EXPERIMENT

Stoichiometry of a Precipitation Reaction

Hands-On Labs, Inc.
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Review the safety materials and wear goggles when working with chemicals. Read the entire exercise before you begin. Take time to organize the materials you will need and set aside a safe work space in which to complete the exercise.

Experiment Summary:

You will learn about precipitation reactions. You will learn how to use stoichiometry to predict the quantities of reactants necessary to produce the maximum amount of precipitated product. Finally, you will calculate percent yield from a precipitation reaction and determine conservation of mass.

Learning Objectives

Upon completion of this laboratory, you will be able to:

- Identify and define the parts of a chemical reaction, including the reactants and products.
- Identify the defining characteristics of a precipitation reaction.
- Define the term stoichiometry, and discuss the importance of accurate calculations in experimental design and outcomes.
- Describe how the molar quantity of a substance is related to its molecular weight and calculate the molar quantity of various substances.
- Define the term hydrate and describe how hydrated compounds influence precipitation reactions.
- Predict and calculate the theoretical maximum amount of product produced in a precipitation reaction, using stoichiometry.
- Perform a precipitation reaction and measure the precipitate to calculate percent yield.
- Explain differences between theoretical and actual yield in a controlled experiment.

Time Allocation: 2.5 hours, plus an overnight drying period.

Materials

Student Supplied Materials

Quantity	Item Description
1	Bottle of distilled water
1	Dish soap
1	Roll of paper towels
1	Source of tap water

HOL Supplied Materials

Quantity	Item Description
1	Digital scale, precision
1	Funnel, 70 mm
2	Glass beakers, 100 mL
1	Graduated cylinder, 25 mL
1	Pair of gloves
1	Pair of safety goggles
1	Experiment Bag: Stoichiometry of a Precipitation Reaction: 1 - $CaCl_2 \bullet 2H_2O$ Calcium chloride, dihydrate - 2.5 g 1 - Filter paper, 12.5 cm 1 - Na_2CO_3 - Sodium carbonate - 2 g 1 - Weighing boat, plastic

Note: *To fully and accurately complete all lab exercises, you will need access to:*

1. A computer to upload digital camera images.
2. Basic photo editing software such as Microsoft Word or PowerPoint, to add labels, leader lines, or text to digital photos.
3. Subject-specific textbook or appropriate reference resources from lecture content or other suggested resources.

Note: *The packaging and/or materials in this LabPaq kit may differ slightly from that which is listed above. For an exact listing of materials, refer to the Contents List form included in your LabPaq kit.*

Background

Chemical Equations

A **chemical equation** is an illustration of the reaction that occurs between two or more specific chemical compounds. Chemical equations use letters and numbers to represent the chemical elements and the amounts or ratios of those elements present in the compounds that are either participating in the reaction or a product of the reaction. For example, one methane molecule contains one carbon atom and four hydrogen atoms and is denoted as CH_4. The chemical compounds that are present before a reaction occurs are called **reactants**, and the compounds produced from the reaction are called **products**. In addition to identifying the products and reactants in a balanced chemical reaction, a chemical equation will also quantitatively identify the proportion of reactants to products. This quantitative proportion is known as **stoichiometry**, and can be used to determine how much of each reactant is needed to produce a specific amount of each product. See Figure 1.

$$\underbrace{Ba(NO_3)_2(aq) + CuSO_4(aq)}_{\text{(Reactants)}} \rightarrow \underbrace{BaSO_4(s) + Cu(NO_3)_2(aq)}_{\text{(Products)}}$$

Figure 1. A balanced chemical equation. The chemical equation shows the chemical reaction between barium nitrate and copper sulfate. The equation shows that when 1 ion of barium nitrate reacts with 1 ion of copper sulfate, 1 ion of barium sulfate and 1 ion of copper nitrate are produced.

