Kinetics of Hydrogen Peroxide Decomposition

Investigation Questions

- Do iron (III) chloride, potassium iodide, or potassium chloride catalyze the decomposition of hydrogen peroxide?
- What is the order of the decomposition of hydrogen peroxide with respect to catalyst and hydrogen peroxide?

Introduction

The reaction you will be studying in this experiment is the decomposition of hydrogen peroxide. The overall equation for this reaction is

$$2\ H_2O_{2\,(aq)} \rightarrow O_{2\,(g)} + 2\ H_2O_{(l)} \qquad (1)$$

Kinetics Background

Rate laws give a description of how a reaction behaves with particular beginning concentrations of reactants. For our reaction, the rate law is:

$$\text{Rate} = k[H_2O_2]^m[\text{catalyst}]^n$$

In this equation, k is the rate constant, while m and n are reaction orders.

We will be using initial rates as a function of concentrations to determine the order of the decomposition of hydrogen peroxide with respect to catalyst and hydrogen peroxide. The following example will walk you through the method for doing this.

Consider the imaginary reaction:

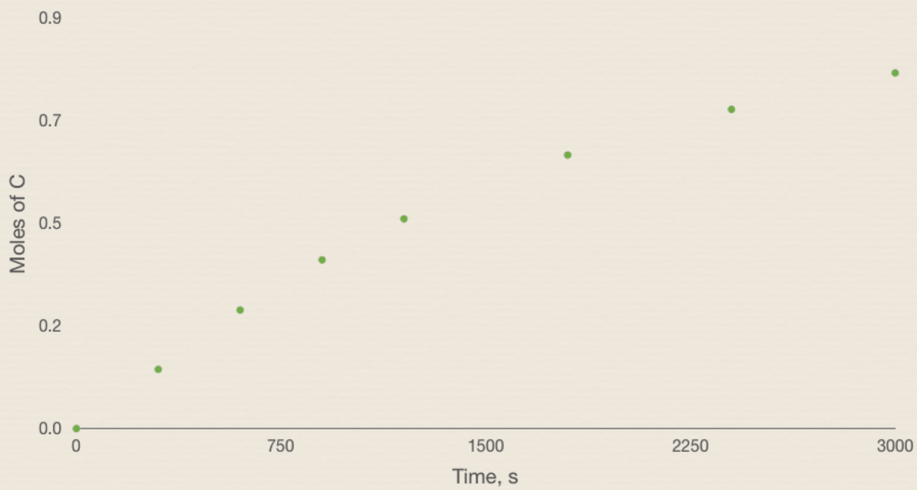
$$A + B \rightarrow C$$

The rate law for this reaction is written as:

$$\text{Rate} = k[A]^m[B]^n$$

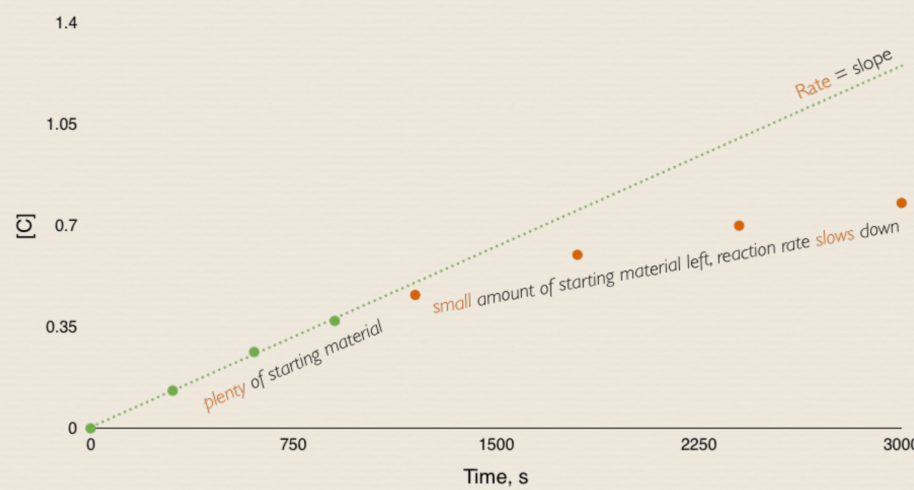
Let's say you chose to use 0.100 M of A and 0.100 M of B for your first reaction and you measure the formation of C. Your results are:

Time, sec	Moles of C
0	0.000
300	0.130
600	0.260
900	0.370
1200	0.460
1800	0.600
2400	0.700
3000	0.780



In order to determine the initial rate of this reaction, we want to consider the part of the curve where the concentration of reactants is still so large that the amount being used up to create products is insignificant. What this means in terms of the above graph, is that we want the beginning part of the graph that is linear. Once the plot starts curving, we know that the rate is being affected by the decrease in amount of reactant. In the above graph, visual inspection shows that the time from 0 to 900 seconds is linear. Fitting a trend line for the linear reaction gives:

Time, sec	Moles of C	Moles of C (for initial rate)
0	0.000	0.000
300	0.130	0.130
600	0.260	0.260
900	0.370	0.370
1200	0.460	
1800	0.600	
2400	0.700	
3000	0.780	



Our slope gives a rate of 4.19×10^{-4} mol/s.

Now we can consider what to do to determine the order of the reaction. You should know the following from lecture:

Order of Reaction	Effect on Rate of Doubling Concentration of Reactant
0	none
1	doubles
2	quadruples

Let's say you double the concentration of A so that it is 0.200 M and leave the concentration of B at 0.100 M. You run the reaction as before and get a rate of 8.00 x 10^{-4} mol/s. According to the table above, that means the reaction is first order with respect to A. Now, let's say you double the concentration of B and leave A at 0.100 M and get a reaction rate of 16.00 x 10-4M. According to the table above, that means the reaction is second order with respect to B. Our rate law is now:

$$\text{Rate} = k[A][B]^2$$

You will do similar calculations for the reaction you are examining today.

Catalyst Background

Even people with very little knowledge about cars (for example, the person writing this introduction) know that a car has something called a catalytic converter. This is a gadget in the car that catalyzes some redox reactions important for reducing the impact of auto use on our environment:

$$2\ NO_x \rightarrow x\ O_2 + N_2$$

$$2CO + O_2 \rightarrow CO_2$$

Combustion of hydrocarbons to CO_2 and H_2O

A substance that catalyzes a reaction, speeds the process without being permanently changed. So if a car doesn't have a catalytic converter, NO_x, CO and hydrocarbons would not undergo the above redox reactions and would build up even more so in the atmosphere. This would not be a good scenario since these substances are toxic.

When a catalyst is involved in a reaction, it is often a multistep reaction. Since we are only trying to determine the rate law for the rate determining (or slowest) step, we include the catalyst in the rate law.

Today you will be looking at decomposition of hydrogen peroxide. This is a spontaneous, but slow reaction. We'll speed it up by using a catalyst and determine the rate law for the slowest step in the reaction.

Procedure Background

The progress of this reaction can be followed by capturing and measuring the volume of oxygen gas given off as the reaction proceeds. Figure 1 shows a simple apparatus for capturing and measuring the volume of oxygen given off during the reaction. The flask you are using is a 250-mL filter flask. Amber tubing connects the side arm of the flask to an adaptor attached to the top opening of a burette tube. The bottom of the burette tube is connected to a plain glass tube by a short piece of tubing. This apparatus is filled with water to a convenient mark on the burette scale such as the 10-mL mark. The plain glass tube is open at the top so the water in this tube is free to move. Initially the level of water in the burette and the level of water in this plain tube are the same.

You will start a reaction by adding the measured reactants into the flask. When the last reactant is added you will stopper the flask so the oxygen that is generated moves from the flask into the burette and pushes on the water in the burette tube. As it pushes on the water it attempts to keep the pressure the same as the atmospheric pressure and some of the water is pushed into the plain glass tube. The gas volume increase in the closed flask-burette system can be read from the markings on the buret.

