Purpose

This lab serves as an introduction to the concept of limiting reagents in chemical reactions by providing hands-on experience with determining the limiting reagent in a reaction between an acid and a base. In addition, theoretical yield and percent yield of a reaction will be discussed.

Learning Objectives

- Reinforce the concepts of limiting and excess reagent(s), theoretical yield and percent yield.
- Practice determining real-world quantities of reagents needed to successfully perform a given chemical reaction.
- Perform calculations such as determination of limiting reagent, amounts of excess reagent remaining in industrial, pharmaceutical and environmental chemistry.
- Capture gaseous reaction products and measure the volumes of evolved gas.
- Reinforce the concept of Ideal Gas Law to calculate the amount of gas that is formed.

Discussion

Limiting Reagent and Excess Reagent

Understanding stoichiometry is a crucial, foundational skill of chemistry. Stoichiometry enables the use of molar coefficients from a chemical reaction to convert quantities into mass, which can then be measured and applied in the real-world scenarios.

As the molar coefficients are ratios, they can be scaled up and down to any size of reaction, from an introductory lab to multinational industrial labs. Importantly, if the masses used in the reaction do not properly match the stoichiometry, there will be a limiting reagent and an excess reagent. limiting reagent is a reactant in a chemical reaction that limits the amount of products that can be formed because it is used up entirely first, stopping the reaction and leaving behind the excess reagent(s). Excess reagent may be used in excess intentionally, however in many cases excess reagent is disposed of, wasting resources. Suppose 2.40 g Mg reacts with 10.0 g O_2:

$$2\,Mg + O_2 \longrightarrow 2\,MgO \qquad \text{(Reaction LR.1)}$$

There are a few steps to find out the limiting and excess reagents:

1. Stoichiometry of the reaction. Make sure your equation is balanced. In Reaction LR.1, 2 moles of Mg react with one mole of oxygen to produce 2 moles of magnesium oxide.
2. Convert the mass to mole.
3. Perform the calculation based on the reactants mole to determine how much product is produced.
4. The reactant that produces a smaller amount of product is the limiting reagent.
5. The reactant that produces a larger amount of product is the excess reagent.
6. Find the amount of remaining excess reactant by subtracting the mass of the excess reagent consumed from the total mass of excess reagent given.

Theoretical Yield and Percent Yield

You can calculate the theoretical yield by finding the amount (g) of product that theoretically is formed. The theoretical yield and actual yield of the reaction. Theoretical yield is the maximum amount of product (g) that would be produced from a given amount of the reactants considering stoichiometry of the reaction. The actual yield is the amount of product (g) that is actually produced during the reaction.

You can calculate the percent yield with the data you have obtained. Ideally, the actual yield would be equal to the theoretical yield, resulting in a percent yield of 100%. However, in reality, the actual yield is almost always less than the theoretical yield, resulting in a percent yield between 0% and 100%. A percent yield greater than 100% could indicate an error in calculation or experiment.

$$\text{Percent Yield} = \frac{\text{Actual Yield (g)}}{\text{Theoretical Yield (g)}} \times 100\% \qquad \text{(Equation LR.1)}$$

Ideal Gas Law

Gases are described by their pressure (P), volume (V), temperature (T), and number of moles (n). These properties are interrelated; the value of any of these properties is determined by the values of the other three. This means, for instance, that if you create a box of gas with a given pressure, volume, and number of moles of particles, then you cannot set the temperature to be any value you may want: the temperature is defined by the other three variables already. Historically, these four properties were investigated by determining the relationship between two of these properties, while holding the other two properties constant. These "mini" gas laws are summarized in Table LR.1:

Table LR.1: Mini Gas Laws

Charles's Law	$V \propto T\ (n, P \text{ constant})$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Boyle's Law	$V \propto \frac{1}{P}\ (n, T \text{ constant})$	$P_1V_1 = P_2V_2$
Avogadro's Law	$V \propto n\ (P, T \text{ constant})$	$\frac{V_1}{n_1} = \frac{V_2}{n_2}$
Combined Law	$V \propto \frac{T}{P}\ (n \text{ constant})$	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

Note that the Kelvin temperature scale must be used in these calculations. The overall equation relating all four properties is called the ideal gas law, seen here in Equation LR.2:

$$PV = nRT \qquad \text{(Equation LR.2)}$$

The gas constant, R has different values when used with different units of pressure and volume. When using the units of atmospheres and liters, $R = 0.08206$ L·atm/mol·K.

In this experiment, the students will collect the produced gas in a flipped graduated cylinder in a water basin in order to measure the volume of the gas produced and calculate the percent yield.

