7

Ionic and Metallic Bonding

INSIDE:

- **7.1** Ions
- **7.2** Ionic Bonds and Ionic Compounds
- **7.3** Bonding in Metals

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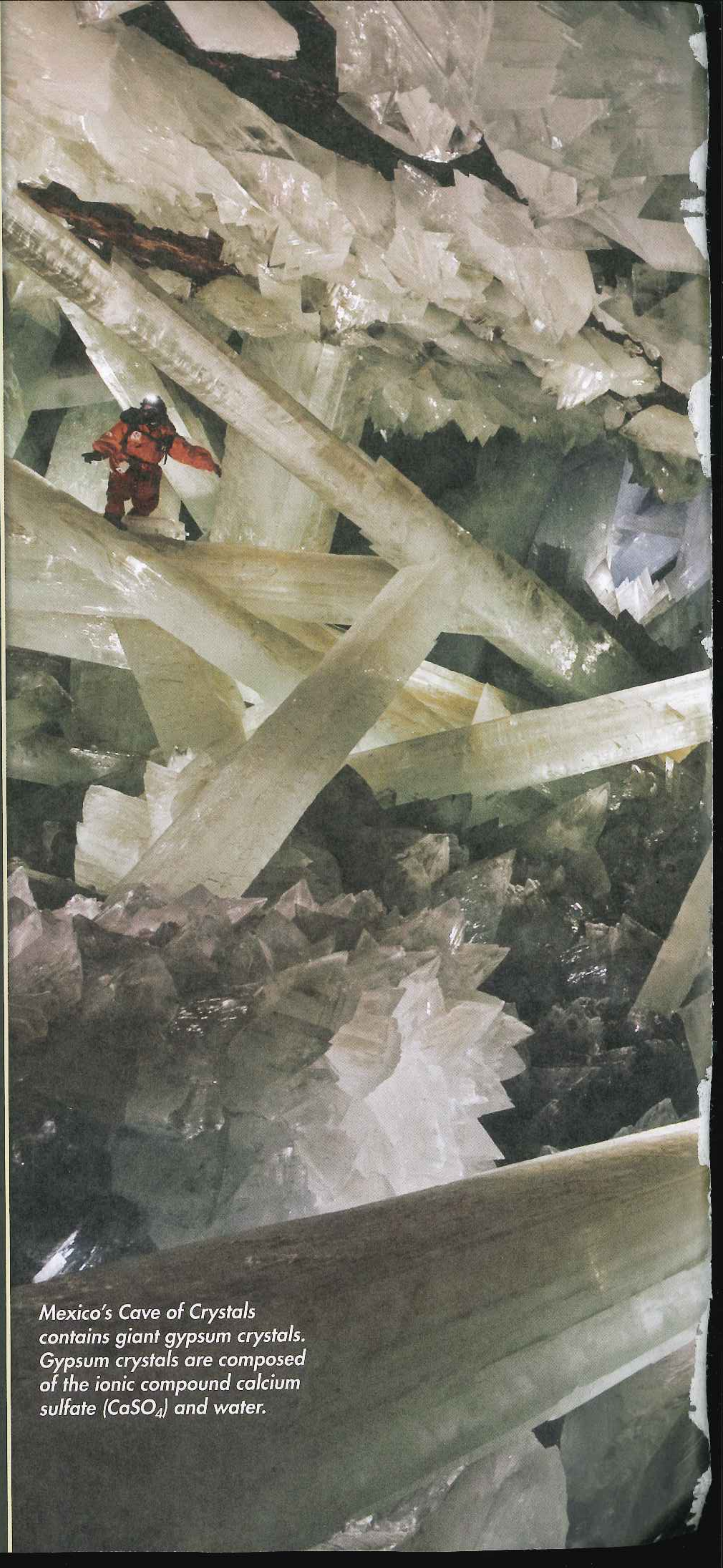
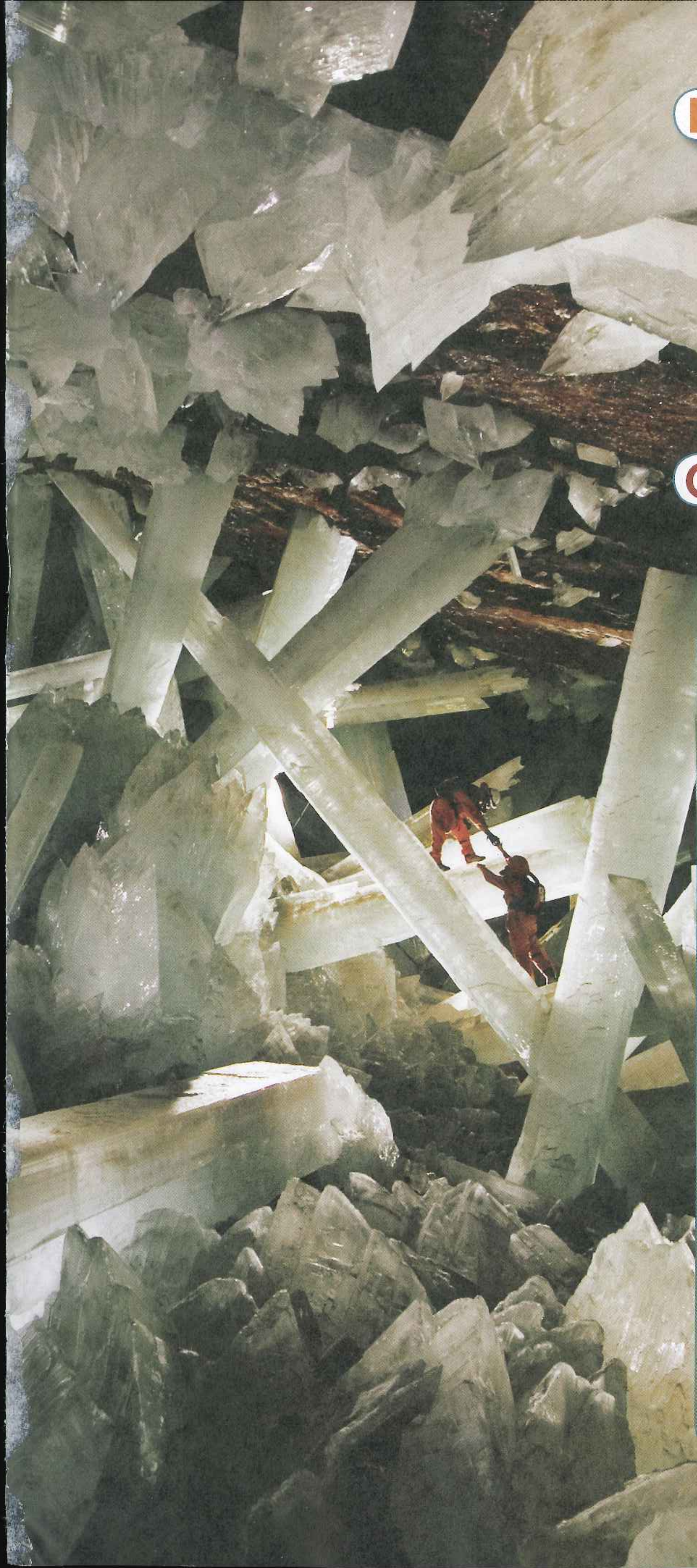


Mexico's Cave of Crystals contains giant gypsum crystals. Gypsum crystals are composed of the ionic compound calcium sulfate ($CaSO_4$) and water.



BIGIDEA

BONDING AND INTERACTIONS

Essential Questions:

1. *How do ionic compounds form?*
2. *How does metallic bonding affect the properties of metals?*

CHEMYSTERY

It's Not Easy Being Green

While strolling through Central Park in New York City, you come across this statue of the composer Ludwig van Beethoven. It appears to be made of metal, but its surface is green in color and not very shiny. Is the statue's green complexion due to green paint, or something else?

After doing some research, you learn that the statue is made out of bronze, which is a mixture of metals. The statue was never painted. Instead, the exposed surface of the bronze underwent a chemical change, forming a green film over time. You wonder what the film is made of and how it formed. Are the properties of the film different from the bronze beneath it?

▶ Connect to the **BIG**IDEA As you read about ionic compounds and metals, think about why the statue changed color. Also, think about how the properties of the green film at the surface differ from the metal beneath it.

NATIONAL SCIENCE EDUCATION STANDARDS

A-1, B-2, B-4

7.1 Ions

CHEMISTRY & YOU

Q: *What is fool's gold?* Pyrite (FeS_2) is often mistaken for gold—hence its nickname, "fool's gold." Pyrite is an example of a crystalline solid. In crystalline solids, the component particles of the substance are arranged in an orderly, repeating fashion. In this chapter, you will learn about crystalline solids, like pyrite, that are composed of ions that are bonded together.

Key Questions

How do you find the number of valence electrons in an atom of a representative element?

How are cations formed?

How are anions formed?

Vocabulary

- valence electron
- electron dot structure
- octet rule
- halide ion

Valence Electrons

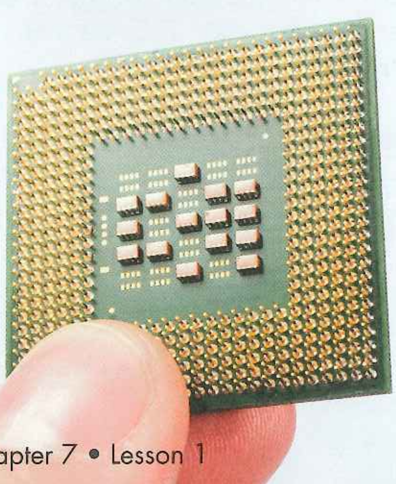
How do you find the number of valence electrons in an atom of a representative element?

Mendeleev used similarities in the properties of elements to organize his periodic table. Scientists later learned that all of the elements within each group of the periodic table react in a similar way because they have the same number of valence electrons. **Valence electrons** are the electrons in the highest occupied energy level of an element's atoms. The number of valence electrons largely determines the chemical properties of an element.

Determining the Number of Valence Electrons The number of valence electrons in an atom of an element is related to the element's group number in the periodic table. **To find the number of valence electrons in an atom of a representative element, simply look at its group number.** For example, atoms of the Group 1A elements (hydrogen, lithium, sodium, and so forth) all have one valence electron, corresponding to the 1 in 1A. Carbon and silicon atoms, in Group 4A, have four valence electrons. Figure 7.1 shows some applications of Group 4A elements. Nitrogen and phosphorus atoms, in Group 5A, have five valence electrons, and oxygen and sulfur atoms, in Group 6A, have six. The noble gases (Group 8A) are the only exceptions to the group-number rule: Atoms of helium have two valence electrons, and atoms of all of the other noble gases have eight valence electrons.

Figure 7.1 Group 4A Elements
Silicon and germanium are Group 4A elements. **a.** Silicon is used in the manufacture of computer chips. **b.** Compounds of germanium are used to make optical fibers.

a



b

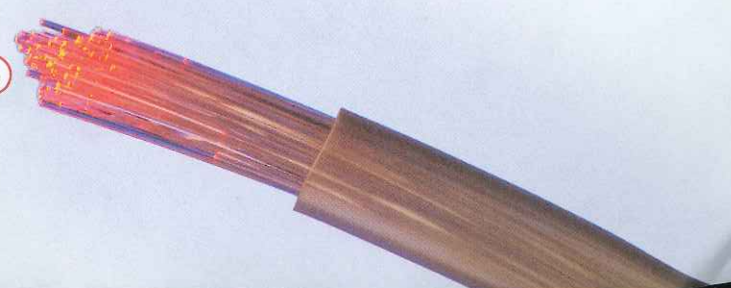


Table 7.1

Electron Dot Structures of Some Group A Elements

Period	Group 1A	2A	3A	4A	5A	6A	7A	8A
1	H·							He:
2	Li·	·Be·	·B·	·C·	·N·	:O·	:F·	:Ne:
3	Na·	·Mg·	·Al·	·Si·	·P·	:S·	:Cl·	:Ar:
4	K·	·Ca·	·Ga·	·Ge·	·As·	:Se·	:Br·	:Kr:

Valence electrons are usually the only electrons involved in chemical bonds. Therefore, as a general rule, only the valence electrons are shown in electron dot structures. **Electron dot structures** are diagrams that show valence electrons in the atoms of an element as dots. Table 7.1 shows electron dot structures for atoms of some Group A elements. Notice that all of the elements within a given group (with the exception of helium) have the same number of electron dots in their structures.

