

## The Empirical Formula of a Copper Oxide

Reading assignment: Chang, Chemistry 10<sup>th</sup> edition, pp. 55-58.

### Goals

The reaction of hydrogen gas with a copper oxide compound will be studied quantitatively. By measuring the masses of copper and oxygen in copper oxide we will determine its empirical formula.

### Equipment and Materials

Solid copper oxide, zinc metal in a hydrogen-generator bottle with thistle tube, 3 M sulfuric acid, a large test tube, a small test tube, two beakers (100 mL), Bunsen burner, calcium sulfate in a drying tube.

**Safety Note:** Safety glasses are required when performing this experiment

### Discussion

Copper was perhaps the first metal to be produced and used by humans. A pendant made of copper discovered in Northern Iraq may have been produced over 10,000 years ago. Native cultures in the American mid-west used copper 6,000 years ago. Copper mines are known to have existed in Egypt at least 3,000 years ago.

Copper is an extremely important material in modern society. The metal has high electrical and thermal conductivities, is resistant to corrosion (oxidation), and can be mixed with other metals to form alloys. Brass is formed from a mixture of copper and zinc. Bronze is formed from copper and tin. In the United States copper is used at a rate of 7.3 billion pounds (3.3 million metric tons) per year.<sup>1</sup>

**Table 1: Major uses of copper.<sup>1</sup>**

Building construction	46%
Electrical/electronic products	23%
Consumer products	11%
Transportation products	10%
Industrial machinery	10%

Owing to its importance in the modern world, copper is mined in large amounts throughout the world. Large copper mining industries exist around the world.

**Table 2: Annual mining production of copper in megatons.<sup>2</sup>**

Nation	Amount
Chile	2.3
United States	1.89
Canada	0.74
Russia	0.60
Australia	0.42
Peru	0.40

The environmental effects of copper mining are significant. Toxic metals can be released into fresh water sources in the process of mining.<sup>3</sup> Copper is a valuable enough resource that it is recycled to a large degree. Approximately 40% of copper is recycled in the United States.

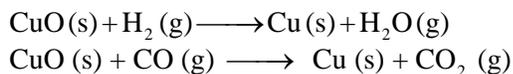
### Oxidation States of Copper

Two forms of copper oxide are found in nature, copper(I) oxide and copper(II) oxide.

CuO copper (II) oxide

Cu<sub>2</sub>O copper (I) oxide

Copper oxides can be converted to metallic copper by reaction with molecular hydrogen or with carbon monoxide at high temperature:

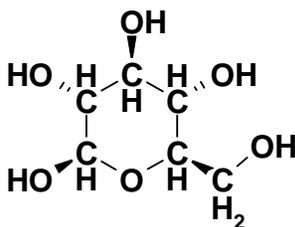


Hydrogen gas can be produced by adding a strong acid like sulfuric acid to zinc metal. The reaction is fast if the concentration of sulfuric acid is high and the surface area of the metallic zinc is large.



### Empirical Formula

The empirical formula of a compound is the simplest whole number ratio of atoms in the compound. For example, the empirical formula for glucose is  $\text{CH}_2\text{O}$ . This means that there is 1 carbon atom per 2 hydrogen atoms per 1 oxygen atom in a molecule of glucose. The empirical formula is useful because it can be used to determine the molecular formula of a compound. The molecular formula gives the actual number of atoms in one molecule of a compound. For glucose, the molecular formula is  $\text{C}_6\text{H}_{12}\text{O}_6$ . If the subscripts of the molecular formula for glucose are divided by 6 then the result is the empirical formula ( $\text{CH}_2\text{O}$ ).



#### formaldehyde

Empirical Formula:  $\text{CH}_2\text{O}$   
Molecular Formula:  $\text{CH}_2\text{O}$

#### glucose

Empirical Formula:  $\text{CH}_2\text{O}$   
Molecular Formula:  $\text{C}_6\text{H}_{12}\text{O}_6$

To determine the empirical formula of a compound we need to know the mass of each element in a sample of the compound.

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### References

1. Copper Development Association of America. For the year 2002.
2. Report from the Mineral Commodity Summary. 1995.
3. U.S. Environmental Protection Agency Report. May 2000.

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### Procedure

#### SAFETY PRECAUTIONS

Safety glasses or goggles are required for this experiment. Sulfuric acid can burn skin and should be handled with care. Hydrogen gas is explosive and must be handled carefully. Flames from the Bunsen burner must be kept away from combustible material like paper and clothing.

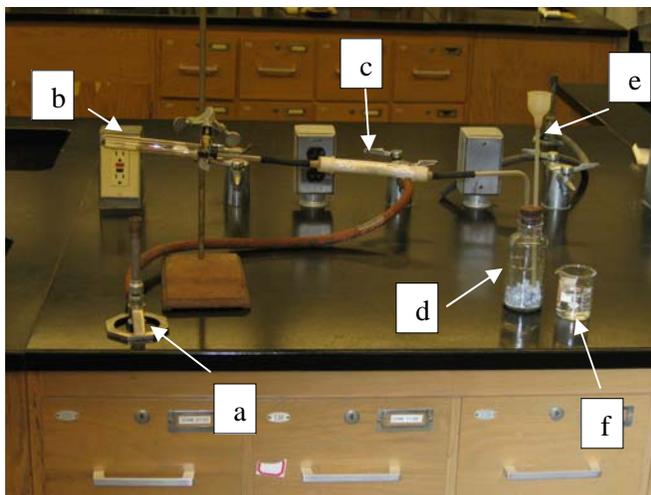
Students work in pairs.

1. Use a digital analytical balance to measure the mass of a clean dry test tube provided by your instructor.

2. Add between 1.300 g and 2.000 g of copper oxide powder to the test tube and re-measure the mass of the tube.
3. Obtain about 60 mL of sulfuric acid solution in a 100-mL beaker.
4. Set up the hydrogen generator apparatus described below.

