions near negative ions, and positive ions are pushed into positions near positive ions. Ions with the same charge repel one another and cause the crystal to shatter.

Section 6.1 Assessment

Reviewing Concepts

1. When is an atom least likely to react?
2. Describe one way an element can achieve a stable electron configuration.
3. What characteristic of ionic bonds can be used to explain the properties of ionic compounds?
4. Use ionization energy to explain why metals lose electrons more easily than nonmetals.
5. Why is a rock salt crystal likely to shatter when struck?

Critical Thinking

6. **Making Generalizations** What will the ratio of ions be in any compound formed from a Group 1A metal and a Group 7A nonmetal? Explain your answer.
7. **Drawing Conclusions** Why do ionic compounds include at least one metal?
8. **Predicting** Based on their chemical formulas, which of these compounds is not likely to be an ionic compound: KBr, SO_2, or $FeCl_3$? Explain your answer.

Connecting Concepts

Reactivity of Metals Use what you know about how ionic bonds form to explain the difference in reactivity between potassium and calcium. If necessary, reread the description of Group 1A and Group 2A properties in Section 5.3.

6.2 Covalent Bonding

Reading Focus

Key Concepts

- How are atoms held together in a covalent bond?
- What happens when atoms don't share electrons equally?
- What factors determine whether a molecule is polar?
- How do attractions between polar molecules compare to attractions between nonpolar molecules?

Vocabulary

- covalent bond
- molecule
- polar covalent bond

Reading Strategy

Relating Text and Visuals Copy the table. As you read, look closely at Figure 9. Complete the table by describing each type of model shown.

Model	Description
Electron dot	a. ___?___
Structural formula	b. ___?___
Space-filling	c. ___?___
Electron cloud	d. ___?___

Plants absorb water through their roots from soil or from a solution containing nutrients, as in Figure 8. Carbon dioxide from the air enters the plants through small openings in their leaves. The plants use the energy from sunlight to convert water and carbon dioxide into a sugar. Energy is stored in the chemical bonds of the sugar.

The elements in sugar are carbon, oxygen, and hydrogen. All three are nonmetals, which have relatively high ionization energies. A transfer of electrons does not tend to occur between nonmetal atoms. So, how are two nonmetals able to form bonds?

Covalent Bonds

You and a friend are participating in a treasure hunt. The rules state that the first person to find all eight items on a list will win an 21-speed bicycle. After about an hour, you have found six of the items on the list and your friend has found the other two. You and your friend have incomplete sets of items. But if you are willing to share your items with your friend, together you will have a complete set of items and qualify for the prize. Of course, you will have to be willing to share the bicycle, too. When nonmetals join together, they display a similar sharing strategy.

Figure 8 When plants are grown in water instead of soil, you can see their roots. Plants absorb water through their roots and carbon dioxide through small openings in their leaves.

Molecular Models	
Electron dot diagram	Structural formula
H:H	H—H
Space-filling model	Electron cloud model
	

Figure 9 As a space shuttle lifts off, it leaves a water vapor trail. A reaction of hydrogen and oxygen produces the water.
Using Models ***How is the bond between hydrogen atoms represented in each model of a hydrogen molecule?***

Sharing Electrons A hydrogen atom has one electron. If it had two electrons, it would have the same electron configuration as a helium atom. Two hydrogen atoms can achieve a stable electron configuration by sharing their electrons and forming a covalent bond. A **covalent bond** is a chemical bond in which two atoms share a pair of valence electrons. When two atoms share one pair of electrons, the bond is called a single bond.

Figure 9 shows four different ways to represent a covalent bond. In the electron dot model, the bond is shown by a pair of dots in the space between the symbols for the hydrogen atoms. In the structural formula, the pair of dots is replaced by a line. The electron cloud model and the space-filling model show that orbitals of atoms overlap when a covalent bond forms.

Figure 10 These space-filling models represent diatomic molecules of five elements.
Using Models ***How many atoms are in a diatomic molecule?***

Molecules of Elements Two hydrogen atoms bonded together form a unit called a molecule. A **molecule** is a neutral group of atoms that are joined together by one or more covalent bonds. The hydrogen molecule is neutral because it contains two protons (one from each atom) and two electrons (one from each atom). What keeps the hydrogen atoms together in the molecule? **The attractions between the shared electrons and the protons in each nucleus hold the atoms together in a covalent bond.**

A chemical formula can be used to describe the molecules of an element as well as a compound. The element hydrogen has the chemical formula H_2. The subscript 2 indicates that there are two atoms in a molecule of hydrogen.

Many nonmetal elements exist as diatomic molecules. *Diatomic* means "two atoms." Four of the models in Figure 10 are of halogens. A halogen atom has seven valence electrons. If two halogen atoms share a valence electron from each atom, both atoms have eight valence electrons.

Quick Lab

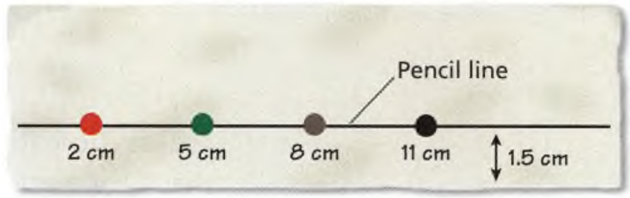
Analyzing Inks

Materials

test paper, metric ruler, felt-tip markers, stapler, beaker, alcohol-water mixture, Petri dish

Procedure

1. Place the test paper on a clean surface. Use the ruler to draw the pencil line shown in the drawing. Use your markers to place color dots at the locations shown in the drawing.
2. With the ink marks on the outside, staple the two ends of the paper together to form a tube.
3. Pour the alcohol-water mixture into the beaker to a depth of 0.5 cm. Stand the paper in the beaker so that the dots are at the bottom. The paper should not touch the sides of the beaker. Invert the Petri dish over the beaker.
4. When the mixture reaches the top of the paper, remove the paper from the beaker. Unstaple the paper and lay it flat. Make a drawing of the results with each colored area labeled.



Analyze and Conclude

1. **Observing** Which markers contained inks that were mixtures of colored substances?
2. **Formulating Hypotheses** How did some molecules in the ink move up the paper?
3. **Predicting** Assume that molecules in the test paper are more polar than molecules in the alcohol-water mixture. Would you expect the most polar molecules in ink to stick tightly to the paper or to move with the liquid? Explain.
4. **Designing Experiments** How could the procedure from this lab be used to identify a black ink whose composition is unknown?

