1 FOCUS

Objectives

6.3.1 **Recognize** and **describe** binary ionic compounds, metals with multiple ions, and polyatomic ions.

6.3.2 **Name** and **determine** chemical formulas for ionic and molecular compounds.

Reading Focus

Build Vocabulary L2

Word-Part Analysis Ask students what words they know that have the prefix *poly-*. *(Polygon, polysyllabic, polyglot, polytechnic,* and *polygraph)* Give a definition of the prefix. *(*Poly- *means "many.")* Have students predict the meaning of the term *polyatomic ion. (A polyatomic ion is a covalently bonded group of atoms that has a positive or negative charge and acts as a unit.)*

Reading Strategy L2

a. and b. Students should assume that any particle described as an ion has a charge. If they know the meaning of *poly-*, they may conclude that the ion contains three or more atoms.

2 INSTRUCT

Integrate Language Arts L2

The production of lime through the decomposition of limestone (or any form of calcium carbonate) has been known for millennia, which is why there is a word for lime in many ancient languages. In Latin, this word is *calx,* which is the source for the name calcium. Have students research the origin of the phrase "in the limelight." *(Drummond developed limelight first as an aid to surveying. When lime was heated in a hydrogen-oxygen flame, it produced a bright, white light. In 1825, a light that Drummond placed on top of a hill in Belfast could be seen in Donegal about 105 km (66 miles) away. Limelight was first used in a theater in 1856, when a lens was placed in front of the limelight to produce a spotlight.)*

Logical

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.

Section Resources

Print

- ***Laboratory Manual,*** Investigation 6A
- ***Guided Reading and Study Workbook With Math Support,*** Section 6.3 and **Math Skill:** Writing Formulas for Ionic Compounds
- ***Transparencies,*** Section 6.3

Technology

- ***iText,*** Section 6.3
- ***Presentation Pro CD-ROM,*** Section 6.3
- ***Go Online,*** NSTA SciLinks, Chemical formulas

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.

Describing Ionic Compounds

Address Misconceptions L2

Some students may think that a material's particles possess the same properties as the material. For example, they may think that the atoms that compose the copper oxides in Figure 15 are red or black. Challenge this misconception by noting that the black and red copper oxides both contain the same two elements—copper and oxygen—yet they are different colors.
Logical

FYI

The copper oxides differ in more than color. Copper(I) oxide melts at 1235°C and has a density of 6.0 g/cm^3. Copper(II) oxide melts at 1446°C and has a density of 6.31 g/cm^3.

Build Reading Literacy L1

Outline Refer to page **156D** in this chapter, which provides the guidelines for an outline.

Have students read the text on pp. 171–175 related to describing ionic and molecular compounds. Then, have students use the headings as major divisions in an outline. Have students refer to their outlines when answering the questions in the Section 6.3 Assessment.
Visual

Customize for Inclusion Students

Behaviorally Disordered
Have students work in groups and use index cards to create a classroom set of flashcards. Students can use the cards to support each other in small, noncompetitive study groups. Each card should contain information about a metal or nonmetal element that forms ions. One side of the card should list the name of an element (for example, chlorine), the formula for an ionic compound that contains the element (for example, NaCl), and four categories of color-keyed questions: Group in periodic table; Name of ion; Charge on ion; Other ion in compound. Color key the answers on the other side of the card. *(Halogens* or *7A; Chloride; 1−; Sodium)*

Answer to . . .

Figure 15 *They must be different compounds because their colors vary, and the properties of a compound should be consistent.*

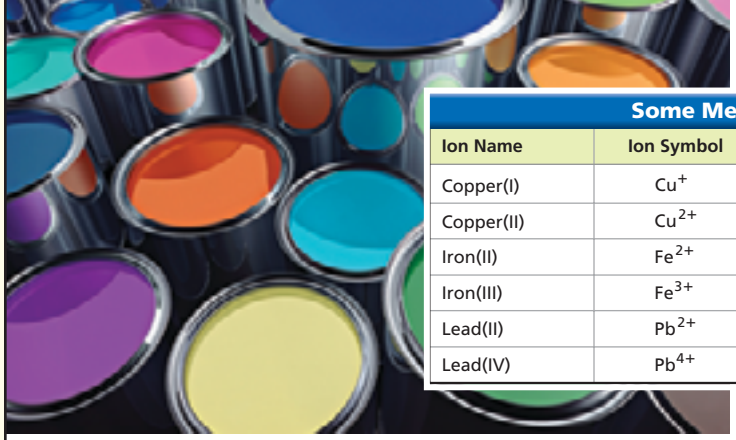
Use Visuals

L1

Figure 18 Have students compare the two models of an ammonium ion. Have them discuss the advantages of each type of model. *(Both models show the number and types of atom in the ion. The electron dot diagram shows the valence electrons. The space-filling model shows the relative sizes of the atoms and how they are arranged in space.)* Point out that the brackets in the electron dot diagram indicate that the group of atoms as a whole, not any specific atom, has a positive charge. Ask, **What is the charge on an ammonium ion?** *(1+)* **How many covalent bonds are in an ammonium ion?** *(Four)* **How many valence electrons are involved in the bonds in the ammonium ion?** *(Eight)* **Visual**

FYI

Paint is a mixture of nonvolatile ingredients (the pigment and the binder) that are dispersed in a volatile liquid. A pigment is a substance that provides the color.



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?***

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.

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.

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?

172 Chapter 6

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?***

Quick Lab

Modeling Molecules L2

Objective
After completing this activity, students will be able to
- use physical models to compare the shapes of molecules.

Skills Focus **Using Models**

Prep Time 10 minutes

Advance Prep Plastic-foam balls are available from craft supply stores. If black and blue foam balls are not available, wrap other foam balls in colored foil, glue colored tissue paper around them, or spray-paint them to match the colors used in this book to represent atoms of carbon and nitrogen.

Class Time 20 minutes

Safety Tell students not to eat the gumdrops or anything else in the laboratory.

Expected Outcome Students will make tetrahedral (pyramidal) models of methane molecules.

Analyze and Conclude
1. The methane molecule is a tetrahedron (equal-sided triangular pyramid) and the ammonia molecule has a triangular shape.
2. The carbon atom is in the center because each of the four hydrogen atoms must bond to one carbon atom.
Visual, Kinesthetic

Build Science Skills L2

Inferring Molecules of NH_3 and NF_3 have the same shape, but bonds in NH_3 are shorter than bonds in NF_3. In other words, the hydrogen atoms are closer to the nitrogen atom in an ammonia molecule than the fluorine atoms are to the nitrogen atom in nitrogen trifluoride. Ask, **What does this data imply about the relative sizes of hydrogen and fluorine atoms?** *(The data confirms that a hydrogen atom has a smaller atomic radius than does a nitrogen atom.)* **Logical**

Answer to . . .

Figure 17 *The Roman numeral is equal to the charge on the ion.*

Figure 19 *Oxygen*

Reading Checkpoint *When the metal in the compound can form more than one type of ion*

Build Math Skills

L1

Positive and Negative Numbers
Remind students that the charges in an ionic compound must cancel each other. Ask, **How many atoms of a halogen would combine with one atom of an alkaline earth metal? Why?** *(Two atoms; the alkaline earth metal atom loses two electrons but each halogen atom needs only one electron to become stable.)* **Logical**

Direct students to the **Math Skills** in the **Skills and Reference Handbook** at the end of the student text for additional help.

Math Practice

L2

Solutions
1. It takes one calcium ion with a charge of 2+ to balance one oxide ion with a charge of 2−. The formula is CaO.
2. Two copper(I) ions, each with a charge of 1+, balance one sulfide ion with a charge of 2−. The formula is Cu_2S.
3. Two sodium ions, each with a charge of 1+, balance one sulfate ion with a charge of 2−. The formula is Na_2SO_4.
4. In the formula, Na represents the sodium ion and OH represents the hydroxide ion. The name of the compound is sodium hydroxide. **Logical**

For Extra Help

L1

Make sure the first step students take is to find the symbols and charges on the ions. Then, check that they are able to balance the charges.
Logical

Additional Problems

1. Write the formula for lithium oxide. *(Li_2O)*
2. Write the formula for iron(III) oxide. *(Fe_2O_3)*
Logical

Describing Molecular Compounds

FYI

There are two exceptions to the general rule for naming molecular compounds. Hydrogen is treated as though it were positioned between Group 5A and Group 6A, and oxygen is treated as though it were positioned after chlorine but before fluorine.

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?

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.

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.

Go Online NSTA SCILINKS

For: Links on chemical formulas
Visit: www.SciLinks.org
Web Code: ccn-1063

Go Online NSTA SCILINKS

Download a worksheet on chemical formulas for students to complete, and find additional teacher support from NSTA SciLinks.

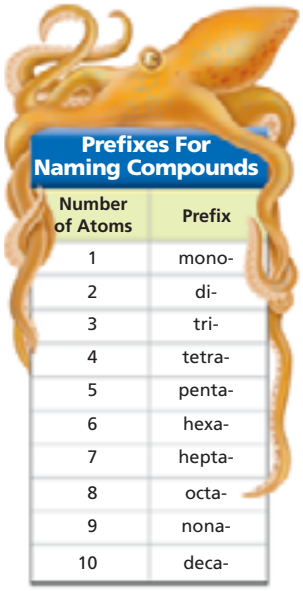
174 Chapter 6

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?

Integrate Language Arts L2

To help students learn the prefixes used in molecular compounds, have them think of words they know that contain the Greek prefixes listed in Figure 20. If they are having trouble, encourage them to use a dictionary to find words. Examples include *monochrome, dichotomy, tricycle, tetrahedron, pentagon, hexadecimal, heptad, octave, nonagenarian,* and *decathlon.*

Verbal

3 ASSESS

Evaluate Understanding L2

Note that the process of writing molecular formulas is the reverse of the process for naming them. Have students write chemical formulas for three substances and chemical names for another three substances. Have students exchange the formulas and names with a partner to check and review their work.

Reteach L1

Use the tables on pp. 171–173 and the Math Skills on p. 174 to review naming and writing formulas for ionic compounds. Use the table on p. 175 to review naming and writing formulas for molecular compounds.

Math Practice

Solutions

8. Lithium chloride, barium oxide, sodium nitride, lead sulfate

9. Diphosphorus pentaoxide (pentoxide) and carbon monoxide

10. K_2S because it takes two potassium ions, each with a charge of 1+, to balance one sulfide ion with a charge of 2−

iText If your class subscribes to iText, use it to review key concepts in Section 6.3.

Section 6.3 Assessment

1. The formula of an ionic compound describes the ratio of the ions in the compound.
2. The name and the formula of a molecular compound describe the type and number of atoms in a molecule of the compound.
3. *-ide*
4. The Roman numerals help distinguish the multiple ions of transition metals.
5. A covalently bonded group of atoms that has a positive or negative charge and acts as a unit
6. The explanation for binary compounds is that metals can form more than one type of cation. (Unless students have seen a more complete table of polyatomic ions, they are unlikely to know a second possible explanation: Some polyatomic ions contain the same elements, e.g., sulfate and sulfite ions.)
7. Three