9.5

1 FOCUS

Objectives

9.5.1 **Define** the laws of definite proportions and multiple proportions.

9.5.2 **Apply the rules** for naming chemical compounds by using a flowchart.

9.5.3 **Apply the rules** for writing the formulas of chemical compounds by using a flowchart.

Guide for Reading

Build Vocabulary L2

List the Parts You Know A scientific law is a statement of a relationship that is invariable so far as it is known. Thus, the law of definite proportions and the law of multiple proportions are invariable statements governing the formation of compounds.

Reading Strategy L2

Think Aloud As you familiarize students with the flowcharts in Figures 9.20 and 9.22, verbalize the routes to a name or formula by asking and answering the questions posed at each intersection.

2 INSTRUCT

Connecting to Your World

Ask, **What would be the ratio of candles to birthday cake at a seventeenth birthday?** *(17:1)* **What would be the ratio of candles on two birthday cakes, one at a seventeenth birthday and the other at a fourth birthday?** *(17:4)*

The Laws of Definite and Multiple Proportions

Use Visuals L1

Figure 9.16 Ask students to use the models to determine the formulas for the two compounds. *(H_2O and H_2O_2)* Ask, **In what other way can you tell that the two compounds are different?** *(One bleaches cloth, the other does not.)*

9.5 The Laws Governing Formulas and Names

Guide for Reading

Key Concepts

- What are the two laws that describe how compounds form?
- How do you use a flowchart to write the name of a chemical compound?
- What four guidelines should you follow to write the formula of a chemical compound?

Vocabulary

law of definite proportions

law of multiple proportions

Reading Strategy

Relating Text and Visuals As you read, use Figure 9.20 and Figure 9.22 to help you become thoroughly familiar with writing the names and formulas for chemical compounds.

Connecting to Your World A birthday cake for a four-year-old has four candles. The ratio of candles to birthday cake is 4:1. A sixteen-year-old's birthday cake has 16 candles. The ratio of candles to cake is also a whole number ratio, 16:1. Is there a whole number ratio between the numbers of candles on one cake at two different birthdays? For the sixteenth and fourth birthdays, the ratio is 16:4 or 4:1. In chemistry, similar relationships exist among the masses of elements as they combine in compounds.

The Laws of Definite and Multiple Proportions

The rules for naming and writing formulas for compounds are possible only because compounds form from the elements in predictable ways. **These ways are summed up in two laws: the law of definite proportions and the law of multiple proportions.**

The Law of Definite Proportions A chemical formula tells you, by means of subscripts, the ratio of atoms of each element in the compound. Ratios of atoms can also be expressed as ratios of masses. Magnesium sulfide (MgS) is composed of magnesium cations and sulfide anions. If you could take 100.00 g of magnesium sulfide and break it down into its elements, you will obtain 43.13 g of magnesium and 56.87 g of sulfur. The Mg:S ratio of these masses is 43.13/56.87 or 0.758:1. This mass ratio does not change no matter how the magnesium sulfide is formed or the size of the sample. Magnesium sulfide illustrates the **law of definite proportions,** which states that in samples of any chemical compound, the masses of the elements are always in the same proportions. Because atoms combine in simple whole-number ratios, it follows that their proportions by mass must always be the same.

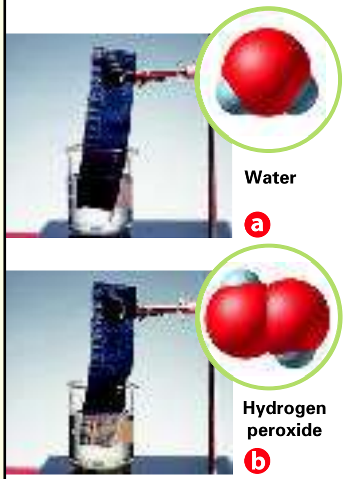


Figure 9.16 Water and hydrogen peroxide contain the same two elements, but they have different properties. **a** Water does not bleach dyes. **b** Hydrogen peroxide is a bleach.

