The Decomposition of Potassium Chlorate

Small quantities of molecular oxygen ($O_2$) can be obtained from the thermal decomposition of certain oxides, peroxides, and salts of oxoacids. Some examples of these reactions are

\[
\begin{align*}
2 \text{Ag}_2\text{O}(s) & \rightarrow 4 \text{Ag}(s) + O_2(g) \\
2 \text{BaO}_2(s) & \rightarrow 2 \text{BaO}(s) + O_2(g)
\end{align*}
\]

The reaction that will be studied in this experiment, the decomposition of potassium chlorate, ($\text{KClO}_3$) includes manganese(IV) oxide ($\text{MnO}_2$) as a catalyst to ensure that the reaction goes to completion. A **catalyst** is a substance that causes an increase in the rate of a chemical reaction without being used up in the reaction. It is this

The identity of the solid that remains after the decomposition can be determined from the quantity of oxygen that is evolved. Identification can then be made by comparing the measured mass of the solid product with a calculated value based on the quantity of $O_2$.

There are several possibilities of solid product that could result from the thermal decomposition of $\text{KClO}_3$. $\text{KClO}_2$ (potassium chlorite), $\text{KClO}$ (potassium hypochlorite) or $\text{KCl}$ (potassium chloride) as final product would give different amounts of $O_2$. This experiment will investigate these possibilities. The three reactions that could possibly occur can be written and balanced based on these predictions.

A sample of $\text{KClO}_3$ of known mass will be heated with $\text{MnO}_2$ a catalyst until the evolution of oxygen is complete. Oxygen will be collected in a flask by the displacement of water. The volume of water displaced equals the volume of $O_2$ gas produced. In order to determine the correct stoichiometry of this reaction, **you will need to obtain the number of moles of $O_2$ that have been evolved.** You can calculate this quantity from the rearranged form of the ideal gas law:

\[
n = \frac{PV}{RT}
\]

where $P$ refers to the **partial pressure of oxygen** in the collected gas mixture, $V$ is the volume of water displaced, $T$ is the Kelvin temperature of the gas mixture, and $R$ is the constant. A commonly used value for $R$ is 0.082056 L·atm/mol·K. If this value for $R$ is used, then $P$ must be expressed in atmospheres and $V$ in liters.

Since the oxygen is collected over water, water vapor will also be present in the gas. The experiment is designed so that the total pressure of the oxygen and water vapor will be equal to the atmospheric pressure:

\[
P_{\text{Total}} = P_{O_2} + P_{\text{H}_2\text{O}}
\]
you can easily measure atmospheric pressure with a barometer. **The partial pressure of oxygen in the flask can be calculated by subtracting the vapor pressure of water from the atmospheric pressure.** Table I gives the vapor pressure of water at various temperatures.

Figure I shows the apparatus for this experiment. The sample of KClO₃ is placed in the test tube and the Erlenmeyer flask is filled with water. Some of the water is displaced by oxygen and is pushed into the beaker. The volume of water in the beaker will be identical to the volume of oxygen in the flask.

**Procedure**

1. Record the atmospheric pressure from the laboratory barometer. This will equal the pressure of the \((O_2 + H_2O)\) gas mixture that develops in your Erlenmeyer flask.

2. **Caution:** KClO₃ is a very strong oxidizing agent. Make certain you place the lid back on the bottle containing the KClO₃ after you obtain your sample. Do not let this substance contact paper or the rubber stopper in the test tube of the apparatus. Clean any spills with a damp paper towel and rinse down the drain.

3. Make sure that the side-arm test tube is clean and dry. Take the test tube (supported in a 400-mL beaker) to the top-loading balances. Fill a sample vial with KClO₃. Weigh about 1.0 g into the side-arm test tube by difference (using a paper collar). A sample in the range of 0.9 g to 1.1 g of KClO₃ will work. Record the mass to 0.1 mg.

4. In a 50-mL beaker, place about 0.5 g of MnO₂. Record the mass of the beaker and MnO₂ to 0.1 mg (paper collar). Carefully pour the MnO₂ into the side-arm test tube and weigh the beaker again. The difference is the amount of catalyst added. This will be subtracted from the final mass to determine mass of solid **product**. Mix the solids thoroughly by shaking.