The Octet Rule You learned in Chapter 6 that noble gases, such as neon and argon, are nonreactive in chemical reactions. That is, they are stable. In 1916, chemist Gilbert Lewis used this fact to explain why atoms form certain kinds of ions and molecules. He called his explanation the octet rule. The **octet rule** states that in forming compounds, atoms tend to achieve the electron configuration of a noble gas. An octet is a set of eight. Recall that atoms of each of the noble gases (except helium) have eight electrons in their highest occupied energy levels and the general electron configuration of $ns^2 np^6$. The octet rule takes its name from this fact about noble gases.

Atoms of metals tend to lose their valence electrons, leaving a complete octet in the next-lowest energy level. Atoms of some nonmetals tend to gain electrons or to share electrons with another nonmetal atom or atoms to achieve a complete octet. Although exceptions occur, the octet rule applies to atoms in most compounds.

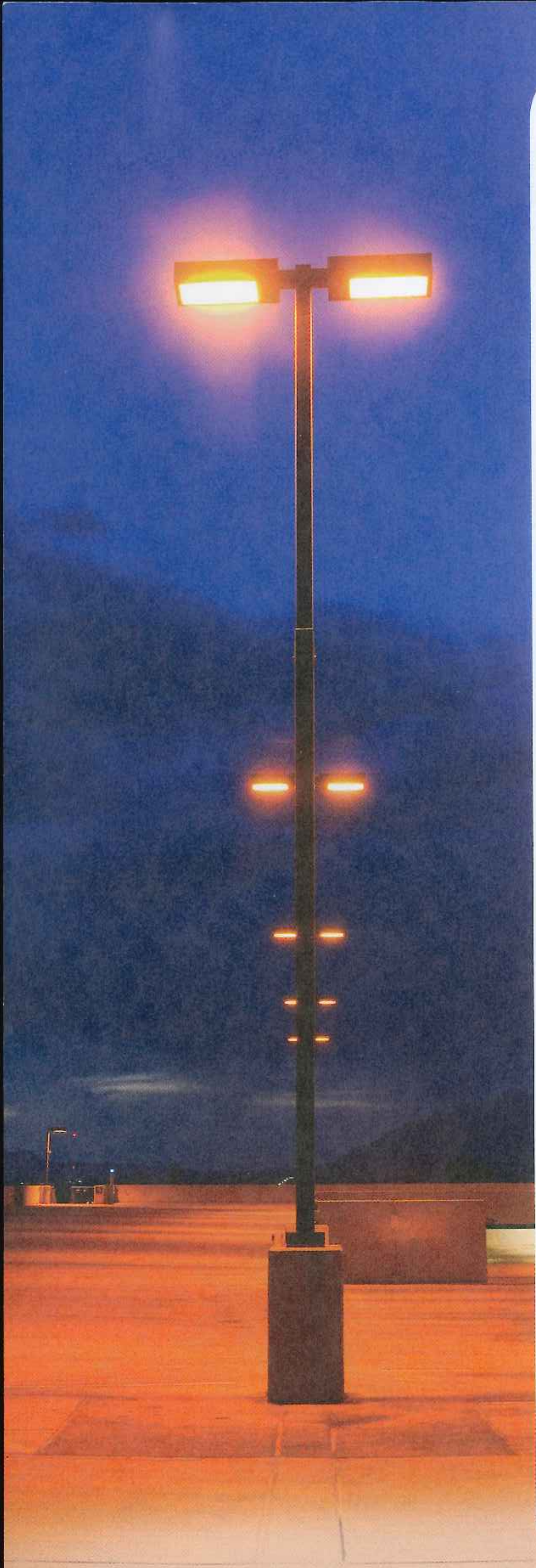
READING SUPPORT

Build Vocabulary: *Word Origins* *Octet* comes from the Greek word *okto,* meaning "eight." There are eight electrons in the highest occupied energy level of the noble gases, except for helium. ***How do you think the term octet might also be applied to music or poetry?***

Formation of Cations

How are cations formed?

An atom is electrically neutral because it has equal numbers of protons and electrons. An ion forms when an atom or group of atoms loses or gains electrons. **A positively charged ion, or a cation, is produced when an atom loses one or more valence electrons.** Note that for metals, the name of the cation is the same as the name of the element. For example, a sodium atom (Na) forms a sodium cation (Na^+). Likewise, a calcium atom (Ca) forms a calcium cation (Ca^{2+}). Although their names are the same, metals and their cations have many important chemical differences. Sodium metal, for example, reacts explosively with water. By contrast, sodium cations are quite nonreactive. As you may know, sodium cations are a component of table salt, a compound that is very stable in water.



Group 1A Cations The most common cations are those produced by the loss of valence electrons from metal atoms. Most of these atoms have one to three valence electrons, which are easily removed. Sodium (atomic number 11) is in Group 1A of the periodic table. Sodium atoms have a total of eleven electrons, including one valence electron. A sodium atom can lose an electron to become a positively charged sodium ion. Sodium atoms become sodium ions in a sodium vapor lamp, which is shown in Figure 7.2. The sodium ion has an electron configuration that is identical to the noble gas neon.

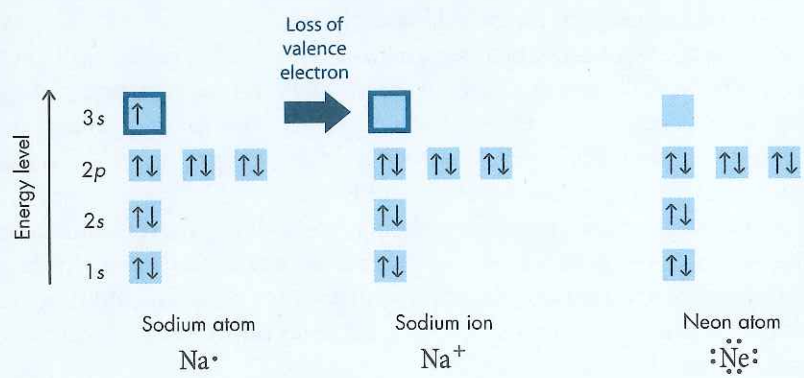
When forming a compound, a sodium atom loses its one valence electron and is left with an octet (eight electrons) in what is now its highest occupied energy level. The number of protons in the sodium nucleus is still eleven, so the loss of one unit of negative charge produces a cation with a charge of 1+. You can represent the loss of the electron, or ionization, of the sodium atom by writing the complete electron configuration of the atom and of the ion formed.

$$\text{Na} \quad 1s^22s^22p^63s^1 \xrightarrow{-e^-} \text{Na}^+ \quad 1s^2\underbrace{2s^22p^6}_{\text{octet}}$$

Notice that the electron configuration of the sodium ion ($1s^2 2s^2 2p^6$) is the same as that of a neon atom.

$$\text{Ne} \quad 1s^2\underbrace{2s^22p^6}_{\text{octet}}$$

The diagrams below help illustrate this point.



Both the sodium ion and the neon atom have eight electrons in their valence shells (highest occupied energy levels). Using electron dot structures, you can show the ionization more simply.

$$\text{Na}\cdot \xrightarrow[\text{ionization}]{\text{loss of one valence electron}} \text{Na}^+ + e^-$$

Na·		Na+		e−
Sodium atom (electrically neutral, charge = 0)		Sodium ion (plus sign indicates one unit of positive charge)		Electron (minus sign indicates one unit of negative charge)

Figure 7.2 Sodium Vapor Lamp
The sodium atoms (Na) in a sodium vapor lamp ionize to form sodium cations (Na^+).
Apply Concepts ***How many electrons are in the highest occupied energy level of Na^+?***

Group 2A Cations Magnesium (atomic number 12) belongs to Group 2A of the periodic table, so magnesium atoms have two valence electrons. A magnesium atom attains the electron configuration of a neon atom by losing both valence electrons and producing a magnesium cation with a charge of 2+.

$$\cdot\mathrm{Mg}\cdot \xrightarrow{\text{loss of two valence electrons}} \mathrm{Mg}^{2+} + 2e^-$$

Magnesium atom (electrically neutral, charge = 0)	Magnesium ion (2+ indicates two units of positive charge)	Electrons (2 in front of e^- indicates two units of negative charge)

Figure 7.3 lists the symbols of the cations formed by metals in Groups 1A and 2A. Cations of Group 1A elements always have a charge of 1+. Cations of Group 2A elements always have a charge of 2+. This consistency can be explained in terms of the loss of valence electrons by metal atoms: The atoms lose the number of electrons necessary to attain the electron configuration of a noble gas.

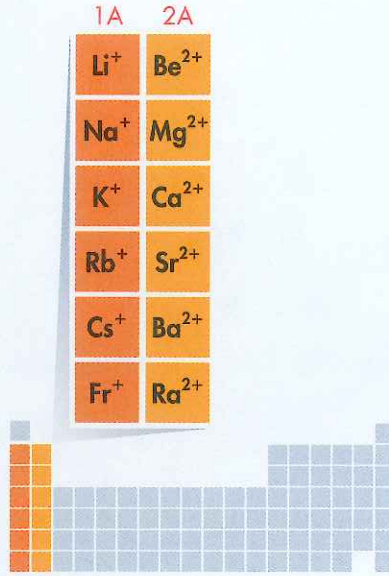
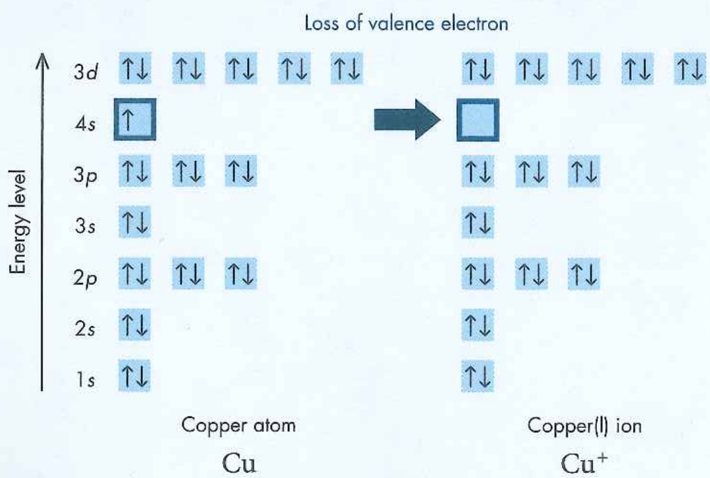


Figure 7.3
Group 1A and 2A Cations
Cations of Group 1A elements have a charge of 1+. Cations of Group 2A elements have a charge of 2+.

Transition Metal Cations The charges of cations of the transition metals may vary. An atom of iron, for example, may lose two valence electrons, forming the Fe^{2+} cation, or three valence electrons, forming the Fe^{3+} cation.

Some ions formed by transition metals do not have noble-gas electron configurations (ns^2np^6) and are therefore exceptions to the octet rule. Silver, with the electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^1$, is an example. To achieve the structure of krypton, which is the preceding noble gas, a silver atom would have to lose eleven electrons. To acquire the electron configuration of xenon, which is the following noble gas, a silver atom would have to gain seven electrons. Ions with charges of three or greater are uncommon. Thus silver does not achieve a noble-gas configuration. However, if a silver atom loses its $5s^1$ electron, forming a positive ion (Ag^+), the configuration that results ($4s^2 4p^6 4d^{10}$), with 18 electrons in the highest occupied energy level and all of the orbitals filled, is relatively favorable. Such a configuration is known as a pseudo noble-gas electron configuration. Other elements that behave similarly to silver are found at the right of the transition metal block of the periodic table. A copper atom loses its lone 4*s* electron to form a copper ion (Cu^+) with a pseudo noble-gas electron configuration as illustrated below.



