Empirical Formulas

Objectives

- Understand what an empirical formula is
- Observe the laws of Conservation of Mass and Definite Proportions
- Determine the empirical formula of a compound from experimental data

Introduction

A new compound is formed when atoms of different elements combine. Reactions such as combustion (or oxidation) can be performed to quantitatively determine the formula of a compound from its constituent elements. This lab illustrates two fundamental laws governing chemical reactions in the chemistry laboratory; the Law of Conservation of Mass and the Law of Definite Proportions.

Background

The empirical formula is defined as the lowest whole number ratio of the elements in a compound. The element magnesium is classified as an active (or base) metal. When magnesium is heated with oxygen, the following chemical reaction occurs:

$$2\mathrm{Mg}(s) + O_2(g) \longrightarrow 2\mathrm{MgO}(s)$$

If the masses of magnesium and oxygen are carefully measured, the empirical formula for the compound, MgO, can be determined from the experimental data.

Calculating Empirical Formula

The mass of the magnesium metal can be determined using an analytical balance. However, the mass of the oxygen that combines to form magnesium oxide must be determined by an indirect method. Since the difference in the mass of the magnesium and the mass of the product formed is due to the oxygen, the mass of oxygen can be determined by subtracting the mass of the reactant from the mass of the product.

$$\mathrm{Mass\ O_2} = [\mathrm{Mass\ Mg_xO_y}] - [\mathrm{Mass\ Mg}]$$

Although heating magnesium metal in air seems simple enough, there is a complication. Air is not composed of just oxygen gas. In fact, oxygen (21%) is a minority component of air. Another component of the air, nitrogen gas (79%) also reacts with the magnesium metal to produce the compound magnesium nitride.

$$3\mathrm{Mg}(s) + \mathrm{N_2}(g) \longrightarrow \mathrm{Mg_3N_2}(s)$$

The reaction forming Mg_3N_2 is called a "competing reaction" or a "side reaction." The competing reaction prevents some of the magnesium from forming magnesium oxide. Unless, a way is found to account for (or reverse) the Mg_3N_2 reaction, there is no way to determine just how much of the weighed magnesium has reacted to form MgO and how much has reacted to form Mg_3N_2.

Fortunately, it is possible to convert the Mg_3N_2 to MgO by reacting the magnesium nitride with water after it is formed:

$$\mathrm{Mg_3N_2}(s) + 6\mathrm{H_2O}(l) \longrightarrow 3\mathrm{Mg(OH)_2}(s) + 2\mathrm{NH_3}(g)$$

$$\mathrm{Mg(OH)_2}(s) \longrightarrow \mathrm{MgO}(s) + \mathrm{H_2O}(g)$$

The Mg_3N_2 is combined with a small amount of water and then heated. The excess water is evaporated and only MgO remains. An additional experimental consideration remains: When magnesium is heated in open air, the reaction with oxygen is rapid and spectacular. Magnesium is often used as a component in "sparklers," flares, and fireworks. When the metal catches fire, it burns intensely with a white flame and produces white smoke. To control the reaction so that the masses can be measured accurately, the reaction can be slowed by limiting the supply of oxygen the reaction receives. In this experiment, you will limit the amount of oxygen by placing a cover over the heating container.

Safety Precautions

Goggles or safety glass must be worn at all times in the lab.

Work in the hood!

DO NOT stare at burning magnesium! It is bright enough to damage your retina.

Handle the glassware with care as it is quite fragile.

Cold glassware looks like hot glassware. Take precautions when handling hot glassware.

Procedure

The empirical formula is defined as the simplest whole number ratio of the atoms involved in the make-up of a compound. The determination of the empirical formula, and the subsequent determination of the molecular formula, is an important experimental procedure carried out by chemists. In this experiment, we will prepare a compound of magnesium (Mg) and chlorine (Cl) and then determine the empirical formula of the compound. It is useful to recall that the atomic theory tells us that the atom ratio in a compound must be in small whole numbers and cannot be fractional values.

