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.

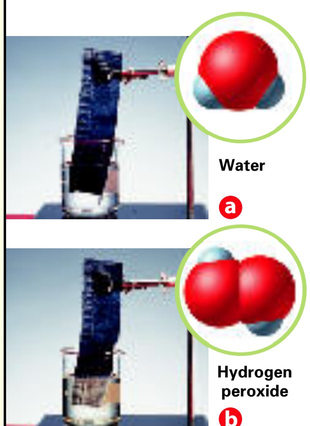

Figure 9.16 Water and hydrogen peroxide contain the same two elements, but they have different properties. (a) Water does not bleach dyes. (b) Hydrogen peroxide is a bleach.

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.

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.

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

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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.

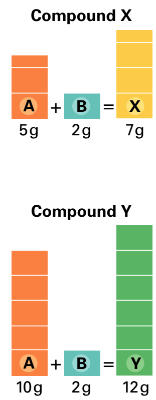

Figure 9.17 The diagram illustrates the law of multiple proportions. Two compounds, X and Y, contain equal masses of element B. The ratio of the masses of A in these compounds is 5:10 or 1:2 (a small whole number ratio). **Applying Concepts** ***Would the ratio be different if samples of X and Y contained 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 $\frac{2.41 \text{ g C}}{3.22 \text{ g O}} = \frac{0.748 \text{ g C}}{1.00 \text{ g O}}$
- Compound B $\frac{6.71 \text{ g C}}{17.9 \text{ g O}} = \frac{0.375 \text{ g C}}{1.00 \text{ g O}}$

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.

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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.

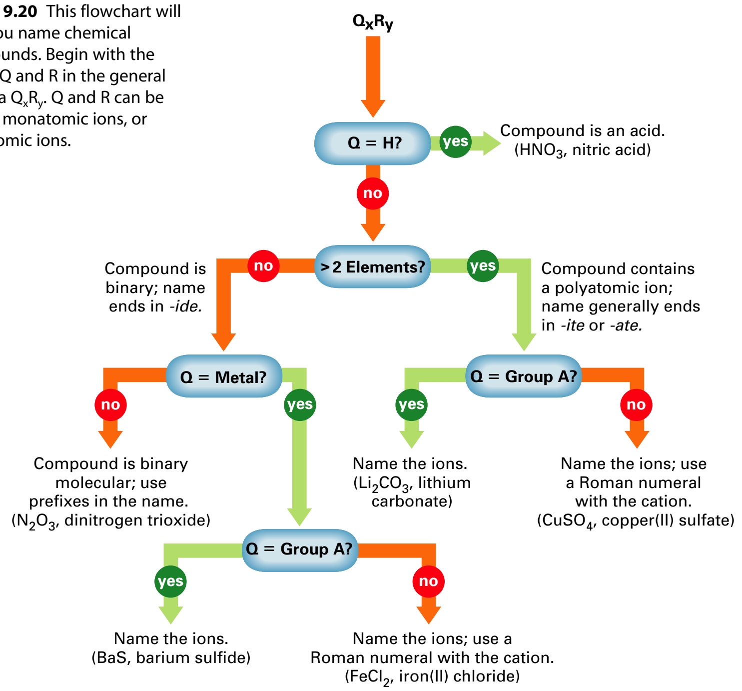
In this chapter, you learned two basic skills that could help you to deal with an emergency involving chemicals: writing chemical formulas and naming chemical compounds. If this is the first time you have tried to master these skills, you may feel a little overwhelmed. For example, you may find it difficult 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.

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.

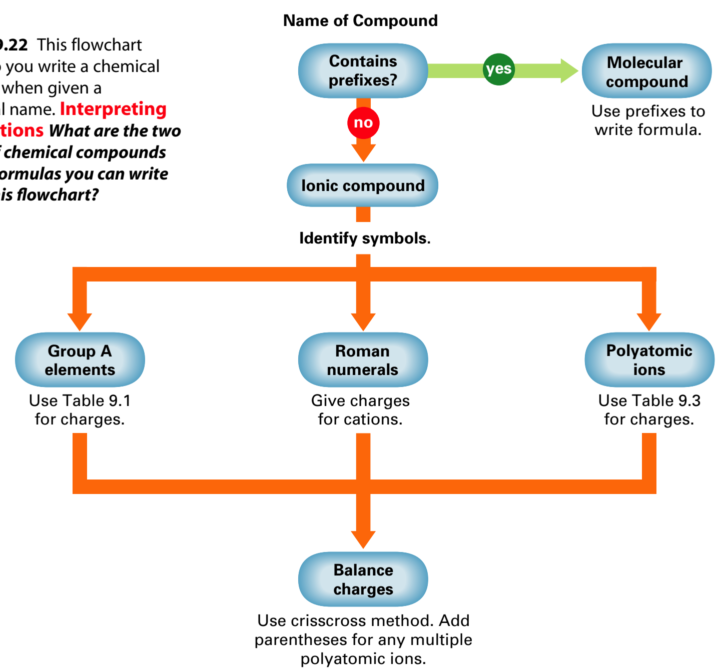
Practicing Skills: Writing Chemical Formulas

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?***



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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.

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