

# Determining the Empirical Formula of Magnesium Oxide

**Objectives:** To synthesize a compound containing magnesium and oxygen, and to determine its empirical formula.

**Materials:** Magnesium ribbon; Bunsen burner; crucible and lid; tongs; clay triangle; iron ring and ring stand; ceramic-coated wire gauze pad; sand paper

**Safety:** Handle hot crucible with tongs. Do not look directly at the intense white flame produced by burning magnesium; it can cause eye damage. Safety goggles should be worn at all times.

**Waste Disposal:** All materials may be placed in the solid waste container.

**Review:** You should be familiar with the technique for measuring mass, and how to calculate the number of moles of an element based on its mass; you should understand the relationship between a chemical formula and the composition of a substance.

## INTRODUCTION

The composition of a compound is represented using its **chemical formula**. The chemical formula contains very important and useful information. It identifies both the elements that make up the compound, as well as the number of atoms of each element in a molecule or formula unit of that compound. This information can be used to distinguish between different substances, and to explain the physical and chemical properties of a given substance.

There are two kinds of chemical formulas. The **molecular formula** indicates the actual number of atoms of each element in a molecule or formula unit of the compound. The **empirical formula** indicates the simplest whole-number ratio of the different atoms in the compound. The molecular formula is always a whole-number multiple of the empirical formula. It is possible for two substances to have identical empirical formulas but significantly different molecular formulas. Consider the following example:

**Example 1.** Propene is the precursor used to synthesize polypropylene. It is composed only of carbon (C) and hydrogen (H). A propene molecule contains 3 carbon atoms and 6 hydrogen atoms. What is the empirical formula of propene?

**Solution:** The molecular formula for propene is  $C_3H_6$ . To find the empirical formula we reduce the C:H atom ratio to the smallest whole-number ratio as shown below:

$$\frac{\text{number of C atoms}}{\text{number of H atoms}} = \frac{3}{6} = \frac{1}{2}$$

*The empirical formula represents this simplest whole-number atom ratio, CH<sub>2</sub>.*

The empirical formula of a substance can be determined experimentally if we know the identities of the elements in the compound, and the amount of each element (in mass or moles). In this lab we will determine the empirical formula of a compound by synthesizing a sample of that compound. In a **synthesis** reaction, a substance is created by mixing and reacting appropriate amounts of the constituent elements. If we know the masses of each element used to synthesize the new compound, we can calculate the number of moles of each element in our sample. The simplest whole-number molar ratio of the elements gives us the empirical formula. An example of an empirical formula determination for a synthesis reaction follows.

**Example 2.** A sample of aluminum sulfide is synthesized by mixing 1.80 g of aluminum (Al) powder with an excess of sulfur (S). The mixture is heated until the Al reacts with the sulfur to produce aluminum sulfide. Continued heating vaporizes the unreacted S. The final mass of aluminum sulfide product obtained was 5.01 g. Determine the empirical formula of aluminum sulfide.

**Solution:** *The empirical formula will be represented as Al<sub>x</sub>S<sub>y</sub>, where x:y is the simplest whole-number ratio of the moles of Al and S, respectively, in our sample of aluminum sulfide. We know that we used 1.80 g Al to synthesize our product. We can convert this mass of Al to moles using the atomic mass of Al:*

$$(1.80 \text{ g Al}) \left( \frac{1 \text{ mole Al}}{26.97 \text{ g}} \right) = 0.0667 \text{ mol Al}$$

*The total mass of aluminum sulfide obtained in the synthesis reaction is 5.01 g. Since our product contains only Al and S, we can calculate the mass of S in our product as the difference between the mass of product and the initial mass of Al. Using the mass of S, we can calculate the moles of S in our product:*

$$(5.01 \text{ g product} - 1.80 \text{ g Al}) = 3.21 \text{ g S}$$

$$(3.21 \text{ g S}) \left( \frac{1 \text{ mole S}}{32.06 \text{ g}} \right) = 0.100 \text{ mol S}$$

*The empirical formula is the simplest whole-number molar ratio of Al:S in the sample. The simplest ratio is easier to find if the smaller number of moles is placed in the denominator.*

$$\frac{\text{mol S}}{\text{mol Al}} = \frac{0.100 \text{ mol S}}{0.0667 \text{ mol Al}} = \frac{1.5 \text{ mol S}}{1 \text{ mol Al}}$$

*If our empirical formula is represented as Al<sub>x</sub>S<sub>y</sub>, then x = 1 and y = 1.5. To convert this ratio to the simplest whole-number ratio we can multiply both the numerator and the denominator by 2 to yield an empirical formula of Al<sub>2</sub>S<sub>3</sub>.*

In this lab exercise we burn magnesium ribbon in air to synthesize a new compound. Since air contains significant amounts of both oxygen and nitrogen, the combustion of Mg in air actually yields two different products: magnesium oxide (containing Mg and O), and magnesium nitride (containing Mg and N). Adding water to this mixture of products and heating will convert the magnesium nitride to magnesium oxide. Thus, the final product of the synthesis will be pure magnesium oxide. Using calculations similar to those presented in Example 2, you will determine the empirical formula of the magnesium oxide product.