As shown in Figure 1, chemical equations often denote the physical states of the reactants and products. The reaction in Figure 1 is a **precipitation reaction**, where two solutions are mixed and an insoluble substance (precipitate) forms, which is then able to be separated or removed from the solution. The (s) after $BaSO_{4(s)}$, denotes that a solid was formed as a product from the two aqueous (aq) reactants. The stoichiometry of a balanced chemical equation can be used to calculate the mass and number of moles of each reactant and each product in a chemical reaction.

Moles and the Periodic Table

A **mole** (η or mol) is a unit of measure, describing the amount of a chemical substance that contains as many atoms, ions, or molecules as there are in exactly 12 grams of pure Carbon (^{12}C). One mole of a substance has 6.022×10^{23} atoms (for an element) or molecules (for a compound) or ions (for an ionic compound), and is equal to its molecular weight (formula mass). For example, the element nitrogen has a molecular weight of 14.01 grams, thus 1 mole of nitrogen is equal to 14.01 grams. Likewise, the compound H_2O has a molecular weight of H + H + O (1.008 + 1.008 + 16.00), thus 1 mole of H_2O is equal to 18.016 grams. The molecular weight of each element is found in the periodic table. See Figure 2.

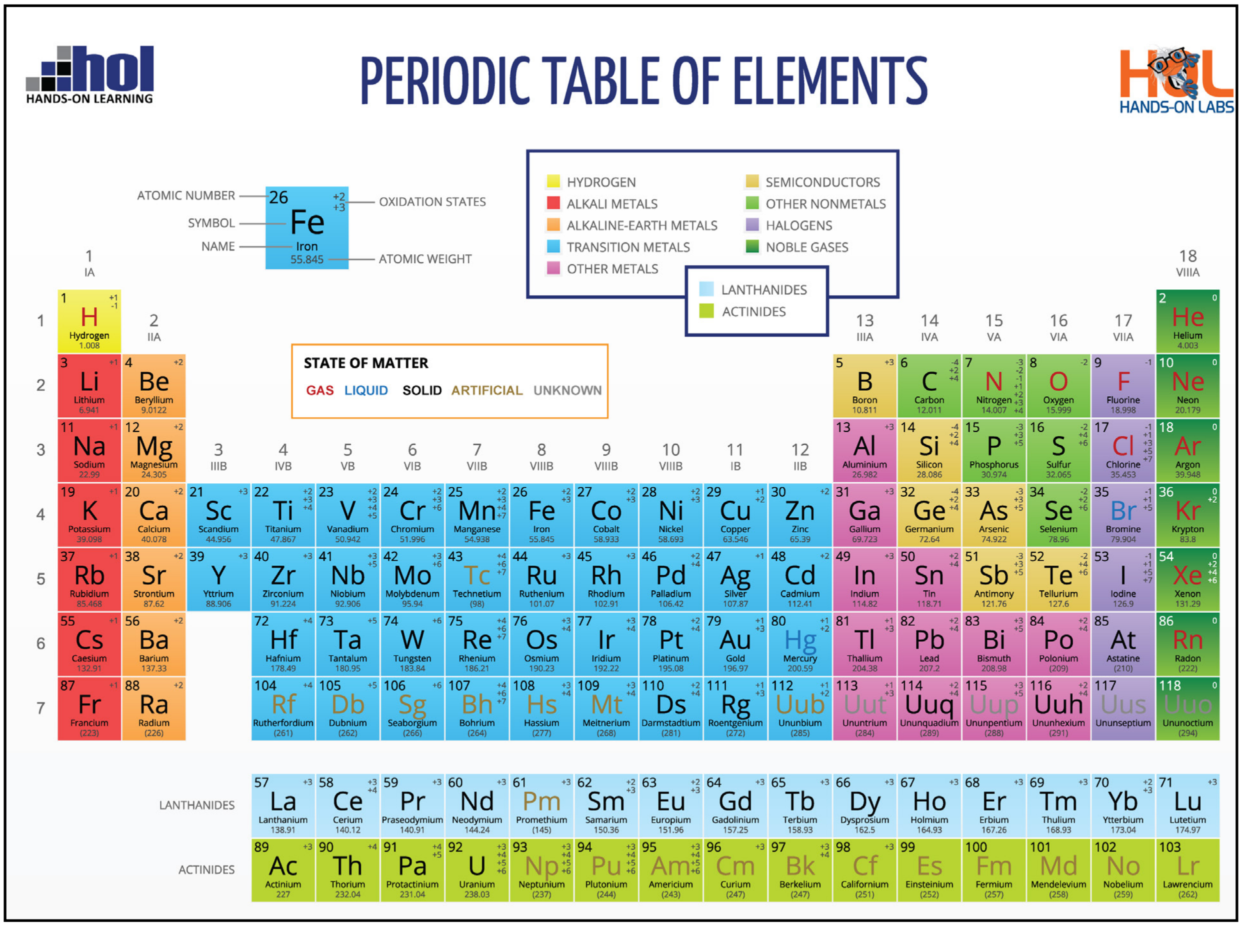


Figure 2. Periodic Table of Elements. The molar mass of an element is equal to the mass in grams required to equal 1 mole of the substance.

Stoichiometric Quantities and Calculations

In addition to determining the amount of product formed in a reaction, stoichiometry can be used to determine how much of each reactant is required for all reactants to be used up at the same time. The quantities of reactants that are needed to fully react with one another at the same time are known as **stoichiometric quantities**. Stoichiometric quantities can be used to maximize the amount of product produced from the chemical reaction. For example, if you were performing the reaction in Figure 1 and had 3 grams of $CuSO_4$, you can use the balanced chemical equation and stoichiometry to determine how many grams of $Ba(NO_3)_2$ you would need to create the maximum amount of $BaSO_4$.