Multiple Covalent Bonds Nitrogen has five valence electrons. If two nitrogen atoms shared a pair of electrons, each one would have only six valence electrons. If they shared two pairs of electrons, each atom would have only seven valence electrons. When the atoms in a nitrogen molecule (N_2) share three pairs of electrons, each atom has eight valence electrons. Each pair of shared electrons is represented by a long dash in the structural formula N≡N. When two atoms share three pairs of electrons, the bond is called a triple bond. When two atoms share two pairs of electrons, the bond is called a double bond.

Reading Checkpoint *What does the subscript 2 in the formula for a hydrogen molecule indicate?*

Unequal Sharing of Electrons

In general, elements on the right of the periodic table have a greater attraction for electrons than elements on the left have (except for noble gases). In general, elements at the top of a group have a greater attraction for electrons than elements at the bottom of a group have. Fluorine is on the far right and is at the top of its group. It has the strongest attraction for electrons and is the most reactive nonmetal.

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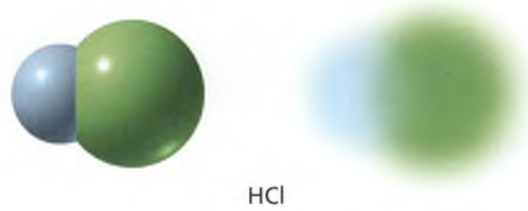


Figure 11 Shared electrons in a hydrogen chloride molecule spend less time near the hydrogen atom than near the chlorine atom. **Inferring** ***Which element has a greater attraction for electrons—hydrogen or chlorine?***

Polar Covalent Bonds In a molecule of an element, the atoms that form covalent bonds have the same ability to attract an electron. Shared electrons are attracted equally to the nuclei of both atoms. In a molecule of a compound, electrons may not be shared equally.

Figure 11 shows models of the molecule that forms when hydrogen reacts with chlorine. A chlorine atom has a greater attraction for electrons than a hydrogen atom does. In a hydrogen chloride molecule, the shared electrons spend more time near the chlorine atom than near the hydrogen atom. A covalent bond in which electrons are not shared equally is called a **polar covalent bond.** (One meaning of the term *polar* is "opposite in character, nature, or direction.")

When atoms form a polar covalent bond, the atom with the greater attraction for electrons has a partial negative charge. The other atom has a partial positive charge. The symbols $\delta-$ and $\delta+$ are used to show which atom has which charge. (δ is the lowercase version of the Greek letter delta.)

Polar and Nonpolar Molecules Can you assume that a molecule that contains a polar covalent bond is polar? If a molecule has only two atoms, it will be polar. But, when molecules have more than two atoms, the answer is not as obvious. **The type of atoms in a molecule and its shape are factors that determine whether a molecule is polar or nonpolar.**

Compare the models of carbon dioxide and water in Figure 12. In carbon dioxide, there are double bonds between each oxygen atom and the central carbon atom. Because oxygen has a greater attraction for electrons than carbon does, each double bond is polar. However, the molecule is linear: all three atoms are lined up in a row. The carbon-oxygen double bonds are directly opposite each other. There is an equal pull on the electrons from opposite directions. The pulls cancel out and the molecule as a whole is nonpolar.

There are two single bonds in a water molecule. The bonds are polar because oxygen has a greater attraction for electrons than hydrogen does. Because the water molecule has a bent shape rather than a linear shape, the polar bonds do not cancel out. The two hydrogen atoms are located on the same side of the molecule, opposite the oxygen atom. The oxygen side of the molecule has a partial negative charge. The hydrogen side of the molecule has a partial positive charge.

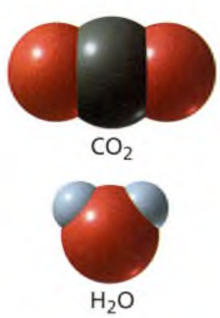


Figure 12 In a carbon dioxide (CO_2) molecule, the polar bonds between the carbon atom and the oxygen atoms cancel out because the molecule is linear. In a water (H_2O) molecule, the polar bonds between the oxygen atom and the hydrogen atoms do not cancel out because the molecule is bent.

Attraction Between Molecules

In a molecular compound, there are forces of attraction between molecules. These attractions are not as strong as ionic or covalent bonds, but they are strong enough to hold molecules together in a liquid or solid. **Attractions between polar molecules are stronger than attractions between nonpolar molecules.**

Water molecules are similar in mass to methane (CH_4) molecules. Yet, methane boils at −161.5°C and water boils at 100°C because methane molecules are nonpolar and water molecules are polar. Each dashed line in Figure 13 represents an attraction between a partially positive hydrogen atom in one water molecule and a partially negative oxygen atom in another. Molecules on the surface of a water sample are attracted to molecules that lie below the surface and are pulled toward the center of the sample. These attractions increase the energy required for water molecules to evaporate. They raise the temperature at which vapor pressure equals atmospheric pressure—the boiling point.

Attractions among nonpolar molecules are weaker than attractions among polar molecules, but they do exist. After all, carbon dioxide can exist as solid dry ice. Attractions among nonpolar molecules explain why nitrogen can be stored as a liquid at low temperatures and high pressures. Because electrons are constantly in motion, there are times when one part of a nitrogen molecule has a small positive charge and one part has a small negative charge. At those times, one nitrogen molecule can be weakly attracted to another nitrogen molecule.

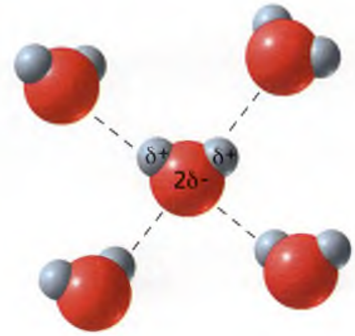


Figure 13 Each dashed line in the drawing represents an attraction between a hydrogen atom and an oxygen atom. **Interpreting Diagrams** ***In a water molecule, which atom has a partial negative charge? Which has a partial positive charge?***

Section 6.2 Assessment

Reviewing Concepts

1. What attractions hold atoms together in a covalent bond?
2. What happens to the charge on atoms when they form a polar covalent bond?
3. Name the two factors that determine whether a molecule is polar.
4. Compare the strength of attractions between polar molecules to the strength of attractions between nonpolar molecules.
5. What is a molecule?

Critical Thinking

6. **Applying Concepts** Which of these elements does not bond to form molecules: oxygen, chlorine, neon, or sulfur?
7. **Inferring** Why is the boiling point of water higher than the boiling point of chlorine?
8. **Using Diagrams** Based on their electron dot diagrams, what is the formula for the covalently bonded compound of nitrogen and hydrogen?