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## Pre-Lab Questions

1. What safety precautions are taken in this lab? Briefly explain why these precautions are necessary.
2. A compound composed of phosphorus and oxygen has 2.5 moles of O for every mole of P. Write the empirical formula for this compound. Show your work.
3. A student used the procedures outlined in this lab to determine the empirical formula for a compound containing lead (Pb) and oxygen. Consider the following data:

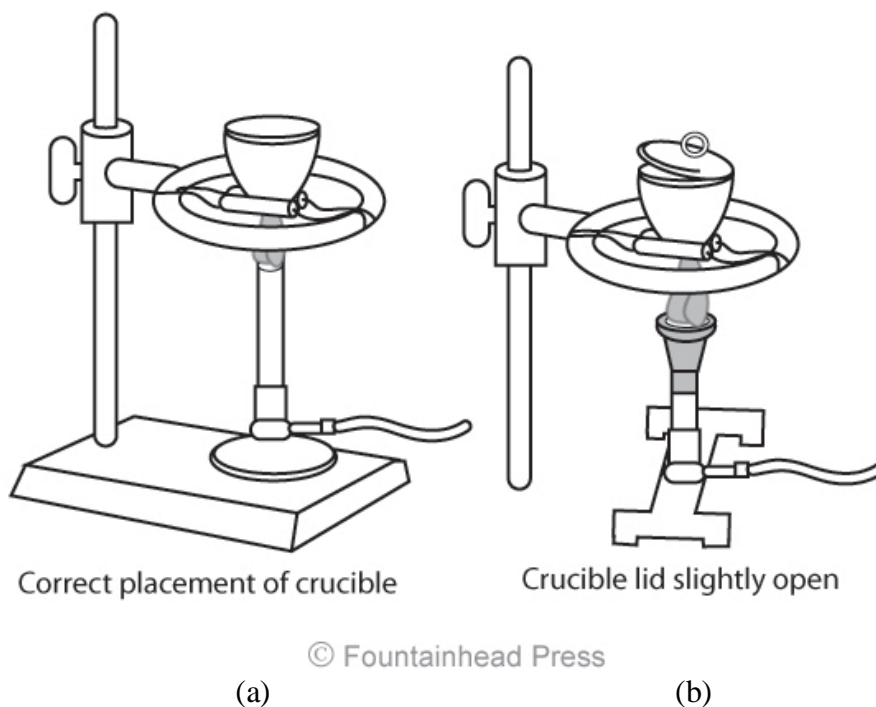
Mass of crucible plus cover (g)	22.36 g
Mass of crucible, cover and Pb (g)	25.08 g
Mass of crucible, cover and lead oxide (g)	25.50 g

  - (a) Calculate the mass of Pb in the lead oxide.
  - (b) Calculate the mass of O in the lead oxide.
  - (c) Calculate the number of moles of Pb in the lead oxide.
  - (d) Calculate the number of moles of O in the lead oxide.
  - (e) Calculate the molar ratio of Pb:O in the lead oxide.
  - (f) Write the empirical formula for lead oxide.

## PROCEDURE

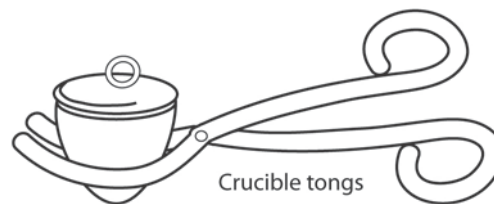
**Note:** Use the same analytical balance for all mass measurements during the lab exercise. Record all masses to the nearest milligram (0.001 g). Do not handle the crucible and lid with bare hands, as the oil from your fingers will add to the mass of the crucible.

