Magnesium Oxide

Percent Composition and Empirical Formula

Introduction

There is an official database that keeps track of the known chemical compounds that exist in nature or have been synthesized in the lab. The database is updated daily. Currently, over 20 million different inorganic and organic compounds have been recognized. Twenty million compounds—how is it possible to identify so many different compounds and tell them apart?

Concepts

- Percent composition
- Empirical formula
- Molecular formula
- Percent yield

Background

The composition of a chemical compound—what it is made of—can be described at least three different ways. The *percent composition* gives the percent by mass of each element in the compound and is the simplest way experimentally to describe the composition of a substance. According to the law of definite proportions, which was first formulated in the early 1800s by Joseph Proust, the elements in a given compound are always present in the same proportion by mass, regardless of the source of the compound or how it is prepared. Calcium carbonate, for example, contains calcium, carbon, and oxygen. It is present in eggshells and seashells, chalk and limestone, minerals and pearls. Whether the calcium carbonate comes from a mineral supplement on a drugstore shelf, or from seashells at the ocean shore, the mass percentage of the three elements is always the same: 40% calcium, 12% carbon, and 48% oxygen.

The percent composition of a compound tells us what elements are present in the compound and their mass ratio. In terms of understanding how elements come together to make a new compound, however, it is more interesting to know how many atoms of each kind of element are in a compound. Since all the atoms of a given element in a compound have the same *average atomic mass,* the elements that are present in a fixed mass ratio in a compound must also be present in a fixed number ratio as well. The *empirical formula* describes the composition of a compound in terms of the simplest, whole-number ratio of atoms in a molecule or formula unit of the compound. The formula of calcium carbonate, for example, is $CaCO_3$. The empirical formula gives the ratio of atoms in a compound and does not necessarily represent the actual number of atoms in a molecule or formula unit. It is possible, in fact, for many different compounds to share the same empirical formula.

The organic compounds acetylene and benzene, for example, have the same empirical formula, CH—one hydrogen atom for every carbon atom. These two compounds, however, have different properties and different molecular formulas—C_2H_2 for acetylene and C_6H_6 for benzene. Notice that in both cases the molecular formula is a simple multiple of the empirical formula. The *molecular formula* of a compound tells us the actual number of atoms in a single molecule of a compound. In order to find the molecular formula of a compound whose empirical formula is known, the molar or molecular mass of the compound must also be known.

In this experiment, the percent composition and empirical formula of magnesium oxide, the main compound that is formed when magnesium metal combines with oxygen in air, will be determined. Heating magnesium in the presence of air causes the metal to ignite and burn—lots of light and heat are given off and a new compound is obtained. According to the law of conservation of mass, the total mass of the products of a chemical reaction must equal the mass of the reactants. In the case of the combustion of magnesium, the following equation must be true:

$$\text{Mass of magnesium} + \text{Mass of oxygen} = \text{Mass of magnesium oxide}$$

If both the initial mass of magnesium and the final mass of the magnesium oxide are measured, the increase in mass must correspond to the mass of oxygen that combined with magnesium. The percent composition and empirical formula of magnesium oxide can then be calculated, based on the combining ratios of magnesium and oxygen in the reaction. Finally, once the formula of magnesium oxide is known, the amount of magnesium oxide that was produced can be compared against the maximum amount possible based on 100% conversion of the magnesium used in the experiment. This information can be used to calculate the *percent yield* of magnesium oxide in the reaction.

Experiment Overview

The purpose of this classic experiment is to determine the percent composition and empirical formula of magnesium oxide.

Lab Questions

A piece of iron weighing 85.65 g was burned in air. The mass of the iron oxide produced was 118.37 g.

1. Use the law of conservation of mass to calculate the mass of oxygen that reacted with the iron.
2. Use the molar mass of oxygen to calculate the number of moles of oxygen atoms in the product.
3. Use the molar mass of iron to convert the mass of iron used to moles.
4. Use the ratio between the number of moles of iron and number of moles of oxygen atoms to calculate the empirical formula of iron oxide. *Note:* Fractions of atoms do not exist. In the case where the ratio of atoms results in a decimal fraction, such as 1.5:1, the ratio should be simplified by converting it to the nearest whole number ratio. The ratio 1.5:1, for example, is converted to 3:2 by multiplying both terms by two.

ɘrials

Magnesium ribbon, 25 cm
Crucible and crucible lid, 15- or 30-mL
Crucible tongs
Bunsen burner
Ring stand and ring clamp
Balance, centigram (0.01-g precision)
Clay triangle
Scissors
Wire gauze with ceramic center
Laboratory Techniques Guide (optional)

Safety Precautions

Magnesium is a flammable metal. Magnesium burns with an intense flame. Do not look directly at burning magnesium. The light contains ultraviolet light that may hurt your eyes. Do not inhale the smoke produced when magnesium is burned. Handle the crucible and its lid only with tongs. Do not touch the crucible with fingers or hands. There is a significant burn hazard associated with handling a crucible—remember that a hot crucible looks exactly like a cold one. Always keep your face at arm's length from the crucible. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Set up a Bunsen burner on a ring stand beneath a ring clamp holding a clay pipestem triangle. (See Figure 1.) Do NOT light the Bunsen burner.
2. Adjust the height of the ring clamp so that the bottom of a crucible sitting in the clay triangle is about 1 cm above the burner. This will ensure that the crucible will be in the hottest part of the flame when the Bunsen burner is lit (step 7).
3. Using tongs to handle the crucible (see Figure 2), measure the mass of a clean, dry empty crucible and its lid to the nearest 0.01 g. Record the mass in the data table.
4. Measure a 25-cm length of magnesium ribbon and cut the magnesium to this length.
5. Wearing gloves, coil the metal ribbon around a pencil to obtain a loose ball of metal.
6. Place the coiled magnesium ribbon in the bottom of the crucible and measure the combined mass of the crucible, crucible lid, and magnesium. Record the mass in the data table.
7. Place the covered crucible with its lid on the clay triangle as shown in Figure 1. Light the Bunsen burner and brush the bottom of the crucible with the flame for 2–3 minutes to slowly heat the crucible and its contents.