Connecting Concepts

Viscosity Review the description of the physical property viscosity in Section 2.2. Then write a paragraph explaining how attractions between molecules might affect the viscosity of a liquid.

6.3 Naming Compounds and Writing Formulas

Reading Focus

Key Concepts

- What information do the name and formula of an ionic compound provide?
- What information do the name and formula of a molecular compound provide?

Vocabulary

- polyatomic ion

Reading Strategy

Predicting Copy the table. Before you read, predict the meaning of the term *polyatomic ion.* After you read, if your prediction was incorrect, revise your definition.

Vocabulary Term	Before You Read	After You Read
Polyatomic ion	a. ?	b. ?

Thomas Drummond was a Scottish surveyor and inventor. Around 1826, he discovered that a white solid called lime emits a bright light when heated to a high temperature. This discovery was extremely useful in the era before electric lighting. Limelight was used to produce a light that could be focused on a single spot on a stage. It also was used to produce lighthouse beams that could be seen from a great distance.

People have used mixtures of lime and water for centuries to whitewash houses and fences. The flowerpots in Figure 14 were coated with a lime wash to which paint pigments were added. Other names for lime are quicklime and unslaked lime. Having two or more names for a compound can be confusing. Also, names like lime or quicklime don't tell you much about the composition of a compound.

There is much less confusion when everyone is using the same name for a given compound. Chemists use a system for naming compounds that is based on composition. In this system, the chemical name for lime is calcium oxide and its chemical formula is CaO. This formula tells you that there is a one-to-one ratio of calcium ions to oxide ions in calcium oxide. The formula of a compound serves as a reminder of the composition of the compound.

Figure 14 These flowerpots were coated with a solution of lime and water. Paint pigments were mixed with the lime wash to produce the different colors. The chemical name for lime is calcium oxide.

Figure 15 The brass vase on the left is coated with an oxide of copper that is red. Most of the surface of the plate on the right is coated with an oxide of copper that is black.
Classifying ***How can you be sure that the oxides of copper are different compounds?***

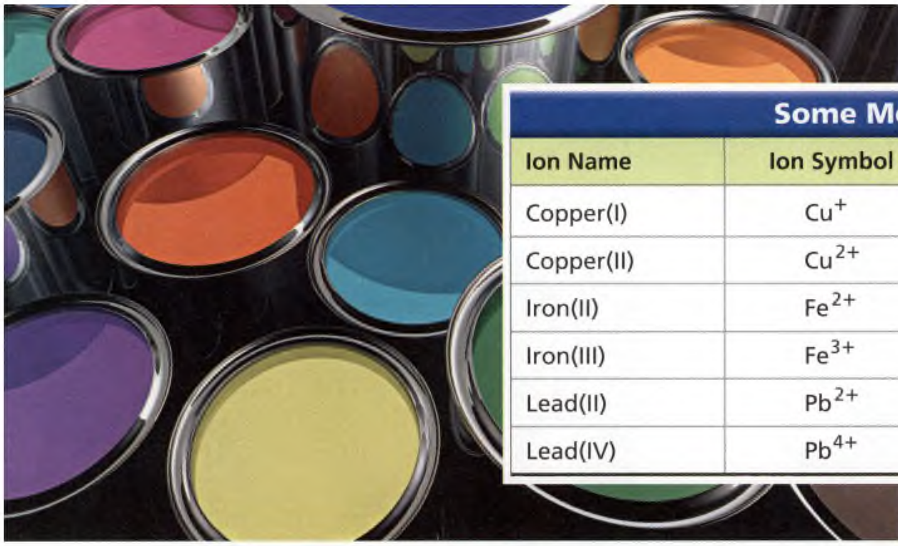
Describing Ionic Compounds

Both of the objects in Figure 15 are coated with compounds of copper and oxygen. Based on the two colors of the coatings, copper and oxygen must form at least two compounds. One name cannot describe all the compounds of copper and oxygen. There must be at least two names to distinguish red copper oxide from black copper oxide. **The name of an ionic compound must distinguish the compound from other ionic compounds containing the same elements. The formula of an ionic compound describes the ratio of the ions in the compound.**

Binary Ionic Compounds A compound made from only two elements is a binary compound. (The Latin prefix *bi-* means "two," as in bicycle or bisect.) Naming binary ionic compounds, such as sodium chloride and cadmium iodide, is easy. The names have a predictable pattern: the name of the cation followed by the name of the anion. Remember that the name for the cation is the name of the metal without any change: sodium atom and sodium ion. The name for the anion uses part of the name of the nonmetal with the suffix *–ide:* iodine atom and iodide ion. Figure 16 shows the names and charges for eight common anions.

Common Anions			
Element Name	Ion Name	Ion Symbol	Ion Charge
Fluorine	Fluoride	F^-	1–
Chlorine	Chloride	Cl^-	1–
Bromine	Bromide	Br^-	1–
Iodine	Iodide	I^-	1–
Oxygen	Oxide	O^{2-}	2–
Sulfur	Sulfide	S^{2-}	2–
Nitrogen	Nitride	N^{3-}	3–
Phosphorus	Phosphide	P^{3-}	3–

Figure 16 The table lists the element names, ion names, symbols, and charges for eight anions. The name of an anion is formed by adding the suffix *–ide* to the stem of the name of the nonmetal.



Some Metal Cations			
Ion Name	Ion Symbol	Ion Name	Ion Symbol
Copper(I)	Cu^{+}	Chromium(II)	Cr^{2+}
Copper(II)	Cu^{2+}	Chromium(III)	Cr^{3+}
Iron(II)	Fe^{2+}	Titanium(II)	Ti^{2+}
Iron(III)	Fe^{3+}	Titanium(III)	Ti^{3+}
Lead(II)	Pb^{2+}	Titanium(IV)	Ti^{4+}
Lead(IV)	Pb^{4+}	Mercury(II)	Hg^{2+}

Figure 17 Many paint pigments contain compounds of transition metals. These metals often form more than one type of ion. The ion names must contain a Roman numeral. **Using Tables** ***How is the Roman numeral in the name related to the charge on the ion?***

Metals With Multiple Ions The alkali metals, alkaline earth metals, and aluminum form ions with positive charges equal to the group number. For example, the symbol for a potassium ion is K^{+}, the symbol for a calcium ion is Ca^{2+}, and the symbol for an aluminum ion is Al^{3+}.