Cations of gold (Au^+), cadmium (Cd^{2+}), and mercury (Hg^{2+}) also have pseudo noble-gas electron configurations.

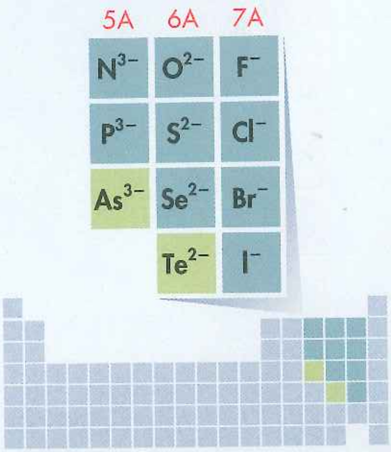


Figure 7.4
Group 5A, 6A, and 7A Anions
Atoms of nonmetals and metalloids form anions by gaining enough valence electrons to attain the electron configuration of the nearest noble gas.
Interpret Diagrams ***To which group of the periodic table do the elements bromine and iodine belong?***

CHEMISTRY & YOU

Q: *Fool's gold is composed of iron(II) cations (Fe^{2+}) and disulfide anions (S_2^{2-}). Write the electron configuration of the Fe^{2+} ion.*

Formation of Anions

How are anions formed?

An anion is an atom or group of atoms with a negative charge. **An anion is produced when an atom gains one or more valence electrons.** Note that the name of an anion of a nonmetallic element is *not* the same as the element name. The name of the anion typically ends in *-ide*. Thus, a chlorine atom (Cl) forms a chloride anion (Cl^-), and an oxygen atom (O) forms an oxide anion (O^{2-}). Figure 7.4 shows the symbols of the anions formed by some elements in Groups 5A, 6A, and 7A.

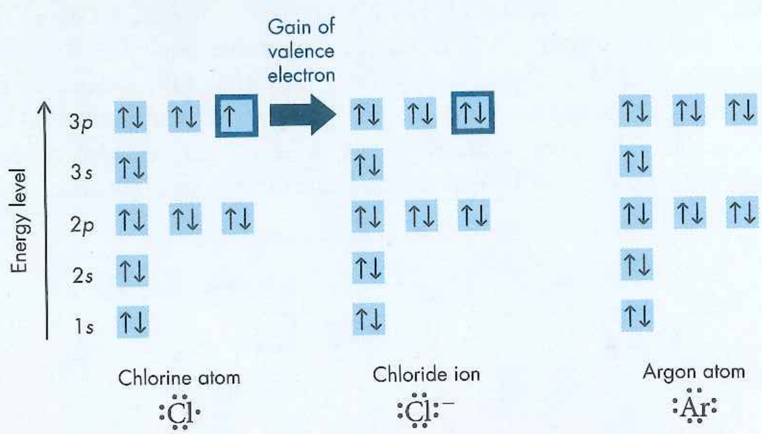
Atoms of nonmetallic elements attain noble-gas electron configurations more easily by gaining electrons than by losing them because these atoms have relatively full valence shells. For example, chlorine belongs to Group 7A (the halogen family). Atoms of chlorine have seven valence electrons. A gain of one electron gives a chlorine atom an octet and converts a chlorine atom into a chloride ion.

$$\text{Cl}\ \ 1s^22s^22p^63s^23p^5 \xrightarrow{+e^-} \text{Cl}^-\ \ 1s^22s^22p^6\underbrace{3s^23p^6}_{\text{octet}}$$

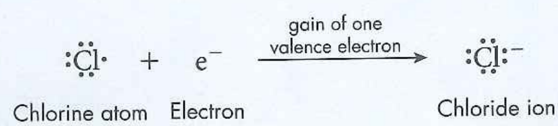
The chloride ion has a single negative charge. Notice that the electron configuration of the chloride ion ($1s^2 2s^2 2p^6 3s^2 3p^6$) is the same as that of an argon atom.

$$\text{Ar}\ \ 1s^22s^22p^6\underbrace{3s^23p^6}_{\text{octet}}$$

Chlorine atoms, therefore, need one more valence electron to achieve the electron configuration of the nearest noble gas. The diagrams below illustrate how both the chloride ion and the argon atom have an octet of electrons in their highest occupied energy levels.

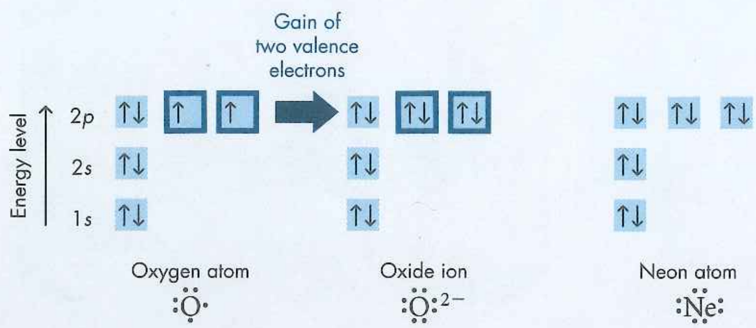


You can use electron dot structures to write an equation showing the formation of a chloride ion from a chlorine atom.



The ions produced when atoms of chlorine and other halogens gain electrons are called **halide ions.** All halogen atoms have seven valence electrons and need to gain only one electron to achieve the electron configuration of a noble gas. Thus, all halide ions (F^-, Cl^-, Br^-, and I^-) have a charge of 1−. The seawater in Figure 7.5 contains many different ions, but the anions are mostly chloride ions.

Oxygen is in Group 6A, and an oxygen atom has six valence electrons. An oxygen atom attains the electron configuration of neon by gaining two electrons, as shown in the diagrams below.



The resulting oxide anion (O^{2-}) has a charge of 2−. You can write the equation for the formation of oxide anions by using electron dot structures.

$$:\ddot{\text{O}}\cdot + 2e^- \longrightarrow :\ddot{\text{O}}:^{2-}$$

Table 7.2 lists some common anions that you will be learning about in this book.

Figure 7.5 Ions in Seawater Chloride (Cl^-), sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+) ions are abundant in seawater.

Table 7.2

Some Common Anions

Name	Symbol	Charge
Fluoride	F^-	1−
Chloride	Cl^-	1−
Bromide	Br^-	1−
Iodide	I^-	1−
Oxide	O^{2-}	2−
Sulfide	S^{2-}	2−
Nitride	N^{3-}	3−
Phosphide	P^{3-}	3−

ONLINE PROBLEMS

7.1 LessonCheck

1. **Explain** How can you determine the number of valence electrons in an atom of a representative element?
2. **Describe** How do cations form?
3. **Describe** How do anions form?
4. **Make Generalizations** Atoms of which elements tend to gain electrons? Atoms of which elements tend to lose electrons?
5. **Apply Concepts** How many valence electrons are in each atom?
   a. potassium
   b. carbon
   c. magnesium
   d. oxygen
6. **Use Models** Draw the electron dot structure for each element in Question 5.
7. **Apply Concepts** How many electrons will each element gain or lose in forming an ion?
   a. calcium
   b. fluorine
   c. aluminum
   d. oxygen
8. **Infer** Identify the charge of the ion formed when
   a. a potassium atom loses one electron.
   b. a zinc atom loses two electrons.
   c. a fluorine atom gains one electron.
9. **Describe** Write the electron configuration of Cd^{2+}.

Small-Scale Lab

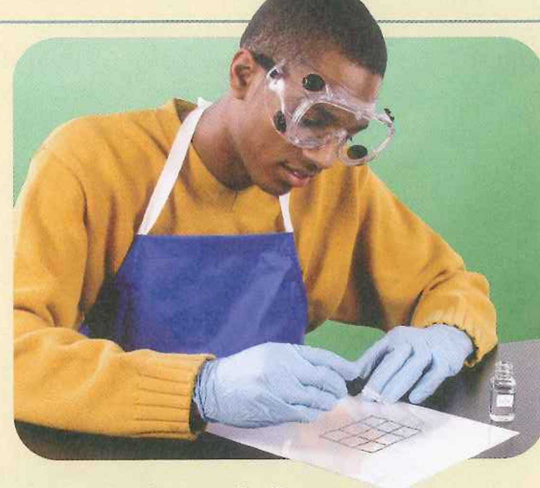
Electron Configurations of Ions

Purpose

To relate the presence of color in an ionic solution as a characteristic of electron configurations

Materials

- reaction surface
- micropipettes or droppers
- chemicals shown in the grid below
- sodium hydroxide (NaOH) solution



Procedure

1. On separate sheets of paper, draw two grids similar to the one below. Make each square 2 cm on each side.

2. Place a reaction surface over one of the grids, and add one drop of each solution in the indicated places. Record the color of each solution on the other grid.

3. A precipitate is a solid that separates upon mixing solutions. Predict which of the metal cations will form colored precipitates upon the addition of NaOH. Add one drop of NaOH to find out. Record your results.

$NaCl$	$MgSO_4$	$AlCl_3$
$FeCl_3$	$CaCl_2$	$NiSO_4$
$CuSO_4$	$ZnCl_2$	$AgNO_3$

Analyze and Conclude

1. Draw Conclusions Transition-metal ions with partially filled *d* orbitals usually have color. Based on your observations, which solutions contain transition-metal ions with partially filled *d* orbitals?

2. Analyze Data Write the electron configurations of Cu^{2+} and Ag^{+}. Is each electron configuration consistent with the color you observed for each cation? Explain.

3. Infer What does the color of the solution containing Zn^{2+} ions suggest about its electron configuration? Write the electron configuration of Zn^{2+}.

4. Predict Which of the following transition-metal ions do you think have color: Cr^{3+}, Cd^{2+}, Hg^{2+}, V^{2+}? Explain your answers.

5. Draw Conclusions Do the colored precipitates all contain transition-metal ions with partially filled *d* orbitals?

You're the Chemist

1. Design an Experiment Predict which of the metal cations in this experiment will form colored precipitates upon the addition of sodium carbonate (Na_2CO_3). Design an experiment to find out.

2. Design an Experiment Design and carry out an experiment to find out which metal ions form precipitates with sodium phosphate (Na_3PO_4). What color are the precipitates?

7.2 Ionic Bonds and Ionic Compounds

CHEMISTRY & YOU

Q: *Where does table salt come from?* Sodium chloride, or table salt, has been used by people for centuries to add flavor to food and for preserving food. In some countries, salt is obtained by the evaporation of seawater. In other countries, salt is mined from rock deposits deep underground. In this lesson, you will learn how cations and anions combine to form stable compounds such as sodium chloride.

Key Questions

What is the electrical charge of an ionic compound?

What are three properties of ionic compounds?

Vocabulary

- ionic compound
- ionic bond
- chemical formula
- formula unit
- coordination number

Formation of Ionic Compounds

What is the electrical charge of an ionic compound?

Sodium chloride, or table salt, is an ionic compound consisting of sodium cations and chloride anions. An **ionic compound** is a compound composed of cations and anions. **Although they are composed of ions, ionic compounds are electrically neutral.** The total positive charge of the cations equals the total negative charge of the anions.

