Experiment 1

DETERMINATION OF THE CHEMICAL FORMULA OF A COMPOUND

Objective

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

Lab techniques

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

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. Two methods are usually employed in this task, namely the analytical and synthetic methods.

In the analytical method, a fixed amount of a compound is broken into its component elements. We can thus deduce the relative amounts of these elements in the compound and determine their combination ratio. For instance, 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:

$$\text{No. of moles of Cu} = \frac{2.35\ \text{g}}{63.5\ \text{g/mol}} = 0.0370\ \text{mol}$$

$$\text{No. of moles of Cl} = \frac{2.65\ \text{g}}{35.5\ \text{g/mol}} = 0.0746\ \text{mol}$$

Molar ratio of Cu and Cl atoms = 0.0370 ： 0.0746 = 1.00 ： 2.02

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

In the synthetic method, usually a known weight 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 of the elements A and B 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

$$\text{No. of moles of O} = \frac{0.66\ \text{g}}{16.0\ \text{g / mol}} = 0.041\ \text{mol}$$

$$\text{No. of mole of Mg} = \frac{1.00\ \text{g}}{24.3\ \text{g/mol}} = 0.0412\ \text{mol}$$

Mole ratio of Mg and O atoms = 0.0412 ： 0.041 = 1.0 ： 1.0

Hence the empirical formula of the compound is MgO.

In this experiment, students will use zinc granules react with hydrochloric acid to generate hydrogen gas (1-1). Then, use the hydrogen gas to reduce copper oxide to elemental copper upon heating (1-2). Analyze the mass content of copper in the sample, and finally determine the empirical formula of copper oxide.

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

$$CuO(s) + H_2(g) \xrightarrow{\Delta} Cu(s) + H_2O(g) \qquad (1\text{-}2)$$

Apparatus

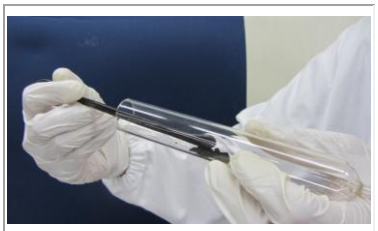
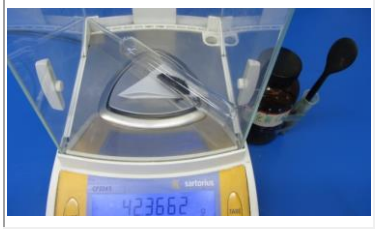
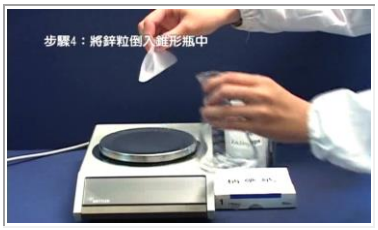
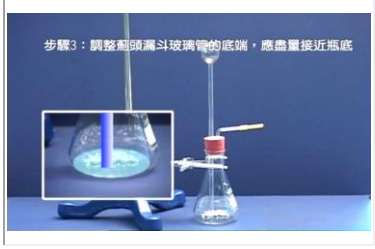
Hydrogen gas generator (Erlenmeyer flask, thistle tube, rubber stopper), drying tube, large test tube, test tubes, plastic basin, alcohol lamp, rubber tube, wind shields, and cotton.

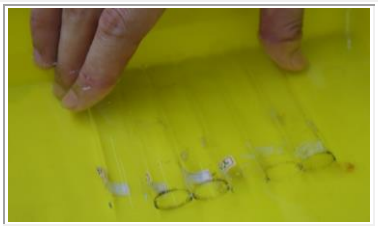
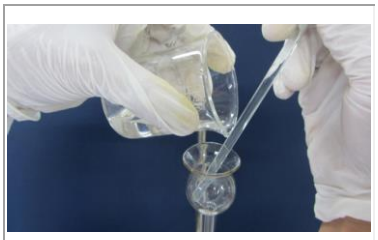
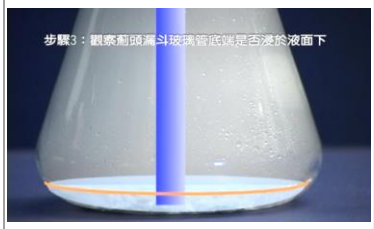
Chemicals

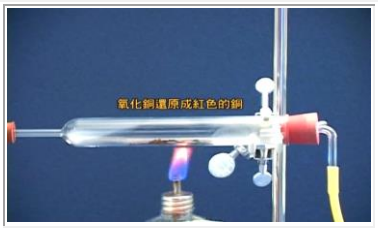
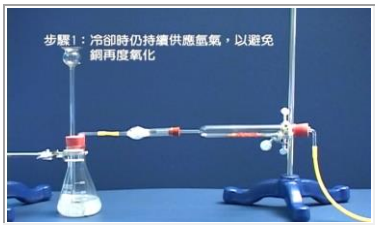
Zinc granules
Copper(II) oxide (pre-heated to remove water of crystallization)
Calcium chloride, $CaCl_2$
6 M Hydrochloric acid, HCl(aq)
95% Ethanol, CH_3CH_2OH