Many transition metals form more than one type of ion. Notice the two copper ions listed in Figure 17, a copper(I) ion with a 1+ charge and a copper(II) ion with a 2+ charge. When a metal forms more than one ion, the name of the ion contains a Roman numeral to indicate the charge on the ion. These ion names can distinguish red copper(I) oxide from black copper(II) oxide. The formula for "copper one oxide" is Cu_2O because it takes two Cu^{1+} ions to balance the charge on an O^{2-} ion. The formula for "copper two oxide" is CuO because it takes only one Cu^{2+} ion to balance the charge on an O^{2-} ion.

Ammonium ion
(NH_4^{+})

Figure 18 The atoms in an ammonium ion are joined by covalent bonds. The ion loses a valence electron as it forms. This loss leaves only 10 electrons to balance the charge on 11 protons.

Polyatomic Ions The electron dot diagram in Figure 18 describes a group of atoms that includes one nitrogen and four hydrogen atoms. It is called an ammonium ion. The atoms are joined by covalent bonds. Why does the group have a positive charge? The nitrogen atom has seven protons, and each hydrogen atom has one proton—eleven in total. But the group has only ten electrons to balance the charge on the protons—eight valence electrons and nitrogen's two inner electrons.

A covalently bonded group of atoms that has a positive or negative charge and acts as a unit is a **polyatomic ion.** The prefix *poly-* means "many." Most simple polyatomic ions are anions. Figure 19 lists the names and formulas for some polyatomic ions. Sometimes there are parentheses in a formula that includes polyatomic ions. For example, the formula for iron(III) hydroxide is $Fe(OH)_3$. The subscript 3 indicates that there are three hydroxide ions for each iron(III) ion.

Reading Checkpoint ***When are Roman numerals used in compound names?***

Quick Lab

Modeling Molecules

Materials

blue plastic-foam ball, black plastic-foam ball, 7 white gumdrops, toothpicks

Procedure

1. To make a model of an ammonia molecule (NH_3), insert a toothpick in each of 3 gumdrops. The gumdrops represent hydrogen atoms and the toothpicks represent bonds.
2. An ammonia molecule is like a pyramid with the nitrogen at the top and the hydrogen atoms at the corners of the base. Insert the toothpicks in the blue foam ball (nitrogen) so that each gumdrop is the same distance from the ball.
3. The hydrogen atoms in a methane molecule (CH_4) are equally spaced around the carbon. Use the black ball to make a model of methane.

Analyze and Conclude

1. **Comparing and Contrasting** Compare the shapes of the methane and ammonia molecules.
2. **Using Models** Why is carbon in the center of the methane molecule?

Writing Formulas for Ionic Compounds If you know the name of an ionic compound, you can write its formula. Place the symbol of the cation first, followed by the symbol of the anion. Use subscripts to show the ratio of the ions in the compound. Because all compounds are neutral, the total charges on the cations and anions must add up to zero.

Suppose an atom that gains two electrons, such as sulfur, reacts with an atom that loses one electron, such as sodium. There must be two sodium ions (Na^+) for each sulfide ion (S^{2-}). The formula for sodium sulfide is Na_2S. The 2− charge on one sulfide ion is balanced by the 1+ charges on two sodium ions.

Some Polyatomic Ions			
Name	**Formula**	**Name**	**Formula**
Ammonium	NH_4^+	Acetate	$C_2H_3O_2^-$
Hydroxide	OH^-	Peroxide	O_2^{2-}
Nitrate	NO_3^-	Permanganate	MnO_4^-
Sulfate	SO_4^{2-}	Hydrogen sulfate	HSO_4^-
Carbonate	CO_3^{2-}	Hydrogen carbonate	HCO_3^-
Phosphate	PO_4^{3-}	Hydrogen phosphate	HPO_4^{2-}
Chromate	CrO_4^{2-}	Dichromate	$Cr_2O_7^{2-}$
Silicate	SiO_3^{2-}	Hypochlorite	OCl^-

Figure 19 This table lists the names and formulas of some polyatomic ions. Except for the ammonium ion, all the ions listed are anions. **Using Tables** ***Which element is found in all the anions whose names end in -ate?***

Math Skills

Writing Formulas for Ionic Compounds

What is the formula for the ionic compound calcium chloride?

1 Read and Understand

What information are you given?

The name of the compound is calcium chloride.

2 Plan and Solve

List the symbols and charges for the cation and anion.

Ca with a charge of 2+ and Cl with a charge of 1−

Determine the ratio of ions in the compound.

It takes two 1− charges to balance the 2+ charge. There will be two chloride ions for each calcium ion.

Write the formula for calcium chloride.

$CaCl_2$

3 Look Back and Check

Is your answer reasonable?

Each calcium atom loses two electrons and each chlorine atom gains one electron. So there should be a 1-to-2 ratio of calcium ions to chloride ions.

Math Practice

1. Write the formula for the compound calcium oxide.
2. Write the formula for the compound copper(I) sulfide.
3. Write the formula for the compound sodium sulfate.
4. What is the name of the compound whose formula is NaOH?

Describing Molecular Compounds

Like ionic compounds, molecular compounds have names that identify specific compounds, and formulas that match those names. With molecular compounds, the focus is on the composition of molecules. **The name and formula of a molecular compound describe the type and number of atoms in a molecule of the compound.**

Naming Molecular Compounds The general rule is that the most metallic element appears first in the name. These elements are farther to the left in the periodic table. If both elements are in the same group, the more metallic element is closer to the bottom of the group. The name of the second element is changed to end in the suffix *-ide,* as in carbon dioxide.

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Two compounds that contain nitrogen and oxygen have the formulas N_2O_4 and NO_2. The names of these two compounds reflect the actual number of atoms of nitrogen and oxygen in a molecule of each compound. You can use the Greek prefixes in Figure 20 to describe the number of nitrogen and oxygen atoms in each molecule.

In an N_2O_4 molecule, there are two nitrogen atoms and four oxygen atoms. The Greek prefixes for two and four are *di-* and *tetra-*. The name for the compound with the formula N_2O_4 is dinitrogen tetraoxide. In an NO_2 molecule, there are one nitrogen atom and two oxygen atoms. The Greek prefixes for one and two are *mono-* and *di-*. So a name for the compound with the formula NO_2 is mononitrogen dioxide. However, the prefix *mono-* often is not used for the first element in the name. A more common name for the compound with the formula NO_2 is nitrogen dioxide.