Ionic Bonds Anions and cations have opposite charges and attract one another by means of electrostatic forces. The electrostatic forces that hold ions together in ionic compounds are called **ionic bonds.**

Sodium chloride provides a simple example of how ionic bonds are formed. Consider the reaction between a sodium atom and a chlorine atom. The sodium atom has a single valence electron that it can easily lose. (If the sodium atom loses its valence electron, it achieves the stable electron configuration of neon.) The chlorine atom has seven valence electrons and can easily gain one electron. (If the chlorine atom gains a valence electron, it achieves the stable electron configuration of argon.) When sodium and chlorine react to form a compound, the sodium atom transfers its one valence electron to the chlorine atom. Thus, sodium and chlorine atoms combine in a one-to-one ratio, and both ions have stable octets.

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

$$1s^22s^22p^63s^1 \quad 1s^22s^22p^63s^23p^5 \qquad 1s^2\underbrace{2s^22p^6}_{\text{octet}} \quad 1s^22s^22p^6\underbrace{3s^23p^6}_{\text{octet}}$$

$$\mathrm{Ne} \qquad\qquad \mathrm{Ar}$$

$$1s^2\underbrace{2s^22p^6}_{\text{octet}} \qquad 1s^22s^22p^6\underbrace{3s^23p^6}_{\text{octet}}$$

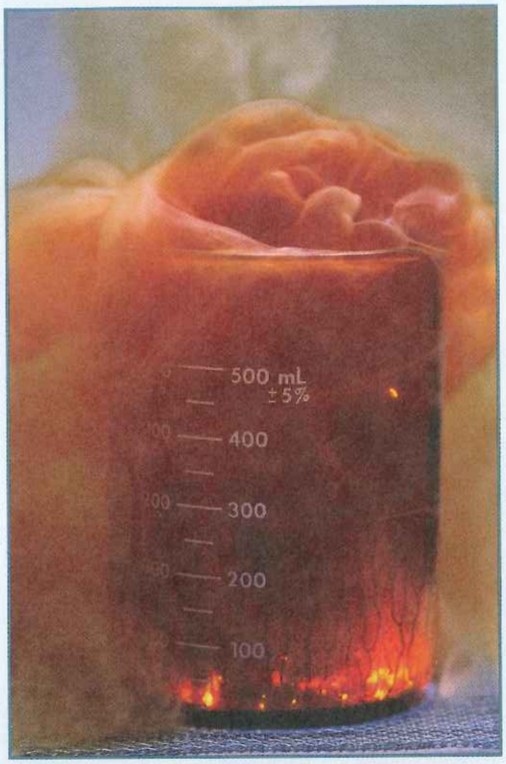


Figure 7.6 Formation of Aluminum Bromide Aluminum metal and the nonmetal bromine react violently to form the ionic solid aluminum bromide.

Figure 7.6 shows the reaction of aluminum (Al) and bromine (Br_2) to form the ionic compound aluminum bromide ($AlBr_3$). Each aluminum atom has three valence electrons to lose. Each bromine atom has seven valence electrons and readily gains one additional electron. Therefore, when aluminum and bromine react, three bromine atoms combine with each aluminum atom.

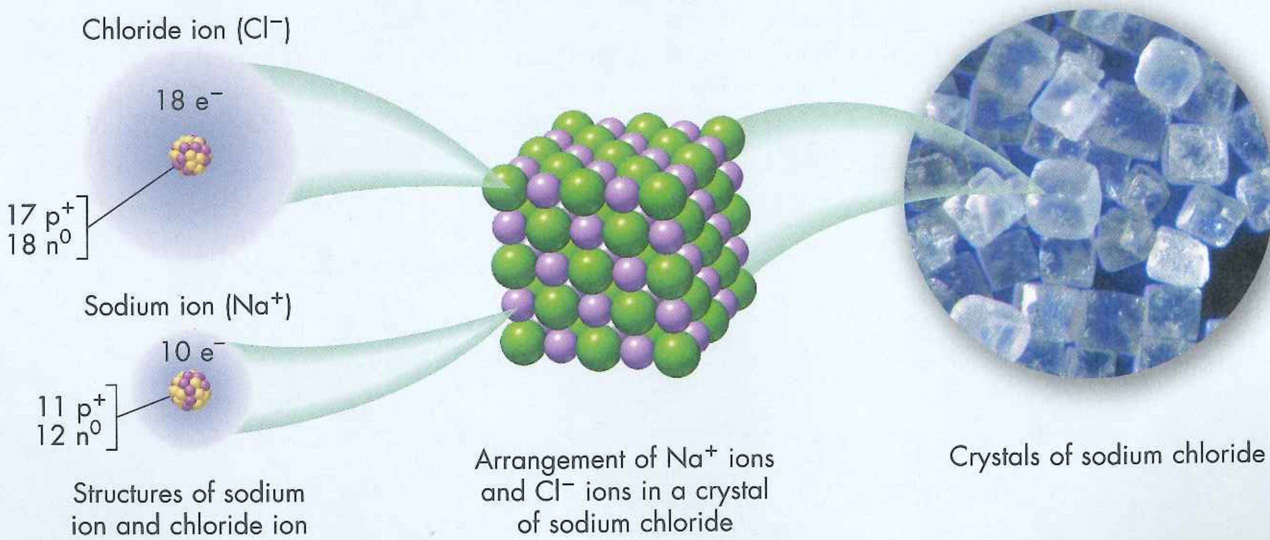
Formula Units The ionic compound sodium chloride is composed of equal numbers of sodium cations (Na^+) and chloride anions (Cl^-). Chemists represent the composition of substances by writing chemical formulas. A **chemical formula** shows the numbers of atoms of each element in the smallest representative unit of a substance. For example, NaCl is the chemical formula for sodium chloride.

Note that the formula NaCl does not represent a single physical unit. As shown in Figure 7.7, the ions in solid sodium chloride are arranged in an orderly pattern. Ionic compounds do not exist as single discrete units, but as collections of positively and negatively charged ions arranged in repeating patterns. Therefore, the chemical formula of an ionic compound refers to a ratio known as a formula unit. A **formula unit** is the lowest whole-number ratio of ions in an ionic compound. For sodium chloride, the lowest whole-number ratio of the ions is 1:1 (one Na^+ ion to each Cl^- ion). Thus, the formula unit for sodium chloride is NaCl. Although ionic charges are used to derive the correct formula, they are not shown when you write the formula unit of the compound.

The ionic compound magnesium chloride contains magnesium cations (Mg^{2+}) and chloride anions (Cl^-). In magnesium chloride, the ratio of magnesium cations to chloride anions is 1:2 (one Mg^{2+} ion to two Cl^- ions). Therefore, the formula unit for magnesium chloride is $MgCl_2$. The compound has twice as many chloride anions (each with a 1− charge) as magnesium cations (each with a 2+ charge), so it is electrically neutral. In aluminum bromide, the ratio of aluminum cations to bromide anions is 1:3 (one Al^{3+} ion to three Br^- ions), so the formula unit is $AlBr_3$. Again, the compound is electrically neutral.

Figure 7.7 Formation of Sodium Chloride Sodium cations and chloride anions form a repeating three-dimensional array in sodium chloride (NaCl).

Infer ***How does the arrangement of ions in a sodium chloride crystal help explain why the compound is so stable?***



Sample Problem 7.1

Predicting Formulas of Ionic Compounds

Use electron dot structures to predict the formulas of the ionic compounds formed from the following elements:

a. potassium and oxygen
b. magnesium and nitrogen

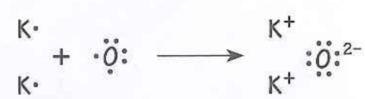
1 Analyze **Identify the relevant concepts.** Atoms of metals lose valence electrons when forming an ionic compound. Atoms of nonmetals gain electrons. Enough atoms of each element must be used in the formula so that electrons lost equals electrons gained.

2 Solve **Apply the concepts to this problem.**

Start with the atoms.

a. K· and ·Ö:

In order to have a completely filled valence shell, the oxygen atom must gain two electrons. These electrons come from two potassium atoms, each of which loses one electron.



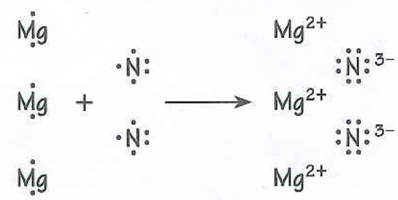
Express the electron dot structure as a formula.

The formula of the compound formed is K_2O (potassium oxide).

Start with the atoms.

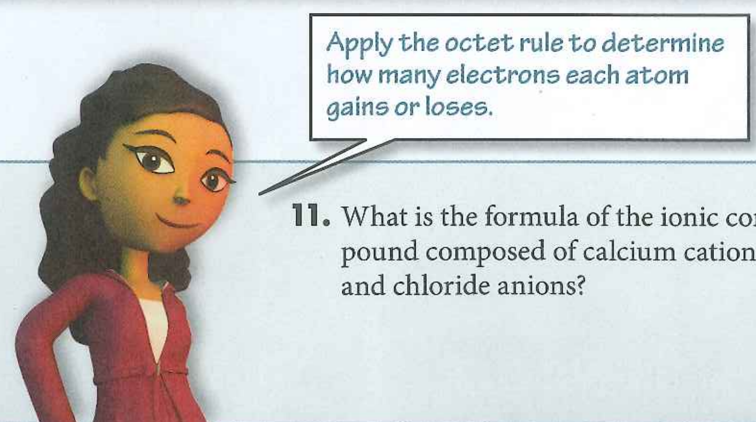
b. Mg and ·N:

Each nitrogen atom needs three electrons to have an octet, but each magnesium atom can lose only two electrons. Three magnesium atoms are needed for every two nitrogen atoms.



Express the electron dot structure as a formula.

The formula of the compound formed is Mg_3N_2 (magnesium nitride).



10. Use electron dot structures to determine formulas of the ionic compounds formed when
a. potassium reacts with iodine.
b. aluminum reacts with oxygen.

11. What is the formula of the ionic compound composed of calcium cations and chloride anions?

Properties of Ionic Compounds

What are three properties of ionic compounds?

CHEMISTRY & YOU

Q: *Would you expect to find sodium chloride in underground rock deposits as a solid, liquid, or gas? Explain.*

Figure 7.8 shows the striking beauty of the crystals of some ionic compounds. **Most ionic compounds are crystalline solids at room temperature.** The component ions in such crystals are arranged in repeating three-dimensional patterns. In solid sodium chloride, each sodium ion is surrounded by six chloride ions, and each chloride ion is surrounded by six sodium ions. In this arrangement, each ion is attracted strongly to each of its neighbors, and repulsions are minimized. The large attractive forces result in a very stable structure. This stability is reflected in the fact that NaCl has a melting point of about 800°C. **Ionic compounds generally have high melting points.**

Figure 7.8 Crystalline Solids
The beauty of crystalline solids, such as these, comes from the orderly arrangement of their component ions.

CONCEPTS IN ACTION — *Go online to learn about* **properties of ionic compounds.**


Fluorite (CaF_2)


Grossularite ($Ca_3Al_2(SiO_4)_3$)


Aragonite ($CaCO_3$)


Barite ($BaSO_4$)


Wulfenite ($PbMoO_4$)


Beryl ($Be_3Al_2(SiO_3)_6$)


Hematite (Fe_2O_3)

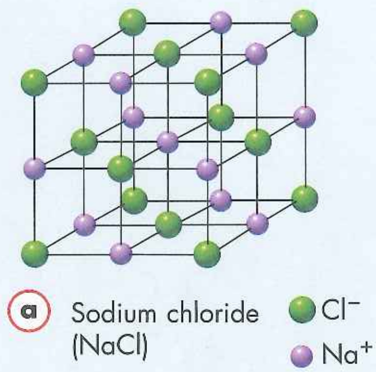

Cinnabar (HgS)

The **coordination number** of an ion is the number of ions of opposite charge that surround the ion in a crystal. Figure 7.9a shows the three-dimensional arrangement of ions in NaCl. The coordination number of Na^+ is 6 because each Na^+ ion is surrounded by six Cl^- ions. The coordination number of Cl^- is also 6 because each Cl^- ion is surrounded by six Na^+ ions. Cesium chloride (CsCl) has a formula unit that is similar to that of NaCl. As Figure 7.9b illustrates, both compounds have cubic crystals, but their internal crystal structures are different. Each Cs^+ ion is surrounded by eight Cl^- ions, and each Cl^- ion is surrounded by eight Cs^+ ions. Therefore, each anion and each cation in cesium chloride has a coordination number of 8.