More specifically, to quantitatively calculate the maximum amount of product expected through a chemical reaction, you need only a balanced chemical equation, the atomic mass of each substance, and the quantity of substance available for only one of the reactants.

A step-by-step example of this process, using the balanced equation from Figure 1, is shown below:

$$Ba(NO_3)_2(aq) + CuSO_4(aq) \rightarrow BaSO_4(s) + Cu(NO_3)_2(aq)$$

Assuming there are only 5.7 grams of $CuSO_4$ available, how many grams of $Ba(NO_3)_2$ are necessary to reach stoichiometric quantities? How many grams of solid $BaSO_4$ are expected to be produced?

Step 1. Check to ensure that the equation is balanced. To do this, ensure that there is the same number of atoms from each element on both sides of the equation.

Step 2. Convert the 5.70 grams of $CuSO_4$ to moles of $CuSO_4$.

$$5.70\text{ g }CuSO_4 \times \frac{1\text{ mol }CuSO_4}{159.62\text{ g}} = 0.0357\text{ mol }CuSO_4$$

Step 3. Evaluate the molar ratio between $CuSO_4$ and $Ba(NO_3)_2$.

$$0.0357\text{ mol }CuSO_4 \times \frac{1\text{ mol }Ba(NO_3)_2}{1\text{ mol }CuSO_4} = 0.0357\text{ mol }Ba(NO_3)_2$$

The chemical equation states that for 1 mole of $CuSO_4$, 1 mole of $Ba(NO_3)_2$ is needed for stoichiometric quantities. Using the information calculated in step 2, if there are 0.0357 moles of $CuSO_4$, then 0.0357 moles of $Ba(NO_3)_2$ are required for a complete reaction.

Step 4. Convert moles of $Ba(NO_3)_2$ to grams of $Ba(NO_3)_2$.

$$0.0357\text{ mol }Ba(NO_3)_2 \times \frac{261.32\text{g }Ba(NO_3)_2}{1\text{ mol }Ba(NO_3)_2} = 9.33\text{g }Ba(NO_3)_2$$

This shows that 9.33 grams of $Ba(NO_3)_2$ are required to completely react with the 5.70 grams of $CuSO_4$.