Writing Molecular Formulas Writing the formula for a molecular compound is easy. Write the symbols for the elements in the order the elements appear in the name. The prefixes indicate the number of atoms of each element in the molecule. The prefixes appear as subscripts in the formulas. If there is no prefix for an element in the name, there is only one atom of that element in the molecule.

What is the formula for diphosphorus tetrafluoride? Because the compound is molecular, look for elements on the right side of the periodic table. Phosphorus has the symbol P. Fluorine has the symbol F. *Di-* indicates two phosphorus atoms and *tetra-* indicates four fluorine atoms. The formula for the compound is P_2F_4.

Prefixes For Naming Compounds

Number of Atoms	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Figure 20 These Greek prefixes are used to name molecular compounds. The prefix *octa-* means "eight," as in the eight tentacles of an octopus.

Section 6.3 Assessment

Reviewing Concepts

1. What does the formula of an ionic compound describe?
2. What do the name and formula of a molecular compound describe?
3. What suffix is used to indicate an anion?
4. Why are Roman numerals used in the names of compounds that contain transition metals?
5. What is a polyatomic ion?

Critical Thinking

6. **Applying Concepts** How is it possible for two different ionic compounds to contain the same elements?
7. **Calculating** How many potassium ions are needed to bond with a phosphate ion?

Math Practice

8. What are the names of these ionic compounds: LiCl, BaO, Na_3N, and $PbSO_4$?
9. Name the molecular compounds with these formulas: P_2O_5 and CO.
10. What is the formula for the ionic compound formed from potassium and sulfur?

6.4 The Structure of Metals

Reading Focus

Key Concepts

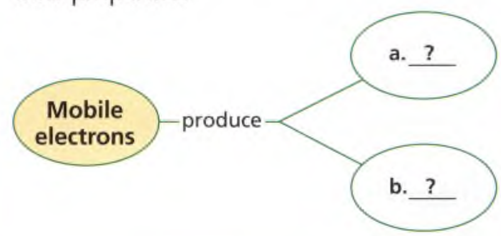
- What are the forces that give a metal its structure as a solid?
- How do metallic bonds produce some of the typical properties of metals?
- How are the properties of alloys controlled?

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.



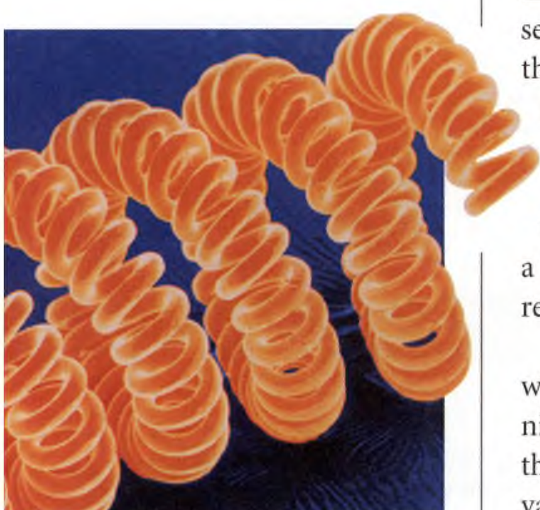


Figure 21 This photograph of the tungsten filament from a light bulb was taken with a scanning electron microscope. Color was added to the photo. The filament is magnified more than 100 times. The diameter of the wire is about 15 μm, or 0.0015 cm.

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.

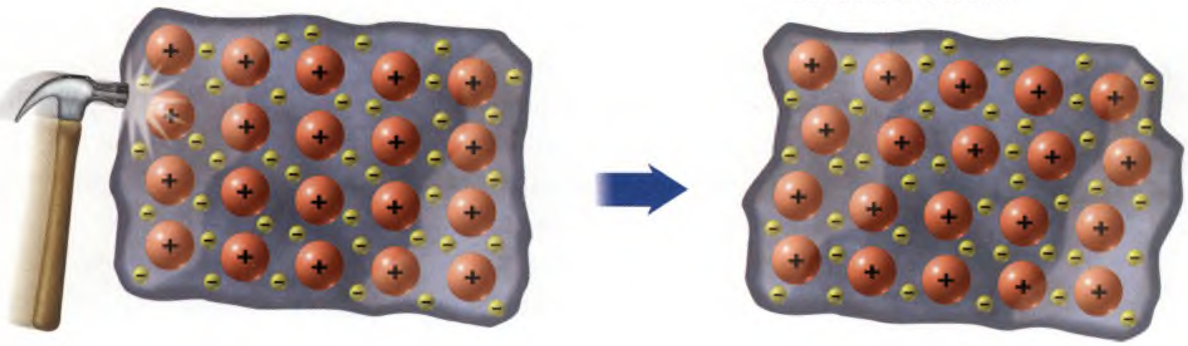


Figure 22 In a metal, cations are surrounded by shared valence electrons. If a metal is struck, the ions move to new positions, but the ions are still surrounded by electrons. **Classifying** ***What property of metals is displayed when a hammer strikes a metal?***

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?*

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.

DK 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

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.

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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

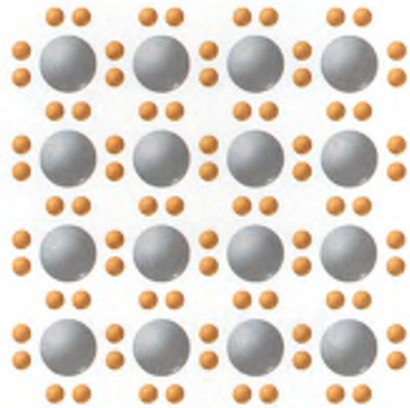
Compare-Contrast Paragraph Write a paragraph comparing the properties of ionic compounds and alloys. Relate their properties to the structure of their lattices.

CONCEPTS in Action

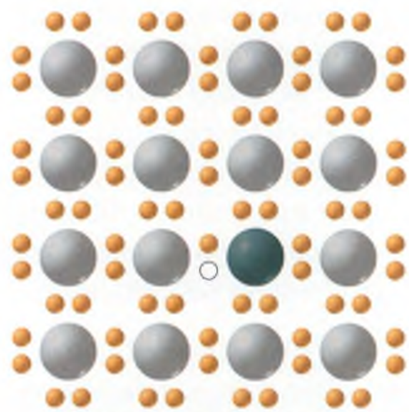
Chipping In

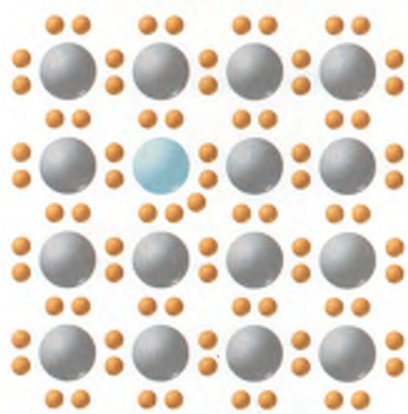
Tasks done by computers that filled an entire room in the 1950s are now done by devices the size of a credit card. This miniaturization in the electronics industry is due to semiconductors.