The figure to the right shows the experimental apparatus used to reduce copper oxide. The important components are:

- a. Bunsen burner with gas hose.
- b. Test tube containing copper oxide.
- c. Drying tube.
- d. Hydrogen generator containing zinc.
- e. Thistle tube and funnel for transferring sulfuric acid.
- f. 100 mL beaker containing sulfuric acid solution.



The hydrogen gas generator with thistle tube is used to produce hydrogen gas. Sulfuric acid is poured into the funnel and down the thistle tube. Use a pipe cleaner, if needed, to remove water in the system between the drying tube and the nozzle tip. All connections must be firm. The test tube must be clamped right at the mouth and must have a very slight tilt downward at the mouth to allow water to flow away from the copper oxide. The copper oxide must be confined to the rear half of the tube and not be touched by the long tubing.

### Generating Hydrogen Gas

1. Ignite the Bunsen burner. Do not start heating the sample yet.
2. Slowly pour about one-half to two-thirds of the 60 mL of 3 M sulfuric acid ( $\text{H}_2\text{SO}_4$ ) into the thistle tube. As the sulfuric acid oxidizes the zinc metal there should be a bubbling gas visible in the generator bottle. The sulfuric acid should be added slowly so that the mixture does not bubble out through the thistle tube. The reaction produces a large amount of heat and can boil the water in the sulfuric acid solution, so adding slowly will decrease the likelihood that the solution will bubble out of the funnel.
3. The glass tubing that is connected to the test tube is fitted with an opening that allows excess hydrogen to flow out of the system. This hydrogen flowing out of the system can be ignited and burned by collecting some of it with a small test tube and then igniting the collected gas with the Bunsen burner. If the test tube is quickly returned to the overflow opening then the heat generated can also ignite the hydrogen flowing out of the opening.
4. Continue adding the sulfuric acid into the thistle tube as the reaction proceeds.
5. Place an upside down test tube on the nozzle for about 5-10 seconds. Then quickly remove the tube and bring it to the flame and place the tube's opening to the edge of the flame. There may be a soft or loud popping sound. If so, return the tube to the overflow tube and ignite the hydrogen flowing out of the opening.

6. Do **not** ignite the hydrogen with a burner or match. If after several tries you have not succeeded in igniting the hydrogen, ask for help from your instructor.
7. Place a dry upside down beaker (100 mL or 250 mL from your drawer) over the burning hydrogen flame. You should see the condensation of water on the inside surface of the beaker.

### **Reaction of Hydrogen with a Copper Oxide**

1. Heat the tube containing the copper oxide gently with the Bunsen burner.
2. After a few minutes of gentle heating, apply a strong and hot flame to one part of the oxide for 5 minutes, then move the flame to another part of the oxide for an additional 10 minutes, repeating until all the oxide has had a chance to react completely with hydrogen.
3. Heating the oxide may cause the hydrogen flame to extinguish. There is no need to re-ignite it.
4. After a total of 15 to 20 minutes of heating the oxide should be red, indicating that the material has been reduced to metallic copper.
5. Turn off the Bunsen burner and allow the test tube to become cool to the touch while continuing the flow of hydrogen.
6. Keep the test tube clamped to the ring stand while you detach the stopper and tubing unit so that no liquid runs back into the solid powder.
7. Use a paper towel to wipe away all the water in the tube.
8. Measure the mass of the test tube on the analytical balance.
9. Do not discard the test tube contents until you have shown the data to the instructor.
10. Disconnect the generator bottle and fill it with water to stop the hydrogen evolution. Pour the liquid into the sink. Do not allow the zinc metal to fall into the sink since it can be re-used.

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### **Calculating the Empirical Formula of a Copper Oxide**

1. Copper oxide is composed of copper and oxygen. Calculate the masses of copper oxide, copper, and oxygen from the mass measurements on the data sheet. The mass of the copper is measured after the reaction is complete. The mass of oxygen is the difference between the mass of CuO and the mass of the copper.
2. Use the atomic mass of copper to determine the number of moles of copper present in the copper oxide sample:

$$\text{moles Cu} = (\text{mass of Cu}) \left( \frac{1 \text{ mol Cu}}{63.546 \text{ g Cu}} \right)$$

3. Use the atomic mass of oxygen to determine the number of moles of oxygen present in the copper oxide sample.

$$\text{moles O} = (\text{mass of O}) \left( \frac{1 \text{ mol O}}{16.00 \text{ g O}} \right)$$

4. The empirical formula is the smallest whole number ratio of copper to oxygen atoms. To obtain the empirical formula divide the number of moles of both copper and oxygen by the smaller of the two numbers.
5. After dividing by the smaller of the two numbers round each to the nearest whole number.

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**Observations and Notes**  
**The Empirical Formula of a Copper Oxide**

Date \_\_\_\_\_

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**Data and Report Sheet**  
**Empirical Formula of a Copper Oxide**

Name \_\_\_\_\_ Section \_\_\_\_\_ Date \_\_\_\_\_

Partner's Name \_\_\_\_\_

1. Mass of empty test tube \_\_\_\_\_ g
2. Mass of copper oxide + test tube \_\_\_\_\_ g
3. Mass of copper + test tube \_\_\_\_\_ g
4. Mass of copper oxide \_\_\_\_\_ g
5. Mass of copper \_\_\_\_\_ g
6. Mass of oxygen \_\_\_\_\_ g
7. Moles of copper (use atomic mass of Cu) \_\_\_\_\_ mol
8. Moles of oxygen (use atomic mass of O) \_\_\_\_\_ mol
9. Empirical formula of copper oxide \_\_\_\_\_

