Stoichiometry and Limiting Reagent

Topic

The limiting reagent can be calculated for a reaction that produces calcium carbonate.

Introduction

In a precipitation reaction, two aqueous solutions are mixed to yield one aqueous solution and a *precipitate,* a solid that is insoluble in water. The solid results from the rearrangement of *cations* and anions in the reactants. In the reaction that produces calcium carbonate, or chalk, sodium carbonate and calcium chloride react as follows:

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

The balanced reaction equation shows that the reactants interact in specific mole (mol) ratios, in this case a 1:1 ratio. Calcium carbonate cannot be produced without both reactants. If only 1 mol of Na_2CO_3 and 2 mol of $CaCl_2$, were available, only 1 mol of $CaCO_3$ could be produced. In this example, Na_2CO_3 is the limiting reagent, or the reagent that is used up first. The number of moles of Na_2CO_3 determines the number of moles of $CaCO_3$ produced. Any other reagent is considered an excess reagent. In this experiment, you will use *stoichiometry* to determine which reagent is the limiting reagent in two different trials of a reaction.

Time Required

45 minutes for part 1

15 minutes for part 2

5 minutes for part 3

Materials

- 50 milliliters (ml) of 0.5 M $CaCl_2$ solution
- 20 ml of 1.5 M Na_2CO_3 solution
- 125-ml Erlenmeyer flask
- 25-ml graduated cylinder
- 10-ml graduated cylinder
- watch glass
- filter paper
- glass funnel
- 250-ml beaker
- wash bottle of distilled water
- oven (optional)
- science notebook

Safety Note **Please review and follow the safety guidelines. Wear goggles and gloves when working with chemicals.**

Procedure: Part 1

1. Using the 25-ml graduated cylinder, measure 20.0 ml of 0.5 M $CaCl_2$. Pour this solution into the Erlenmeyer flask. On Data Table 1, record the exact amount of calcium chloride used in the row titled "Trial 1."
2. Using the 10-ml graduated cylinder, measure 10 ml of 1.5 M Na_2CO_3. Add this amount to the Erlenmeyer flask. Record the exact amount of sodium carbonate added on Data Table 1 in the row titled "Trial 1."

Data Table 1					
	ml Na_2CO_3	ml $CaCl_2$	Mass of filter paper (g)	Mass of watch glass (g)	Mass of $CaCO_3$ formed (g)
Trial 1					
Trial 2					

3. Gently swirl the Erlenmeyer flask; a white precipitate should quickly form.
4. Weigh a piece of filter paper and record its weight on Data Table 1 in the row titled "Trial 1."
5. Gravity filter the white solid. To do so:
   a. Fold a piece of filter paper into quarters, then separate two layers to make a filter funnel (see Figure 1). Place this filter funnel inside the glass funnel.
   b. Position the glass funnel over the beaker.
   c. Pour the solution into the center of the filter paper, taking care not to let it get above the level of the filter paper.

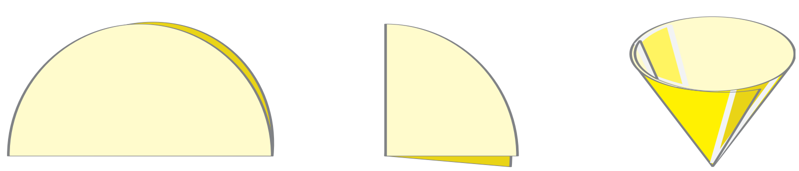

Figure 1

6. Wash the sides of the Erlenmeyer flask with a small amount of distilled water and add this to the filter paper. Repeat this rinse until the flask appears clean.
7. Weigh the watch glass and record its weight on Data Table 1 in the row titled "Trial 1."
8. Carefully remove the filter paper from the funnel and place it on the watch glass. The filter paper and the precipitate must be allowed to dry completely. This can be done by letting it sit overnight, or by placing the watch glass in an oven if one is available.

