Experiment 2

DETERMINATION OF THE CHEMICAL FORMULA OF A COMPOUND

Objective

The purpose of this experiment is to investigate the empirical formula of copper oxide by the analytical method.

Lab techniques

- Weighing chemicals
- Using the alcohol lamp
- Producing and collecting hydrogen gas over water

Introduction

Compounds are composed of elements that are bonded together in definite proportions. If the constituent elements are different, or if these elements are bonded in different ratios, the resulting compounds will have different properties. For instance, both water (H_2O) and hydrogen peroxide (H_2O_2) are composed of hydrogen and oxygen atoms, but the composition ratios are different, producing two substances with distinct properties. Therefore, it is very important to determine the chemical formula of a compound.

The formula showing the simplest whole-number ratio of atoms present in a compound is called the empirical formula. Two methods are usually employed in this task, namely analytical and synthetic methods. In the analytical method, a fixed amount of a compound is decomposed into its component elements. We can thus deduce the relative amounts of these elements in the compound and determine their combination ratio. For example, from a chemical analysis of a 5.00 g sample of copper chloride, it is found that the sample contains 2.35 g copper and 2.65 g chlorine. From this information, we can calculate its empirical formula:

$$\text{No. of moles of Cu} = \frac{2.35\ \text{g}}{63.55\ \text{g/mol}} = 0.0370\ \text{mol}$$

$$\text{No. of moles of Cl} = \frac{2.65\ \text{g}}{35.45\ \text{g/mol}} = 0.0748\ \text{mol}$$

The molar ratio of Cu to Cl atoms = 0.0370 : 0.0748 = 1.00 : 2.02

Hence the compound's empirical formula is $CuCl_2$.

In the synthetic method, a known mass of element A is allowed to react completely with an excess of element B to form a fixed amount of the compound. The amount of element B in this compound can then be determined and the composition ratio of the two elements can be calculated. For example, a 1.00 g magnesium strip is strongly heated in a crucible until it is completely oxidized. The amount of magnesium oxide obtained is 1.66 g, so the empirical formula of magnesium oxide is:

Mass of O = 1.66 g − 1.00 g = 0.66 g

$$\text{No. of moles of O} = \frac{0.66\ \text{g}}{16.00\ \text{g/mol}} = 0.041\ \text{mol}$$

$$\text{No. of moles of Mg} = \frac{1.00\ \text{g}}{24.31\ \text{g/mol}} = 0.0411\ \text{mol}$$

The molar ratio of Mg to O atoms = 0.0411 : 0.041 = 1.0 : 1.0

Hence the empirical formula of the compound is MgO.

In this experiment, we analyze the copper and oxygen contents in copper oxide to determine the simplest whole-number ratio between the two elements and obtain its empirical formula. Refer to the apparatus setup shown in Fig. 2-1. Zinc granules react with hydrochloric acid to produce hydrogen gas (2-1). Then, the hydrogen gas is used to reduce copper oxide to elemental copper upon heating (2-2). By analyzing the mass contents of copper and oxygen in the sample, respectively, the empirical formula of copper oxide can be determined.

$$Zn(s) + 2\,HCl(aq) \rightarrow H_2(g) + ZnCl_2(aq) \qquad (2\text{-}1)$$

$$CuO(s) + H_2(g) \xrightarrow{\Delta} Cu(s) + H_2O(g) \qquad (2\text{-}2)$$

Apparatus

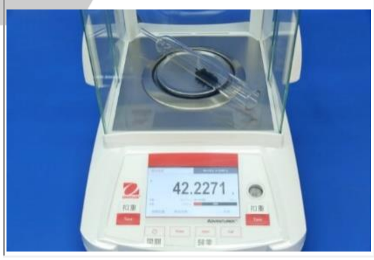
Hydrogen gas generator (250 mL Erlenmeyer flask, thistle tube, and rubber stopper), three-prong clamp (2), drying tube, large test tube, test tube (10), plastic basin, alcohol lamp, matches, rubber tube, windshield, tweezers, and cotton wool.
Shared: electronic balance and analytical balance.