Step 5. Determine the amount (moles) of $BaSO_4$ expected from the reaction.

$$0.0357 \text{ mol } CuSO_4 \times \frac{1 \text{ mol } Ba(NO_3)_2}{1 \text{ mol } CuSO_4} = 0.0357 \text{ mol } Ba(NO_3)_2$$

The chemical equation states that for every 1 mole of $CuSO_4$ used, 1 mole of $BaSO_4$ is expected. This means that the 0.0357 moles of $CuSO_4$ should produce 0.0357 moles of $BaSO_4$.

Step 6. Convert moles of $BaSO_4$ to grams of $BaSO_4$.

$$0.0357 \text{ mol } BaSO_4 \times \frac{233.37\text{g } BaSO_4}{1 \text{ mol } BaSO_4} = 8.33\text{g } BaSO_4$$

To double-check the results of the calculations, the law of the conservation of mass can be applied. The **Law of the Conservation of Mass** states that the total mass, in a closed system, does not change as the result of reactions between its parts. Theoretically, this means that the total mass of the reactants should equal the total mass of the products. However, in practical experimentation, a system is seldom completely closed. As a result, one should realistically expect a slightly smaller amount of product, as the theoretical yield is rarely obtained. This deviation, from theoretical yield to actual yield, is called the **percent yield** and can be calculated.

Step 7. Double-check the conservation of mass [calculate the mass of $Cu(NO_3)_2$ that is expected from the reaction]. With a 1:1 ratio, 0.0357 moles of $Cu(NO_3)_2$ are expected.

$$0.0357 \text{ mol } Cu(NO_3)_2 \times \frac{187.57\text{g } Cu(NO_3)_2}{1 \text{ mol } Cu(NO_3)_2} = 6.70\text{g } Cu(NO_3)_2$$

Step 8. Calculate the theoretical yield to double-check results.

$$9.33\text{g } Ba(NO_3)_2 + 5.70\text{g } CuSO_4 = 8.33\text{g } BaSO_4 + 6.70\text{g } Cu(NO_3)_2$$

Note: *Always watch significant figures during calculations, or theoretical yield of the products and reactants may differ slightly.*

Through comparing the result from the calculation in Step 8 with the previous results, one can verify if the calculations are correct and have confidence in the series of stoichiometric calculations.

Step 9. Determine the percent yield.

Assume that the actual yield was 8.15 g $BaSO_4$.

$$\frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\% = \text{Percent Yield}$$

Using the yields both given and calculated:

$$\frac{8.15\text{g BaSO}_4}{8.33\text{g BaSO}_4} \times 100\% = 97.8\%$$

Hydrates

In this experiment, you will use stoichiometry to determine the quantities necessary for a complete precipitation reaction between aqueous sodium carbonate (Na_2CO_3) and aqueous calcium chloride dihydrate ($CaCl_2•2H_2O$). A **hydrate** is a solid compound that contains water molecules. Hydrates are named by adding the Greek prefixes mono-, di-, tri-, tetra-, penta-, hexa-, hepta-, etc., to the end of the standard name of the compound to describe moles of water held in the compound. For example:

$CuSO_4•5H_2O$ = Copper (II) sulfate pentahydrate

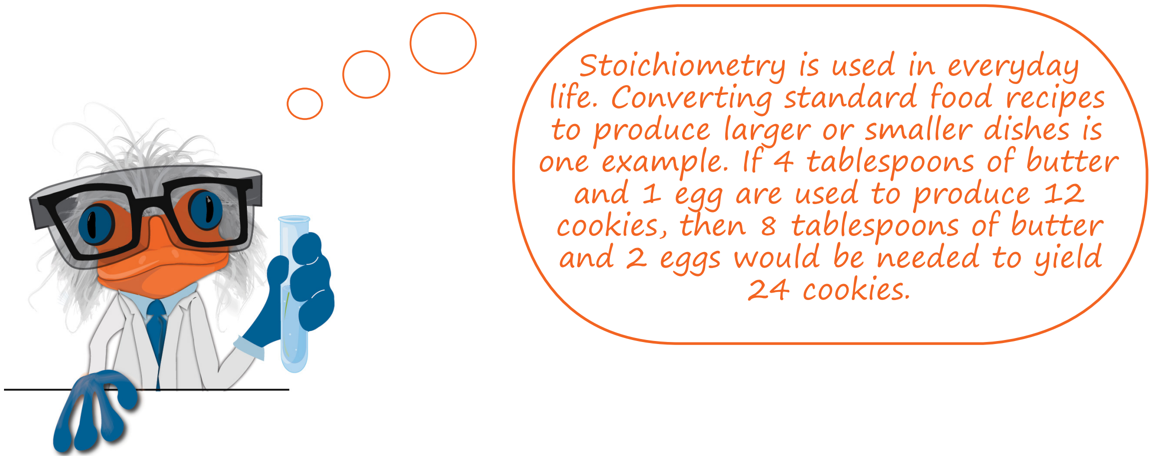
$MgSO_4•7H_2O$ = Magnesium sulfate heptahydrate

The equations above state that 1 mole of $CuSO_4•5H_2O$ contains 1 mole of $CuSO_4$ and 5 moles of H_2O; and 1 mole of $MgSO_4•7H_2O$ contains 1 mole of $MgSO_4$ and 7 moles of H_2O. As the water is loosely held in the compound, it is easily separated from the compound upon heating, or in the case of the calcium chloride dihydrate, upon addition to water (where it will dissolve). Thus, while the molecular weight of the $CaCl_2•2H_2O$ compound includes the two water molecules, only the $CaCl_2$ portion of the compound is available to react with the sodium carbonate.

Assume that there were 5.0g of $CaCl_2•2H_2O$, and you needed to determine the moles of $CaCl_2$ available in that 5.0g to react in an aqueous solution with Na_2CO_3. Convert the 5.0 grams of $CaCl_2•2H_2O$ to moles of $CaCl_2•2H_2O$.

$$5.0\text{ g CaCl}_2•2\text{H}_2\text{O} \times \frac{1\text{ mol CaCl}_2•2\text{H}_2\text{O}}{146.99\text{ g}} = 0.034\text{ mol CaCl}_2•2\text{H}_2\text{O}$$

Thus, in 5.0 grams of $CaCl_2•2H_2O$ there are 0.034 moles of $CaCl_2$ available to react in an aqueous solution with Na_2CO_3. If the stoichiometry of the reaction was 1:1, then 0.034 moles of Na_2CO_3 would be required to reach stoichiometric quantities and fully react with all of the $CaCl_2$ in solution.


Stoichiometry is used in everyday life. Converting standard food recipes to produce larger or smaller dishes is one example. If 4 tablespoons of butter and 1 egg are used to produce 12 cookies, then 8 tablespoons of butter and 2 eggs would be needed to yield 24 cookies.

Exercise 1: Stoichiometry and a Precipitation Reaction

In this exercise, you will use stoichiometry to determine the amount of reactant needed to create the maximum amount of product in a precipitation reaction. After performing the reaction, you will calculate the percent yield of product.