Equipment

- Plastic container filled 2/3 with tap water (NOT DI water)
- One 250 mL side arm Erlenmeyer flask with stopper (size 6)
- One 1000 mL waste beaker
- One 18″ length of tube attached to side arm flask with copper wire
- One 100 mL graduated cylinder
- One 50 mL graduated cylinder
- 250 mL volumetric flask
- 25 mL serological pipette with red pipet pump
- Weigh boats
- Kimwipes

Chemicals

- 40 mL acetic acid (5% white vinegar)
- Sodium bicarbonate (pure baking soda)
- ~450 mL of deionized water
- Bromothymol blue indicator in dropper bottle

Procedure

In this experiment you will add three different amounts of sodium bicarbonate, (0.25, 0.5 and 0.75 g) to acetic acid solution to react and record the collected gas volume. Each measurement will be repeated twice so in total you will have 6 trials.

1. Measure and record the room temperature.

2. Using a 250 mL volumetric flask, prepare a 0.5% acetic acid solution in DI water using the 5% vinegar stock solution provided. Be ready to prepare more if necessary to complete all trials.

3. Fill the plastic container 2/3 full with tap water. DO NOT USE DI WATER.

4. Lower the 100 mL graduated cylinder horizontally into the water until it is full. With the open end remaining in the water, lift the bottom of the cylinder up and attach it to the ring stand upside down as shown in Figure LR.1. Make certain there are no bubbles trapped in the cylinder. If bubbles are present, repeat the filling process.

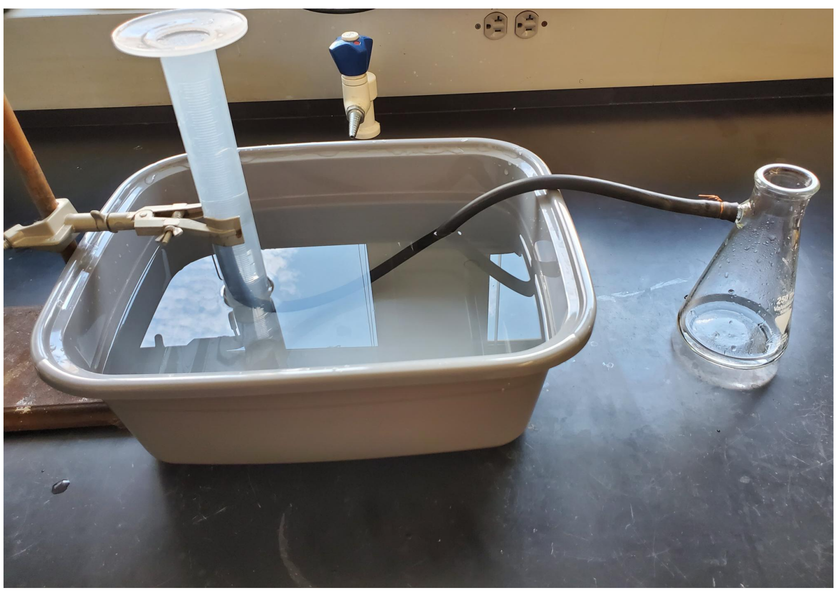

Figure LR.1: Set up for the reaction.

5. Run tubing from sidearm flask under water into the graduated cylinder. Check the tubing to make sure there is a tight connection to the flask.

6. Measure 40 mL of 0.5% acetic acid solution using a 50 mL-graduated cylinder and transfer into side arm flask.

7. Add 10 drops of bromothymol blue indicator into side-arm flask. Record the color of vinegar solution and take a photo.

8. Label 3 plastic weigh boats with 0.25 g, 0.5 g, and 0.75 g. Place ONE cut square piece of Kimwipe into each labelled weigh boat. Tare the weigh boat and Kimwipe on balance and measure the appropriate amount of sodium bicarbonate. Carefully fold the sodium bicarbonate and Kimwipe into a loose pellet. Keep the correct sized pellet in the appropriate weigh boat (Figure LR.2.