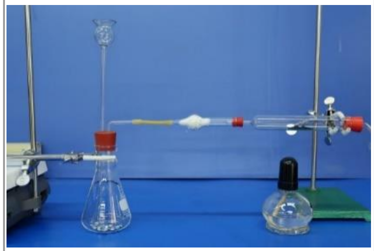
Chemicals

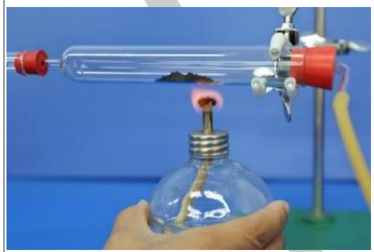
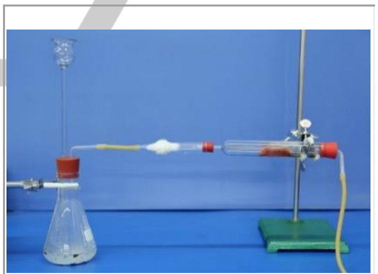
Zinc granules, Zn
Copper(II) oxide (pre-heated to remove moisture)

Calcium chloride, $CaCl_2$
6 *M* Hydrochloric acid, $HCl(aq)$
95% Ethanol, CH_3CH_2OH

Procedure

	Procedure	Illustration
1.	Wash and oven-dry a large test tube and a drying tube, and then allow them to cool to room temperature.	
2.	Fill the drying tube with $CaCl_2$. Stuff both ends of the drying tube with appropriate amounts of cotton wool to prevent the $CaCl_2$ from falling out. Note: $CaCl_2$ and cotton wool should not be stuffed too tightly that may obstruct the hydrogen gas flow.	
3.	(1) Use an analytical balance to measure the weight of an empty large test tube and record the accurate weight. (2) Use a lab spoon to add about 1 g of copper oxide into the tube, and measure the total weight accurately. Note 1: Copper oxide should be placed in the middle of the test tube. Note 2: Use the same analytical balance throughout the experiment. Note 3: Keep the large test tube away from the windshields of analytical balance.	  
4.	Measure about 15 g of zinc granules into the Erlenmeyer flask.	

5.	Set up the apparatus (Fig. 2-1). Adjust the thistle tube such that the end of the glass pipe nearly touches the bottom of the flask. Note 1: Adjust the height of the thistle tube by rotating its glass pipe, with a piece of dishcloth wrapped around it. Note 2: Wet the rubber tube with water before connecting it to the drying tube. Note 3: Gently rotate all rubber stoppers *ca.* 15° to make sure they are tightly sealed. Check that the rubber tube is not twisted to avoid obstruction of the gas flow.	  Rotate the rubber stopper
6.	Immerse 10 test tubes into a plastic basin filled with about 2/3 water. Fill all test tubes with water and make sure there are no air bubbles in them. Place the opening of the rubber tube into one of the test tube.	
7.	Use a 100 mL beaker to take about 20 mL of 6 *M* HCl (strong acid) and then pour it into the thistle tube at once. Make sure that the end of the thistle tube is immersed in the solution. Caution: This experiment produces H_2(g) vigorously, which can cause the explosion of glassware. You must be extremely careful. The laboratory doors and windows must be kept open to prevent the accumulation of hydrogen gas, which can be dangerous.	 
8.	Collect hydrogen gas over water in 10 test tubes, and place the tubes upside down on the bench top.	

9.	(1) Bring a flame to the opening of the inverted tube and test for any ‘pop’ sound one by one. (2) There will be a loud ‘pop’ sound in the beginning and the sound becomes very quiet. It ensures that the produced hydrogen gas has flushed out all the air inside the system and you may proceed to the next step.	
10.	Before heating, remove the rubber tube from the water. Make sure that it is not twisted and the gas flow is free from obstruction.	
11.	(1) Add another 20 mL of 6 *M* HCl to maintain the supply of hydrogen gas. (2) Heat the large test tube containing copper oxide by using an alcohol lamp carefully and evenly, until there are no more visible changes in its content and no visible moisture in the tube. Stop heating and allow the system to cool down. Caution: Pay attention to the operation of the alcohol lamp; do not overturn it which may cause a burn. Avoid the flame staying on the rubber stopper to prevent it from melting. Note: If it is necessary, a small portion of 6 *M* HCl may be added to maintain the supply of hydrogen gas as the reaction proceeds.	 
12.	(1) In the cooling process, maintain the connection of the apparatus and the supply of hydrogen gas to the large test tube. (2) When the tube is cool to room temperature, disconnect it from the apparatus and measure its total weight.	