The Law of Multiple Proportions Figure 9.16 shows two compounds, water (H_2O) and hydrogen peroxide (H_2O_2). Although these compounds are formed by the same two elements, they have different physical and chemical properties. Each compound obeys the law of definite proportions. In every sample of hydrogen peroxide, 16.0 g of oxygen are present for each 1.0 g of hydrogen. The mass ratio of oxygen to hydrogen is always 16:1. In every sample of water, the mass ratio of oxygen to hydrogen is always 8:1. If a sample of hydrogen peroxide has the same mass of hydrogen as a sample of water, the ratio of the mass of oxygen in the two compounds is exactly 2:1.

$$\frac{16\text{ g O (in } H_2O_2 \text{ sample that has 1 g H)}}{8\text{ g O (in } H_2O \text{ sample that has 1 g H)}} = \frac{16}{8} = \frac{2}{1} = 2:1$$

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 9.5
- **Core Teaching Resources,** Section 9.5
- **Transparencies,** T100–T103

Technology

- **Interactive Textbook with ChemASAP,** Problem-Solving 9.34, Assessment 9.5

Using the results from studies of this kind, John Dalton stated the **law of multiple proportions:** Whenever the same two elements form more than one compound, the different masses of one element that combine with the same mass of the other element are in the ratio of small whole numbers. Figure 9.17 illustrates the law of multiple proportions.

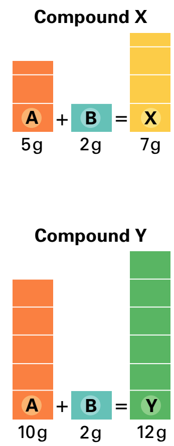


Figure 9.17 The diagram illustrates the law of multiple proportions. Two compounds, X and Y, contain equal masses of element B. The ratio of the masses of A in these compounds is 5:10 or 1:2 (a small whole number ratio). **Applying Concepts** ***Would the ratio be different if samples of X and Y contained 3 g of B?***

SAMPLE PROBLEM 9.1

Calculating Mass Ratios

Carbon reacts with oxygen to form two compounds. Compound A contains 2.41 g of carbon for each 3.22 g of oxygen. Compound B contains 6.71 g of carbon for each 17.9 g of oxygen. What is the lowest whole number mass ratio of carbon that combines with a given mass of oxygen?

1 Analyze ***List the knowns and the unknown.***

Knowns

- Compound A = 2.41 g C and 3.22 g O
- Compound B = 6.71 g C and 17.9 g O

Unknown

- Lowest whole number ratio of carbon per gram of oxygen in the two compounds = ?

Apply the law of multiple proportions to the two compounds. For each compound, find the grams of carbon that combine with 1.00 g of oxygen by dividing the mass of carbon by the mass of oxygen. Then find the ratio of the masses of carbon in the two compounds by dividing the larger value by the smaller. Confirm that the ratio is the lowest whole number ratio.

2 Calculate ***Solve for the unknown.***

- Compound A $\quad \frac{2.41\text{ g C}}{3.22\text{ g O}} = \frac{0.748\text{ g C}}{1.00\text{ g O}}$
- Compound B $\quad \frac{6.71\text{ g C}}{17.9\text{ g O}} = \frac{0.375\text{ g C}}{1.00\text{ g O}}$

Compare the masses of carbon per gram of oxygen in the compounds.

$$\frac{0.748\text{ g C (in compound A)}}{0.375\text{ g C (in compound B)}} = \frac{1.99}{1} = \text{roughly } \frac{2}{1} = 2:1$$

The mass ratio of carbon per gram of oxygen in the two compounds is 2:1.

3 Evaluate ***Does the result make sense?***

The ratio is a low whole number ratio, as expected. For a given mass of oxygen, compound A contains twice the mass of carbon as compound B.

Practice Problems

34. Lead forms two compounds with oxygen. One contains 2.98 g of lead and 0.461 g of oxygen. The other contains 9.89 g of lead and 0.763 g of oxygen. For a given mass of oxygen, what is the lowest whole number mass ratio of lead in the two compounds?

Math Handbook

For help with using a calculator go to page R62.