Procedure

1. Review the following reaction, where sodium carbonate and calcium chloride dihydrate react in an aqueous solution to create calcium carbonate, a salt (sodium chloride), and water.

$$Na_2CO_3(aq) + CaCl_2 \bullet 2H_2O(aq) \rightarrow CaCO_3(s) + 2NaCl(aq) + 2H_2O(aq)$$

2. Put on your safety gloves and goggles.
3. Use the graduated cylinder to measure 25 mL of distilled water. Add 25 mL of distilled water to each of the two 100 mL glass beakers.
4. Turn on the digital scale, place the plastic weigh boat on the scale and tare the scale so that it reads 0.00 g.
5. Measure 1.00 grams of the $CaCl_2 \bullet 2H_2O$.
6. Carefully add the $CaCl_2 \bullet 2H_2O$ to one of the beakers with 25 mL of distilled water in it and swirl the beaker until the $CaCl_2 \bullet 2H_2O$ is fully dissolved into the water.
7. Rinse the weigh boat with distilled water and fully dry the weigh boat with paper towels.
8. Use the information and examples provided in the background to calculate how many moles of $CaCl_2 \bullet 2H_2O$ are present in 1.00 g of $CaCl_2 \bullet 2H_2O$ and then calculate how many moles of pure $CaCl_2$ are present in the 1.00 g of $CaCl_2 \bullet 2H_2O$. Record the answers in **Data Table 1** of your **Lab Report Assistant**.
9. Use the information and examples provided in the **Background** (and values input into **Data Table 1**, in step #6) to determine how many moles of Na_2CO_3 are necessary to reach stoichiometric quantities. From that calculation, determine how many grams of Na_2CO_3 are necessary to reach stoichiometric quantities. Record both values in **Data Table 1**.
10. Turn on the digital scale, place the plastic weigh boat on the scale and tare the scale so that it reads 0.00 g.
11. Measure the calculated amount of Na_2CO_3, and carefully add it to the 25 mL of distilled water in the second 100 mL glass beaker.
12. Swirl the beaker until the Na_2CO_3 is fully dissolved into the water.

13. Pour the Na_2CO_3 solution from the 100 mL glass beaker into the beaker containing the $CaCl_2 \cdot 2H_2O$ solution. Swirl the beaker to fully mix the 2 solutions and the precipitate of calcium carbonate will form instantly.

14. Use the information and examples provided in the **Background** to determine the maximum (theoretical) amount of $CaCO_3$, in grams, that can be produced from the precipitation reaction. Record this value in **Data Table 1**.

15. Wash the now empty 100 mL glass beaker (that contained the Na_2CO_3 solution) with soap and water. Rinse the beaker with distilled water and thoroughly dry with paper towel.

16. Place the funnel on the beaker.

17. Fold the round filter paper into a cone shape, as shown in Figure 3.

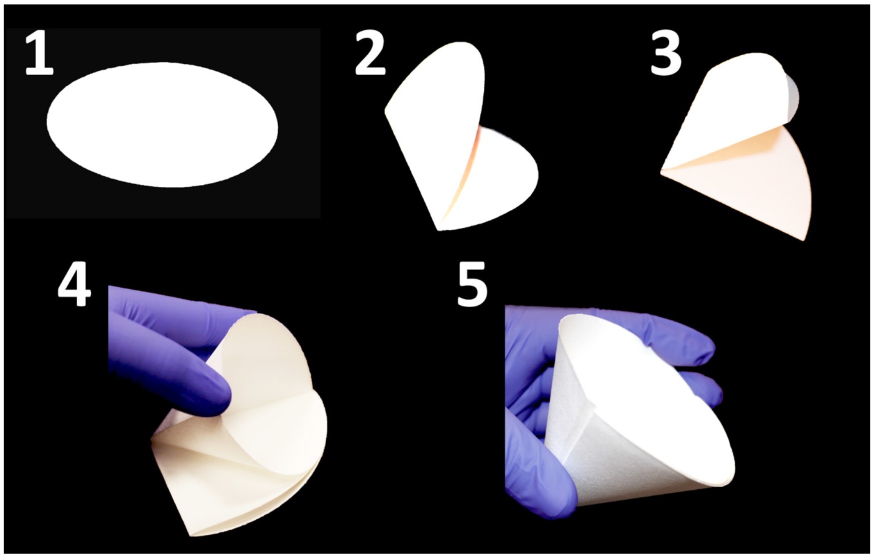


Figure 3. Folding of filter paper.