13.	(1) At the end of the experiment, dispose of the used cotton wool, $CaCl_2$, unreacted Zn granules (rinsed), HCl(aq), and the produced copper into their respective recycling bottles. (2) Wash the apparatus, clean up your benchtop, and complete the experiment.	

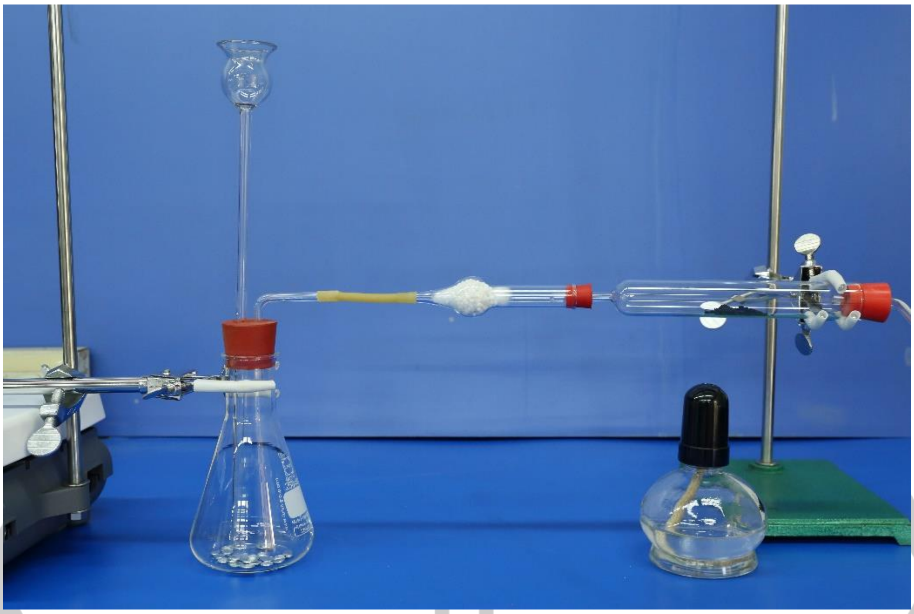


Figure 2-1 The setup of producing hydrogen gas to reduce copper oxide

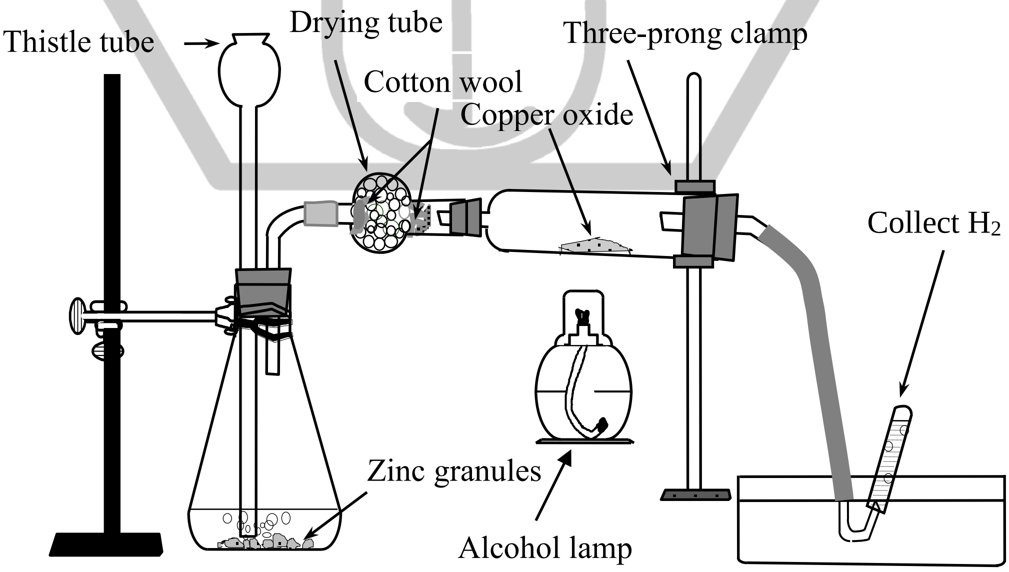


Figure 2-2 Collecting hydrogen gas over water