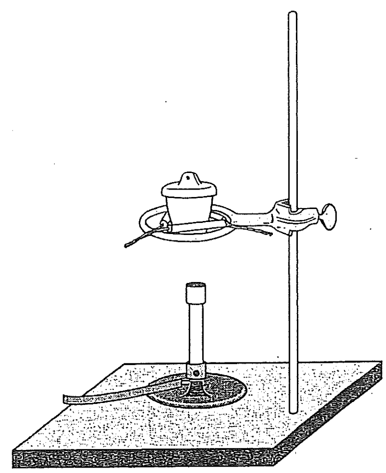

Figure 1.

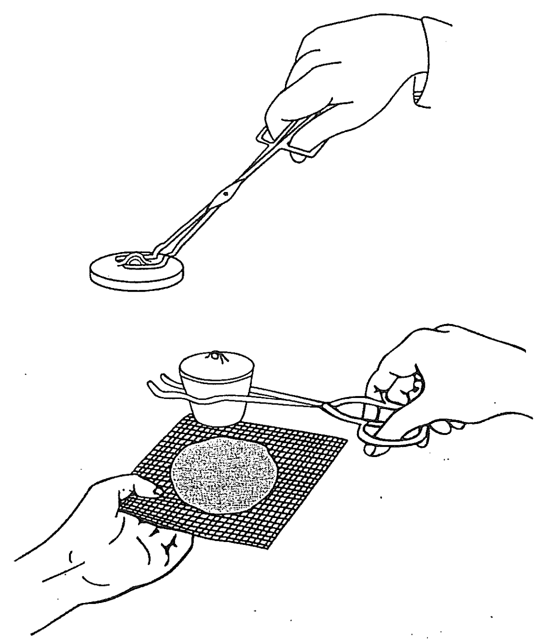

Figure 2.

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8. Place the burner on the ring stand and heat the crucible in the hottest part of the flame. (See Figure 3.) Note the approximate time.

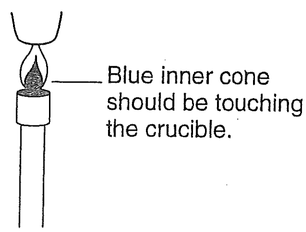

Figure 3.

9. After 3 minutes, use crucible tongs to carefully lift the lid a small amount. This will allow air to enter the crucible. *Caution:* Do not open the lid too far, because doing so will allow the metal to ignite. There will be some smoke produced. Do not inhale the smoke! Do not lean over the crucible. Keep the crucible at arm's length at all times.

10. Replace the lid and continue to heat the crucible. After 3 minutes, again lift the crucible lid to allow more air to enter the crucible. Replace the lid immediately if the metal starts to burn or the amount of smoke increases greatly.

11. Continue heating the crucible for a total of 15 minutes. Approximately every three minutes, lift the crucible lid to allow air to enter.

12. After 15 minutes, turn off the gas source and remove the burner.

13. Using tongs, remove the crucible lid and place it on a wire gauze on the bench top. With the tongs, remove the crucible from the clay triangle and place it on the wire gauze as well. (See Figure 2.)

14. Allow the crucible and its contents to cool completely on the wire gauze for at least 10 minutes.

15. Measure the combined mass of the crucible, crucible lid, and magnesium oxide product. Record the mass in the data table.

16. *(Optional)* If time permits, dump the contents of the crucible onto a watch glass. Using a spatula, break up the solid and note the appearance and consistency of the product. Is any magnesium ribbon still present? Record all observations in the data table.

17. Dump the contents of the crucible into the wastebasket and carefully clean the crucible and crucible lid.

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Magnesium Oxide

Data Table

Mass of Crucible and Lid	
Mass of Crucible, Lid, and Mg Ribbon	
Mass of Crucible, Lid, and Product	
Appearance of Product	

Post-Lab Calculations and Analysis

(Show all work on a separate sheet of paper.)

1. Calculate the mass of magnesium metal and the mass of the product. Use the law of conservation of mass to calculate the mass of oxygen that combined with the magnesium.
2. Calculate the percent composition of magnesium oxide.
3. Use the molar masses of magnesium and oxygen atoms to calculate the number of moles of each reactant.
4. Calculate the ratio between the number of moles of magnesium used and the number of moles of oxygen in the product. What is the empirical formula of magnesium oxide?
5. Write a balanced chemical equation for the formation of magnesium oxide from magnesium metal and oxygen gas.
6. Use the mole ratio of magnesium oxide to magnesium from the balanced chemical equation and the molar mass of magnesium oxide to calculate the *theoretical yield* of product. The theoretical yield of a product in a chemical reaction is the maximum mass of product that can be obtained, assuming 100% conversion of the reactant(s).
7. The percent yield reflects the actual amount of product formed as a percentage of the maximum that might have been obtained. Use the following equation to calculate the percent yield of magnesium oxide produced in this experiment.

$$\%\text{ yield} = \frac{\text{actual mass of product (g)}}{\text{theoretical mass (g)}} \times 100\%$$

8. Discuss sources of error in this experiment that might account for a percent yield lower than 100%. Be specific.