Figure 7.10 shows the crystalline form of titanium dioxide (TiO_2), also known as rutile. In this compound, the coordination number for the cation (Ti^{4+}) is 6. Each Ti^{4+} ion is surrounded by six O^{2-} ions. The coordination number of the anion (O^{2-}) is 3. Each O^{2-} ion is surrounded by three Ti^{4+} ions.

See **crystal structures of ionic compounds** ***online.*** KINETIC ART

Figure 7.9
Coordination Numbers
Sodium chloride and cesium chloride form cubic crystals. **a.** In NaCl, each ion has a coordination number of 6. **b.** In CsCl, each ion has a coordination number of 8.



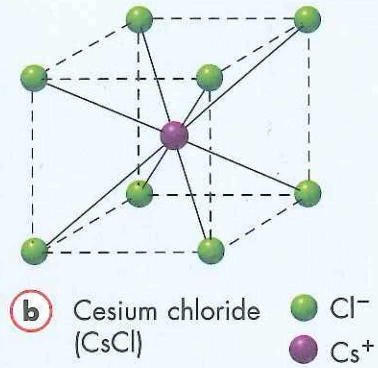
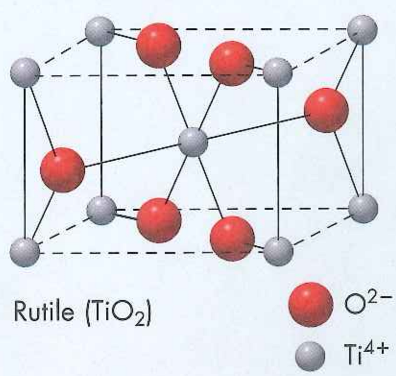


Figure 7.10 Rutile
Titanium dioxide, or rutile, forms tetragonal crystals. In TiO_2, each Ti^{4+} ion has a coordination number of 6, while each O^{2-} ion has a coordination number of 3.



Another characteristic property of ionic compounds relates to conductivity. **Ionic compounds can conduct an electric current when melted or dissolved in water.** When sodium chloride is melted, the orderly crystal structure breaks down. As Figure 7.11a shows, if a voltage is applied across this molten mass, cations migrate freely to one electrode and anions migrate to the other. This movement of ions allows electric current to flow between the electrodes through an external wire. For a similar reason, ionic compounds also conduct electric current if they are dissolved in water. When dissolved, the ions are free to move about in the solution.

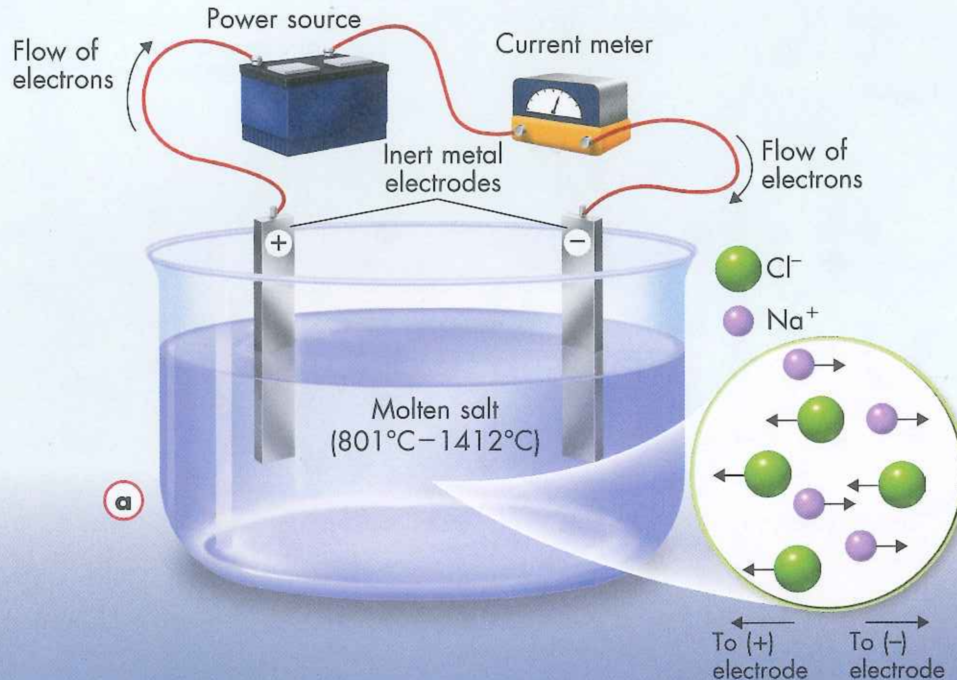
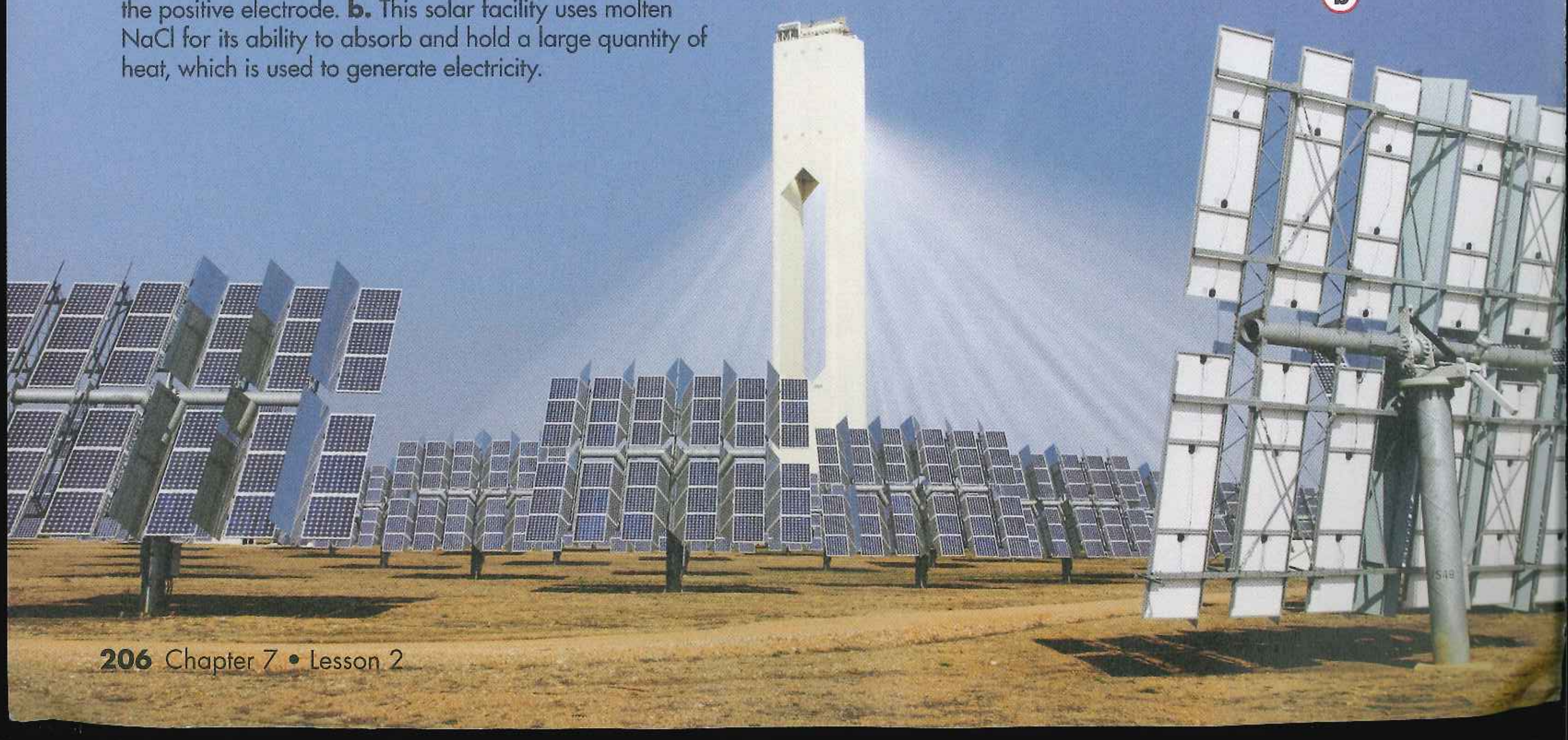


Figure 7.11 Molten NaCl
Sodium chloride melts at about 800°C. **a.** If a voltage is applied to molten NaCl, positive sodium ions move to the negative electrode, and negative chloride ions move to the positive electrode. **b.** This solar facility uses molten NaCl for its ability to absorb and hold a large quantity of heat, which is used to generate electricity.



Quick Lab

Solutions Containing Ions

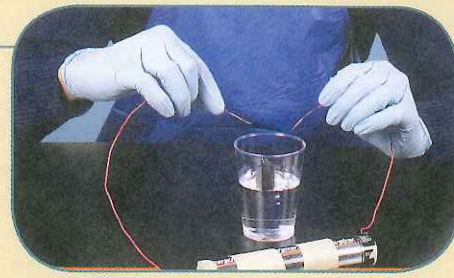
Purpose To show that ions in solution conduct an electric current

Materials
- 3 D-cell batteries
- masking tape
- 2 30-cm lengths of bell wire with ends scraped bare
- clear plastic cup
- distilled water
- tap water
- vinegar (acetic acid, $C_2H_4O_2$)
- table sugar (sucrose, $C_{12}H_{22}O_{11}$)
- table salt (sodium chloride, NaCl)
- baking soda (sodium hydrogen carbonate, $NaHCO_3$)

Procedure

1. Tape the batteries together so the positive end of one touches the negative end of another. Tape the bare end of one wire to the positive terminal of the battery assembly and the bare end of the other wire to the negative terminal. **CAUTION** *Bare wire ends can be sharp and scratch skin. Handle with care.*

2. Half fill the cup with distilled water. Hold the bare ends of the wires close together in the water.



3. Look for the production of bubbles. They are a sign that the solution conducts electric current.

4. Repeat Steps 2 and 3 with tap water, vinegar, and concentrated solutions of table sugar, table salt, and baking soda.

Analyze and Conclude

1. Observe Which samples produced bubbles of gas? Which samples did not produce bubbles of gas?

2. Draw Conclusions Which samples conducted an electric current? What do these samples have in common?

3. Predict Would you expect the same results if you used only one battery? If you used six batteries? Explain your answers.

7.2 LessonCheck

ONLINE PROBLEMS

12. Describe How can you describe the electrical charge of an ionic compound?

13. Identify What properties characterize ionic compounds?

14. Apply Concepts Write the correct chemical formula for the compounds formed from each pair of elements.
- **a.** potassium and sulfur
- **b.** calcium and oxygen
- **c.** sodium and oxygen
- **d.** aluminum and nitrogen

15. Describe Write formulas for each compound.
- **a.** barium chloride
- **b.** magnesium oxide
- **c.** lithium oxide
- **d.** calcium fluoride

16. Describe How can you describe the arrangement of sodium ions and chloride ions in a crystal of sodium chloride?

17. Relate Cause and Effect Why do ionic compounds conduct electric current when they are melted or dissolved in water?

18. Apply Concepts Read about restoring electrolytes on page R4 of the Elements Handbook. Write electron configurations for the two principal ions found in body fluids.