VERY IMPORTANT: <u>Do Not Change the Stirring Speed During the Experiment!!!</u>

Figure 1. Apparatus for measuring the volume of oxygen gas

When the water is pushed into the plain glass tube the pressure on the gas in the flask-burette system is increased slightly. This causes the volume of the gas to be slightly smaller than it would be at atmospheric pressure; however the difference is small enough that it can be ignored for this experiment.

Part 1: Some Preliminary Experiments

You will work in pairs for the entire experiment.

Investigate

One of your investigation questions is:

- Do iron(III) chloride, potassium iodide, or potassium chloride catalyze the decomposition of hydrogen peroxide?

You will answer this question during this part by doing some quick tests with small amounts.

Equipment

Small test tubes

Chemicals and Safety Information (for Parts 1-2)

WEAR GLOVES, SAFETY GLASSES AND LAB COAT WHEN WORKING IN LAB.

Compound	Hazards
3% hydrogen peroxide $H_2O_{2\ (aq)}$	May cause skin or potentially severe eye irritation
0.5 M potassium iodide $KI_{(aq)}$	May cause eye and skin irritation
1.0 M potassium chloride $KCl_{(l)}$	May cause mild irritation
0.1 M iron (III) chloride $FeCl_{3\ (aq)}$	May cause irritation and possible burns

Experimental Procedure

a. You will test the following to see if they will catalyze the decomposition of hydrogen peroxide:

   0.5 M KI

   1.0 M KCl

   0.1 M FeCl3

b. Record observations *before*, *during* and *after* the addition of potential catalyst.

Experiment	Before	During	After
description	*observation*	*observation*	*observation*

c. Add about 2 mL of potential catalyst to about 2 mL of hydrogen peroxide in a small test tube for each test.

Enter your results in a class data table for use in the Analysis Question Discussion. Include the class data table for part 1 in your ELN report.

Waste Disposal

All waste solutions from this experiment can be properly disposed of by pouring down the sink.

Analysis Questions Part 1

Your TA will guide you in a class discussion to answer the following questions.

1. How could you tell if the potential catalyst was speeding up the reaction? What happened if the potential catalyst had no effect on the decomposition of hydrogen peroxide?
2. Which of the three solutions was most effective in increasing the rate of decomposition of hydrogen peroxide?
3. Which was least effective?
4. These solutions are all strong electrolytes. Which ion is most effective in increasing the rate of decomposition of hydrogen peroxide?
5. Were any other ions also effective at increasing the rate of the reaction?
6. Did any of the ions show no effect at all?

Part 2: Measuring the Rate of Catalyzed Decomposition of Hydrogen Peroxide

Investigate

During Part 2, you will use the catalyst that your class decided was most effective to answer the second investigation question:

- What is the rate law for the catalyzed decomposition of hydrogen peroxide?

As mentioned in the introduction, the rate law for this reaction is:

$$\text{Rate} = k[H_2O_2]^m[\text{catalyst}]^n$$

Your job is to find determine the rate at various concentrations of hydrogen peroxide and catalyst and then use that information to find m, n and k.

Equipment

- 10-ml measuring pipet
- 250-ml filter flask
- stir bar
- gas measuring apparatus (shown in Figure 1)
- timer

Experimental Procedure

Helpful Information: You will need to determine how to vary the amounts of hydrogen peroxide and catalyst in order to get the information you need to determine the reaction orders. Reading the procedure carefully and making a plan BEFORE you come to class will make the experiment go much more smoothly and give you better data.

A general guide to the volumes of solutions you should consider using is summarized here.

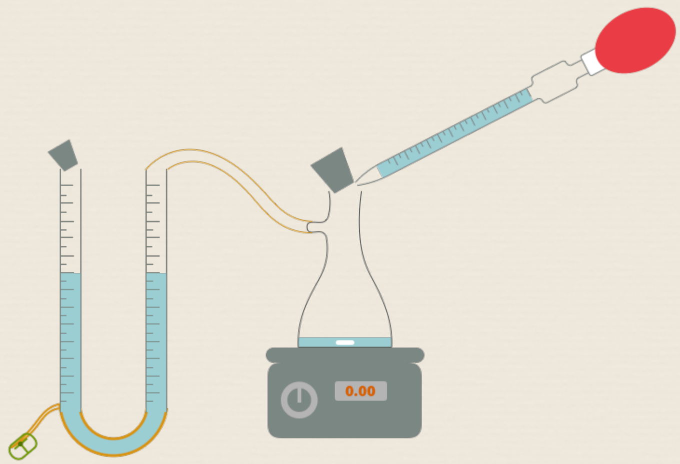
- use volumes from 5 up to 15 mL of 1 M H_2O_2
- use volumes from 2 up to 6 mL of the catalyst solution
- use a total solution volume between 15 mL to 30 mL
- all reactions should have deionized water added to keep total volumes the same.

a. Make a table in your ELN which shows what volumes you will use of hydrogen peroxide, catalyst, and deionized water.
   i. Plan what volumes you will use to start with for each and enter this into your table.
   ii. Plan what volumes you will change for the next run of the reaction. Be sure that these volume changes are meaningful and that your total volume is kept constant.
   iii. Plan what volume change your will use for your last run. Be sure that these volume changes are meaningful and that your total volume is kept constant.

b. Also make a table in Google Sheets for recording time and volume of oxygen produced for run.

c. Get your apparatus ready
   i. Make sure the stopper in the Ostwald burette is removed and that it is filled with deionized water to approximately 10 mL.
   ii. Clean and rinse the filter flask VERY carefully since many substances catalyze the decomposition of hydrogen peroxide.
   iii. Make sure you have a clean stir bar in your filter flask since you need to stir the reaction to keep production of oxygen steady.
   iv. Place the filter flask on a magnetic stirrer (NO HEAT) and connect to Ostwald burette as shown in figure 1.

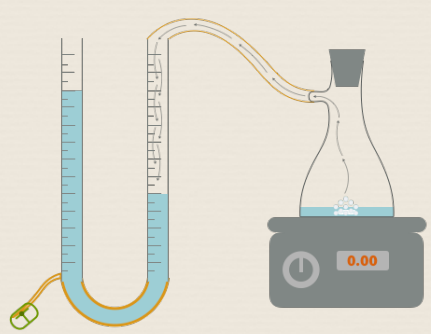
d. Run your reaction
   i. Have the stir bar stirring at a moderate speed.
   ii. Using the most accurate and precise volume measuring device you have available, put the required amount of deionized water in your filter flask.
   iii. Do the same for the catalyst.
   iv. Before starting record the volume in the Ostwald burette. This will be your zero time volume and should be recorded in your Google Sheets table.
   v. Add the required amount of hydrogen peroxide and stopper flask immediately. Simultaneously start the timer.



vi. Record the elapsed time as the volume of oxygen captured in the burette just passes the ½ mL and full mL markings on the burette. This will be much easier than attempting to read the volume of gas in the burette at precise time intervals.

vii. Record the time and mark readings for 10 minutes (600 seconds) or until you have captured at least 30 mL of oxygen, whichever comes first.

viii. Repeat for each run.



Waste Disposal

All waste solutions from this experiment can be properly disposed of by pouring down the sink.

Analysis Questions Part 2

Do as much of the analysis as you can before the post lab discussion.

1. What do you need to plot in order to determine initial rates for each of your reaction runs? Go ahead and make these plots in Google Sheets for each of your runs.
2. Determine the initial rate for each of the runs. (see introduction if you're not sure how to do this) The units will be strange since we are recording volume of product instead of moles of product. Since volume of gas is directly proportional to moles, this still works.
3. How do the initial rates vary as amount of each reactant is varied? What does this tell you about reaction orders? Determine m and n for the reaction. How do the initial rates vary as amount of each reactant is varied? What does this tell you about reaction orders? Determine m and n for the reaction.
4. Determine k for each of your runs (see introduction if you're not sure how). As mentioned in question 2, your units will be strange.
5. For each run, enter the following information into a class data table:

   Volume of hydrogen peroxide (mL)

Volume of catalyst (mL)
Total volume (mL)
Initial rate (k)

The class data table should be included in your ELN report and will be used for the post lab discussion.

Post Discussion Questions

- To review:
  - Which of the provided solutions served as a catalyst for the decomposition of hydrogen peroxide? What evidence do you have?
  - Which ions in the provided solution caused the catalytic effect? What evidence do you have?
- What is the order of the reaction with respect to hydrogen peroxide and catalyst?
  - What data and observations did you use to determine this rate law?
- Did everyone is the class get similar results?
  - If not, what were some SPECIFIC possible sources of error?

Finishing Up

Create a heading that says "Reflective Writing" and complete the reflective writing portion of your lab notebook after lab class. See the ELN rubric (below) for details about what to include.

Submit your lab report by clicking on the "Submit" button within your LabArchives at the top of your ELN using the assignment link given in the content area labeled "Week 1" on Canvas. The assignment link is labeled "ELN".

REMEMBER TO LOGOUT BEFORE YOU LEAVE.

Remember to take your **post-lab quiz** for this lab and the **pre-lab quiz** for the next lab by the appropriate deadlines (below).

Deadlines

	Deadline	Points
Pre-lab Quiz	BEFORE performing the experiment	20
Pre-lab Writing	BEFORE coming to lab class	Part of ELN Report
ELN Report	11:59 PM the third day after performing the experiment	40
Post-lab Quiz	BEFORE performing the NEXT experiment	40

ELN Rubric

Category	Requirements	Points
Basic	**What to look for: if any one of these is missing, it will be zero points.** • *Title of the experiment* • *Partner's name* • *Use of headings*	**0-1**
Pre-lab Writing	**This section MUST be completed before lab as evidenced by timestamp. Any part that is copied and pasted from the lab manual will receive zero points. Everything in this section must be rewritten in your own words.** Student must include: • *(2 pts) Restate investigation questions* • *(3 pts) Experimental procedure (use numbered list)* • *(2 pts) List of safety hazards specific to this experiment*	**0-7**
TA Points	**TA choice** *Includes lab cleanliness, respectful behavior.*	**0-4**
Procedure Changes, Raw Data Recording, Observations	**This section MUST have lab period timestamp.** • *Any changes from the procedure described in the procedure list are noted (please refer to the number in the list for easy referral). Please list ONLY changes to the general procedure.* • *Raw Data and Observations: any tables, observations, measurements, etc. indicated in the lab reading must be included in this section.*	**0-6**
Analysis & Data Manipulation	**This section might be completed outside the lab period.** *Answers to ALL analysis questions are given. Any required calculations are given and work is shown.*	**0-10**

Reflective Writing	**This section might be completed outside the lab period.** • *(7 pts)* ***Explain:*** *ALL Post Discussion Questions are answered and justified using data and observations.* • *(2 pts)* ***Evaluate:*** *Discussion of whether answers to Investigation Questions and Post Discussion questions make sense based on what students have learned in lecture. Specifically:* ‣ *Are your conclusions consistent with what is expected?* ‣ *Are your results consistent with your entire class? If not, why not?* ‣ *What would you do differently in order to get even better results? Saying anything that has to do with "human error" will not receive any credit.* • *(3 pts)* ***Extend:*** *Discussion of how what was learned in lab ties in with anything related to your major (or other scientific field if this does not apply to your major). Two specific examples must be shown (this might require some independent literature search).*	**0-12**