Procedure: Part 2

1. When the paper and solid are dry, weigh the watch glass and its contents. Subtract the weight of the watch glass and filter paper to find the weight of calcium carbonate formed. Record this value on Data Table 1 in the row titled "Trial 1."
2. Repeat the steps in Part 1 using 25 ml of 0.5 M $CaCl_2$ and 5.0 ml of 1.5 Na_2CO_3. Record the results on Data Table 1 in the row titled "Trial 2."

Procedure: Part 3

1. Repeat step 1 Part 2.

Analysis

1. Complete Data Table 2 using stoichiometry and your data above.

Data Table 2			
	Moles Na_2CO_3 used	**Moles $CaCl_2$ used**	**Moles $CaCO_3$ formed**
Trial 1			
Trial 2			

2. Which reagent was the limiting reagent in trial 1? Which was limiting in trial 2?
3. The equation for percent yield is:

$$\text{percent yield} = \frac{\text{actual mass of product}}{\text{theoretical mass of product}} \times 100\%$$

   Use this equation to determine the percent yield for each trial.
4. What are some possible sources of error in this experiment that would have a caused a percent yield less than 100?
5. If you were the manager of a chemical manufacturing facility, why would it be useful to know which reagent is the limiting reagent in your reactions?

What's Going On?

The reaction in this experiment is a double-displacement reaction in which the sodium and calcium cations switch anions. The products are sodium chloride and calcium carbonate. Sodium chloride is soluble in water and remains in solution. However, the calcium carbonate is insoluble and will form a white solid. This solid can be isolated and weighed to determine the percent yield, or efficiency of the reaction.

The balanced reaction equation above shows that Na_2CO_3 and $CaCl_2$ react in a 1:1 ratio to form 1 mol of $CaCO_3$. In this case, the reagent in shortest supply is the limiting reagent. In trial 1, the limiting reagent is $CaCl_2$. This reaction should have produced approximately 1.0 g $CaCO_3$. The limiting reagent in trial 2 is Na_2CO_3. This trial should have produced approximately 0.75 g $CaCO_3$. The yield of these reactions should be greater than 80 percent. Percent yields less than this amount indicate incorrect measurements and/or inefficient lab practices.

Want to Know More?

See Our Findings.

OUR FINDINGS

STOICHIOMETRY AND LIMITING REAGENT

Suggestion for class discussion: Compare the reagents used in a chemical reaction to the ingredients of a recipe. Show the class a recipe, and tell them that only half the amount required of one of the ingredients is available. Have them explain how this problem will affect the final product.

Teacher notes: If an oven is available for drying the filter paper and its contents, it should be used. Filter papers will dry faster and more efficiently, and measurements will be more accurate. A Bunsen burner may not be used because it does not allow for enough control and the students are more likely to burn their product than to dry it. The solution that remains cannot be boiled off, because it contains an aqueous solution of sodium chloride, which will be added to your product.

Analysis

1. Answers will vary. On the data table, answers assume perfect measurements and 100 percent yield.

Data Table

	Moles Na_2CO_3 used	Moles $CaCl_2$ used	Moles $CaCO_3$ formed
Trial 1	0.015 mol	0.01 mol	0.01 mol
Trial 2	0.0075	0.0125 mol	0.0075 mol

2. $CaCl_2$; Na_2CO_3
3. Answers will vary. Ideally these should be around 80 percent.
4. Answers will vary. Some possibilities include poor measurements, loss of product during filtering, not removing enough of the liquid, and sodium chloride depositing with the product as it dries.
5. In a production facility, it is important to make the limiting reagent the more expensive chemical. Any excess reagent is not likely to be reusable, so it should be expendable. It also allows a manager to calculate the efficiency of the process.

SAFETY PRECAUTIONS

Review Before Starting Any Experment

Each experiment includes special safety precautions that are relevant to that particular project. These do not include all the basic safety precautions that are necessary whenever you are working on a scientific experiment. For this reason, it is absolutely necessary that you read and remain mindful of the General Safety Precautions that follow. Experimental science can be dangerous, and good laboratory procedure always includes following basic safety rules. Things can happen very quickly while you are performing an experiment. Materials can spill, break, or even catch fire. There will be no time after the fact to protect yourself. Always prepare for unexpected dangers by following the basic safety guidelines during the entire experiment, whether or not something seems dangerous to you at a given moment.