BIGIDEA BONDING AND INTERACTIONS

19. Which pairs of elements are likely to form ionic compounds? Explain your choices and write the formulas for the compounds that will form.
- **a.** Cl, Br
- **b.** K, He
- **c.** Li, Cl
- **d.** I, Na

Ionic Crystals

What ionic crystal is essential to human life, was found among the funeral offerings of ancient Egyptians, created and destroyed empires, and is now commonly used to season foods? If you said table salt, you'd be right! Table salt, or sodium chloride (NaCl) is an ionic compound composed of sodium cations (Na^+) and chloride anions (Cl^-).

Crystals of ionic compounds, such as sodium chloride, can be grown by a process called nucleation. During nucleation, the ionic compound that is to be crystallized is dissolved in a solvent, such as water. In the dissolution process, the positive and negative ions break away from each other. As the solvent is removed, the ions join together again to form a repeating three-dimensional pattern. Sodium chloride has a cubic crystal structure, but different ionic compounds form crystals with different shapes. Try the On Your Own activity at home and compare the shapes of two different ionic crystals.

On Your Own

1. For this activity you will need **sea salt, Epsom salts, hot tap water, 2 pie plates, a measuring cup, and a stirring rod or spoon.** Epsom salts can be found in the medicine department of most grocery stores.

2. Mix together 1/4 cup of the sea salt and 1/4 cup of hot water in one of the pie plates. Stir to dissolve most of the salt. In the other pie plate, mix together 1/4 cup of the Epsom salts and 1/4 of hot water. Again, stir until most of the salt has dissolved.

3. Place both pie plates in the refrigerator for three hours. Once the crystals have formed, compare the shapes of the crystals made from the two substances. Record your observations.

Think About It

1. Compare and Contrast Describe the shapes of the crystals of sea salt and Epsom salts. How are they the same? How are they different?

2. Identify Epsom salts are magnesium sulfate ($MgSO_4$) crystals. A magnesium sulfate formula unit consists of a magnesium cation and a sulfate (SO_4^{2-}) anion. What is the charge on the magnesium cation?

3. Control Variables What factors do you think affect crystal growth? Identify two possible factors, then repeat the activity to test your hypotheses.

7.3 Bonding in Metals

CHEMISTRY & YOU

Q: *What are some properties that are unique to metals?* You have probably seen decorative fences, railings, or weather vanes 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. These properties derive from the way that metal ions form bonds with one another.

Key Questions

How can you model the valence electrons of metal atoms?

Why are alloys important?

Vocabulary

- metallic bond
- alloy

Metallic Bonds and Metallic Properties

How can you model the valence electrons of metal atoms?

Metals consist of closely packed cations and loosely held valence electrons rather than neutral atoms. **The valence electrons of atoms in a pure metal 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** are the forces of attraction between the free-floating valence electrons and the positively charged metal ions. These bonds hold metals together.

Properties of Metals The sea-of-electrons model explains many physical properties of metals. Metals are good conductors of electric current because electrons can flow freely in the metal. As electrons enter one end of a bar of metal, an equal number of electrons leaves 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 pressed into shapes.

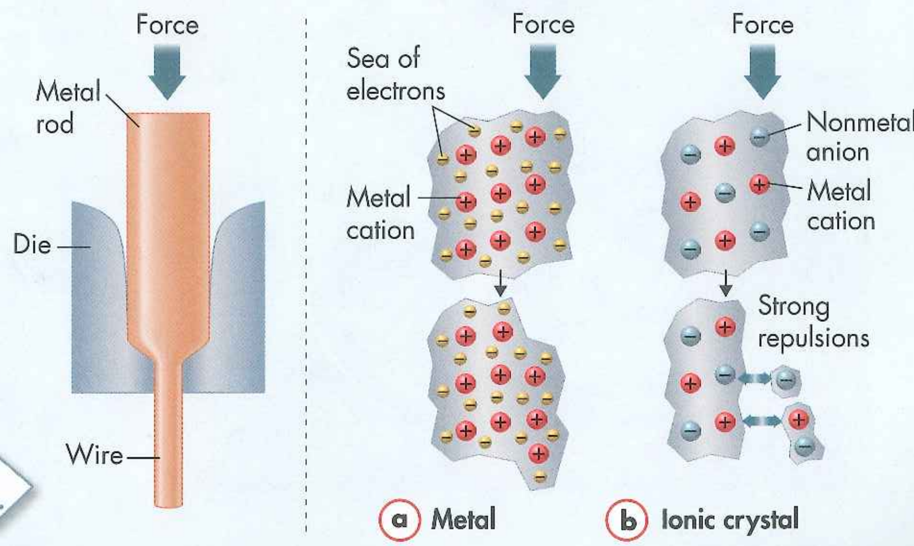


Figure 7.12 Comparing Metals and Ionic Compounds
A metal rod can be forced through a narrow opening to produce wire. **a.** As this occurs, the metal changes shape but remains in one piece. **b.** If an ionic crystal were forced through the opening, it would shatter.
Interpret Diagrams *What causes the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

KINETIC ART *Go online to compare* **metal vs. ionic compounds.**

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. The positive ions repel one another, and the crystal shatters.

CHEMISTRY & YOU

Q: *How are metals and ionic compounds different? How are they similar?*

Crystalline Structure of Metals The next time you visit a grocery store, take a look at how the apples or oranges 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 oranges as possible to be stacked up high.

Similar close-packed 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, several closely packed arrangements are possible. Figure 7.14 on the following page shows three such arrangements: body-centered cubic, face-centered cubic, and hexagonal close-packed.

In a body-centered cubic structure, every atom (except those on the surface) has eight neighbors. The metallic 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 structure are copper, silver, gold, aluminum, and lead. In a hexagonal close-packed arrangement, every atom also has twelve neighbors. However, because of its hexagonal shape, the pattern is different from the face-centered cubic arrangement. Metals that have a hexagonal close-packed crystal structure include magnesium, zinc, and cadmium.

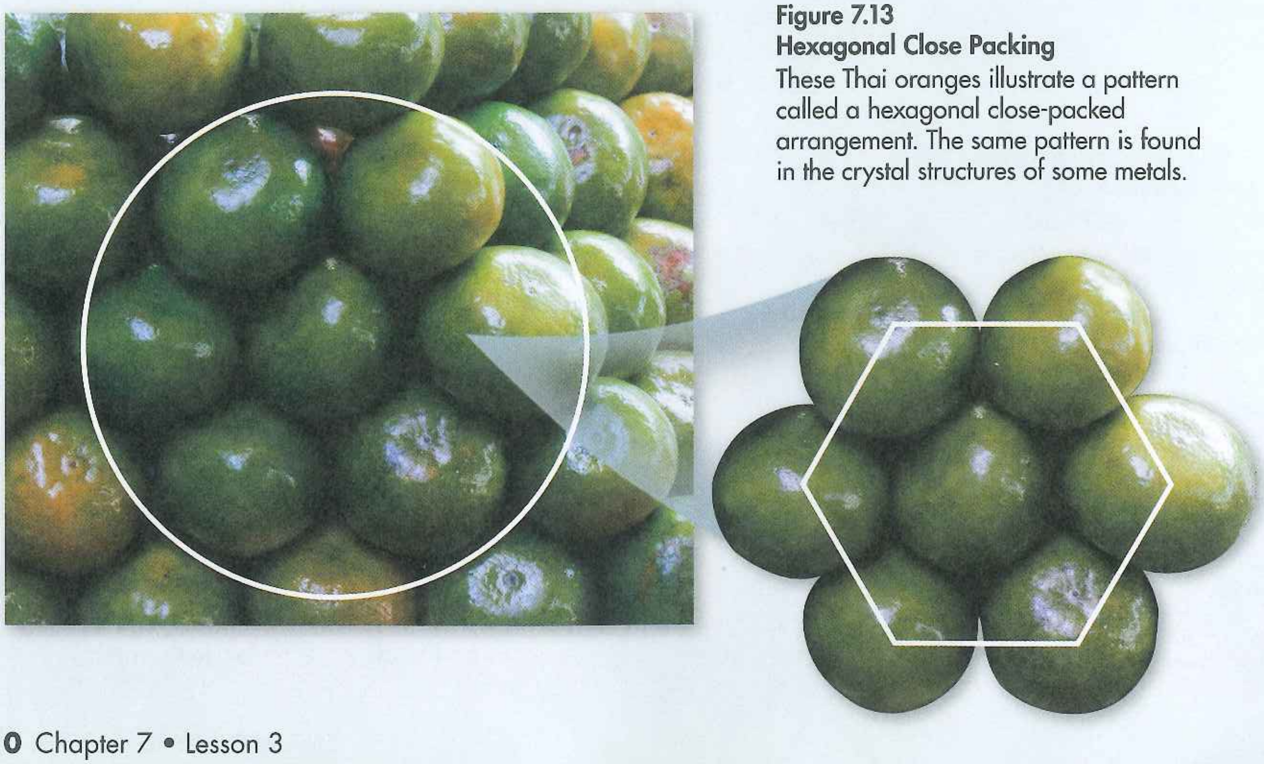


Figure 7.13
Hexagonal Close Packing
These Thai oranges illustrate a pattern called a hexagonal close-packed arrangement. The same pattern is found in the crystal structures of some metals.

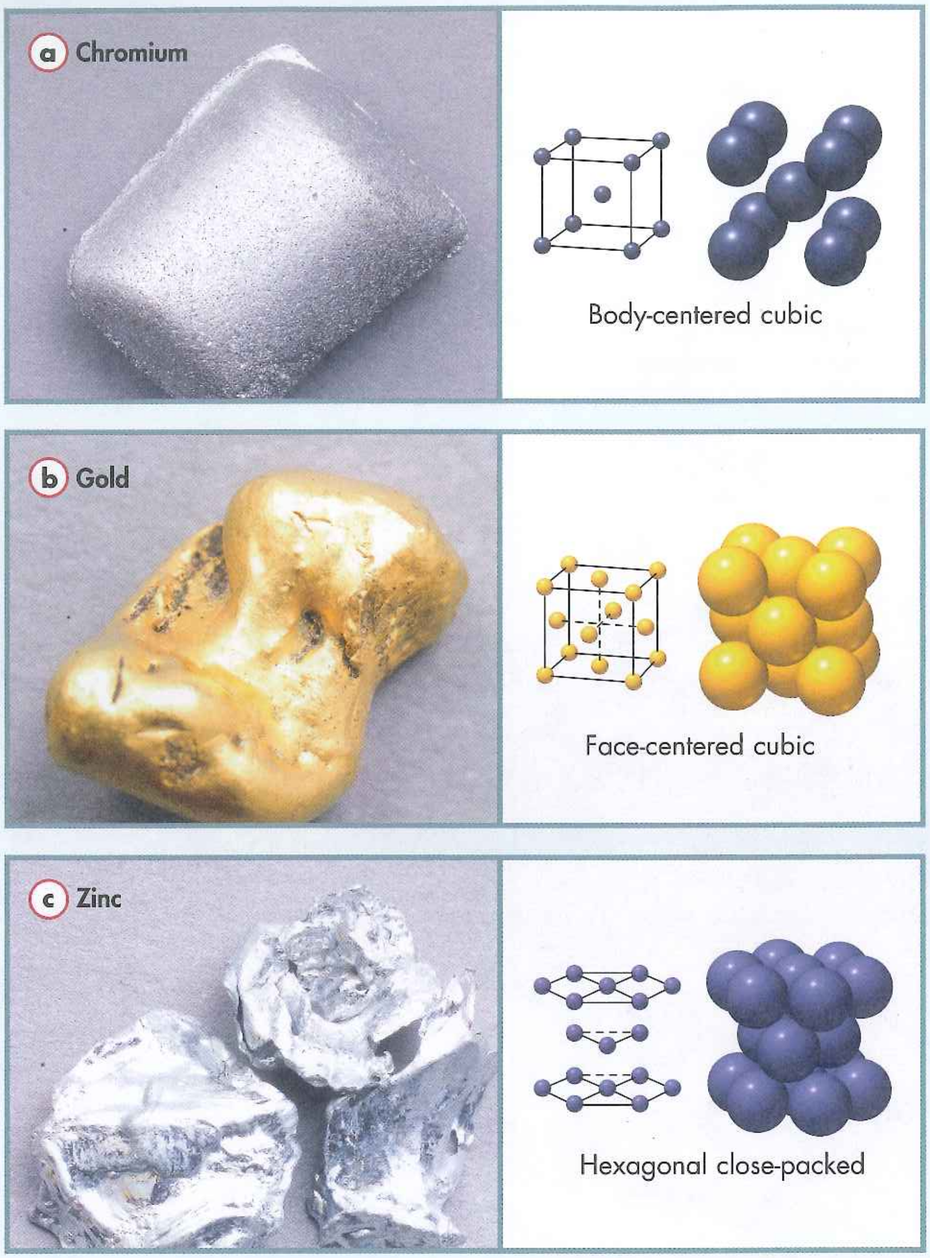


Figure 7.14 Crystalline Structures of Metals
Metal atoms crystallize in characteristic patterns.
a. Chromium atoms have a body-centered cubic arrangement.
b. Gold atoms have a face-centered cubic arrangement.
c. Zinc atoms have a hexagonal close-packed arrangement.
Interpret Diagrams ***Which of these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

Alloys

Why are alloys important?