18. Place the folded filter paper onto the tared scale and record the mass of the filter paper in **Data Table 1**.

19. Place the folded filter paper into the funnel. Swirl the contents of the beaker to dislodge any precipitate from the sides and while holding the filter paper open, slowly pour the contents of the beaker into the filter-paper lined funnel.

Note: *Be careful not to overfill the funnel. It may be necessary to gently swirl the funnel to keep the precipitate from clogging the paper.*

20. Add 2-3 mL of distilled water to the beaker and swirl the water around the sides of the beaker to collect any precipitate stuck to the sides of the beaker. Pour into the filter-paper lined funnel.

21. Allow all of the liquid to drain from the funnel into the beaker. This may take 10-15 minutes.

22. After all liquid has drained from the funnel, carefully remove the filter paper from the funnel and place it on paper towels in a warm location, such as a window that receives a lot of sunlight, where it will not be disturbed. See Figure 4.

23. Allow the filter paper to completely dry, which will require at least an overnight drying period.

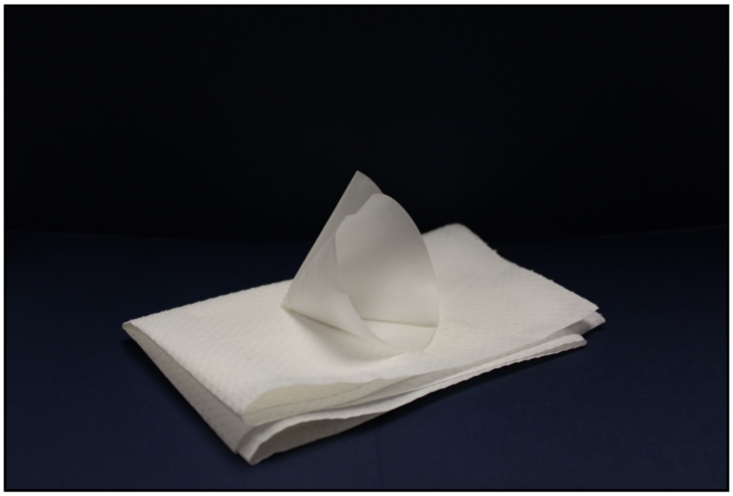


Figure 4. Filter paper with precipitate set on paper towel to dry.

24. When the filter paper with precipitate is completely dry, tare the scale and place the paper onto the scale to obtain the mass. Record the mass of the filter paper and precipitate in **Data Table 1**.

25. Calculate the actual mass of the precipitate and record in **Data Table 1**.

26. Calculate the percent yield of the precipitate and record in **Data Table 1**.

27. When you are finished uploading photos and data into your **Lab Report Assistant**, save and zip your file to send to your instructor. Refer to the appendix entitled "Saving Correctly," and the appendix entitled "Zipping Files," for guidance with saving the **Lab Report Assistant** in the correct format.

Cleanup:

28. Dispose of chemicals properly.

29. Clean all equipment and thoroughly dry.

30. Return cleaned materials to the lab kit for future use.

Questions

A. A perfect percent yield would be 100%. Based on your results, describe your degree of accuracy and suggest possible sources of error.

B. What impact would adding twice as much Na_2CO_3 than required for stoichiometric quantities have on the quantity of product produced?

C. Determine the quantity (g) of pure $CaCl_2$ in 7.5 g of $CaCl_2 \bullet 9H_2O$.

D. Determine the quantity (g) of pure $MgSO_4$ in 2.4 g of $MgSO_4 \bullet 7H_{2O.}$

E. Conservation of mass was discussed in the background. Describe how conservation of mass (actual, not theoretical) could be checked in the experiment performed.