1. Wash a crucible and lid using detergent and tap water. Rinse with distilled water and dry.
2. Obtain a ring stand and iron ring, and situate the iron ring at an appropriate height above a bunsen burner. Use tongs to place the crucible at a slight angle on a clay triangle on the ring stand, as illustrated in Figure 1a.
3. Use tongs to place the lid on the crucible, with the cover slightly ajar as illustrated in Figure 1b.
4. Light the Bunsen burner and place it beneath the crucible. Heat the crucible and lid slowly at first, then more vigorously until the bottom of the crucible glows red. This should take about 5 min.
5. Use tongs to remove the crucible and lid from the clay triangle, and place them on the ceramic-coated wire gauze to cool. The crucible is cool when you can no longer feel heat when holding your hand 1-2 cm from the crucible.
6. Measure the mass of the crucible + lid and record this mass on your Data Sheet.
7. Obtain a piece of magnesium ribbon weighing about 0.03-0.05 g. Using sandpaper, gently clean the surface of the Mg ribbon. Roll the magnesium ribbon into a ball and place it in your crucible. Place the lid back on your crucible. Weigh the crucible and lid with the Mg ribbon and record this mass on your Data Sheet. **REMEMBER: DO NOT HANDLE THE CRUCIBLE WITH YOUR BARE HANDS!**



**Figure 1. Proper placement of crucible (a) and lid (b) on a clay triangle.**

8. Place the crucible and lid on the clay triangle as indicated in Figure 1b.
9. Light the Bunsen burner and move slowly back and forth beneath the crucible to heat it gently. When you see white smoke escaping from the crucible, remove the flame. Use your tongs to move the lid so that it completely covers the crucible. (NOTE: the white smoke is magnesium oxide particles. Covering the crucible completely prevents loss of product.)
10. Heat the crucible gently for 10–15 seconds. Using your tongs, remove the lid to see if there is any more smoke present. If there is smoke present, replace the lid and continue heating. Repeat this process until there is no longer any smoke present.
11. Position the crucible lid so that it is slightly ajar. Adjust the Bunsen burner flame and heat the crucible strongly until the bottom of the crucible is red. Continue heating for 10 min.
12. Remove the crucible lid and place it upside down on the ceramic-coated wire gauze. The lid must be inverted to prevent loss of any product that might be adhering to the crucible lid. Let the lid and crucible cool.
13. Once the crucible has cooled, use a dropper to add 10 drops of distilled water to the crucible. **DO NOT ADD WATER TO A HOT CRUCIBLE! ADDING WATER TO A HOT CRUCIBLE MAY CAUSE IT TO CRACK.**
14. Replace the crucible lid so that it is slightly ajar. Gently heat the crucible for 5 min by moving the Bunsen burner slowly back and forth beneath the crucible. Adjust the flame and heat the crucible strongly for 5 min.
15. Using tongs, remove the crucible lid and place it upside down on the ceramic-coated wire gauze. Also transfer the crucible and contents to the wire gauze to cool. The appropriate technique for transferring the crucible is illustrated in Figure 2.
16. Once the crucible and lid have cooled, replace the crucible lid and weigh the crucible, contents and lid. Record this mass on your Data Sheet.
17. Discard the crucible contents in the solid waste container.
18. Wash the crucible and lid, rinse and dry.
19. Perform a second determination repeating Steps 2–18.



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**Figure 2. Technique for transferring crucible using tongs.**

## Data Sheet

	<i>Determination</i>	
	1	2
Mass of crucible + lid (g)	_____	_____
Mass of crucible, lid, and Mg (g)	_____	_____
Mass of crucible, lid, and magnesium oxide (g)	_____	_____

## Results

	<i>Determination</i>	
	1	2
Mass of Mg (g)	_____	_____
Mass of magnesium oxide (g)	_____	_____
Mass of O combined with Mg (g)	_____	_____
Moles of Mg in magnesium oxide (mol)	_____	_____
Moles of O in magnesium oxide (mol)	_____	_____
Molar ratio, mol Mg : mol O	_____	_____
Simplest whole-number ratio, mol Mg : mol O	_____	_____
Empirical formula for magnesium oxide	_____	_____

**CALCULATIONS** (Show all work. Use additional paper if necessary.)

## Post-Lab Questions

1. Compare the empirical formulas you obtained for your two determinations. How well do they agree? Discuss briefly sources of error that would cause the results of the two determinations to differ.

2. Using the equation below and the data for your two determinations calculate the mass percent of Mg in your magnesium oxide samples.

$$\text{Mass percent Mg (\%)} = \frac{\text{mass of Mg (g)}}{\text{mass of magnesium oxide (g)}} \times 100\%$$

3. The charge (or oxidation number) usually assigned to oxygen in compounds is -2. Based on your empirical formula, what must be the oxidation number of Mg in magnesium oxide?
4. Based on the empirical formula you obtained in this experiment, complete and balance the following chemical reaction:

