Lab 4. Reaction of Hydrogen Peroxide and Bleach: Stoichiometry, Limiting Reagents and Percent Yield

Prelab Assignment

*Before* coming to lab:

- Use the handout "Lab Notebook Policy" as a guide to complete the following sections of your report for this lab exercise *before* attending lab: Title and Date of Lab, Introduction, Materials/Methods and Data Table (e.g. see the table 1 on page 2). An outline or flow chart of the procedure is appropriate for the Materials/Methods section. Ensure that the table of contents of your lab notebook is current.

**Purpose**

In this laboratory you will use the reaction of hydrogen peroxide with bleach to gain experience in the concepts of limiting reagent, theoretical yield, experimental yield and percent yield, and use MS Excel to do the calculations and to graphically represent these concepts.

**Introduction**

When *hydrogen peroxide* (H₂O₂, sold as a 3.0% w/v solution in water as a disinfectant for cuts) is mixed with *bleach* (the active ingredient is *sodium hypochlorite*, NaClO, sold as a 5.3% w/v solution in water) aqueous sodium chloride, water, and bubbles of oxygen gas are formed:

\[
\text{Hydrogen peroxide + Sodium hypochlorite} \rightarrow \text{Sodium chloride + Water + Oxygen}
\]

In this experiment, you will measure the volume of oxygen produced when known amounts of hydrogen peroxide solution are mixed with known amounts of bleach. You will predict, and then observe, how the volume of oxygen gas formed varies with the quantity of bleach or peroxide used. You will also calculate the expected (theoretical) yield of oxygen gas and compare that to the actual (experimental) yield.

The concentration units used above may be new to you. When the concentration of a solution is expressed as a w/v percent, it refers to the mass of solute per 100 mL of solution. For example, if a solution has a concentration of 5.0% NaCl (w/v), then there are 5.0 grams of NaCl per 100 mL of total solution. Notice that the denominator refers to the total solution volume (solute plus solvent) and not just to the solvent. It is understood that the solvent in this case is water.

There are two sets of experiments for this lab as shown in the table on the next page. In the first set, the volume of hydrogen peroxide is kept constant and the volume of bleach will vary. In the second set, the volume of bleach is constant and the volume of hydrogen peroxide will vary.

- How will the volume of oxygen gas produced vary in each case? Take several minutes to think hard about this. Then……..

- *Before coming to the lab*, express your hypotheses by *sketching two different graphs* in the introduction section of your lab report for this experiment. The first should show the volume of O₂ produced (y-axis) as a function of the volume of peroxide added (x-axis). The second graph should show the volume of oxygen produced as a function of the amount of bleach added. The graphs do not need to be precise since they are simply a visual reflection of your hypotheses about the experiment. *Below each graph, write a few sentences explaining your reasoning.*
Procedure

Table 1. The table below indicates the volumes of bleach and hydrogen peroxide to be used in each set of experiments. Half the class will perform set A, the other half set B. Your instructor will let you know which set you and your lab partner will perform.

<table>
<thead>
<tr>
<th>Run</th>
<th>Team data: Volume O₂ Produced (mL)</th>
<th>Class ave.: Volume O₂ Produced (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.0 mL</td>
<td>Run 1 1.5 mL</td>
</tr>
<tr>
<td>2</td>
<td>4.0 mL</td>
<td>Run 2 2.5 mL</td>
</tr>
<tr>
<td>3</td>
<td>4.0 mL</td>
<td>Run 3 3.5 mL</td>
</tr>
<tr>
<td>4</td>
<td>4.0 mL</td>
<td>Run 4 4.5 mL</td>
</tr>
<tr>
<td>5</td>
<td>4.0 mL</td>
<td>Run 5 5.5 mL</td>
</tr>
<tr>
<td>6</td>
<td>4.0 mL</td>
<td>Run 6 6.5 mL</td>
</tr>
<tr>
<td>7</td>
<td>4.0 mL</td>
<td>Run 7 7.5 mL</td>
</tr>
</tbody>
</table>

Before beginning, obtain the following items from the lab cart:

- Tweezers
- Small vial
- Rubber tubing
- Rubber stopper (one-hole #7) with glass tubing
- 250 mL Erlenmeyer flask
- Water trough

Directions

In this laboratory you are to work with a partner.

1. **Preparation of the oxygen collecting apparatus**: Fill a water trough with tap water. Remove the plastic end from a 100 mL graduated cylinder and then completely immerse the graduated cylinder in the water trough, filling it with water. Turn the cylinder upside down, keeping the mouth below the surface of the water in the trough. Clamp the cylinder onto a ring stand with enough room beneath it to slip a piece of rubber tubing into the mouth of the cylinder. At this point the up–ended graduated cylinder should be full of water (NO AIR BUBBLES) and securely fastened onto the ring stand. This is the oxygen–measuring vessel. Gas formed during the reaction will bubble into the up–ended graduated cylinder, where it will displace some of the water. You can then read the volume displaced directly from the graduations on the cylinder.

2. **Label two clean, dry 150 mL beakers**, one for bleach and one for hydrogen peroxide. Obtain approximately 45 mL of bleach (5.3% sodium hypochlorite) and 45 mL of hydrogen peroxide (3.0% $\text{H}_2\text{O}_2$).
3. Label two 10 mL graduated cylinders, one for bleach and one for hydrogen peroxide. Using a disposable pipette, transfer the designated amount of bleach (4.0 mL for Set A, reaction 1) into the 10 mL graduated cylinder. Since the experiments are to be semi-quantitative, it is necessary to measure the quantities exactly. Pour the bleach into the Erlenmeyer flask.

4. Measure out the designated amount of hydrogen peroxide (1.5 mL for Set A, reaction 1) into the second 10 mL graduated cylinder. Pour the hydrogen peroxide into the small vial, and then use tweezers to lower the vial into the Erlenmeyer flask, taking care not to tip over the vial. (See figure 1)

5. Again, taking care not to tip over the vial, stopper the flask with the #7 rubber stopper with glass tubing. Push it in firmly to form a good seal. Attach the rubber tubing to the glass tubing, and then place the loose end of the tubing into the mouth of the up-ended graduated cylinder. You may have to hold the tubing to prevent it from flopping around. Don’t worry if a bubble or two escapes from the tubing into the cylinder. (See figure 1)

6. Once the setup is complete as shown below in figure 2, jiggle the reaction flask until the vial tips over and spills the hydrogen peroxide onto the bleach. Swirl the flask to ensure complete mixing. Some reactions may finish quite rapidly, while others may take several minutes. Wait until the mixture in the flask stops fizzing and oxygen stops bubbling into the graduated cylinder, then record the amount of gas that was produced by reading the graduated cylinder. Remember that the cylinder is upside down when you read the markings. Your objective is to read the volume of gas (not water) in the cylinder.

Figure 1. It is very important that the vial’s exterior is completely clean and no residual liquid that is in the vial is present.

Figure 2. This is the complete setup. The graduated cylinder must held in place by clamping it onto a ring stand (not shown above) with enough space beneath it to slip a piece of rubber tubing into the mouth of the cylinder.
7. Empty the flask by pouring the reaction solution into your own ‘waste container’ at your desk. (Use a 250 mL beaker to collect the waste from the various reactions. When your beaker is full transfer the waste into the waste container in the hood.) Rinse the flask and vial several times with water (the flask and the vial do not have to be dry for the subsequent runs).

8. Repeat all of the reaction steps above for Reaction Sets A and B.

Analysis and Calculations

1. Prepare an Excel Spreadsheet: Begin by writing the balanced chemical equation for the reaction. Then prepare a spreadsheet using Excel that will calculate the mass and then moles of each reactant for each run of the experiment (see the sample table on the next page). (Sets A and B) Include a sample calculation in your lab notebook. Print two copies of the Excel spreadsheet and cut and paste a copy onto both the original and copy pages in your lab notebook.

Table 2. Sample data table and Excel spreadsheet format for reaction between H₂O₂ and NaClO

<table>
<thead>
<tr>
<th></th>
<th>Volume of Bleach (mL)</th>
<th>Volume of H₂O₂ (mL)</th>
<th>Mass of NaClO (g)</th>
<th>Mass of H₂O₂ (g)</th>
<th>Moles NaClO</th>
<th>Moles H₂O₂ (predicted)</th>
<th>Moles O₂ (predicted)</th>
<th>Volume O₂ (mL) (predicted)</th>
<th>Volume O₂ (mL) (actual)</th>
<th>% Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set A</td>
<td>Run 1</td>
<td>4.0</td>
<td>1.5</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 2</td>
<td>4.0</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Run 3</td>
<td>4.0</td>
<td>3.5</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Run 4</td>
<td>4.0</td>
<td>4.5</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Run 5</td>
<td>4.0</td>
<td>5.5</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 6</td>
<td>4.0</td>
<td>6.5</td>
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</tr>
<tr>
<td>Run 7</td>
<td>4.0</td>
<td>7.5</td>
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<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Set B</th>
<th>Volume of Bleach (mL)</th>
<th>Volume of H₂O₂ (mL)</th>
<th>Mass of NaClO (g)</th>
<th>Mass of H₂O₂ (g)</th>
<th>Moles NaClO</th>
<th>Moles H₂O₂ (predicted)</th>
<th>Moles O₂ (predicted)</th>
<th>Volume O₂ (mL) (predicted)</th>
<th>Volume O₂ (mL) (actual)</th>
<th>% Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>1.5</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run 2</td>
<td>2.5</td>
<td>4.0</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Run 3</td>
<td>3.5</td>
<td>4.0</td>
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<tr>
<td>Run 4</td>
<td>4.5</td>
<td>4.0</td>
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<td></td>
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<tr>
<td>Run 5</td>
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<td>4.0</td>
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<tr>
<td>Run 6</td>
<td>6.5</td>
<td>4.0</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Run 7</td>
<td>7.5</td>
<td>4.0</td>
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<td></td>
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</table>
Analysis and Calculations (cont.)

2. **Determine the Theoretical Yield (moles of O\(_2\))**: By looking at the balanced equation and the number of moles of each reactant, determine the theoretical yield (in moles) of oxygen gas for each run. You will not be able to enter a simple formula to do this since you must pay attention to which reactant is limiting. You can either enter two separate formulas, or enter the values manually. Include a sample calculation in your lab notebook.

3. **Determine the Theoretical Yield (mL of O\(_2\))**: Calculate the theoretical yield of oxygen gas in mL by assuming that every one mole of oxygen gas produced will occupy a volume of 24 L. We’ll learn why this is true later in the quarter. For now, just use this value to calculate the expected volume of oxygen produced in each run. Include a sample calculation in your lab notebook.

4. **Determine the % Yield**: Next to the column containing the theoretical yield of O\(_2\), enter the actual yield obtained from reading the graduated cylinder. Then, in the next column, calculate the percent yield. Don’t expect great results for the percent yield, as there are a number of places for error in this experiment. Still, it will be interesting to see if the actual results follow the trend that is predicted by the theoretical results. Include a sample calculation in your lab notebook.

5. **Create a Graph with Excel**: Lastly, create one graph with Excel that has two curves on it (one for the runs for Set A, the other curve for Set B) that you can use to test the two hypotheses you made before coming to lab. For the first curve, plot the experimental volume of O\(_2\) produced vs. the volume of H\(_2\)O\(_2\) used. For the second curve, use the bleach volumes instead of hydrogen peroxide. Label directly on the graph for Set A (i.e. the curve where the vol. of H\(_2\)O\(_2\) varies) where hydrogen peroxide is the limiting reagent and where hydrogen peroxide is in excess (not all of the reactant is consumed) then explain why the graph levels off.

6. As always, include a detailed discussion of your results in the Analysis of Results section of your lab report—do so by following the guidelines in the “Lab Notebook Policy” handout.

   - Are any of the % yields a little under or just above 100%? If so, give the most likely reason(s) that account for the runs that are just under or just above 100%.
   - It is not uncommon to have several runs with a % yield significantly above 100% due to one of the reactants being more concentrated than stated on the label. If this is the case you must…
     - Explain why some of the runs have a % yield significantly greater than 100%, using specific experimental data to support your response.
     - Correctly identify which solution is responsible for some of the runs having a % yield more than 100%, being careful to use specific experimental data as support.
     - Correctly calculate the true concentration of the solution responsible for yields being greater than 100%.
Lab Report Guidelines
As indicated previously, be sure to include all your lab data and calculations in your report, according to the guidelines in the “Lab Notebook Policy” handout. Below is a checklist of what should appear in each of the 5 sections of your lab report.

Lab 4 Report Checklist

1. Introduction
   - Goals/purpose of the lab is stated clearly?
   - Includes summary of background information (e.g. w/v %)
   - Includes the balanced chemical equation for the reaction?
   - Includes graphs of hypothesis and reasoning?

2. Materials and Methods
   - Procedure is brief, but detailed enough that a competent student could use it to replicate the experiment?
   - Uses own words—doesn’t plagiarize the procedure from the handout?

3. Results
   - Ruled and easy to read data table(s)?
   - Data table(s) are numbered consecutively and each one has an informative caption?
   - All or most data summarized in one table?
   - Correct use of Sig figs?
   - Correct use of Units?

4. Analysis of Results
   - Uses Excel spreadsheet for all calculations?
     o Uses correct sig figs and units?
     o Excel spreadsheet is cut and pasted onto both the original and copy pages in lab notebook?
   - Includes sample Calculations?
   - Excel Graphs:
     o $V_{O2}$ vs. $V_{Bleach}$
     o $V_{O2}$ vs. $V_{H2O2}$
     o Both curves on the same graph?
     o Explains why the curves level off?
     o Correctly labels directly on the graph for Set A where $H_2O_2$ is limiting and in excess?
     o Excel graph is cut and pasted onto both the original and copy pages in lab notebook?
   - Error analysis
     o Discusses why % yields are just under, just over or significantly over 100%? Uses specific experimental data as support?
     o Correct ID of solution(s) with inaccurate concentration? Uses specific experimental data as support?
     o Correctly calculates the concentration of the solution(s) responsible for % yields significantly over 100%?

5. Conclusion
   - Uses “bullets” to summarize concisely the major conclusions?
   - Quotes specific experimental results?
   - Summarizes sources of error?

Overall quality: the report is neat, easy to follow, uses proper format, completed at a depth appropriate for a college chemistry class?
**Lab 4 Prelab Questions**

**Reaction of Hydrogen Peroxide and Bleach**

**Instructions:** Complete the following questions and hand in at the start of your lab period. Show your work with units and correct significant figures for all questions that involve a calculation—no work, no credit. _Circle all numerical answers._

1. Do the calculations below for run 4 of Set A and enter your answers in the following table.

<table>
<thead>
<tr>
<th>Set A</th>
<th>Volume of 6.0% Bleach (mL)</th>
<th>Volume of 3.0% H₂O₂ (mL)</th>
<th>Mass of NaClO (g)</th>
<th>Mass of H₂O₂ (g)</th>
<th>Moles NaClO</th>
<th>Moles H₂O₂</th>
<th>Limiting Reactant</th>
<th>Moles O₂ (predicted)</th>
<th>Volume O₂ (mL) (predicted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 4</td>
<td>4.0</td>
<td>4.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

a) Write the balanced chemical equation for the reaction between bleach (an aqueous solution of sodium hypochlorite) and hydrogen peroxide. _Include the physical states of all reactants and products._

b) Calculate the mass in grams of sodium hypochlorite in 4.0 mL of a 6.0 % (m/v) bleach solution. _Circle your answer and enter it in the table above._

c) Calculate the mass in grams of hydrogen peroxide present in 4.5 mL of a 3.0 % (m/v) hydrogen peroxide solution. _Circle your answer and enter it in the table above._

d) Use your answer in part b above to calculate the moles of NaClO present in 4.0 ml 6.0% NaClO. _Circle your answer and enter it in the table above._

e) Use your answer in part c above to calculate the moles of H₂O₂ present in 4.5 ml 3.0% H₂O₂. _Circle your answer and enter it in the table above._

f) What is the limiting reactant in the reaction between 4.0 ml 6.0% NaClO and 4.5 ml 3.0% H₂O₂? _Explain your reasoning and enter your answer in the table above._

g) If the reaction in run #4 goes to completion, calculate the maximum number moles of oxygen gas and its volume in mL that the reaction could produce. Assume 1 mol of a gas at room conditions occupies 24L. _Circle your answers and enter them in the table above._