AP Chemistry - Determination of the Empirical Formula of Magnesium Oxide - Student Guide
IS 8025

INTRODUCTION

Antoine Lavoisier is considered by many to be the "father of modern chemistry." Raised as a legal and financial professional, Lavoisier's first true love was science. Even in spite of the demands of his professional career, Lavoisier still pursued scientific studies and research, all fields of science, with an unquenchable desire. Lavoisier helped establish a new system of chemical nomenclature, a great deal of which is still used today. He correctly identified (and named) both oxygen and hydrogen.

At the time Lavoisier began his scientific pursuits, it can be argued that chemistry was not even a science. Chemicals, and chemical reactions, were known to exist but all research related to how they affected other fields of science, such as geology and life sciences. The relationships and reactions between many solid and liquid substances were quite well known but the concept of gases was just starting to emerge, and poorly understood.

In many ways, it can be said that Lavoisier did not really discover anything. The importance of Lavoisier's work was in demonstrating the interrelationships between all the information that was discovered by other scientists of the time. In other words, while many things were known to occur, Lavoisier explained why they occurred. For example, the existence of oxygen and hydrogen (termed "inflammable air" at the time) had been speculated but Lavoisier demonstrated the role of each in several processes, such as the role of oxygen in combustion. Lavoisier showed a predictable set of rules and reactions, an order and consistency, and discreet chemical properties. While it was known that the burning of phosphorus and sulfur in air caused the resultant product to have more mass, Lavoisier demonstrated that this mass was coming from the air, which lost mass during the reaction.

The result of this was Lavoisier's development of the Law of Conservation of Mass. He stated that while chemical reactions may cause a change in form or state, mass does not change. Any mass lost by a component of the reaction must be gained elsewhere and vice versa. This moved chemistry from a qualitative to a quantitative science and began the evolution of chemistry as it is known today.

Conservation of Mass and Stoichiometric Relationships

The law of conservation of mass states that the total mass of the final products must be the same as the initial mass of the starting reactants. Another important law in chemical reactions is the Law of Constant Composition. This states that any portion of a chemical compound will have the same ratio of masses as the elements that compose the compound. As the properties of a compound can be described in various ways, the molecular composition may also be described in a variety of ways. Three ways of expressing molecular composition are:

- The mass of each element per mole of compound.
- The number of each type of atom per formula unit.
- The mass of each element as a percentage of the total mass of the compound (mass percent).

Chemical compounds can be quite complex. In turn, chemical formulae may also be quite complex. A molecular formula describes the actual number of atoms of each element in one molecule of a compound. In some cases, the determination of the relative percent of composition of a specific element may be necessary. For this, an empirical formula may be used. As opposed to the actual number of each atom of an element in a molecule, the empirical formula gives the lowest whole number ratio of element per molecule of compound. For example, the sugar glucose has a molecular formula of:

$$C_6H_{12}O_6$$

In other words, one molecule of glucose consists of six carbon atoms, twelve hydrogen atoms, and six oxygen atoms. However, if expressed empirically, glucose could be noted as:

$$CH_2O$$

The empirical formula shows that for every glucose molecule there is one part carbon to two parts hydrogen to one part oxygen. Now consider the molecular formula for formaldehyde:

$$CH_2O$$

The molecular formula for formaldehyde demonstrates two noteworthy concepts. First, the formula for formaldehyde cannot be further simplified. The molecular formula for formaldehyde is the same as the empirical formula for formaldehyde. Second is the comparison of the empirical (molecular) formula for formaldehyde to that of the empirical formula for glucose. They are identical. This shows that that multiple compounds, while having different molecular formulae, may have the same empirical formulae.

Experimental Determination of Empirical Formula

The empirical formula can be determined experimentally. The elemental metal magnesium can be oxidized by oxygen gas (O_2) to produce the compound magnesium oxide. Upon the application of heat, the metal will react strongly with oxygen in the air. While the oxygen is very reactive with the heated magnesium a small amount of the magnesium will react with nitrogen gas (N_2) also found in the air. Though nitrogen is more prevalent than oxygen in air, it is not as reactive as the oxygen and therefore only a small amount of the magnesium undergoes this side reaction. The reaction can be written as:

$$Mg(s) + N_2(g) + O_2(g) \qquad MgO(s) + Mg_3N_2(l)$$

The magnesium nitride, though in small quantity, must be removed. This can be accomplished by reacting the product of the above reaction with water. This converts the small amount of magnesium nitride to ammonia gas and magnesium hydroxide as follows:

$$MgO(s) + Mg_3N_2(s) + H_2O \longrightarrow Mg(OH)_2(s) + NH_3(g)$$

Applying more heat to these products will drive off the water and convert magnesium hydroxide, resulting from the magnesium nitride, to magnesium oxide:

$$MgO(s) + Mg(OH)_2(s) \longrightarrow Mg_{(?)}O_{(?)}(s) + H_2O(g)$$

Upon completion of the three reactions, and using the mass of the initial magnesium metal and the mass of the resulting product, the moles of both magnesium and oxygen in the final product can be determined as follows:

$$\text{mass Mg} + \text{mass O} = \text{mass } Mg_{(?)}O_{(?)}$$

or, rearrange the formula to solve for oxygen:

$$\text{mass O} = \text{mass } Mg_{(?)}O_{(?)} - \text{mass Mg}$$

Using the mass of the magnesium and oxygen, convert both to moles:

$$\text{moles Mg} = \frac{\text{mass Mg}}{\text{molecular weight Mg}}$$

$$\text{moles O} = \frac{\text{mass O}}{\text{molecular weight O}}$$

After determining both the moles of magnesium and oxygen consumed in the reaction, the empirical formula can be determined by finding the lowest possible whole number ratio between the two values.

Procedure

Materials Needed per Group

Ring stand
Bunsen burner
Ring support/clay triangle
Crucible w/lid
Crucible tongs

Shared Materials

Magnesium ribbon
Analytical balance (0.0001g)
Distilled or deionized water

Safety - Rubber gloves, Lab apron, Safety goggles

Safety note: *During the procedure, open flame will be used. Remove any flammable items from the immediate work area. After heating items, assume everything is hot. Never touch the crucible, lid, ring stand, support, or clay triangle with your hands. Always use tongs. Never place hot items on the balance.*

1. Set up the ring stand, support, and clay triangle. Position the crucible and lid in the clay triangle and set the height of the support so the Bunsen burner will fit below.

2. Light the Bunsen burner and heat the crucible and lid to remove any moisture or other contaminants. Heat the crucible until the bottom glows red hot for approximately 20-30 seconds.

3. Remove from heat and allow the crucible and lid to cool.

4. Using the analytical balance, record the mass of the cooled crucible and lid. Be sure to use tongs when weighing the crucible. Record the mass, to the resolution of the balance, in the Data Analysis section of the lab.

5. Using the analytical balance, obtain approximately 0.3g of magnesium ribbon. Record the actual mass, to the resolution of the balance, in the Data Analysis section.

Note to Students: *Be sure to wear gloves while handling the magnesium ribbon to avoid accidentally getting any contaminants on the metal.*

6. Place the sample of magnesium metal in the crucible. If necessary, fold the metal ribbon so the entire sample is in the bottom of the crucible.

7. Using tongs, record the mass of the crucible, lid, and magnesium ribbon in the Data Analysis section.

8. Place the crucible with the magnesium ribbon back into the clay triangle and place the lid on the crucible slightly to the side. The lid should leave enough of a space to allow air to enter the crucible but prevent the products from escaping.

9. Light the Bunsen burner and gently heat the crucible by running the flame back and forth across the bottom of the crucible for 1-2 minutes.

10. After the gentle heating period, place the Bunsen burner directly below the crucible and allow the reaction to proceed under strong heat.

11. Continue the application of strong heat until all of the magnesium ribbon has turned to a white/gray-white powder.

12. After all of the magnesium ribbon has reacted, remove the burner and allow the crucible and lid, as well as the contents, to cool completely.

13. Using tongs, remove the crucible lid. Use a pipette to add approximately 1ml distilled or deionized water to the powder in the crucible. Be careful as the addition of water will cause the generation of a small amount of ammonia gas.

14. Allow the reaction with water to proceed for a couple of minutes and then replace the crucible lid, slightly to the side again, with tongs.

15. Repeat the gentle heating process for another 1-2 minutes, and then place the burner below the crucible and apply strong heat for approximately 5 minutes to drive any water from the product.

16. Remove the heat and allow the crucible and lid, as well as the contents, to cool completely.

17. After everything has cooled completely, use tongs and the balance to determine the mass of the crucible, lid, and product to the resolution of the balance. Record this value in the Data Analysis section.

18. Clean up according to your instructor and wash hands thoroughly before leaving the lab.

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Name:	Instructor:
Date:	Class/Lab Section:

DATA ANALYSIS

Mass Crucible & Lid	
Mass Magnesium	
Mass Crucible, Lid & Magnesium	
Mass Crucible, Lid & Product	
Mass Product (Mass Crucible, Lid & Product - Mass Crucible & Lid)	

Mass Oxygen (Mass Product - Mass Magnesium)	
mol Mg (mass Mg/24.305)	
mol O (mass Oxygen/15.9994)	

Empirical Formula for Magnesium Oxide ______________________________

Name:	Instructor:
Date:	Class/Lab Section:

DATA ANALYSIS

Questions

1. Why do you think that the magnesium and oxygen had to be converted to moles to determine the empirical formula as opposed to using a mass:mass ratio?

2. Will determining the empirical formula of a compound allow you to correctly identify the compound?

3. What are some of the possible sources of error that you think could occur during this procedure?

Name:	Instructor:
Date:	Class/Lab Section:

DATA ANALYSIS

4.What is the theoretical yield of magnesium oxide based on the amount of magnesium you used?

5. What, if anything, was the percent error of your actual yield?