Although the final compound we produce will be composed of magnesium and chlorine, the chemical reaction that will be carried out will involve hydrochloric acid (HCl) and magnesium. Caution should be used in working with the hydrochloric acid. Be certain that safety glasses are worn throughout the experiment.

1. Set up a ring stand with a medium ring and wire gauze pad.
2. Hook up a Bunsen burner to the gas outlet in your workstation. This will be used during the heating step. Adjust the ring and wire gauze so that it will be above the flame of the burner.
3. Obtain an evaporating dish and watch glass large enough to cover the evaporating dish. Clean and dry them.
4. Using an electronic balance, weigh the watch glass and evaporating dish together and record the mass to the nearest 0.01 g in your data table.
5. Following the directions given by your laboratory instructor, place between 0.22 and 0.28 grams of magnesium ribbon into the evaporating dish. Be sure the Mg ribbon has a clean surface.

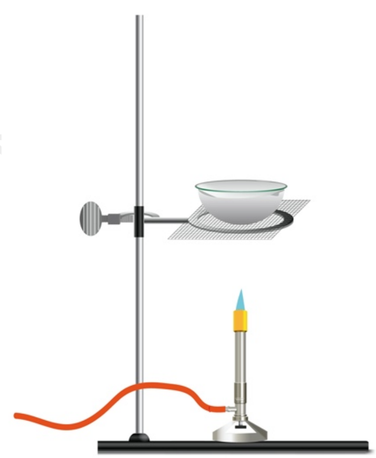

Figure 1 Setup

6. Weigh the evaporating dish, watch glass, and Mg and record the mass to the nearest 0.01 g. Record your data.

7. Gradually add the HCl to the magnesium using a dropper. Allow the drops to enter at the lip of the evaporating dish and flow slowly onto the Mg.

8. Continue to add the acid until the reaction has stopped. This will be evidenced by the lack of any more bubbles being formed and all the magnesium metal is gone. Do not add more HCl than necessary, as this will cause an irritating odor when evaporating the resulting solution in the next step.

9. When all of the Mg has reacted, carefully place the evaporating dish and cover on the wire gauze pad. (See Figure 1). Begin heating the evaporating dish with a low flame. It is best to hold the Bunsen burner in your hand and slowly rotate it beneath the evaporating dish. As the material in the evaporating dish begins to become a solid, you may witness some popping and spattering. If this occurs, heat more slowly.

10. Heat the evaporating dish until the contents are nearly dry as indicated by the fact that everything is a powdery white looking material. Heat for an additional three to four minutes – until there is NO condensation on the watch glass.

11. Stop the heating by turning off the gas to the Bunsen burner. Using a pair of crucible tongs, carefully remove the watch glass and set it on the red silicon hot pad, being careful not to lose any of the solid that may be sticking to it. **Caution**: The glass may still be very hot.

12. Use the tongs to remove the evaporating dish and place it on the hot pad also.

13. Place the watch glass back on the evaporating dish and allow the total system to cool for several minutes. While the compound is cooling, calculate the total number of moles of Mg that were reacted.

14. After the system has cooled to the point you can touch it with your fingers, place it on the electronic balance and weigh the entire system. Record the mass to the nearest 0.01 g.

15. Complete calculations to determine the empirical formula of the compound.

16. Clean up your lab station by scraping the compound into the trash can, then washing all equipment with soap and water. Give a final rinse with DI water and dry completely.

17. Leave all materials at your lab bench clean and neatly organized.

18. Be sure the gas is turned off completely

Name____ Section________________

Lab Partner____ Date__________________

Empirical Formula Report Sheet

Here are the 9 entries that are going to be included in the report.

Data Table

Mass of empty system (g)	________________
Mass of system with Mg (g)	________________
Mass of system once cooled (g)	________________
Calculate the mas of Mg (g)	________________
Calculate mass of product (g)	________________
Calculate mass of Cl (g)	________________
Moles Mg (mol)	________________
Moles Cl (mol)	________________
Write your empirical formula	________________