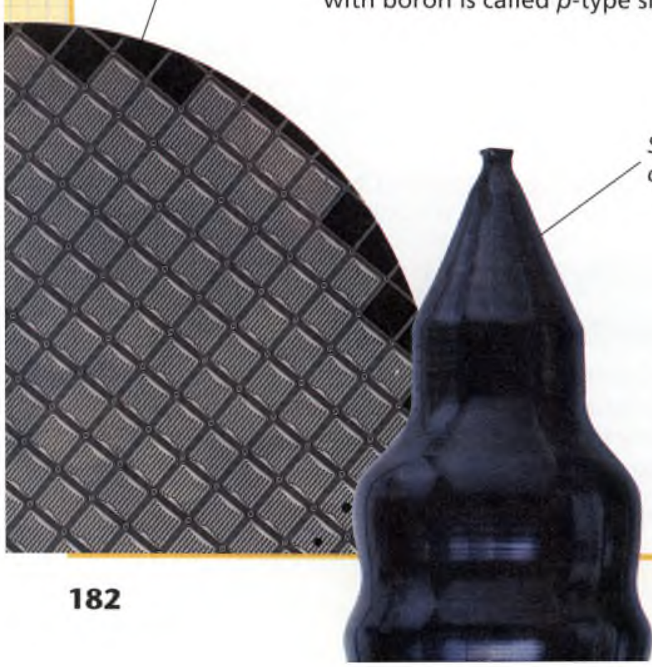
Semiconductors are solid substances, such as silicon, that have poor electrical conductivity at ordinary temperatures. Silicon has four valence electrons. In pure silicon, each atom forms single bonds with four other atoms. This arrangement leaves no electrons free to move through the silicon. The conductivity of silicon is greatly improved by adding small amounts of other elements to silicon, a process called doping.


Pure Silicon

Doping
An element with five valence electrons, such as phosphorus, can be added to silicon. After a phosphorus atom bonds with four atoms, there is an extra electron that is free to move. Silicon doped with phosphorus is called *n*-type silicon because electrons have a negative charge. An element with three valence electrons, such as boron, can be added to silicon. Adding boron leaves holes to which electrons can move from neighboring atoms. Because the lack of an electron has the effect of a positive charge, silicon with boron is called *p*-type silicon.


Silicon with boron

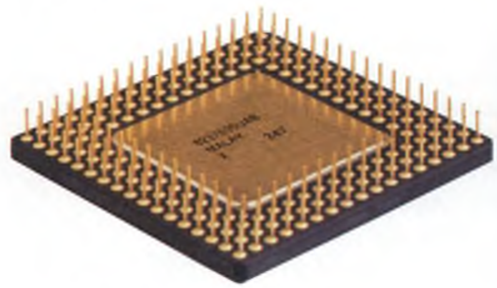

Silicon with phosphorus



Wafers and chips
Silicon crystals are cut into wafer-thin slices. Each wafer can be made into hundreds of silicon chips.

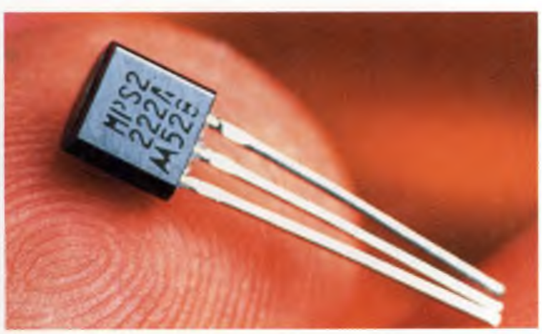
Vacuum tube
Glass vacuum tubes used in early computers were fragile and took up space.

Integrated circuit on a silicon chip



Computer chip
In 1974, the first computer microchip contained 6000 transistors. Today, more than 40 million transistors can be placed on a single computer chip.

Diode
In a diode, a layer of *p*-type silicon is joined to a layer of *n*-type silicon. When the leads on a diode are correctly connected in a circuit, electrons flow toward the junction between the two types of silicon. Electrons from the *n*-type silicon fill holes in the *p*-type silicon. In devices that use batteries, a diode can keep electrons from flowing if the batteries are not inserted correctly. Some diodes emit light when the circuit is complete.



Transistor
In a transistor, there are three layers of doped silicon. There is a layer of *p*-type silicon sandwiched between two layers of *n*-type silicon or a layer of *n*-type silicon between two layers of p-type silicon. Transistors are used to amplify current. A small current applied to the central layer of a transistor can produce a larger current.

Going Further

- Research and write about the development of transistors. Why were researchers looking for a replacement for vacuum tubes? How did replacing vacuum tubes with transistors affect the size of radios and computers?
- Take a Discovery Channel Video Field Trip by watching "Good Conduct."

Discovery Channel School
Video Field Trip

Consumer Lab

Improving the Dyeing of Nonpolar Fabrics

Most natural fibers, such as cotton and wool, consist of large molecules that have regions with a partial positive or partial negative charge. These polar molecules have a strong attraction for dyes that contain either polar molecules or ions.

The molecules in some manufactured fibers, such as nylon, are nonpolar molecules. These synthetic fibers are difficult to dye. Molecules of other synthetic fibers, such as polyester and rayon, have only a few polar regions. As you might suspect, polyester and rayon have intermediate attractions for dyes. In this lab, you will investigate a process for improving a fiber's ability to absorb and retain dye.

Problem

How can you increase the dye-holding capacity of nonpolar fibers?

Materials

- tongs
- 2 fabric test strips
- hot dye bath containing methyl orange
- clock or watch
- paper towels
- scissors
- soap
- hot iron(II) sulfate solution

Skills

Observing, Drawing Conclusions

Procedure

Part A: Dyeing Without Treatment

1. On a sheet of paper, copy the data table shown.
2. Use the tongs to immerse a fabric test strip in the methyl orange dye bath. **CAUTION** *The dye bath is hot. Do not touch the glass. The dye will stain skin and clothing.*
3. After 7 minutes, remove the strip from the dye bath. Allow as much of the dye solution as possible to drip back into the bath as shown on page 185. Rinse off the excess dye with water in the sink.
4. Place the strip on a paper towel to dry. Be careful to avoid splashes when transferring the strip between the dye bath and paper towel. Record your observations in your data table.
5. After the fabric strip is dry, test it for colorfastness, or the ability to hold dye. Cut the strip in half lengthwise and wash one half of the strip in the sink with soap and water.

Data Table

Dye Treatment	Dyeing of Fibers	Colorfastness of Fibers
Methyl orange		
Iron sulfate and methyl orange		

6. Allow the washed half-strip to dry and then compare the washed half to the unwashed half. Record your observations in your data table. Staple the half-strips to a sheet of paper and label each half-strip to indicate how you treated it.

Part B: Dyeing With Treatment

7. Use the tongs to place the second fabric strip in the iron(II) sulfate solution for 25 minutes. Then use tongs to lift the strip and allow it to drain into the iron(II) sulfate solution. Wring the strip as dry as possible over the solution. **CAUTION** *The strip will be hot. Allow it to cool before touching it. Wear plastic gloves.*
8. Repeat Steps 2, 3, and 4 using the strip that you treated with iron(II) sulfate.
9. To test the strip for colorfastness, repeat Steps 5 and 6.
10. Clean up your work area and wash your hands thoroughly with warm water and soap before leaving the laboratory.

Analyze and Conclude

1. **Comparing and Contrasting** How did the color of the untreated strip compare with the color of the treated strip?
2. **Comparing and Contrasting** How did the colorfastness of the untreated strip compare to the colorfastness of the treated strip?
3. **Applying Concepts** Silk blouses and shirts can be purchased in many intense colors. Why do you think silk is able to hold a variety of intense dyes?
4. **Drawing Conclusions** How does iron(II) sulfate affect the ability of a fabric to absorb dyes? (*Hint:* What kind of compound is iron(II) sulfate?)
5. **Predicting** A care label might say *Wash in cold water only.* What might happen to the color of a piece of clothing with this label if you washed the clothing in hot water?

CHAPTER 6

Study Guide

6.1 Ionic Bonding

Key Concepts

- When the highest occupied energy level of an atom is filled with electrons, the atom is stable and not likely to react.
- Some elements achieve stable electron configurations through the transfer of electrons between atoms. An ionic bond forms when electrons are transferred from one atom to another.
- The properties of an ionic compound can be explained by the strong attractions among ions within a crystal lattice.

Vocabulary

electron dot diagram, *p. 158*
ion, *p. 159*
anion, *p. 160*
cation, *p. 160*
chemical bond, *p. 160*
ionic bond, *p. 160*
chemical formula, *p. 161*
crystals, *p. 162*

6.2 Covalent Bonding

Key Concepts

- The attractions between the shared electrons and the protons in each nucleus hold the atoms together in a covalent bond.
- When atoms form a polar covalent bond, the atom with the greater attraction for electrons has a partial negative charge. The other atom has a partial positive charge.
- The type of atoms in a molecule and its shape are factors that determine whether a molecule is polar or nonpolar.
- Attractions between polar molecules are stronger than attractions between nonpolar molecules.

Vocabulary

covalent bond, *p. 166*
molecule, *p. 166*
polar covalent bond, *p. 168*

6.3 Naming Compounds and Writing Formulas

Key Concepts

- The name of an ionic compound must distinguish the compound from other ionic compounds containing the same elements. The formula of an ionic compound describes the ratio of the ions in the compound.
- The name and formula of a molecular compound describe the type and number of atoms in a molecule of the compound.

Vocabulary

polyatomic ion, *p. 172*

6.4 The Structure of Metals

Key Concepts

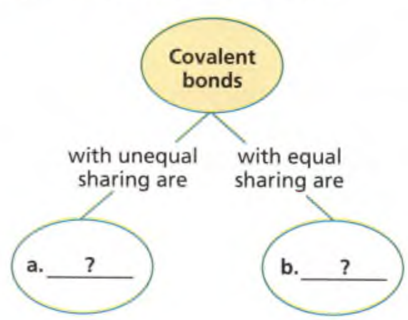
- The cations in a metal form a lattice that is held in place by strong metallic bonds between the cations and the surrounding valence electrons.
- The mobility of electrons within a metal lattice explains some of the properties of metals.
- Scientists can design alloys with specific properties by varying the types and amounts of elements in an alloy.

Vocabulary

metallic bond, *p. 176*
alloy, *p. 178*

Thinking Visually

Concept Map Use information from the chapter to complete the concept map below.



CHAPTER 6

Assessment

Reviewing Content

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

1. When an atom loses an electron, it forms a(n)
   a. anion. **b.** cation.
   c. polyatomic ion. **d.** neutral ion.

2. The charge on a chloride ion in $AlCl_3$ is
   a. 1+. **b.** 3+.
   c. 1−. **d.** 3−.

3. Which pair has the same electron configuration?
   a. Cl^- and Ar **b.** Cl^- and Ar^-
   c. Cl and Ar **d.** Cl^+ and Ar

4. A chemical bond that forms when atoms share electrons is always a(n)
   a. polar bond. **b.** ionic bond.
   c. metallic bond. **d.** covalent bond.

5. When two fluorine atoms share a pair of electrons, the bond that forms is a(n)
   a. polar covalent bond.
   b. ionic bond.
   c. nonpolar covalent bond.
   d. double bond.

6. The chemical formula for magnesium bromide is
   a. MgBr. **b.** $MgBr_2$.
   c. $Mg(II)Br_2$. **d.** Mg_2Br.

7. The compound with the formula $SiCl_4$ is
   a. silicon chloride. **b.** silicon chlorine.
   c. silicon(I) chloride. **d.** silicon tetrachloride.

8. The attraction among water molecules is stronger than the attraction among
   a. sodium and chloride ions.
   b. carbon dioxide molecules.
   c. the atoms in a polyatomic ion.
   d. atoms in a diatomic molecule.

9. Which type of solid is likely to be the best conductor of electric current?
   a. ionic compound **b.** covalent compound
   c. metal element **d.** nonmetal element

10. An alloy contains
    a. at least one metallic element.
    b. at least one nonmetallic element.
    c. only metallic elements.
    d. only nonmetallic elements.

Understanding Concepts

11. What is a stable electron configuration?

12. What does each dot in an electron dot diagram represent?

13. What process changes atoms into ions?

14. What keeps the ions in their fixed positions within a crystal lattice?

15. What are subscripts used for in chemical formulas?

16. Explain why a melted ionic compound is a good conductor of electric current, but a solid ionic compound is a poor conductor of electric current.

17. What distinguishes single, double, and triple covalent bonds?

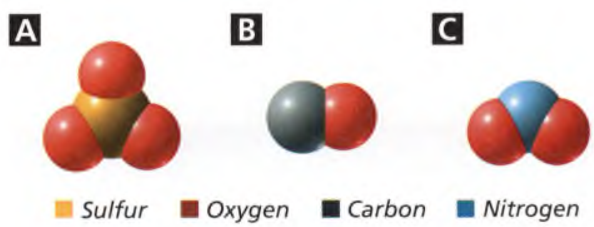
18. Explain why the covalent bonds in molecules of elements are always nonpolar.

19. Explain why, in a covalent bond between oxygen and hydrogen, the hydrogen atom has a partial positive charge and the oxygen atom has a partial negative charge.

20. What is the name of the binary compound formed from potassium and iodine?

21. Write the formulas for the compounds called copper(I) chloride and copper(II) chloride.

22. Name the compounds represented by the space-filling models labeled A, B, and C.



23. In general, what determines the strength of metallic bonds?

24. What properties of copper and tin change when these metals are mixed together to form bronze?

25. What advantage of magnesium is retained in magnesium alloys? What disadvantage is reduced?

Assessment *(continued)*

Critical Thinking

26. **Classifying** What does a fluoride ion have in common with a neon atom and a sodium ion?

27. **Comparing and Contrasting** How are molecules and polyatomic ions similar?

28. **Classifying** Classify the bonds in each of these compounds as ionic, polar covalent, or nonpolar covalent: SO_3, CaO, and I_2.

29. **Applying Concepts** Write the names for the compounds with these chemical formulas: SCl_2, Ag_2SO_4, LiF, CS_2, and $Ca(OH)_2$.

Use these diagrams to answer Questions 30–34.

30. **Using Models** Which of the three elements are metals and which are nonmetals?

31. **Applying Concepts** Element Q forms compounds with element X and with element Z. Write the formulas for these two compounds.

32. **Calculating** What would the formula be for a compound containing chromium(III) ions and ions of element Z?

33. **Applying Concepts** Draw an electron dot structure for a compound of fluorine and Z.

34. **Predicting** If an atom of X reacts with an atom of X, what kind of bond forms?

Math Skills

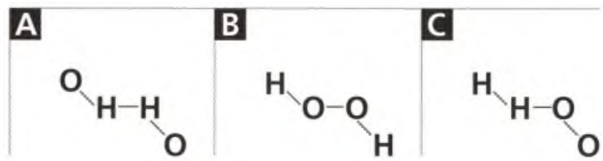
35. **Calculating** What is the total number of shared electrons in a carbon dioxide molecule?

36. **Making Generalizations** What is the ratio of anions to cations in a compound formed by a Group 2A metal and a Group 7A nonmetal?

37. **Applying Concepts** Write the formulas for barium fluoride, sodium oxide, iron(II) sulfate, and ammonium sulfate.

Concepts In Action

38. **Using Models** A solution of hydrogen peroxide (H_2O_2) and water is sometimes used to disinfect a cut. Which of the following formulas is the correct structural formula for hydrogen peroxide?



39. **Relating Cause and Effect** In a carbonated beverage, the main ingredients are water and carbon dioxide. Carbon dioxide gas is released when the bottle is opened. Why is water a liquid but carbon dioxide a gas at room temperature?

40. **Classifying** The shells shown on page 156 contain the compound calcium carbonate ($CaCO_3$). Explain how this compound can contain both ionic and covalent bonds.

41. **Relating Cause and Effect** How does adding some phosphorus to silicon make silicon a better conductor of electric current?

42. **Writing in Science** Compare what happens to the valence electron in a hydrogen atom when the atom bonds with another hydrogen atom and when the atom bonds with an oxygen atom.

Performance-Based Assessment

Designing an Advertisement You own a store that sells bronze bells. Design a quarter-page ad for your store to be published in your local directory of businesses. Write copy for your ad. Describe a photograph to use in the ad. Also supply a sketch showing how you want the copy and the photograph to be laid out on the page.

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Standardized Test Prep

Test-Taking Tip

Paying Attention to the Details
Sometimes two or more answers to a question are almost identical. If you do not read the answers carefully, you may select an incorrect answer by mistake. In the question below, all the answers include the correct elements in the correct order—metal before nonmetal. However, only one of the answers uses the correct rules for naming $CaCl_2$.

The name for the compound with the formula $CaCl_2$ is

(A) calcium(II) chloride.
(B) calcium chlorine.
(C) calcium dichloride.
(D) calcium chloride.
(E) monocalcium dichloride.

(Answer: D)

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

1. How many electrons does a Group 7A atom need to gain in order to achieve a stable electron configuration?
(A) 0
(B) 1
(C) 2
(D) 7
(E) 8

2. What type of bond forms when electrons are transferred from one atom to another?
(A) nonpolar covalent bond
(B) ionic bond
(C) polar covalent bond
(D) polyatomic bond
(E) metallic bond

3. Metallic bonds form between
(A) cations and protons.
(B) anions and protons.
(C) cations and anions.
(D) cations and electrons.
(E) anions and electrons.

Use the table to answer Questions 4 and 5.

Some Ions and Their Symbols

Ion Name	Ion Symbol	Ion Name	Ion Symbol
Copper(I)	Cu^{+}	Nitrate	NO_3^{-}
Copper(II)	Cu^{2+}	Sulfate	SO_4^{2-}
Iron(II)	Fe^{2+}	Carbonate	CO_3^{2-}
Iron(III)	Fe^{3+}	Phosphate	PO_4^{3-}

4. What is the formula for copper(II) nitrate?
(A) $CuNO_3$
(B) $Cu_2(NO_3)_2$
(C) $Cu(NO_3)_2$
(D) Cu_2NO_3
(E) $CuNO_2$

5. In the compound iron(II) carbonate, the ratio of iron(II) ions to carbonate ions will be
(A) one to one.
(B) two to one.
(C) three to one.
(D) one to two.
(E) one to three.

6. All steels contain
(A) copper and zinc.
(B) copper and tin.
(C) iron and chromium.
(D) chromium and carbon.
(E) iron and carbon.

7. What is the reason that water has a higher boiling point than expected?
(A) Attractions among nonpolar water molecules are strong.
(B) Water molecules have a linear shape.
(C) Water molecules are not very massive.
(D) There are strong attractions among polar water molecules.
(E) There are no attractions among water molecules.