5. Place the rubber tubing on the side-arm securely. A drop of water on the side-arm will help. Clamp the test-tube to the ringstand and stopper the test tube.

6. Assemble the apparatus as shown in Figure I. Record the weight of the clean, dry 400-mL beaker on a top-loading balance. Set the beaker aside and use a different beaker in the next step.

7. Fill the Erlenmeyer flask with distilled water, so that the level of the water is about 1 inch below the short glass tube. Open the pinch clamp. Replace the stopper in the test tube with a check valve. Use a suction bulb to force air through the valve until the rubber tube is filled with water and siphons over to the beaker. Allow a little water to enter a beaker. Remove the check valve.

8. Lift the beaker with your hands until the water level in the Erlenmeyer flask is near the top of the flask. Close the pinch clamp and the stopper the test tube. This equalizing
process will ensure that the pressure acting on the water in the beaker (atmosphere) is equal to the pressure acting on the water in the flask.

9. Replace the beaker with your clean, dry 400-mL beaker from step 6.

10. Place the rubber tubing into the beaker and **open the pinch clamp**.

    Caution: If the clamp is not opened at this point, the build-up of gas during heating could cause an explosion, although it is more likely that a stopper would be forced to loosen. Also, make certain that the longer glass rod is not touching the bottom of the Erlenmeyer flask. This would also result in a closed system and an explosion could result.

11. Heat the test tube. Be cautious at first and brush the flame over the test tube. The solid will melt, oxygen will be evolved, and water from the flask will be displaced into the beaker. After a few minutes when the liquid solidifies, the test tube can be heated more strongly. One gram of KClO₃ reactant should cause the displacement of between 250 and 300 mL of water.

12. Heat the solid thoroughly until no more gas is evolved. The contents of the test tube will solidify, since the melting point of the product is greater than that of KClO₃.

13. Turn off the flame and allow the system to come back to room temperature. Allow five minutes for this process.

14. **Keeping the stopper in the test tube**, equalize the water levels (this may require lifting the Erlenmeyer flask) and close the pinch clamp.

15. Remove the tube from the beaker (making sure not to allow any water to come out of the rubber tubing). Record the mass of the beaker plus the water on a top-loading balance. Use Table I to determine the volume of water displaced.

16. Measure the temperature of the water to the nearest degree. Assume this is the temperature of the gas. Determine the appropriate vapor pressure of water from Table II.

17. Obtain the mass of the test-tube and its contents. Calculate and record the mass of the product (remember to subtract the mass of the MnO₂).

18. Repeat with a new sample of KClO₃ and catalyst for a second trial. If time permits, run a third trial **without** the catalyst.
Table I  Density (g/mL) of Water at Various Temperatures (° C)

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Table II  Vapor Pressure of Water (torr) (data from the CRC Handbook of Chemistry and Physics, 49th edition, 1968.)

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Questions

1. Write a **balanced** chemical equation for each of the three possible reactions that could occur when **potassium chlorate**, KClO$_3$ is thermally decomposed.

2. Suppose the atmospheric pressure when you performed your experiment was 751.6 torr. The temperature of your water was found to be 23.0°C. What is the pressure of the oxygen gas, P$_{O_2}$, that is produced?

Data Treatment

1. Determine (for trials 1 and 2):
   a. moles of oxygen that were produced.
   b. moles KClO$_3$ that were reacted.
   c. ratio of the number of moles of oxygen to the number of moles of KClO$_3$.

   Write the chemical equation for the reaction that the data suggest occurred.

2. Using the mass of reactant KClO$_3$ that you used in your most successful trial, calculate how many grams of each of the solid products of each possible reaction would theoretically be produced in the decomposition. Which decomposition reaction occurred, **based on the mass of solid generated in the reaction**? Write the chemical equation for the reaction that the data suggest occurred:

3. You determined which chemical reaction occurred by analyzing the amount of gas produced in the reaction, and the mass of solid product remaining after reaction. Which determination method do you believe is more reliable, the analysis of the mass of the solid product or the analysis of the gas produced? Explain your answer.

4. You did not use a catalyst in the third trial. Did you get the same products for this reaction as you did with the catalyst?