Interactive Textbook

Problem-Solving 9.34 Solve Problem 34 with the help of an interactive guided tutorial.

with ChemASAP

Discuss L2

Students may be able to understand the law of multiple proportions more easily by thinking in terms of atoms. One atom of carbon in CO_2 has the same mass (12 amu) as one atom of carbon in CO. One atom of oxygen (16 amu) combines with 12 amu of carbon in CO. Two atoms of oxygen (32 amu) combine with 12 amu of carbon in CO_2. The ratio of the masses of oxygen in the two compounds is 32:16 or 2:1.

Use Visuals L1

Figure 9.17 Ask students, **How many grams of B are in compound X?** *(2 g)* **How many grams of B are in compound Y?** *(2 g)* Thus two compounds have the same masses of B. Ask, **What is the ratio between the masses of A in these two compounds that have equal masses of B?** *(10 g:5 g or 2:1)* Ask students to name the law illustrated by the figure and define it in their own words. *(the law of multiple proportions; When two compounds are formed from the same two elements, and you take a certain mass of one of the elements, the masses of the other element in the two compounds that combined with that certain mass are in a whole number ratio).*

Math Handbook

For a math refresher and practice, direct students to using a calculator, page R62.

Sample Problem 9.1

Answer

34. 2:1

Practice Problems Plus L2

In the compound iron oxide, also known as rust, the mass ratio of iron to oxygen is 7:3. A 33-g sample of a compound composed of iron and oxygen contains 10 g of oxygen. **Is the sample iron oxide? Explain your answer.** *(Yes, because the ratio in the compound is 2.3:1 and the ratio in iron oxide is 2.3:1)*

Facts and Figures

Proust's Law

In the early 1800s, many scientists were studying chemical reactions by carefully measuring the masses of reactants and products. The French scientist Joseph Proust (1766–1844) demonstrated that samples of copper carbonate always contain 5.3 parts by mass of copper to 4 parts of oxygen and 1 part of carbon. The principle embodied in this discovery became known as Proust's Law and later as the law of definite proportions. Proust's experiments inspired John Dalton to think in terms of atoms. With atoms in mind, Dalton designed experiments that soon led to the law of multiple proportions and Dalton's atomic theory.

Answers to...

Figure 9.17 No, as long as the two samples have the same mass of B.

Practicing Skills: Naming Chemical Compounds

Use Visuals L1

Figure 9.18 Have students read the first paragraph on this page and examine the photograph. Discuss the importance of naming conventions for compounds. Explain that chemists need to be able to understand papers written by colleagues and to reproduce experimental results. Focus on the problems that could occur if common names in multiple languages were the norm. Ask, **Why would knowing the correct name for a chemical be important to a poison-control center worker?** *(The worker needs to know the specific chemical ingested before offering a solution. Administering an antidote for the wrong chemical could cause further harm.)*

Relate L2

Ask students to think of other situations where specific names are important for accurate or fast results. *(When you are ordering items by telephone or on the internet)* Ask, **Why do many bureaucratic agencies use social security or driver's license numbers instead of people's names?** *(Many people could have the same name.)*

Figure 9.18 If someone ingests a poison, the poison control center can provide information about what immediate action to take. **Inferring** ***What information about the poison would be most helpful to the center?***

Practicing Skills: Naming Chemical Compounds

In the average home, you can probably find hundreds of chemicals, including cleaning products, drugs, and pesticides. Figure 9.18 shows a typical warning label on a product that tells about its possible dangers. Most people would not know what to do if some of these chemicals accidentally mixed together and began to react or if a small child ingested one. A phone call to a poison control center can provide lifesaving information to victims of such poisonings. But a poison control center can be much more effective if the caller can supply some information about the name or formula of the substance.