Every day you use metallic items, such as utensils. However, very few of these objects are made out of a single kind of metal. Instead, most of the metals you encounter are alloys. **Alloys** are mixtures 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 percent silver and 7.5 percent copper) is harder and more durable than pure silver, yet is still soft enough to be made into jewelry and tableware. Bronze is an alloy generally containing seven parts copper to one part tin. Bronze is harder than copper and is easier to cast into molds. 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 steels, in addition to iron and carbon, are boron, chromium, manganese, molybdenum, nickel, tungsten, and vanadium. As a result, steels have a wide range of useful properties, such as corrosion resistance, ductility, hardness, and toughness. Figure 7.15 shows some items made of common alloys and their compositions.

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.

Figure 7.15 Common Alloys
Alloys are composed of two or more elements. The compositions (by mass) of sterling silver, cast iron, and stainless steel are shown.

7.3 LessonCheck

20. **Describe** How do chemists model the valence electrons of metal atoms?

21. **Explain** Why are alloys more useful than pure metals?

22. **Explain** What is meant by the terms *ductile* and *malleable?*

23. **Relate Cause and Effect** Why is it possible to bend metals but not ionic crystals?

24. **Use Analogies** How is the arrangement of fruit in a stack of oranges similar to the way some metal atoms are arranged in metallic crystals?

25. **Describe** Name two widely used alloys and describe some of their uses.

BIGIDEA BONDING AND INTERACTIONS

26. Describe how the sea-of-electrons model is used to explain the physical properties of metals.

7 Study Guide

BIGIDEA
BONDING AND INTERACTIONS

Atoms form positive ions (cations) by losing valence electrons and form negative ions (anions) by gaining valence electrons. The electrostatic forces between the oppositely charged ions hold the cations and anions together in an ionic compound. Ionic compounds generally have high melting points and can conduct an electric current in solution and in the molten state. Metals are made up of closely packed cations surrounded by a sea of electrons. The sea-of-electrons model explains why metals are good conductors of electric current and why they are ductile and malleable.

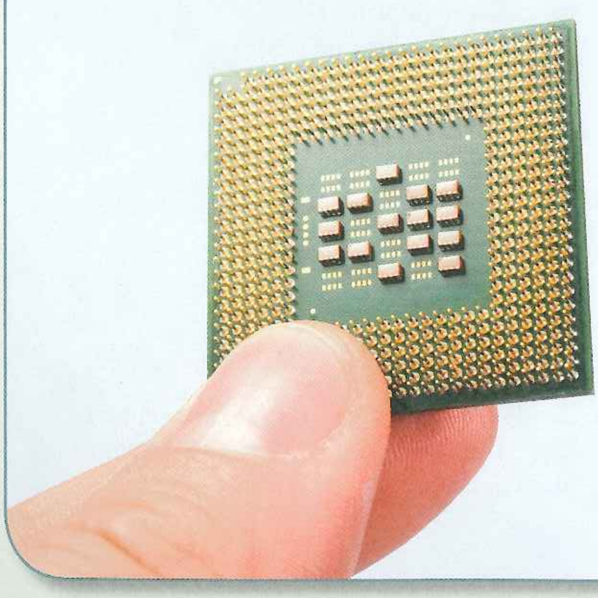
7.1 Ions

To find the number of valence electrons in an atom of a representative element, simply look at its group number.

A positively charged ion, or a cation, is produced when an atom loses one or more valence electrons.

An anion is produced when an atom gains one or more valence electrons.

- valence electron (194)
- electron dot structure (195)
- octet rule (195)
- halide ion (199)



7.2 Ionic Bonds and Ionic Compounds

Although they are composed of ions, ionic compounds are electrically neutral.

Most ionic compounds are crystalline solids at room temperature.

Ionic compounds generally have high melting points.

Ionic compounds can conduct an electric current when melted or dissolved in water.

- ionic compound (201)
- ionic bond (201)
- chemical formula (202)
- formula unit (202)
- coordination number (205)

7.3 Bonding in Metals

The valence electrons of atoms in a pure metal can be modeled as a sea of electrons.

Alloys are important because their properties are often superior to those of their component elements.

- metallic bond (209)
- alloy (211)

7 Assessment

★ Solutions appear in Appendix E

Lesson by Lesson

7.1 Ions

27. What is a valence electron?

★28. To which group in the periodic table does each of the following elements belong? How many valence electrons do atoms of each element have?
   a. nitrogen
   b. lithium
   c. phosphorus
   d. barium
   e. bromine
   f. carbon

29. Write electron dot structures for each of the following elements:
   a. Cl
   b. S
   c. Al
   d. Li

30. Describe two ways that an ion forms from an atom.

★31. How many electrons must an atom of each element lose to attain a noble-gas electron configuration?
   a. Ca
   b. Al
   c. Li
   d. Ba

32. Write the symbol for the ion formed when each of the following elements loses its valence electrons.
   a. aluminum
   b. lithium
   c. barium
   d. potassium
   e. calcium
   f. strontium

33. Why do nonmetal atoms tend to form anions when they react to form compounds?

★34. How many electrons must be gained by each of the following atoms to achieve a stable electron configuration?
   a. N
   b. S
   c. Cl
   d. P

★35. What is the formula of the ions formed when atoms of the following elements gain or lose valence electrons and attain noble-gas configurations?
   a. sulfur
   b. sodium
   c. fluorine
   d. phosphorus

36. State the number of electrons either lost or gained in forming each ion.
   a. Br^-
   b. Na^+
   c. As^{3-}
   d. Ba^{2+}
   e. Ca^{2+}
   f. Cu^+
   g. H^-
   h. Cu^{2+}

37. Name each ion in Problem 36. Identify each as an anion or a cation.

7.2 Ionic Bonds and Ionic Compounds

38. Define an ionic bond.

39. Explain why ionic compounds are electrically neutral.

★40. Which of the following pairs of atoms would you expect to combine chemically to form an ionic compound?
   a. Li and S
   b. O and S
   c. Al and O
   d. F and Cl
   e. I and K
   f. H and N

41. Which of the following pairs of elements will not form ionic compounds?
   a. sulfur and oxygen
   b. sodium and calcium
   c. sodium and sulfur
   d. oxygen and chlorine

42. How can you represent the composition of an ionic compound?

★43. Identify the kinds of ions that form each ionic compound.
   a. calcium fluoride, CaF_2
   b. aluminum bromide, $AlBr_3$
   c. lithium oxide, Li_2O
   d. aluminum sulfide, Al_2S_3
   e. potassium nitride, K_3N

44. Write the formulas for the ions in the following compounds:
   a. KCl
   b. BaS
   c. $MgBr_2$
   d. Li_2O

45. Most ionic substances are brittle. Why?

46. Explain why molten $MgCl_2$ does conduct an electric current although crystalline $MgCl_2$ does not.

7.3 Bonding in Metals

*47. How can you describe the arrangement of atoms in metals?

48. Explain briefly why metals are good conductors of electric current.

*49. Name the three crystal arrangements of closely packed metal atoms. Give an example of a metal that crystallizes in each arrangement.

50. Name some alloys that you have used or seen today.

51. Explain why the properties of all steels are not identical.

Understand Concepts

52. Construct a table that shows the relationship among the group number, valence electrons lost or gained, and the formula of the cation or anion produced for the following metallic and nonmetallic elements: Na, Ca, Al, N, S, Br.

53. Write electron dot structures for the following elements.

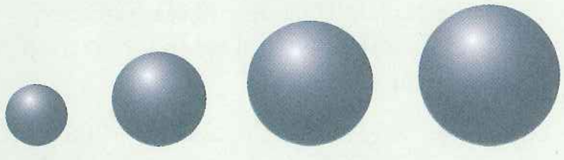
a. C
b. Be
c. O
d. F
e. Na
f. P

54. Show the relationship between the electron dot structure of an element and the location of the element in the periodic table.

*55. In terms of electrons, why does a cation have a positive charge?

56. Why does an anion have a negative charge?

57. The spheres below represent the relative diameters of atoms or ions. Rearrange the sequences in (a) and (b) so the relative sizes of the particles correspond to the increasing size of the particles as shown in the illustration.



a. oxygen atom, oxide ion, sulfur atom, sulfide ion
b. sodium atom, sodium ion, potassium atom, potassium ion

*58. Write the name and symbol of the ion formed when

a. a sulfur atom gains two electrons.
b. an aluminum atom loses three electrons.
c. a nitrogen atom gains three electrons.
d. a calcium atom loses two electrons.

*59. Write electron configurations for the 2+ cations of these elements.

a. Fe
b. Co
c. Ni

60. Write electron configurations for the 3+ cations of these elements.

a. chromium
b. manganese
c. iron

61. Write the symbol for the ion formed when each element gains electrons and attains a noble-gas electron configuration.

a. Br
b. H
c. As
d. Se

*62. Write electron configurations for the following atoms and ions, and comment on the result.

a. Ar
b. Cl^-
c. S^{2-}
d. P^{3-}

63. Write electron configurations for the following atoms and ions and comment on the result.

a. N^{3-}
b. O^{2-}
c. F^-
d. Ne

64. Name the first four halogens. What group are they in, and how many valence electrons does an atom of each element have?

65. Write complete electron configurations for the following atoms and ions. For each group, comment on the results.

a. Ar, K^+, Ca^{2+}
b. Ne, Na^+, Mg^{2+}, Al^{3+}

66. If ionic compounds are composed of charged particles (ions), why isn't every ionic compound either positively or negatively charged?

*67. Which of the following compounds are most likely not ionic?

a. H_2O
b. Na_2O
c. CO_2
d. CaS
e. SO_2
f. NH_3

*68. Write the formulas for each ionic compound that can be made by combining each of pair of ions.

a. Ba^{2+} and Br^-
b. Al^{3+} and S^{2-}
c. K^+ and N^{3-}

69. The atoms of the noble gas elements are stable. Explain.

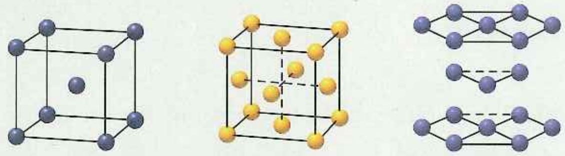
70. What is the simplest formula for the compounds that can form when each of these ions combine with an oxide (O^{2-}) ion?

a. Fe^{3+}
b. Pb^{4+}
c. Li^+
d. Mg^{2+}

71. Can you predict the coordination number of an ion from the formula of an ionic compound? Explain.

*72. Metallic cobalt crystallizes in a hexagonal close-packed structure. How many neighbors will a cobalt atom have?

