EXPERIMENT 5

Simplest Formula of a Compound

Performance Goals

5–1 Prepare a compound and collect data from which you can determine the mass of each element in the compound.

5–2 From the mass of each element in a compound, determine its simplest formula.

CHEMICAL OVERVIEW

Chemical compounds are composed of atoms of different elements. The atoms are held together by chemical bonds. It has been shown experimentally that the ratio of moles of the elements in a compound is nearly always a ratio of small, whole numbers. The few exceptions are known as nonstoichiometric compounds. The formula containing the lowest possible ratio is known as its **simplest formula.** It is also called the **empirical formula.** At times it may be the same as the molecular formula; often, however, the molecular formula is an integral multiple of the simplest, empirical formula. For example, the simplest formula of the compound benzene (C_6H_6) is simply CH, indicating that the ratio of carbon atoms to hydrogen atoms is one to one.

To find the simplest formula of a compound, you will combine the elements in the compound under conditions that will allow you to determine the mass of each element. From these data the moles of atoms of each element may be calculated. By dividing these numbers by the smallest number of moles, you obtain quotients that are in a simple ratio of integers, or are readily converted to such a ratio. The ratio of moles of atoms of the elements in a compound is the same as the ratio of individual atoms that is expressed in the empirical formula.

Remember: The essential information required to find the simplest formula of a compound is the number of grams of each element in a sample of the compound.

In Option 1 you will react a measured mass of copper with excess sulfur. The excess sulfur is burned away as sulfur dioxide. In Option 2 the reaction is between a measured quantity of tin and excess nitric acid. The excess acid is boiled off. Option 3 involves the reaction of a measured mass of magnesium with excess oxygen from the air.

Your instructor may require you to perform the experiment twice to obtain duplicate results, or to complete more than one option. If so, plan your use of time. The procedure includes some periods in which you wait for a crucible to cool. The cooling periods in the first run of the experiment can be used for heating periods in the second run, and vice versa.

SAMPLE CALCULATIONS

A piece of aluminum is ignited in a suitable container, yielding an oxide. Calculate the simplest formula of the oxide from the following data:

Mass of container	17.84 g
Mass of container + aluminum	18.38 g
Mass of container + compound	18.86 g

1. Mass of each element from data:

Mass of container + aluminum	−	mass of container	=	mass of aluminum
18.38 g	−	17.84 g	=	0.54 g aluminum
Mass of container + compound	−	mass of container + aluminum	=	mass of oxygen
18.86 g	−	18.38 g	=	0.48 g oxygen

2. Moles of each element:

$$0.54 \text{ g Al} \times \frac{1 \text{ mole Al atoms}}{27.0 \text{ g Al}} = 0.020 \text{ mole Al atoms}$$

$$0.48 \text{ g O} \times \frac{1 \text{ mole O atoms}}{16.0 \text{ g O}} = 0.030 \text{ mole O atoms}$$

3. Simplest formula ratio:

Obtain the ratio of atoms by dividing the number of moles of each atom by the smallest number of moles:

$$\text{Al:} \quad \frac{0.020}{0.020} = 1.0; \qquad \text{O:} \quad \frac{0.030}{0.020} = 1.5$$

The ratio is 1.0 mole aluminum atoms to 1.5 moles oxygen atoms. Change this ratio to a whole number ratio by multiplying each value by 2:

$$\text{Moles of Al atoms} = 1.0 \times 2 = 2.0$$

$$\text{Moles of O atoms} = 1.5 \times 2 = 3.0$$

The simplest formula is therefore Al_2O_3.

Many students find it convenient to organize their calculations by arranging both data and results in a table as follows:

Element	*Grams*	*Moles*	*Mole Ratio*	*Formula Ratio*
Al	0.54	0.020	1.0	2
O	0.48	0.030	1.5	3

SAFETY PRECAUTIONS AND DISPOSAL METHODS

The safety considerations in this experiment relate to the operation of a Bunsen burner and the handling of hot items. Blue burner flames are visible, but easily lost against a laboratory background. Be careful not to reach through one in reaching for some object behind it. If you have long hair, tie it back so it does not get into the flame. Be sure to use crucible tongs when handling hot crucibles, including the lid. Laboratory hardware gets hot, too. Harmful gases are released in Options 1 and 2. These reactions must be performed in a fume hood, as stated in their procedures. Be careful of hot chemical spattering from crucibles when they are heated. Be sure to wear goggles throughout this experiment.

Dispose of any solid residue as directed by your instructor.

PROCEDURE

Option 1: A Sulfide of Copper

NOTE: All mass measurements in Option 1 are to be recorded in grams to the nearest 0.01 g or 0.001 g if so instructed.

A. The purpose of this step is to remove moisture from the crucible. Support a clean, dry porcelain crucible and its lid on a clay triangle, as shown in Figure 5.1. Heat it slowly at first, and then fairly strongly in the direct flame of a burner for about 4 to 5 minutes. Set the crucible and lid aside on a wire gauze to cool.

B. When the crucible and lid are cool to the touch, weigh them on a centigram balance. Record this value as the mass of the container.

C. Place a loosely rolled ball of copper wire or medium shavings, about 1.5 to 2 g, into the crucible. Weigh them, with the lid, on a centigram or milligram balance, and record the weight as the mass of the container plus metal.

D. Sprinkle about 1 to 1.5 g of powdered sulfur over the copper. Place the lid on the crucible and begin heating it in a fume hood. Heat slowly at first, and then with a moderate flame until the sulfur no longer burns around the lid. Finally, heat the crucible strongly for about 5 minutes, making sure that no excess sulfur is present on the lid or on the sides of the crucible. It sometimes helps to hold the burner at its base and direct the flame under the lip of the lid all the way around.

E. Set the container and its contents aside to cool. Do not open the lid until the crucible is cool, because air oxidation is apt to occur.

F. When the crucible is cool, lift the lid and examine the contents. There should be no evidence of sulfur in the crucible or on the lid. If sulfur is present, heat the crucible again until the sulfur is completely burned away. Allow the crucible to cool.

G. Weigh the container and its contents again. Record your measurement as the mass of the container plus compound.

H. Set the container aside while you complete your calculations. Do not discard your compound until your calculations are finished and satisfactory; if they are not satisfactory, it is possible you may be able to salvage your work if the material is still on hand.

I. Just before discarding the compound, press it to the bottom of the crucible. Notice the difference between the physical properties of the compound and those of the elements from which it was formed. The compound should be discarded as directed by your instructor.

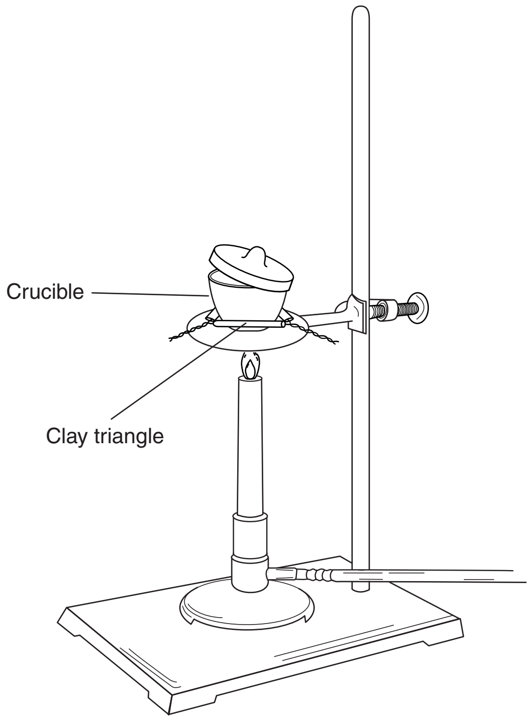

Figure 5.1
Heating of a porcelain crucible

Option 2: An Oxide of Tin

NOTE: All mass measurements in Option 2 are to be recorded in grams to the nearest 0.01 g. or 0.001 g if so instructed.

A. Heat a porcelain crucible and its lid as described in Option 1, Step A. Allow it to cool.

B. Weigh as described in Option 1, Step B.

C. Place a loosely rolled ball of tin foil, weighing 1 to 1.5 g, into the crucible. Weigh the crucible, the lid, and the metal on a centigram balance. Record the mass obtained.

D. Under the fume hood, add concentrated nitric acid, HNO_3, drop by drop, to the crucible until all the tin has reacted and a damp white paste remains.

E. Heat the paste cautiously with a mild flame, taking care not to cause spattering. After all of the liquid has evaporated, heat the crucible with a hot flame for 5 minutes.

F. Cool the crucible and compound to room temperature and weigh it. Record the mass of the container and compound.

G. Keep your compound in the crucible until all calculations are completed. This may save you time if it becomes necessary to add more nitric acid.

Option 3: Magnesium Oxide

NOTE: All mass measurements in Option 3 are to be recorded in grams to the nearest 0.001 g.

A. Heat a porcelain crucible and its lid as described in Option 1, Step A. Allow it to cool.

B. Weigh the crucible and lid on a milligram balance. Record this value on the work page as mass of the container.

C. Place a loosely folded magnesium ribbon, weighing 0.5 to 0.7 g, into the crucible. Weigh the crucible, lid, and metal on a milligram balance and record the mass.

D. Remove the lid and hold it near the crucible with a pair of tongs. Start heating the crucible, and as soon as the magnesium begins to burn, replace the lid. Continue the process, holding the escape of white smoke to a minimum (very finely divided magnesium oxide looks like smoke). When the contents of the crucible no longer burn, cock the lid wide enough to allow a sufficient amount of air to enter to complete the reaction, as shown in Figure 5.1, and heat it strongly for 5 minutes.

E. To convert the possible side product, magnesium nitride, to the oxide, let the crucible cool, add 10 drops of deionized water to it, and then gently heat to vaporize excess water. CAUTION: SPATTERING MAY OCCUR.

F. Finish heating the crucible with a strong flame for 5 to 8 minutes.

G. Allow the crucible to cool, then weigh the cool crucible, lid, and product on a milligram balance.

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Advance Study Assignment

1. Circle one of the following formulas that is correctly written as an empirical formula:

$NaSO_{1.5}$ $(H_2NO)_2$ Fe_3O_4 N_2O_4

2. 6.25 grams of pure iron are allowed to react with oxygen to form an oxide. If the product weighs 14.31 grams, find the simplest formula of the compound.

3. In determining the simplest formula of lead sulfide, 2.46 grams of lead are placed in a crucible with 2.00 grams of sulfur. When the reaction is complete, the product has a mass of 3.22 grams. What mass of sulfur should be used in the simplest formula calculation? Find the simplest formula of lead sulfide.

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Experiment 5

Work Page

Data

Option or Trial Number				
Mass of container (g)				
Mass of container + metal (g)				
Mass of container + compound (g)				

Results for Sample of Compound Prepared

Mass of metal (g)				
Mass of nonmetal element (g)				
Moles of metal				
Moles of nonmetal element				
Ratio: $\frac{\text{moles metal}}{\text{moles nonmetal}}$*	$\frac{\quad}{1}$	$\frac{\quad}{1}$	$\frac{\quad}{1}$	$\frac{\quad}{1}$
Simplest formula				

*Express this ratio as a decimal number over 1(e.g., $\frac{3.044}{1}$).

Show calculations on the reverse side of this page.

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Calculations

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Experiment 5

Report Sheet

Data

Option or Trial Number				
Mass of container (g)				
Mass of container + metal (g)				
Mass of container + compound (g)				

Results for Sample of Compound Prepared

Mass of metal (g)				
Mass of nonmetal element (g)				
Moles of metal				
Moles of nonmetal element				
ratio: $\frac{\text{moles metal}}{\text{moles nonmetal}}$ *	$\frac{\quad}{1}$	$\frac{\quad}{1}$	$\frac{\quad}{1}$	$\frac{\quad}{1}$
Simplest formula				

*Express this ratio as a decimal number over 1 (e.g., $\frac{3.044}{1}$).

Show calculations on the reverse side of this page.

Calculations