In this chapter, you learned two basic skills that could help you to deal with an emergency involving chemicals: writing chemical formulas and naming chemical compounds. If this is the first time you have tried to master these skills, you may feel a little overwhelmed. For example, you may find it difficult to know when you should or should not use prefixes and Roman numerals in a name. Or you may have trouble determining if a compound's name should end in -*ate*, -*ide*, or -*ite*. The flowchart in Figure 9.20 provides you with a sequence of questions for naming a compound when you know its formula. **Follow the arrows and answer the questions on the flowchart to write the correct name for a compound.** The sequence of questions can help you name chemicals you may have in your home as well as the colorful compounds that create the picturesque landscape of Gay Head, Massachusetts shown in Figure 9.19.

The flowchart shows the routes to the names of several compounds: HNO_3, N_2O_3, BaS, Li_2CO_3, $CuSO_4$, and $FeCl_2$. Apply the general formula Q_xR_y to each compound. Q and R can be atoms, monatomic ions, or polyatomic ions. For example, to name HNO_3, let H = Q and NO_3 = R. Follow the first arrow down to the question Q = H? The answer is yes, so the arrow to the right tells you that the compound is an acid. You can then follow the rules for naming acids. HNO_3 is nitric acid.

To name N_2O_3, let Q = N and R = O. The answer to the question Q = H? is no, so follow the arrow down. Does the compound have more than two elements? The answer is no, so follow the arrow to the left. The compound is binary and its name ends in -*ide*. Is Q a metal? The answer is no, so you must use prefixes in the name, which is *di*nitrogen *tri*oxide.

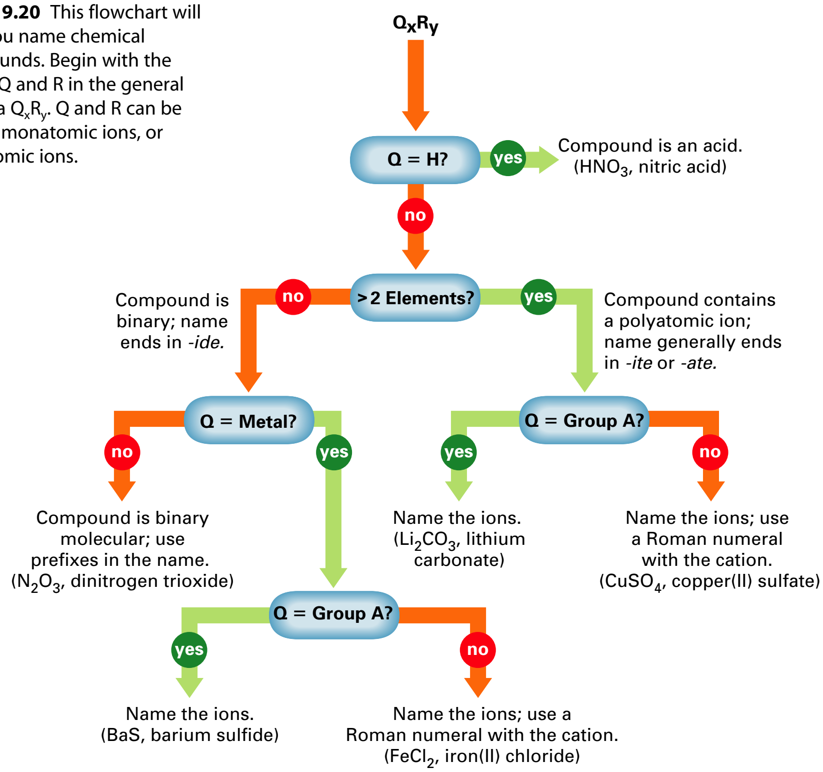
Figure 9.19 A variety of compounds create a colorful display in the clay cliffs at Gay Head, Massachusetts on the island of Martha's Vineyard. Each colored compound can be named by the methods you are learning if you know the compound's formula.

Differentiated Instruction

Special Needs L1

Students who have difficulty with mathematics may need extra help with the laws of definite proportions and the law of multiple proportions. Assign such students to work with students with strong math skills. Encourage students with strong math skills to develop ways of sharing their problem-solving techniques with others.

Figure 9.20 This flowchart will help you name chemical compounds. Begin with the letters Q and R in the general formula Q_xR_y. Q and R can be atoms, monatomic ions, or polyatomic ions.