73. Explain how hexagonal close-packed, face-centered cubic, and body-centered cubic unit cells are different from one another.



Body-centered cubic | Face-centered cubic | Hexagonal close-packed

74. The properties of all samples of brass are not identical. Explain.

*75. For each alloy below, list the elements it contains.

a. brass
b. sterling silver
c. bronze
d. stainless steel

Think Critically

*76. **Make Generalizations** What is the relationship between the number of electrons in the valence shells in an electron configuration diagram for an atom and the number of dots in the corresponding electron dot structure?

77. **Relate Cause and Effect** Why are many elements more stable as ions than they are as atoms?

78. **Make Generalizations** Is it accurate to describe sodium chloride (NaCl) as consisting of individual particles, each made up of one Na^+ cation and one Cl^- anion? Explain your answer.

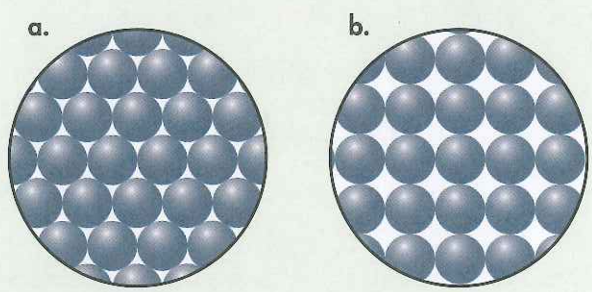
*79. **Infer** For each ionic formula, identify the A-group number to which element X belongs.

a. CaX
b. MgX_2
c. X_3N
d. Al_2X_3
e. XF
f. XS

80. **Compare** How do the motions of sodium ions and chloride ions in molten sodium chloride differ from the motions of these ions in sodium chloride crystals?

81. **Relate Cause and Effect** Two physical properties of metals are ductility and malleability. Explain these properties based on what you know about the valence electrons of metal atoms.

82. **Interpret Diagrams** How atoms and ions are arranged in crystals is not just dependent on size. The spheres in each atomic window below are identical in size. The windows have exactly the same area. In which window are the spheres more closely packed? Explain your reasoning.



*83. **Compare and Contrast** Describe the similarities and differences between ionic compounds and metals in terms of their physical and chemical characteristics.

84. **Relate Cause and Effect** How does the octet rule explain the large increase in energy between the first and second ionization energies of Group 1A metals?

85. **Infer** An atom of the element M forms a stable ion in an ionic compound with chlorine having the formula MCl_2. In this compound, the ion of element M has a mass number of 66 and has 28 electrons.

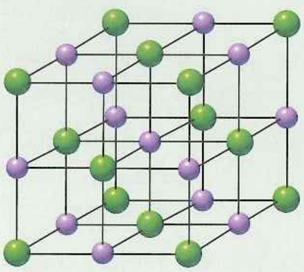
a. What is the identity of the element?
b. How many neutrons does the ion have?

Enrichment

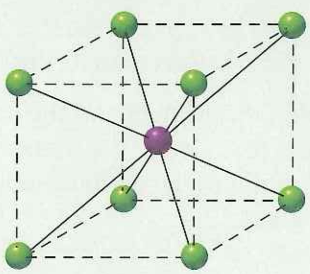
*86. **Apply Concepts** Classify each element in the following list. Will an atom of each element form a cation or an anion, or is the element chemically nonreactive? For the atoms that do form ions during a chemical reaction, write the number of electrons the atom will gain or lose.

- **a.** lithium
- **b.** sodium
- **c.** neon
- **d.** chlorine
- **e.** magnesium

87. **Infer** The chemically similar alkali metal chlorides NaCl and CsCl have different crystal structures, whereas the chemically different NaCl and MnS have the same crystal structures. Why? (*Hint:* Consider periodic and group trends among the properties of the elements.)



Cl^-
Na^+
Sodium chloride (NaCl)



Cl^-
Cs^+
Cesium chloride (CsCl)

88. **Calculate** Silver crystallizes in a face-centered cubic arrangement. A silver atom is at the edge of each lattice point (the corner of the unit cell). The length of the edge of the unit cell is 0.4086 nm. What is the atomic radius of silver?

*89. **Analyze Data** Consider two ionic compounds, NaCl and CaO.

- **a.** In which compound would you expect the electrostatic forces that hold the compound together to be the strongest? Explain.
- **b.** The melting point of NaCl is 801°C. The melting point of CaO is 2614°C. Does this data support your prediction? Why or why not?

Write About Science

90. **Compare** Describe the formation of a cation that is an exception to the octet rule. In your description, compare the electron configuration of the cation to the electron configurations of the nearest noble gases.

91. **Research** Go online and research X-ray diffraction crystallography. How are the samples prepared? How are the X-rays generated and detected? How is this technique used to study the structure of crystalline substances?

CHEMYSTERY

It's Not Easy Being Green

The statue of Ludwig van Beethoven in Central Park is made of bronze. Bronze is an alloy containing copper and tin.

When bronze is exposed to the elements, it reacts with water (H_2O), carbon dioxide (CO_2), and oxygen (O_2) in the air to produce a film of copper(II) carbonate ($CuCO_3$). Copper(II) carbonate is an ionic compound that is blue-green in color. A film of copper(II) carbonate on the Beethoven statue gives the statue its green color. The film also protects the metal against further corrosion.

*92. **Apply Concepts** A copper atom can lose one or two electrons to form a Cu^+ ion or a Cu^{2+} ion, respectively. The charge of the copper ion in $CuCO_3$ is 2+. Write the electron configuration of this cation.

93. **Form an Opinion** Why do you think bronze is often used to create statues?

94. **Connect to the BIGIDEA** How are the properties of the copper(II) carbonate film on the statue different from the properties of the bronze beneath the film? Explain how these properties are a result of the type of bonding present.

Cumulative Review

95. How is organic chemistry distinguished from inorganic chemistry?

96. What is the name given to a chemist who studies the composition of matter?

97. Explain two ways to meet modern society's need for energy.

*** 98.** Classify the following actions as chemical or physical changes.

- **a.** Cookies are baked.
- **b.** A firefly emits light.
- **c.** A figure is carved from wood.
- **d.** Caramel is made from sugar.

99. Which of the following substances are not homogeneous mixtures?

- **a.** gold ring
- **b.** spaghetti sauce
- **c.** cane sugar
- **d.** window glass
- **e.** river water
- **f.** bottled water

*** 100.** What physical state(s) can each of the following substances become as you raise its temperature?

- **a.** silver
- **b.** gasoline
- **c.** ice
- **d.** wax

101. Round each measurement to the number of significant figures indicated in parentheses.

- **a.** 56.55 g (3)
- **b.** 0.004849 m (2)
- **c.** 1.8072 L (3)
- **d.** 4.007×10^3 mg (2)

*** 102.** Which of the following linear measurements is the longest?

- **a.** 6×10^4 cm
- **b.** 6×10^6 mm
- **c.** 0.06 km
- **d.** 6×10^9 nm

103. Helium has a boiling point of 4 K. This is the lowest boiling point of any liquid. Express this temperature in degrees Celsius.

*** 104.** The density of silicon is 2.33 g/cm^3. What is the volume of a piece of silicon that has a mass of 62.9 g?

105. Express the composition of each atom in shorthand form.

- **a.** zinc-64
- **b.** chlorine-37
- **c.** hydrogen-3
- **d.** calcium-40

106. An atom of carbon and an atom of element Z together have a mass of 6 amu less than double the mass of an atom of oxygen. If an atom of oxygen has a mass of 16 amu and the mass of an atom of carbon is 12 amu, what is the mass of an atom of element Z?

107. Determine the number of protons, electrons, and neutrons in each of the three isotopes of oxygen.

*** 108.** How many orbitals are in the following sublevels?

- **a.** 4*s* sublevel
- **b.** 2*p* sublevel
- **c.** 3*s* sublevel
- **d.** 4*d* sublevel

109. Give the symbol for each element and write the electron configuration for each atom.

- **a.** nitrogen
- **b.** beryllium
- **c.** phosphorus
- **d.** potassium

110. An atom of an element has 17 electrons. Give the name and symbol of the element and write the complete electron configuration.

*** 111.** A beam of electromagnetic radiation has a wavelength of 500 nm.

- **a.** What is this wavelength in meters?
- **b.** In what region of the spectrum is this?

*** 112.** Give the symbol of the element and the complete electron configuration of the element found at each location in the periodic table.

- **a.** Group 1A, Period 4
- **b.** Group 3A, Period 3
- **c.** Group 6A, Period 3
- **d.** Group 2A, Period 6

113. Which subatomic particle plays the most important role in chemistry?

114. Give the name and symbol of two elements that have properties similar to those of potassium.

If You Have Trouble With . . .

Question	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114
See Chapter	1	1	1	2	2	2	3	3	3	3	4	4	4	5	5	5	5	6	6	6

Standardized Test Prep

Tips for Success

Review All the Answer Choices Even if you find an answer that looks correct, continue reading until you have looked at *every* answer. There may be more than one correct response, or one may be better than another. Also, "all of the above" may be a possible answer. If you stop reading as soon as you find an answer that is correct, you won't notice this option.

Select the choice that best answers each question or completes each statement.

1. Which of these is not an ionic compound?
   (A) KF
   (B) SiO_2
   (C) Na_2SO_4
   (D) Na_2O

2. Which statements are correct when barium and oxygen react to form an ionic compound?
   I. Each barium atom loses 2 electrons and forms a cation.
   II. Oxygen atoms form oxide anions (O^{2-}).
   III. The ions are present in a one-to-one ratio in the compound.
   (A) I and II only
   (B) II and III only
   (C) I and III only
   (D) I, II, and III

The lettered choices below refer to Questions 3–6. A lettered choice may be used once, more than once, or not at all.

(A) gains two electrons
(B) loses two electrons
(C) gains three electrons
(D) loses one electron
(E) gains one electron

Which choice describes what likely happens as each of the following elements forms an ion?

3. iodine
4. magnesium
5. cesium
6. phosphorus

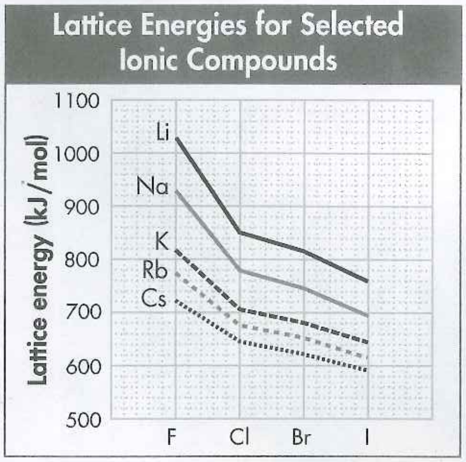
7. How many valence electrons does arsenic have?
   (A) 5
   (B) 4
   (C) 3
   (D) 2

8. Which electron configuration represents a nitride ion?
   (A) $1s^2 2s^2 3s^2 4s^2$
   (B) $1s^2 2s^2 2p^6$
   (C) $1s^2 2s^2 2p^3$
   (D) $1s^2$

9. When a bromine atom gains an electron
   (A) a bromide ion is formed.
   (B) the ion formed has a 1− charge.
   (C) the ion formed is an anion.
   (D) all the above are correct.

Use the description and the graph to answer Questions 10–12.

Lattice energy is the energy required to change one mole (6.02×10^{23} formula units) of a crystalline, ionic solid to gaseous ions. The graph below shows the lattice energies for ionic compounds formed between selected alkali metals and halogens.



10. For a given alkali metal, what is the trend in lattice energy as the atomic radius of the halogen increases?

11. For a given halogen, what is the trend in lattice energy as the atomic radius of the alkali metal increases?

12. Complete this sentence: "As the atomic radius of either the halogen or the alkali metal increases, the lattice energy ________."

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10	11	12
See Lesson	7.2	7.2	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.2	7.2	7.2