QUANTITATIVE DETERMINATION OF AN EMPIRICAL FORMULA

7

According to the atomic theory, in ordinary chemical reactions an atom cannot be divided into smaller parts. Therefore, when two elements combine they must do so in small whole number ratios. For example, when hydrogen and oxygen react to form the compound water the ratio of hydrogen atoms to oxygen atoms in a molecule of water is 2 to 1, never 2.5 to 1 or 1.75 to 1.

It is important to note that one mole of a substance contains 6.02×10^{23} molecules, atoms, or ions (Avogadro's number). Therefore, 6.02×10^{23} molecules of water, H_2O, contain $2 \times 6.02 \times 10^{23}$ atoms of hydrogen and $1 \times 6.02 \times 10^{23}$ atoms of oxygen, again a 2:1 ratio. Likewise, 1 mole of $CaCO_3$ has $1 \times 6.02 \times 10^{23}$ atoms of calcium, $1 \times 6.02 \times 10^{23}$ atoms of carbon, and $3 \times 6.02 \times 10^{23}$ atoms of oxygen.

In order to experimentally determine an empirical formula you will oxidize tin by treating it with nitric acid. You will then calculate the mole ratio of the two elements (oxygen and tin) in one of the products and predict a formula for the resulting compound.

Objectives

In this experiment, you will

- react a carefully determined amount of tin with excess nitric acid,
- form a tin-oxygen crystalline product,
- calculate the mole ratio of tin and oxygen in the crystalline product, and
- predict an empirical formula for the tin-oxygen product.

EQUIPMENT

goggles and apron
evaporating dish
watch glass
balance
hot plate or burner with
ring stand, ring, and wire gauze
forceps
beaker
stirring rod

PROCEDURE

1. Prepare a data table as directed in the Analysis. Safety goggles and lab apron must be worn for this experiment.
2. If a hot plate is to be used, turn it on so that it will warm up.
3. Clean and dry an evaporating dish and a watch glass cover. To dry them, heat strongly for 2 to 3 minutes using a hot plate or burner, and let cool. **CAUTION:** *Hot glass.* Use forceps or tongs to handle the dish and cover throughout the experiment.
4. Place about 2 g of 30-mesh granulated tin in the dish, cover with the watch glass, and measure the mass to the nearest 0.01 g.
5. Wearing goggles, add 5 cm^3 of 8*M* nitric acid, HNO_3, and replace the watch glass. **CAUTION:** *Perform the reaction under a fume hood or in a well ventilated room. HNO_3 causes burns; avoid skin and eye contact. Rinse spills with plenty of water.*
6. After the chemical action has stopped, heat the dish on a hot plate or over a hot water bath as shown in Figure 7-1. (An excessive amount of popping and spattering indicates you are heating too rapidly.) Continue to heat slowly until the contents are nearly dry.

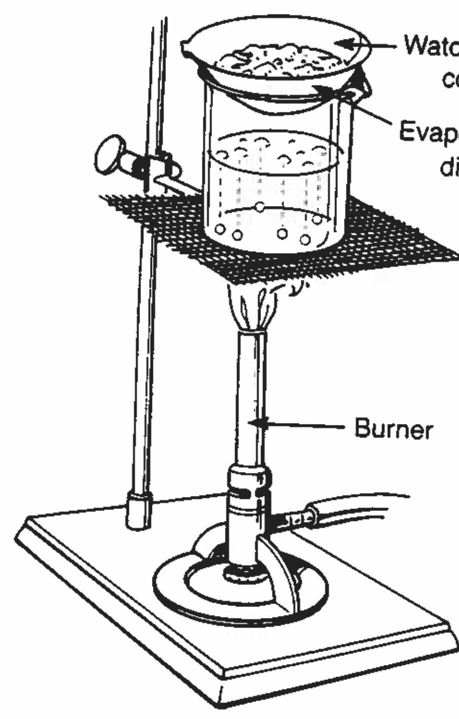

FIGURE 7-1. Apparatus set-up for water bath evaporation.

7. When the popping and spattering no longer occur remove the evaporating dish from the heat source. Remove the watch glass, taking care not to lose any of the product. Do not clean the watch glass until all the measurements in Step 9 have been made. Break up the solid with a stirring rod.
8. Place the dish on the hot plate or position the dish on a wire gauze supported by a ring stand as shown in Figure 7-2. Heat carefully on the hot plate or with a hot flame until the solid becomes pale yellow. Remove the dish from the heat source and allow to cool.

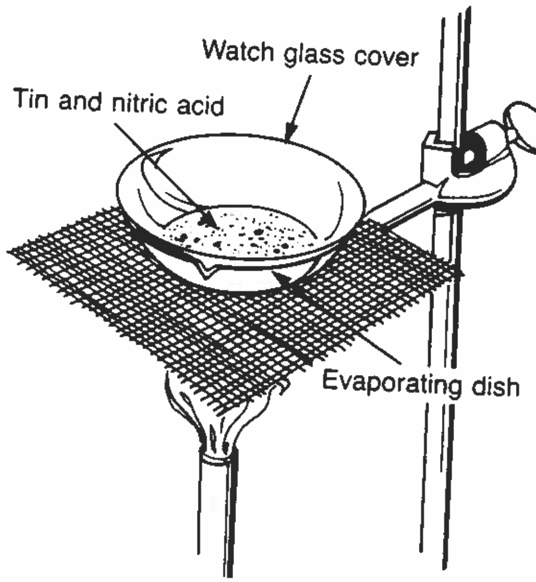

FIGURE 7-2. Apparatus set-up for evaporation by direct heating.

9. After the dish has cooled, replace the watch glass cover and measure the mass of the dish, contents, and cover to the nearest 0.01 g. Reheat the dish for 2 to 3 minutes and allow it to cool again. Determine the mass of the dish, contents, and cover a second time. If this mass value does not agree within 0.02 g with the last mass reading, you must reheat and remeasure the mass until the last two measurements are within that range.
10. Discard the solid material into the waste container designated by your teacher.

ANALYSIS

1. Record your data in a table which includes the following entries.

   mass of evaporating dish and cover
   mass of dish, cover, and tin
   mass of tin
   moles of tin
   mass of dish, cover, and tin-oxygen product
   mass of oxygen
   moles of oxygen
2. Determine the mole ratio of oxygen to tin in the product.

CONCLUSIONS

1. Using the mole ratio calculated in Step 2 of the Analysis, predict the empirical formula for the tin-oxygen product. Name this product.
2. What are the possible oxidation numbers for tin and oxygen? Write the two most probable empirical formulas for tin-oxygen compounds. Does your predicted formula agree with either of these? If not, provide an explanation for the difference. Include any experimental errors that may have occurred.

FURTHER INVESTIGATIONS

1. Determine the percentage composition of the tin-oxygen product.
2. Analysis of a 20.30 g sample of a compound containing phosphorus and oxygen shows that 8.87 g of the sample are phosphorus. Calculate the empirical formula of the compound.
3. Upon analysis a compound is found to contain 7.75% hydrogen and 92.25% carbon by mass. Calculate the empirical formula for this compound.
4. By other experiments, the molecular mass of the compound in Problem 3 is found to be 78. What is the molecular formula?
5. Hydrates are compounds that contain water molecules. For example, when calcium chloride crystallizes from a water solution, two moles of water are contained within one mole of $CaCl_2$. Hence, the formula for the hydrate is $CaCl_2 \cdot 2H_2O$. The empirical formula for a hydrate is determined by including the mass of the water as part of the total mass of the substance. Write the correct formula for the substance having a mass of 322 g, and composed of 63.73% $Na_2S_2O_3$ and 36.27% water.