We have been quite sparing in prescribing safety precautions for the individual experiments. For one reason, we want you to take very seriously every safety precaution that is printed in this book. If you see it written here, you can be sure that it is here because it is absolutely critical.

Read the safety precautions here and at the beginning of each experiment before performing each lab activity. It is difficult to remember a long set of general rules. By rereading these general precautions every time you set up an experiment, you will be reminding yourself that lab safety is critically important. In addition, use your good judgment and pay close attention when performing potentially dangerous procedures. Just because the book does not say "Be careful with hot liquids" or "Don't cut yourself with a knife" does not mean that you can be careless when boiling water or using a knife to punch holes in plastic bottles. Notes in the text are special precautions to which you must pay special attention.

GENERAL SAFETY PRECAUTIONS

Accidents caused by carelessness, haste, insufficient knowledge, or taking an unnecessary risk can be avoided by practicing safety procedures and being alert while conducting experiments. Be sure to check the individual experiments in this book for additional safety regulations and adult supervision requirements. If you will be working in a lab, do not work alone. When you are working off-site, keep in groups with a minimum of three students per groups, and follow school rules and state legal requirements for the number of supervisors required. Ask an adult supervisor with basic training in first aid to carry a small first-aid kit. Make sure everyone knows where this person will be during the experiment.

PREPARING

- Clear all surfaces before beginning experiments.
- Read the instructions before you start.
- Know the hazards of the experiments and anticipate dangers.

PROTECTING YOURSELF

- Follow the directions step by step.
- Do only one experiment at a time.
- Locate exits, fire blanket and extinguisher, master gas and electricity shut-offs, eyewash, and first-aid kit.
- Make sure there is adequate ventilation.
- Do not horseplay.
- Keep floor and workspace neat, clean, and dry.
- Clean up spills immediately.
- If glassware breaks, do not clean it up; ask for teacher assistance.
- Tie back long hair.
- Never eat, drink, or smoke in the laboratory or workspace.
- Do not eat or drink any substances tested unless expressly permitted to do so by a knowledgeable adult.

USING EQUIPMENT WITH CARE

- Set up apparatus far from the edge of the desk.
- Use knives or other sharp-pointed instruments with care.

- Pull plugs, not cords, when removing electrical plugs.
- Clean glassware before and after use.
- Check glassware for scratches, cracks, and sharp edges.
- Clean up broken glassware immediately.
- Do not use reflected sunlight to illuminate your microscope.
- Do not touch metal conductors.
- Use alcohol-filled thermometers, not mercury-filled thermometers.

USING CHEMICALS

- Never taste or inhale chemicals.
- Label all bottles and apparatus containing chemicals.
- Read labels carefully.
- Avoid chemical contact with skin and eyes (wear safety glasses, lab apron, and gloves).
- Do not touch chemical solutions.
- Wash hands before and after using solutions.
- Wipe up spills thoroughly.

HEATING SUBSTANCES

- Wear safety glasses, apron, and gloves when boiling water.
- Keep your face away from test tubes and beakers.
- Use test tubes, beakers, and other glassware made of Pyrex™ glass.
- Never leave apparatus unattended.
- Use safety tongs and heat-resistant gloves.
- If your laboratory does not have heat-proof workbenches, put your Bunsen burner on a heat-proof mat before lighting it.
- Take care when lighting your Bunsen burner; light it with the airhole closed, and use a Bunsen burner lighter in preference to wooden matches.

- Turn off hot plates, Bunsen burners, and gas when you are done.
- Keep flammable substances away from flames and other sources of heat.
- Have a fire extinguisher on hand.

FINISHING UP

- Thoroughly clean your work area and any glassware used.
- Wash your hands.
- Be careful not to return chemicals or contaminated reagents to the wrong containers.
- Do not dispose of materials in the sink unless instructed to do so.
- Clean up all residues and put them in proper containers for disposal.
- Dispose of all chemicals according to all local, state, and federal laws.

BE SAFETY CONSCIOUS AT ALL TIMES!