Kinetics of Catalyzed Decomposition of Hydrogen Peroxide

ACS Chemistry Laboratory Supplement Project-Based Labs

An Open Inquiry Experiment

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LEARNING OBJECTIVES

The objectives of this experiment are to . . .

- introduce the concepts and units of pressure, catalysts and kinetics.
- use pressure to monitor the kinetics of the catalytic decomposition of hydrogen peroxide, H_2O_2, using the ***MicroLAB*** interface system to collect and analyze the data.
- experimentally determine which catalyst is most effective, using the ***MicroLAB*** interface system to collect and analyze the data.

INTRODUCTION

You have been asked by a local high school teacher to help develop a lab experiment for his class. The purpose will be to enable students to investigate the catalyzed decomposition of hydrogen peroxide, H_2O_2. Different conditions and different catalysts, including enzymes and inorganic substances, are to be investigated. The teacher has a limited budget and knows that purchasing pure enzyme preparations is out of the question. You do a little research and find out that catalase, an enzyme that decomposes H_2O_2, is found in many simple biological materials such as yeast, potatoes, turnips, blood, and liver. It also happens that one of your colleagues has some purified enzyme available in her lab and is willing to supply you with a small amount of potato catalyzes in case you wish to try reactions with the purified enzyme. H_2O_2 is inexpensive and readily available in drug stores and supermarkets. It also can be decomposed with a variety of inorganic catalysts, such as potassium iodide, manganese dioxide and iron salts.

Once you understand the relationships among the different catalysts, different conditions, and the decomposition of hydrogen peroxide, you will be able to help the teacher design an experiment that is suitable for a beginning high school class studying kinetics. Keep in mind that safety and economy are important concerns. Your report should contain suitable information for the high school students and enough detail for the high school teacher to prepare and evaluate the experimental results.

PROJECT TASKS

Some of these tasks will be accomplished experimentally and some by library or web-based research in appropriate resources.

1. Investigate the effects of different catalysts, different concentrations and different temperature conditions on the decomposition of hydrogen peroxide.
2. Write a guided-inquiry lab experiment suitable to use with beginning high school students studying kinetics.
3. Write a teacher's guide that gives possible procedures, expected outcomes, and suggested grading scales for student lab reports.
4. Suggest suitable extensions to the experiment that could be used with advanced high school chemistry students.

LEARNING AND PERFORMANCE OBJECTIVES

1. Assemble appropriate equipment to obtain data.
2. Record data and observations accurately.
3. Collect and record data over specific time intervals.
4. Graphically represent data and develop an equation that describes the curve obtained.
5. Determine the rate of reaction with a gaseous product.
6. Determine the rate equation for the reaction.
7. Determine those factors affecting the rate of reaction, including the nature of the catalyst, the pH of the reaction mixture, the mixture's temperature, and others of your choosing.
8. Compare and contrast enzymatic and inorganic catalytic decomposition of H_2O_2.
9. Write a set of guided inquiry lab directions suitable for a beginning high school class.
10. Write a teacher's guide to accompany the student lab experiment.
11. Suggest extensions suitable for advanced students, such as determining the activation energy of the reaction.

Resources Available

1. Suggestions for measuring the rate of the reaction.
2. Considerations for control of variables.

Reports

1. Planning sheets are to be completed as directed by your instructor.
2. You will write two reports for this Experiment.

The first report will be written for the laboratory instructor and illustrate your understanding of Chemical Kinetics. It should include:

1. A cover sheet with a one paragraph abstract summarizing the method, results and explanation of the project for submission to an abstracting journal.
   a. Overall purpose
   b. Description of experimental procedure
   c. Tables and graphs of results with explanations. Be sure to include: data and observations from all group experiments, qualitative and quantitative results
   d. Results with magnitude of errors
   e. Conclusions
   f. Appendixes (as long as you need)
      i. Additional tables and graphs used to interpret material in the main body
      ii. Sample illustration of methods used to calculate results
      iii. factors affecting the source and magnitude of errors in the project
      iv. Difficulties encountered and suggestions for improvement
      v. References from books, journals and web sites
   g. Excluding the cover sheet and the Appendix, the body of this report should be about three pages.

The second report will be written as a separate report to the School Authority requesting the project.

This report may be in the form of a letter detailing all results found and recommendations. It must stand alone from the report written for the instructor above. It should be short and to the point in summarizing methods and results. It should also contain a lesson plan and instructor resources, i.e.,

1. a written laboratory experiment for high school students to use
2. a written (or web-deliverable) teachers' guide for the experiment

The following are some concepts you may want to teach your High School students.

Be sure you understand the concept yourself as explained in the first report to the laboratory instructor. You should include two or more of these concepts in your lesson plan for the High School teachers

CONCEPTS

1. Make a table of Initial Rates for various catalysts to show the effectiveness of different catalysts. Of course a table of specific rate constants for various catalysts would be more meaningful, but specific rate constants may be harder to calculate.
2. Make a study of different ways to determine the Reaction Order
3. Show the Effect of temperature on Initial Reaction Rates. How much does the rate increase for each ten-degree rise in temperature?
4. Determine the order of the reaction with respect to both the catalyst and the peroxide concentration. Then propose a mechanism of elementary reaction steps that is consistent with these reaction orders. Keep in mind the definition of a catalyst.

Materials Available: Chemicals and Equipment

- 3% H_2O_2, 1.0 M KI, 0.1 M iron(III) chloride, potatoes,
- manganese(IV) oxide, bovine liver catalase, dry Baker's yeast, turnips,
- fresh calves' liver (Other materials by request).
- Glassware or plastic equipment suitable for gas pressure measurement.
- **MicroLAB** interface for monitoring the build up of pressure from the O_2 product of the decomposition of H_2O_2.

Safety Information

Although 3% hydrogen peroxide is not very toxic or corrosive, higher concentrations can be quite difficult to handle. Wear gloves if handling 30% H_2O_2. At this concentration, H_2O_2 is a powerful oxidizing agent and can cause severe burns. While you may decide to use this concentration for your own experimentation, remember it cannot be used for the high school experiment. For best results the H_2O_2 concentrations should not exceed 3 percent.

When designing your experiment, be aware that when H_2O_2 decomposes, considerable pressure can be built up from the oxygen gas released in a closed system. Therefore you will need to calculate what volume of H_2O_2 you will need to cause an increase of 100 to 150 torr in your apparatus.

Caution: Be sure to use small amounts of catalyst first to determine how reactive the catalyst is, thus avoiding dangerously high pressures inside of the reaction vessel.

Techniques You May Need

Weighing compounds

- Measuring pH
- Maintaining constant temperature (You can use the ***MicroLAB*** to do this.)
- Collecting gas
- Measuring time and pressure
- Use of the ***MicroLAB*** pressure sensor

Resource: Measuring the Rate of a Reaction

The major experimental problem for this project is deciding how to gather enough data to calculate the rate of the reaction. Reaction rates are usually determined by following the disappearance of one of the reactants or the appearance of one of the products. For a reaction in which a gaseous product is produced several simple approaches can be used. The actual gas may be collected over a period of time or the reaction can be run in a closed container and the increase in pressure measured with time. For a closed gas system with no change in volume or temperature, the pressure of the gas is directly proportional to the moles of gas, $P = n(RT/V)$ since R, T and V are held constant. Due to its simplicity, control of variables and safety features, the ***MicroLAB*** pressure sensor will be used to follow the reaction rate.

A variety of glass and plastic ware is available in the lab to design and assemble your testing apparatus. A simple closed reaction system might consist of:

- A water bath for controlling the temperature.
- A small Erlenmeyer flask with a sealed rubber stopper containing a tube leading to the ***MicroLAB*** pressure sensor.
- A method for stirring the mixture in the reaction flask.

Resource: Considerations of Variables for Control of Reaction Rates

The National Science Education Standards, and most state standards applicable to High School chemistry, expect students to design experiments with consideration of adequate control of variables. The high school teacher will expect this to be explicitly incorporated into your experiment for the students. There are a number of variables that can affect the rate of reaction, including: amount of reactant, amount of catalyst, type of catalyst, temperature of reaction mixture, and pH of reaction mixture. There may be other variables you want to include. Be sure that your own experimental plan reflects control of all of the variables, enabling you to include this feature successfully in your write ups for both students and teachers.

Resource: the *MicroLAB* Pressure Sensors

Please refer to the following sheets on calibration, to the ***MicroLab*** Instruction Program and to your lab teacher for details on the safe use of the ***MicroLAB*** equipment.

MicroLAB* Pressure Calibration Procedure** (Refer to the "MicroLAB*** Power Point Instructions" on your computer for additional help. If they are not there, ask your instructor to put them on the computer.)

1. If you need to know the local barometric pressure. Read a barometer or get it from the local weather report.
2. Connect a 60 ml Syringe with short pieces of plastic tubing to a pressure sensor and to a relief valve by means of a Y tube. The relief valve may be a screw clamp pinching on the plastic tubing.

3. Connect the computer and power source to the back of the ***MicroLAB*** Interface Box. Turn the ***MicroLAB*** Interface on. A green light should be visible. On the Computer Desktop screen click the ***MicroLAB*** icon.

4. When the "Choose an Experiment Type" screen comes up, double click the ***MicroLAB*** **Experiment** Icon, A dialog box opens asking you for the name of the file in which your data will be stored. You should make the name of the file meaningful to you so that you can recognize it for later recovery if needed, e.g., H2O2.KI,JH, where KI is the catalyst, and JH is your initials, then Click OK.

5. The ***MicroLAB*** Main Screen consisting of six sections will open. In the Data Sources/ Formulas section, click on **Add Sensor**. When the **Choose sensor** dialog box appears, click on the down arrow of "Choose sensor." Click on **Keyboard** sensor to select it. When the next window appears change the label notation from **kbd** to **Volume**. Click the next button and in the prompt message box type **Enter Volume**. Click the **Finish** button to return to the Data Source/Formula section

6. You now need to add the pressure sensor. Make sure a tube from the Y is connected to the pressure twist connection at the back corner of the interface box. Again in the Data Sources/ Formulas section, click on **Add Sensor**. When the **Choose sensor** dialog box appears click on the down arrow of the **Choose sensor** window. Click on **Pressure** to select it. The Pressure probe will now be highlighted in the sensor box and the input jack dialog screen will appear. Click on the indicated pressure input jack in red. Also, change the label notation from **Press** to **Pressure**. Now click the **NEXT** button to bring up the calibration window.

7. In the calibration window click on the **Perform New Calibration** button. Click on the **Add Calibration Point** button. Type in the local barometric pressure converted to units of **kilopascals**. Make sure the relief value on the Y tube is open and then when the red needle is in the green field push the OK button (or the enter key). A pressure point will be added to your calibration curve.

8. Again click on the **Add Calibration Point** button. Adjust the syringe to as close to 30 ml as you can and tighten the relief screw to close off the syringe from the local atmosphere. Calculate the pressure (units of **kilopascals**) inside the syringe when the plunger is moved to 20 mL. (This calculated pressure should be greater than one atm)

   [If BP = the local barometric pressure

   V_1 = original volume position of plunger

   V_2 = final volume position of plunger

   V_y = volume of the Y tube system (approximately 1 mL)

   then

   $$P_{\text{inside syringe}} = BP\,(V_1 + V_y)/(V_2 + V_y)$$

   Type in this calculated syringe pressure and after moving the plunger as close to 20 ml as you can, push the OK button. A second calibration point is now added to your calibration curve.

9. Repeat this process again for a third pressure calibration point as above, calculating the pressure inside the syringe when the plunger is moved from 30 ml to 60 mL. (This calculated value should be less than 100 kPa) Type in this calculated syringe pressure and after moving the plunger as close to 60 ml as you can, push the OK button. A third calibration point is now added.

10. After three calibration points have been entered, click the **Accept and Save Calibration** button. Name this file as Press.3.20.DH to save this calibration data, where 3.20 is the day's date, and DH is the student's initials. Click the **Finish** button to return to the Data Source/Formula section

11. Drag the pressure sensor label to the Data Source 2 axis of the graph, to the title of Column B of the spread- sheet and to the Digital Display view. Drag the Volume (Kbd) and Time sensors label to all three views also.

12. The pressure probe is now measuring pressure and displaying it in the Digital Display view. You can CHECK YOUR CALIBRATION by opening the relief value and moving the plunger back and forth. The display pressure should always read the local atmospheric pressure. Now move the plunger to the 20 ml mark and close the relief valve. Push the START button, enter 20 when prompted to enter Volume and then push the OK button. Move the plunger in five ml increments and collect pressure data for several volume readings on the syringe. **Save the file as P.Calib.Check** so you can recall it for each catalyst you use.

13. Using the Add Formula function, calculate RT/P and click-drag to the next free spreadsheet column, then plot a graph of Volume on the Y axis and RT/Pressure on the X axis. (Use R=0.08206 liter-atm/K-mol, T= Kelvin temperature) **Remember to convert the pressure in torr to atmospheres**. You should get a linear trendline with a slope of n= moles of gas in the syringe and an intercept of Volume in the Y tube system.

***MicroLAB* Pressure Procedure for Kinetics of Hydrogen Peroxide**

1. The reaction flask consists of a 50 ml heavy walled Erlenmeyer flask with a rubber stopper containing a short glass tube. See Figure 1. Connect the Reaction Flask to the ***MicroLAB*** pressure sensor with a short piece of plastic tubing.

2. Make sure the computer and interface are connected properly as discussed, then make sure you have the ***kinetics.press.const.T.exp*** program on the screen.

3. Push the ***MicroLAB*** START button and allow the program to run several minutes until a smooth base line has been established on the graph. Place 1 ml of 3% hydrogen peroxide in an automatic pipet or insertion syringe. Remove the rubber stopper from the reaction flask, insert the 1 ml of 3% hydrogen peroxide into the reaction flask, immediately replace the stopper and push it tight to seal off the system from the outside pressure. Watch the pressure increase. Let the program continue to run until the pressure levels out and gives a smooth final base line. Stop the experiment. Be sure to save the data file. Always make sure you obtain a beginning base line value and an ending base line value.

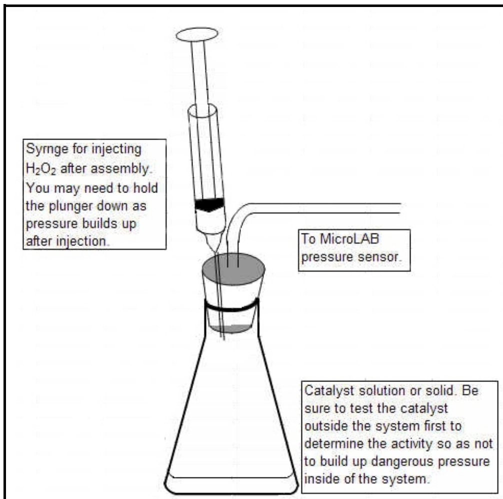

Figure 1. Diagram of reaction vessel. The catalyst is placed in the flask, the H_2O_2 is placed in the syringe, and injected into the flask after assembly is complete and the program is started.

4. Plot a graph of (ending base line pressure minus experimental pressure) on the Y axis and time on the X axis. This should show the rate of change of hydrogen peroxide.

5. Reaction Rate = $d[H_2O_2]/dt = - k [H_2O_2]^x = -(2k/RT) [P_{final} – P]^x$

   a. A plot of O_2 pressure versus time will give a linear plot if the reaction is zero order with respect to H_2O_2, i.e., x = 0. The slope of the line equals the specific rate constant, k.

   b. Using the **Add** Formula function, calculate $[P_{O2\ final} – P_{O2initial}]$, then plot of the log of $[P_{O2\ final} – P_{O2initial}]$ versus time will give a linear plot if the reaction is first order with respect to H_2O_2, i.e., x = 1. The slope of the line equals the specific rate constant, k.

   c. A plot of the $1 / [P_{O2\ final} – P_{O2initial}]$ versus time will give a linear plot if the reaction is second order with respect to H_2O_2, i.e., x = 2. The slope of the line equals the specific rate constant, k.

6. Make a linear plot showing the correct reaction order. Is your reaction a zero order reaction, a first order reaction or a second order reaction? What is the value of the reaction rate constant?

7. You should try different catalysts to see how the rate of the reaction is changed. The order of the reaction should not change. Make a table showing the rates for different catalysts.

Procedure for Temperature variation of the Kinetics of Hydrogen Peroxide (A water bath with temperature control will be needed for this part of the experiment.)

1. Use the same reaction Flask. Support the reaction flask in a temperature controlled water bath.

2. Make sure the computer and interface are connected properly, and you have **YOUR** experiment displayed on the main screen.

3. If needed, re-calibrate the pressure sensor and temperature sensor. In the Data Sources/ Formulas section, highlight the Pressure sensor and then click the "Edit" button. The pressure calibration and type of pressure units can now be modified. If you hi-light the TempIC sensor and then click the "Edit" button, you can re-calibrate the temperature probe, if needed. In the Experiment Steps section of the ***MicroLAB*** Main Screen are the controls for timing the data collection rate. The pressure recording rate is set at 20 seconds. This can be adjusted to other values. Make sure it is functioning properly.

   Make sure that each of the sensors, i.e., pressure, time and temperature have been dragged to the three data views, i.e., Graph, Spreadsheet and Digital Display.

4. Place 20 ml of the catalyzing solution in the reaction flask and allow it to come to temperature equilibrium in the temperature controlled water bath.

5. Push the ***MicroLAB*** START button and allow the program to run until a smooth base line has been established on the graph. Suck 1 ml of 3% hydrogen peroxide into an automatic pipet or insertion syringe and inject it into the reaction flask. Watch the pressure increase on the ***MicroLAB*** **Main Screen** on the computer. Let the program continue to run until the pressure levels out and gives a smooth final ending line, then stop the experiment. Be sure to save the data file as named earlier, but add an abbreviation of the catalyst used in each experiment. Obtain a beginning base line value and an ending base line value.

6. Make a log plot of $[P_{O2\ final} - P_{O2initial}]$ on the Y axis and time on the X axis. This should show the rate of change of hydrogen peroxide and allow you to determine the reaction rate constant.

7. You can now change the temperature of the water bath and repeat steps six through step eight to determine the rate constant at a new temperature. Plotting ln k versus 1/T will give an ARRHENIUS plot, and ln (k/T) vs. 1/T will give an EYRING plot. From these data you may report Activation energy, Heat of Activation and Entropy of Activation.

Additional thoughts and ideas for the Kinetics Experiment

The decomposition of H_2O_2 using KI as a catalyst may be covered in the Kinetics chapter of your Lecture Text. If not, look up some references in the library. Read and study the calculations in this chapter from your text. It should help you understand concepts that you can teach your High School students.

In most cases a ratio between rates, moles or pressure is used so that their individual units cancel. If it is necessary to determine the moles of O_2 produced, the volume and temperature of the reaction flask will be needed to convert pressure of O_2 to moles using the Ideal Gas Law expression. The temperature of your reaction will be obtained from the constant temperature bath column in the Spreadsheet. To determine the volume of your reaction flask, weigh your empty reaction flask with rubber stopper and pressure hose. Fill the flask with water and insert the stopper so that water flows out of the pressure hose. Wipe off all excess water on the outside of the flask and reweigh the flask. Use the density of water to convert weight of water to volume of flask. When using this volume in calculating moles of O_2, be sure to subtract the volume of the reacting solution.

When measuring O_2 pressure during a kinetics run, set the time interval between each data point at 20 seconds or longer. Too many data points results in an unwieldy data base. The ideal is to have at least 50 to 60 points on your curve.

Allow the catalytic reacting solution and reaction flask to reach temperature equilibrium in the water bath before adding the hydrogen peroxide and starting the experiment.

Start the experiment on ***the MicroLAB*** interface several minutes before adding the H_2O_2 into the catalytic solution to obtain a background pressure. Be sure that the rubber stopper containing the pressure tube is inserted tightly into the reaction flask. Continue collecting O_2 pressure data as the pressure rises until the pressure levels off and remains constant.

Be sure to export the Spreadsheet Table for each kinetic's run in a CVS or Excel file so that you can mathematically treat, analyze and graph it at a later date. You will also need it for your report.

If you plan your operations ahead, you should be able to make numerous runs during a lab period. Make several runs with various concentrations of H_2O_2, various concentrations of KI or other catalysts, several different catalysts, and at several different temperatures. Plan ahead as to what you are going to teach your High School students.

Standard Catalytic Solutions:

- 0.100 M K_2CrO_4
- 1.00M KI
- 1.00 M $CuSO_4$
- 1.7 grams of solid MnO_2
- approximately one gram of blended potato in 1 ml of solution

Making changes on ***the MicroLAB*** 402 Sensor Interface Main Screen: Experiment Steps Region

Every place in a ***the MicroLAB*** program there is a logic decision that step can be double clicked to open up a new window containing the logic options. For example, it the **Repeat every 0.5 seconds** is double clicked, a new window opens with three options" (1) Repeat every 0.5 seconds, (2) Repeat when counter changes (grayed out if counter has not been selected as a sensor.) And (3) Repeat upon receiving keyboard input. Clicking on one of these options and then clicking on **OK** will select that option. Of course, the 0.5 seconds can be modified in the time box when that window opens. Similarly, double clicking the **Until Stop Button is Pressed** results in eight options to choose from.

Figure 2. The default Experiment Steps program, which will repeat every 0.5 seconds until the **Stop** button is pressed.

Classroom Kinetics: Planning Sheet 1 Group **Name ____________________**

To be completed and turned in before starting experimentation. Some projects you may want to accomplish this lab period are:

1. The validity of the Ideal Gas Law expression.

2. The order of the reaction with respect to the concentration of the reactant.

3. The order of the reaction with respect to the concentration of the catalyst.

State the overall purposes of this project in your own words.

1. Write the chemical equation for the decomposition of hydrogen peroxide.

2. How do you initially plan to follow the course of the reaction? Explain what equipment you plan to use and what data you plan to gather during your initial trial decompositions?

3. The high school teacher has asked for an experiment that involves comparing and contrasting enzymatic and inorganic catalysts for the decomposition of hydrogen peroxide. How do you expect these types of catalysts to differ in their effect on the decomposition? How will these expected differences influence your experimentation?

4. There are several terms that you will need to use correctly throughout this project. Give a brief explanation of what is meant by each of these terms. If appropriate, also give the units that could be used to express the term's value.

   a. Catalyst   b. enzyme   c. reaction rate   d. reaction time

   e. rate constant   f. rate law   g. activation energy

5. What do you think the term "guided-inquiry" mean as applied to the experiment you will write up for the high school students? How does it compare to the project-based laboratory experiments in this ACS Chemistry Laboratory Supplement?

6. Explain how you will calculate the rate of the reaction.

7. Explain how you will determine the order of the reaction.

Classroom Kinetics: Planning Sheet 2 **Name:_________________**

To be completed and turned in before starting this period.

Some projects you may want to accomplish this lab period are:

1. The order of the reaction with respect to the concentration of the reactant.

2. The order of the reaction with respect to the concentration of the catalyst.

3. The effect of various catalysts on the rate of the reaction.

State the purposes of this week's lab in your own words.

1. What experimental approaches were used last period to study the decomposition of hydrogen peroxide? Include a sketch of the equipment to be used.

2. Organize and report in tabular form the experimental data you gathered last period. Be sure to label all data clearly.

3. What qualitative and quantitative conclusions did you draw from the data gathered last period? Explain the supporting evidence for your conclusions.

4. Are there any modifications to your procedures that you will implement in this week's lab?

5. Explain what variables will be controlled in your experiments today?

6. What additional data will you need before you are ready to write up the experiment for both the students and the teacher?

Classroom Kinetics: Reflection and Planning Sheet 3 Group **Name:__________________**

To be completed and turned in before starting this lab period.

Some projects you may want to accomplish this lab period are:

1. The effect of temperature on the rate of the reaction.

2. The determination of activation energy.

State the purposes of this week's lab in your own words.

3. Organize and report in tabular form the experimental data you have gathered so far. Be sure to label all data clearly.

4. What qualitative and quantitative conclusions can you draw from the data gathered so far? Explain the supporting evidence for your conclusions.

5. What will you include in the experimental write up for the high school students? How will you organize the write up? Outline your group's ideas.

6. What will you include in the experimental write up for the high school teacher? How will you organize the write up? Outline your group's ideas.

7. Explain how you will calculate activation energy.