Another example shown on the flowchart is $CuSO_4$. In this case, Q = Cu and R = SO_4. Q does not equal H. The compound does have more than two elements, so it contains a polyatomic ion. Thus you should expect that the name will end in *-ite* or *-ate*. The answer to the next question, Q = Group A? is no, so you must name the ions and use a Roman numeral to identify the charge of the transition metal. The name is copper(II) sulfate. A sample of copper(II) sulfate is shown in Figure 9.21. Practice with the other compounds listed above, and then use the flowchart when doing naming exercises. Soon you won't need it anymore.

Checkpoint ***Identify Q and R in the compound*** $MgSO_4$.

Figure 9.21 Blue copper(II) sulfate contains water in its crystal structure. When it is heated, it loses water and turns white. When the white solid absorbs water, it turns blue again.

Differentiated Instruction

Gifted and Talented L3

Challenge advanced students to use the flowchart as a model for writing a computer program for naming chemical compounds.

Use Visuals L1

Figure 9.20 Tell students that the flowchart is like a road map. At every intersection you need to make a decision and when you make the right decisions you are led to your destination (the correct name for the compound). Lead them through a few examples asking them to respond to the questions at each intersection. Then have volunteers from the class take the lead to continue the exercise.

Use Visuals L1

Figure 9.21 Students may ask about the two forms of copper sulfate (white and blue). Tell them that the blue form is called a hydrate because it has water molecules incorporated into its crystal structure. In the hydrate, each formula unit of $CuSO_4$ is accompanied by five molecules of water. Ask, **Would equal masses of the white and the blue compounds contain the same number of formula units of copper sulfate?** *(No, some of the mass of the hydrate is water.)*

Relate L2

While students are involved in developing their skills in writing formulas for ionic and molecular compounds, you may have the opportunity to comment on the characteristics of representative ionic and molecular compounds found in Figure 9.20. For example, call attention to the high melting points of ionic compounds. Iron(II) chloride melts at 677°C; lithium carbonate at 723°C. In addition, a large amount of energy (heat of fusion) is required to melt these ionic compounds. By contrast, the molecular compound dinitrogen trioxide melts at –101°C and methane at –182°C.

Make the point that ionic and molecular compounds do not differ just in the way that they are named but fundamentally in the bonding that holds the atoms together in the compound.

Answers to...

Figure 9.18 the formula, the name, and possibly the concentration

Checkpoint Q is Mg^{2+}; R is SO_4^{2-}.

Practicing Skills: Writing Chemical Formulas

Discuss L2

Have students summarize the rules for writing formulas and naming compounds. Point out that naming compounds and writing formulas becomes easier with practice because chemical names and formulas are systematized. Ask students to consider how difficult the task would be if the names were assigned randomly. Because chemists adhere to an established system of naming, it is possible to quickly locate information on physical constants such as melting point, boiling point, and density in chemical handbooks such *Lange's Handbook of Chemistry, The Merck Index,* and the *CRC Handbook of Chemistry and Physics. The Merck Index* is particularly helpful to organic chemists interested in the synthesis and identification of a particular compound. Encourage students to look for these books in their local public library.

3 ASSESS

Evaluate Understanding L2

Give students formulas for compounds and have them use Figure 9.20 to determine their names. Then give them names for different compounds and have them use Figure 9.22 to write their formulas.

Reteach L1

Review the four guidelines for writing chemical formulas by asking students in turn what it means when each of the following is included in the name of a compound: an *-ide* ending, an *-ite* or *-ate* ending, a prefix, or a Roman numeral. Then give them the following names of compounds containing one of these components: hydrogen cyanide, potassium chromate, sulfur tetrafluoride, copper(I) chloride. Ask them to use Figure 9.22 to determine their formulas.

Practicing Skills: Writing Chemical Formulas

In writing a chemical formula from a chemical name, it is helpful to remember the following guidelines.

1. **An -*ide* ending generally indicates a binary compound.**
2. **An -*ite* or -*ate* ending means a polyatomic ion that includes oxygen is in the formula.**
3. **Prefixes in a name generally indicate that the compound is molecular.**
4. **A Roman numeral after the name of a cation shows the ionic charge of the cation.**

These guidelines and the questions in the flowchart in Figure 9.22 will help you write the formula for a compound when you know its name. For example, use the flowchart to write the formula for sodium chromate. The name does not contain prefixes, so it is ionic. The ions are sodium ion and chromate ion. Follow the arrows to the right and left. Sodium is a Group A element, so use the periodic table or Table 9.1 to obtain its ionic charge (1+). Chromate ion is a polyatomic ion, so use Table 9.3 to obtain its charge (2−). Balance the charges to obtain the formula Na_2CrO_4. Practice formula writing using the flowchart until you don't need it anymore.

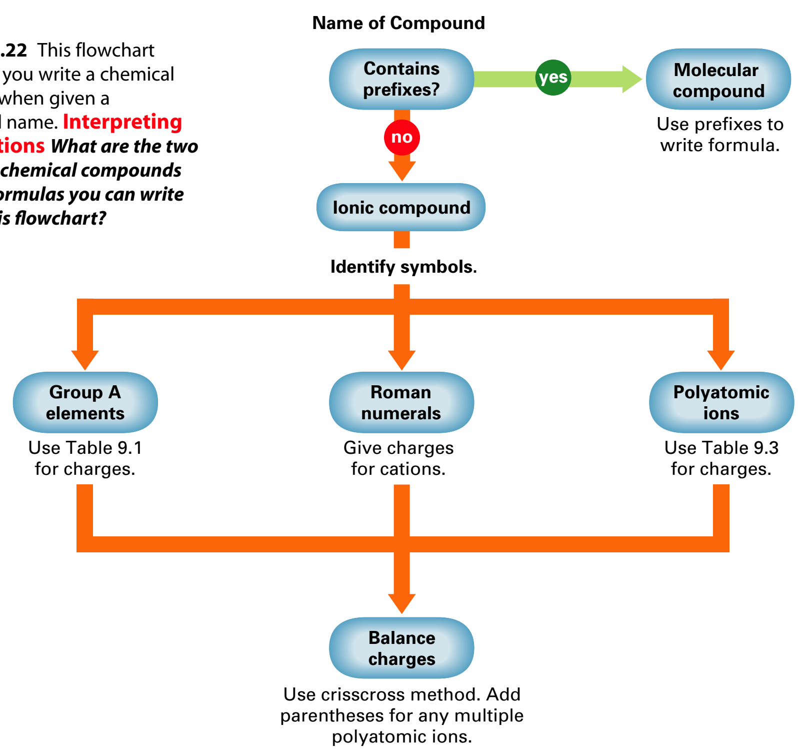


Figure 9.22 This flowchart will help you write a chemical formula when given a chemical name. **Interpreting Illustrations** ***What are the two types of chemical compounds whose formulas you can write using this flowchart?***

Facts and Figures

Other Molecular Compounds

The binary molecular compounds constitute only a small fraction of molecular compounds. An enormous number of compounds containing principally carbon, hydrogen, oxygen, nitrogen, and sulfur are classified as organic chemicals. A different, more complex but precise system of naming makes it possible for large and complex molecules to be precisely identified.

Quick LAB

Making Ionic Compounds

Purpose

To mix solutions containing cations and anions to make ionic compounds.

Materials

- 9 small test tubes
- test tube rack
- paper, pencil, ruler
- 6 solutions in plastic dropper bottles containing the following ions:

Solution A (Fe^{3+} ion)	Solution X (CO_3^{2-} ion)
Solution B (Ag^{+} ion)	Solution Y (OH^{-} ion)
Solution C (Pb^{2+} ion)	Solution Z (PO_4^{3-} ion)

Procedure

1. Label three test tubes A, three test tubes B, and three test tubes C.
2. Add 10 drops (approximately 0.5 mL) of solutions A, B, and C to appropriately labeled test tubes.
3. Add 10 drops of solution X to one test tube of A, 10 drops to one test tube of B, and 10 drops to one test tube of C. Observe each for the formation of a solid.

4. Make a 3-by-3 inch grid in which to record your observations. Label the rows A, B, and C. Label the columns X, Y, and Z. Describe any solid material you observe.
5. Repeat Step 3, adding 10 drops of solution Y to test tubes A, B, and C. Record your observations.
6. Repeat Step 3, adding 10 drops of solution Z to test tubes A, B, and C. Record your observations.

Analyze and Conclude

1. Some ionic compounds are insoluble (do not dissolve in water). Explain what you observed.
2. Write the formula for each ionic compound formed.
3. Name each ionic compound formed.
4. Will mixing any cation with any anion always lead to the formation of an insoluble ionic compound? Explain.

9.5 Section Assessment

35. **Key Concept** What two laws describe how chemical compounds form?
36. **Key Concept** How should you use a flowchart to name a chemical compound?
37. **Key Concept** What are four guidelines for writing the formulas of chemical compounds?
38. Two compounds containing copper and oxygen were found to contain the following masses:
    Compound A: 32.10 g Cu and 17.90 g Cl
    Compound B: 23.64 g Cu and 26.37 g Cl
    Are the compounds the same? If not, what is the lowest whole number mass ratio of copper that combines with a given mass of chlorine?
39. Name these compounds.
    a. $CaCO_3$ **b.** $PbCrO_4$ **c.** $SnCr_2O_7$
40. Write formulas for these compounds.
    a. tin(II) hydroxide **b.** barium fluoride
41. Identify the incorrect names or formulas.
    a. calcium(II) oxide **b.** aluminum oxide
    c. $Na_2C_2O_4$ **d.** $Mg(NH_4)_2$

Connecting Concepts

Ionic Bonds Review ionic bonds in Section 7.2 and show by means of electron dot structures why an ionic compound always has a charge of zero. Use magnesium bromide as an example.

Interactive Textbook

Assessment 9.5 Test yourself on the concepts in Section 9.5.

with ChemASAP

Section 9.5 Assessment

35. law of definite proportions and law of multiple proportions
36. Follow the arrows and answer the questions on the flowchart.
37. See the four guidelines on the facing SE page (page 278).
38. no; 2:1
39. **a.** calcium carbonate **b.** lead(II) chromate **c.** tin(II) dichromate
40. **a.** $Sn(OH)_2$ **b.** BaF_2
41. **a.** incorrect; a Roman numeral is not used with a Group A metal, calcium oxide **b.** correct **c.** correct **d.** incorrect; ammonium ion, a polyatomic cation, will not form a compound with a monatomic cation.

Quick LAB

Making Ionic Compounds L2

Objective Students form precipitates and write their formulas and names.

Skills Focus Observing, applying rules

Prep Time 30 minutes

Solution	Preparation
0.05*M* $AgNO_3$	2.1 g in 250 mL
0.2*M* $Pb(NO_3)_2$	16.6 g in 250 mL
1.0*M* $NaCO_3$	26.5 g in 250 mL
0.5*M* NaOH	5.0 g in 250 mL
0.1*M* $Na_3(PO_4)_2$	9.5 g $Na_3PO_4{\cdot}12H_2O$ in 250 mL
0.1*M* $FeCl_3$	6.8 g $FeCl_3{\cdot}6H_2O$ in 25 mL of 1.0*M* NaCl; dilute to 250 mL

Class Time 20 minutes

Analyze and Conclude

1. An insoluble compound formed in every tube.
2. $Fe_2(CO_3)_3$, $Fe(OH)_3$, $FePO_4$, Ag_2CO_3, AgOH, Ag_3PO_4, $PbCO_3$, $Pb(OH)_2$, $Pb_3(PO_4)_2$
3. iron(III) carbonate, iron(III) hydroxide, iron(III) phosphate, silver carbonate, silver hydroxide, silver phosphate, lead(II) carbonate, lead(II) hydroxide, lead(II) phosphate
4. No, NaCl, for example, is soluble.

Connecting Concepts

Magnesium loses its two valence electrons. Two bromine atoms each gain one electron.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 9.5.

with ChemASAP

Answers to...

Figure 9.22 ionic compounds and binary molecular compounds