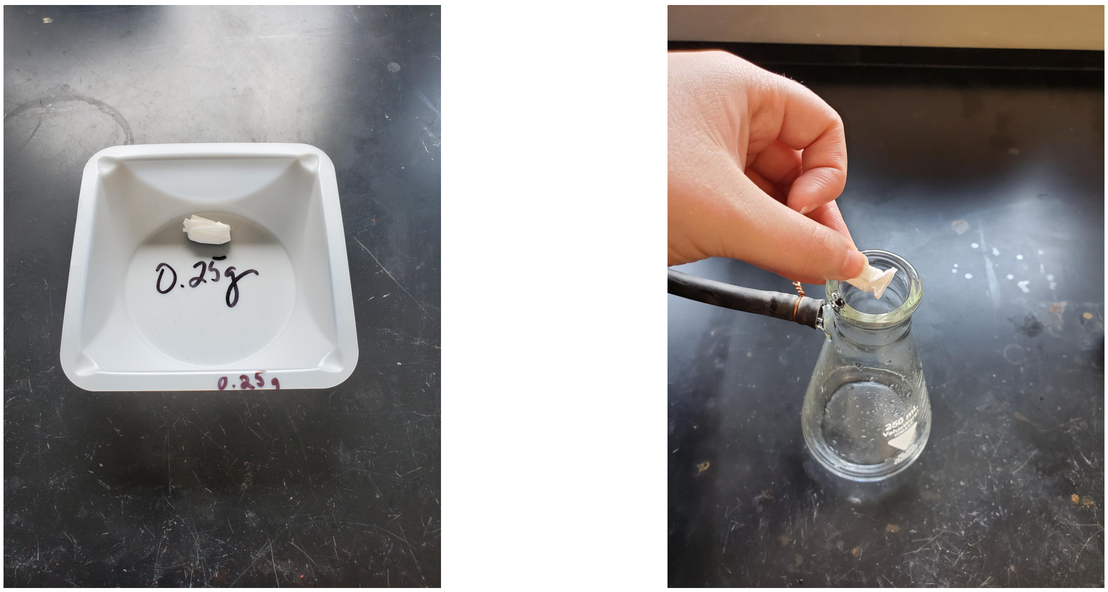

Figure LR.2: Left: measured sodium bicarbonate in the weight boat. Right: loose pellet to be added to the acid solution flask.

9. Add the first sodium bicarbonate pellet to the flask containing 0.5% acetic acid and bromothymol blue solution and promptly replace the stopper on the flask. Make sure the stopper is tight to avoid any gas escape.

10. Wait 10 seconds and begin swirling the flask vigorously. Bubbles will start to evolve and gather in the cylinder. Keep the end of the tube under the water line in the cylinder to be able to see the bubbles evolving. Continue swirling the flask until there are no more bubbles in the flask (5–7 min). Ensure there are no bubbles trapped under the Kimwipe. Gently shake the tubing to release any trapped bubble if needed.

11. Record the final volume of the gas generated by measuring the water displaced in the graduated cylinder.

12. Record the color of the solution in flask after the reaction is completed and take a photo.

13. Empty the reaction flask into the large, 1 L beaker at your station. Rinse the flask thoroughly three times with DI water.

14. Repeat steps 6–13 for the various masses of the sodium bicarbonate pellet for the remaining trial.

15. Dump liquid waste from the 250 mL flask into the appropriate carboy in the hood. Don't remove the Kimwipe as it will dissolve in the solution.

In-Lab Worksheet

Room temperature: ______ °C

Report Table LR.1: Data, Observations, and Initial Results

	Sodium bicarbonate (g)	Gas generated (mL)	Initial color of the solution	Final color after reaction completion	Limiting reagent, according to reaction color
Trial 1a	______	______	______	______	______
Trial 1b	______	______	______	______	______
Trial 1 average	______	______	NA	NA	NA
Trial 2a	______	______	______	______	______
Trial 2b	______	______	______	______	______
Trial 2 average	______	______	NA	NA	NA
Trial 3a	______	______	______	______	______
Trial 3b	______	______	______	______	______
Trial 3 average	______	______	NA	NA	NA

Upload one photo of each trial after you add the indicator and after the reaction.

1. Write the balanced equation for the reaction performed in this experiment.

    - Which chemical did you add to the flask first? What is the concentration?
    - What is the gas that evolves?
    - Which chemical did you weigh to add to the flask?

2. Determine the limiting reagent and excess reagent of each trial 1, 2 and 3 using the average gas volume. (Assume that the atmospheric pressure of the gas is 1 atm.)

Report Table LR.2: Limiting and Excess Reagent

	Average amount of sodium bi-carbonate available before reaction (mol)	**Amount of acetic acid available before reaction (mol)**	**Amount of gas generated (mol)**	**Limiting reagent based on gas volume**	**Excess reagent based on gas volume**	**Amount of excess reagent remaining after reaction (mole)***
Trial 1	___________	___________	___________	___________	___________	___________
Trial 2	___________	___________	___________	___________	___________	___________
Trial 3	___________	___________	___________	___________	___________	___________

* Assume 100% yield of gas

Upload an image of your calculations for preparing 0.5% acetic acid from 5% acetic acid.

Upload an image of your calculation for determining the limiting reagent and excess reagent.

Report Table LR.3: Percent Yield

	Theoretical yield of gas (mol)	**Percent yield (%)**
Trial 1	______________________	______________________
Trial 2	______________________	______________________
Trial 3	______________________	______________________

Upload an image of your calculations for determining the theoretical and percent yield for each trial.