Procedure

★ Demo video: http://www.youtube.com/user/ntuchemistrylab

	Procedure	Illustration
1.	Wash and dry a large test tube and drying tube, and then allow them to cool.	
2.	Fill the drying tube with $CaCl_2$. Stuff both ends of the drying tube with just enough cotton to prevent the $CaCl_2$ from falling out. Note: $CaCl_2$ and cotton wool should not be stuffed so tightly that may obstruct the hydrogen gas flow.	
3.	Measure and record the accurate weight of large test tube. Add 1~1.2 g copper oxide to the tube, and measure its accurate weight with the content. Note 1: Copper oxide should be placed in the middle of the test tube. Use the same analytical balance throughout the experiment. Note 2: Refer to the experimental skills videos to learn how to weigh chemicals.	 
4.	Measure about 15 g zinc granules to the Erlenmeyer flask and use 100 mL beaker to take about 20 mL of 6 M HCl. Caution: HCl(aq) is strong acid.	
5.	Set up the apparatus (Fig. 1-1). 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.	 

6.	Fill 10 test tubes with water to the brim. Invert the test tubes and immerse into a plastic basin filled with 2/3 water to collect hydrogen gas over the water.	
7.	Pour 20 mL of 6 M HCl(aq) into the thistle tube at once. Make sure that the end of the thistle tube is immersed in the solution and the rubber tube is not twisted and the gas flow is free from obstruction. Caution: This experiment produces $H_2(g)$ vigorously, which can cause explosion of glassware. Must be extremely careful. The laboratory doors and windows must keep open to prevent accumulation of hydrogen gas, which can be dangerous.	 
8.	Collect hydrogen gas over the water. Bring a flame to the opening of the inverted tube and test for any 'pop' sound. When there is a loud 'pop' sound, continue collecting the gas until the sound becomes very quiet. It ensures that the hydrogen gas produced has flushed out the air inside the system. Make sure this step is completed before proceeding to the next step. Note: Refer to the experimental skills videos to learn how to collect gases over water.	 
9.	Before heating, remove the rubber tube from the water. Make sure that it is not twisted and the gas flow is free from obstruction. Add another 20 mL of 6 M HCl to maintain the supply of hydrogen gas.	
10.	Heat the large test tube containing copper oxide with an alcohol lamp carefully and evenly, until no more visible changes in its content and no visible moisture in the tube. Stop heating and allow the system to cool down. Note 1: Refer to the experimental skills videos to learn how to use an alcohol lamp. Also be careful	

	not to burn the rubber stopper. Note 2: As the reaction proceeds, add small portions of 6 M HCl(aq) if necessary to maintain the supply of hydrogen gas.	
11.	In the cooling process, maintain the connection of the apparatus and the supply of hydrogen gas to the large test tube. When the tube is cool, disconnect it from the apparatus and measure its weight.	
12.	At the end of the experiment, dispose the used cotton wool, $CaCl_2$, unreacted Zn granules (rinsed), HCl(aq), and the produced copper into their respective recycling bottles.	

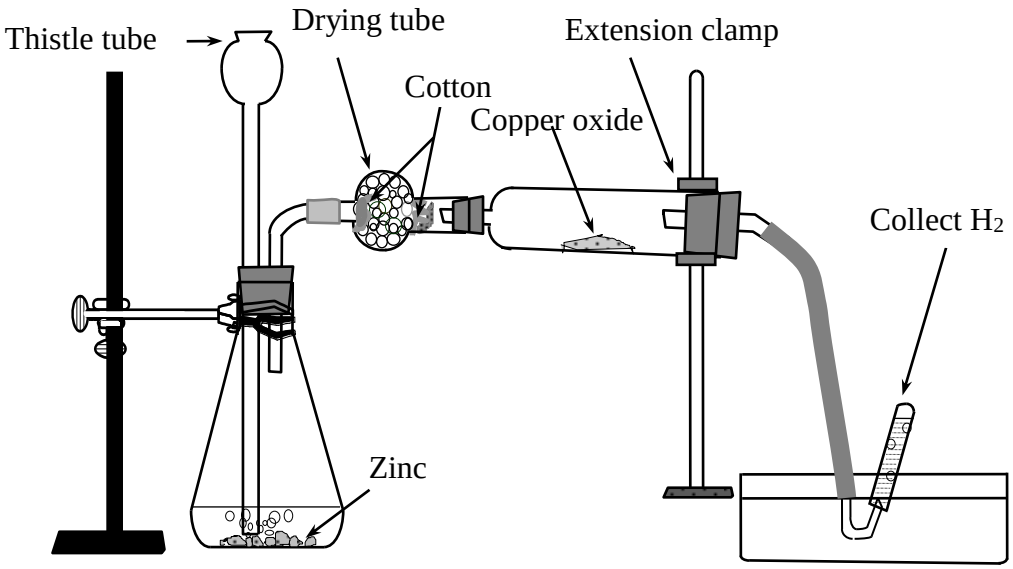


Figure 1-1 Collect hydrogen gas over water