A Kinetic Study: Catalase

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Introduction:

Humans and other living things find hydrogen peroxide to be toxic within tissues. There are biological catalysts, or enzymes present to catalyze the decomposition of H_2O_2 into it's harmless products, H_2O and O_2. The role of a catalyst is to increase the speed at which a reaction takes place. Catalysts play a significant role in chemical reactions as they provide a more efficient pathway for the reaction to occur. Catalysts are responsible for lowering the activation energy of a reaction by providing a different pathway for the reaction to occur. The process of lowering the activation energy will cause more successful collisions between the particles in the reaction, which allow the reaction to progress at a much faster rate. In this experiment, we will be analyzing and comparing the decomposition rate of hydrogen peroxide when two different catalysts are used. The purpose of this experiment will be to identify which catalysts can be used so that the minimal amount of energy is needed for the chemical reaction to occur.

$$\mathbf{2H_2O_{2\,(l)} \rightarrow 2H_2O_{(l)} + O_{2\,(g)}}$$

This experiment involves two catalysts which will be used to determine which is the most effective in the decomposition of hydrogen peroxide. The first catalyst that will be experimented with is known as catalase, a naturally occurring enzyme in lettuce. The second catalyst that will be used is potassium iodide. The effectiveness of the catalysts will be determined by comparing the activation energies of each catalyst used. In order to find which catalyst is most effective in terms of rate and activation, the rate constant (k), gas constant (R) , and temperature in (K) can be used in the Arrhenius equation to find the activation energy. The activation energy of a reaction can be determined by first calculating the order of the overall reaction. The order of the reaction can be found by finding the rate constant from the rate equation. The activation energy and order of both potassium iodide (KI) and catalase can be determined using the equations below.

$$k = A e^{-E_A / RT} \qquad \text{Rate} = k\,[H_2O_2]^x[\text{catalyst}]^y \qquad \ln k = \ln A - \frac{E_A}{RT}$$

The study of kinetic mechanisms allow us to identify which catalysts will be most appropriate to use for a particular reaction. Since the role of catalysts are to form more efficient pathways for a chemical reaction to occur, it is very important to analyze the activation energy. By studying the activation energies of two different catalysts, we can determine which catalyst produces the lowest activation energy. By the end of this experiment, the lowest activation will be determined from the two catalysts, in order to identify which catalyst is most appropriate to use for this particular chemical reaction.

Works Cited

General Chemistry Laboratory Manual, R.Venkateswaran , 2018, Experiment 5,, pages 43-48

Silberberg, Martin S., et al. *Chemistry: the Molecular Nature of Matter and Change*. McGraw-Hill Education, 2018.

Procedure:

Part 1: Extracting catalase from the lettuce

1. Extract catalase from the lettuce using blender until the lettuce has liquified.
2. Pour the mixture into a cloth to strain the lettuce into a large beaker.

Part 2: Determine the partial order with respect to the peroxide, in the presence of the catalyst catalase, in the rate law

3. Measure 10 mL of the lettuce catalase and pour it into a Erlenmeyer flask.
4. Measure 2 mL of hydrogen peroxide and pour it into a small vial.
5. Using the forceps place the vial containing the hydrogen peroxide into the Erlenmeyer. flask, while making sure that the hydrogen peroxide does not spill into the flask.
6. Secure the gas pressure sensor on top of the Erlenmeyer flask, and connect it to LabQuest.

7. Using LabQuest, start graphing the gas pressure inside the flask once you have begun mixing the Erlenmeyer flask.
8. Save this data onto a USB.
9. Repeat steps 3-8 three more times for three different concentrations of water, while keeping the volume of catalase and hydrogen peroxide constant; (3 trials using 0 mL of water, 3 trials of 0.5 mL of water, and 3 trials of 1 mL of water).

Part 3: Activation energy of catalase-catalysed H_2O_2

1. Prepare temperature probe and gas pressure sensor by plugging them into the LabQuest
2. Prepare three water baths of different temperatures (around 5℃, 20℃, and 30℃)
3. Prepare the 5℃ bath by adding ice to the bath and monitoring the temperature with a temperature probe until temperature is correct
4. Prepare 20℃ bath by adding room temperature water
    - Prepare 30℃ bath by placing water bath on hot plate and heating up on low; monitoring temperature with temperatures was probe

5. Take note of these initial temperatures
6. Measure out small vial of 2mL of hydrogen peroxide
7. Measure 10 mL of catalase and place in Erlenmeyer flask
8. Ensure to equilibrate both reactants to the bath temperature (catalase and hydrogen peroxide) by keeping them in the water bath for approximately 10 minutes
9. Once the containers with reactants have equilibrated, use tongs to place the vial of hydrogen peroxide in the erlenmeyer flask of catalase
10. Close off the container with the gas pressure sensor, and start trial on the LabQuest
11. Shake the flask until the vial inside spills and the reactants mix
12. Stop LabQuest trial after reaction has gone to completion
13. Take note of final temperature of the water bath using the temperature probe and note the pressure values (initial and final) from the LabQuest
14. Repeat steps 7-13 for other two water bath temperatures (repeat two trials in the room temperature water)
15. Using the data collected, using the constant catalase and hydrogen peroxide amounts, find the rates of reactions at the different temperatures.

Part 4: Activation energy of KI-catalysed H_2O_2

1. Connect a pressure sensor to a stopper and a labquest while ensuring there is no damage to the tubing.
2. Set the labquest to a time based entry
3. Measure and pour 10 ml of potassium iodide into an erlenmeyer flask
4. Measure and pour 2 ml of hydrogen peroxide into a vial.
5. Using forceps lower the vial filled with hydrogen peroxide into the erlenmeyer flask making sure that none of the hydrogen peroxide spills out of the vial.
6. Plug the erlenmeyer flask with the stopper connected to the pressure sensor
7. Carefully place the erlenmeyer flask into a water bath at 15℃
8. Allow the measured pressure to stabilize before starting the labquest graph. Record this initial pressure.
9. Begin shaking the erlenmeyer flask, so as to allow the H_2O_2 and KI to mix.
10. Stop the labquest and shaking the erlenmeyer flask once the pressure has stabilized once more. Record this final pressure.
11. Repeat steps 1-10 twice more
12. Repeat steps 1-11 for water baths with temperatures of 30℃ and 45℃

Data:

Part 2: Catalase catalyzed decomposition of H_2O_2

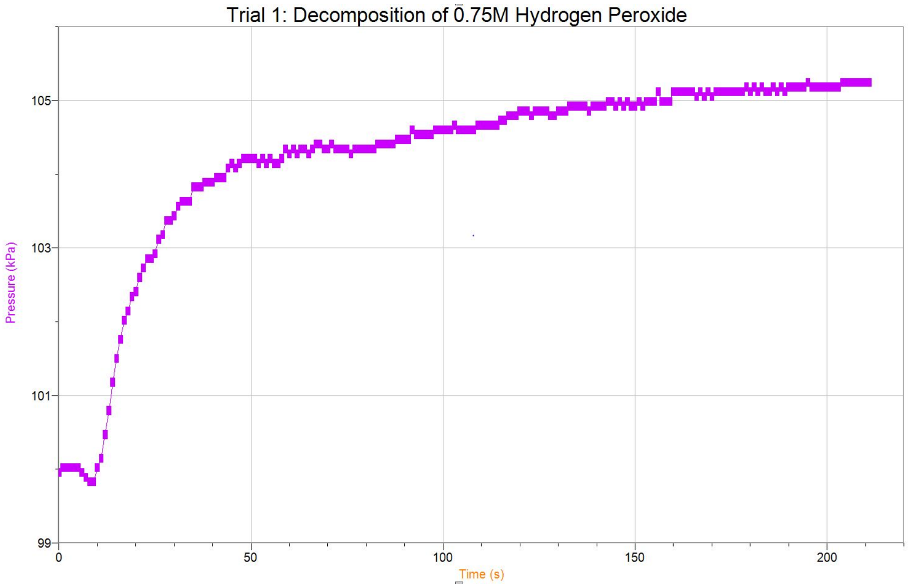
Trial 1:

$[H_2O_2]$= 0.75M

Initial Pressure= 99.96 kPa

Final Pressure= 105.25 kPa

Final time= 212 seconds



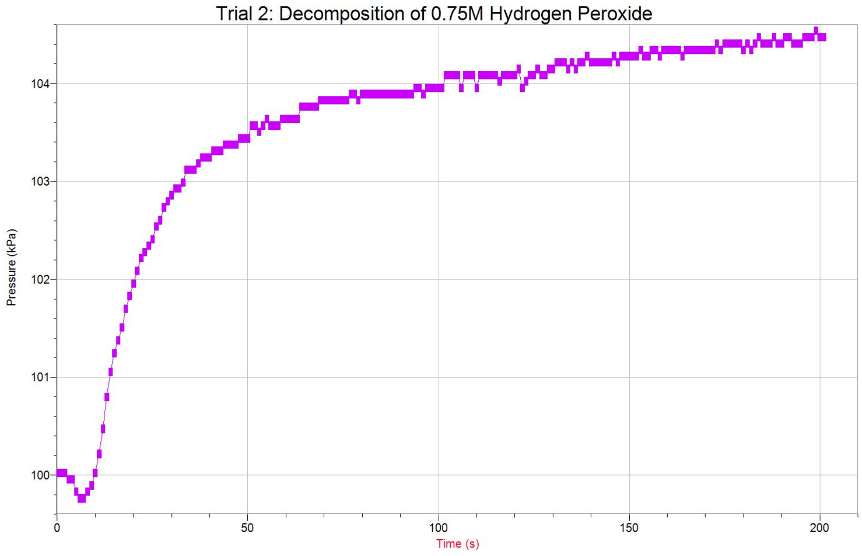
Trial 2:

$[H_2O_2]$= 0.75M

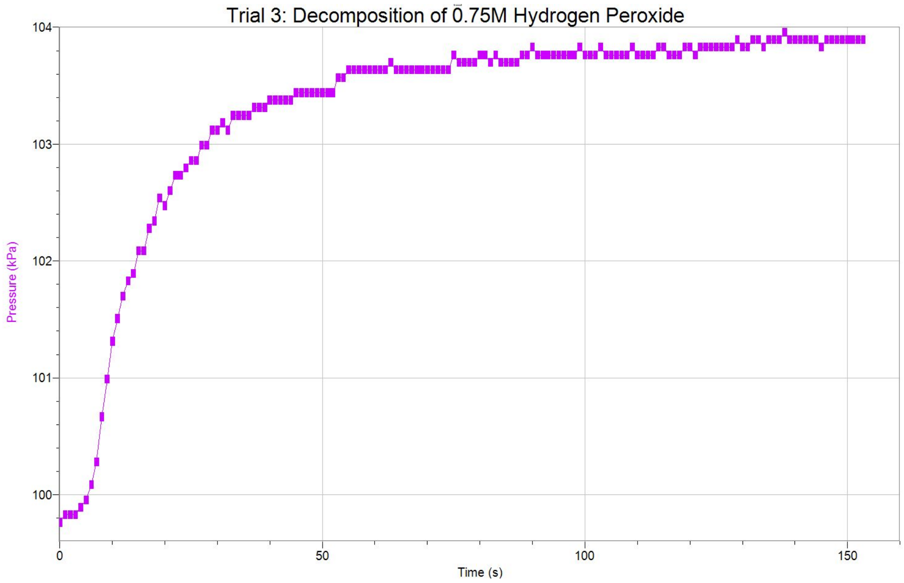
Initial Pressure= 100.02 kPa

Final Pressure= 104.47 kPa

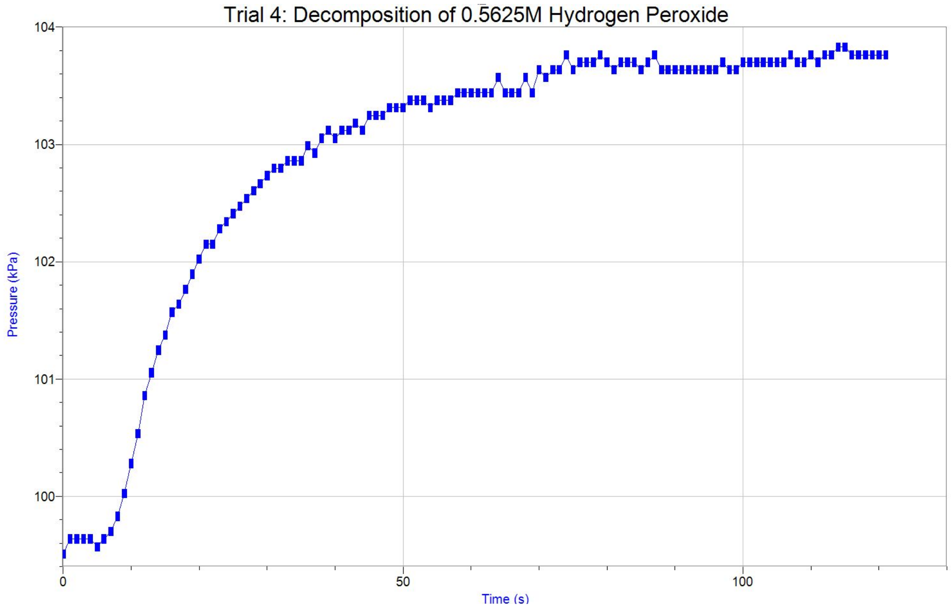
Final time= 201 seconds



Trial 3:
[H_2O_2]= 0.75M
Initial Pressure= 99.76 kPa
Final Pressure=103.89
Final Time=153 seconds



Trial 4
[H_2O_2]= 0.5625M
Initial Pressure= 99.51 kPa
Final Pressure= 103.76 kPa
Final Time=121 seconds



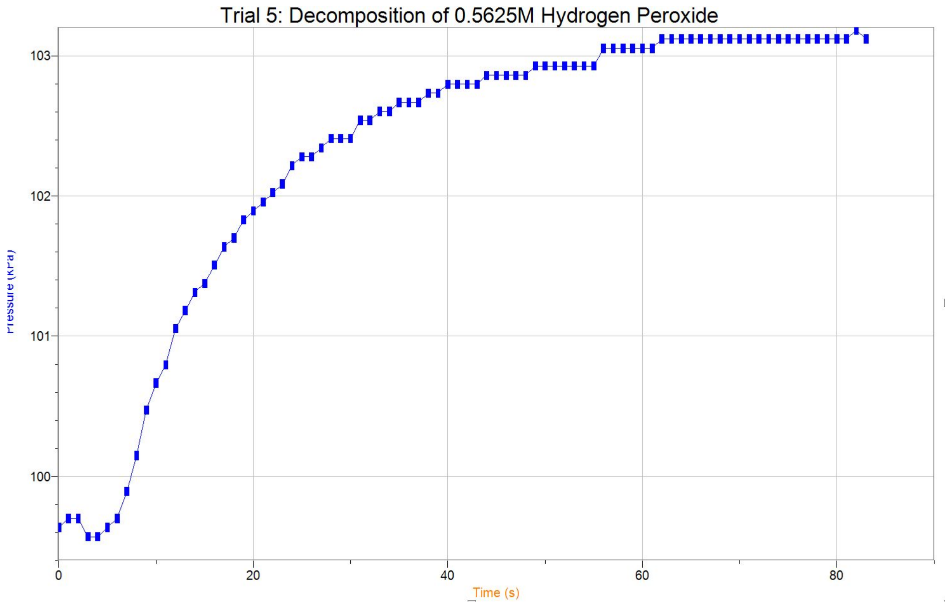
Trial 5

$[H_2O_2]$= 0.5625M

Initial Pressure= 99.64 kPa

Final Pressure= 103.12 kPa

Final Time= 83 seconds



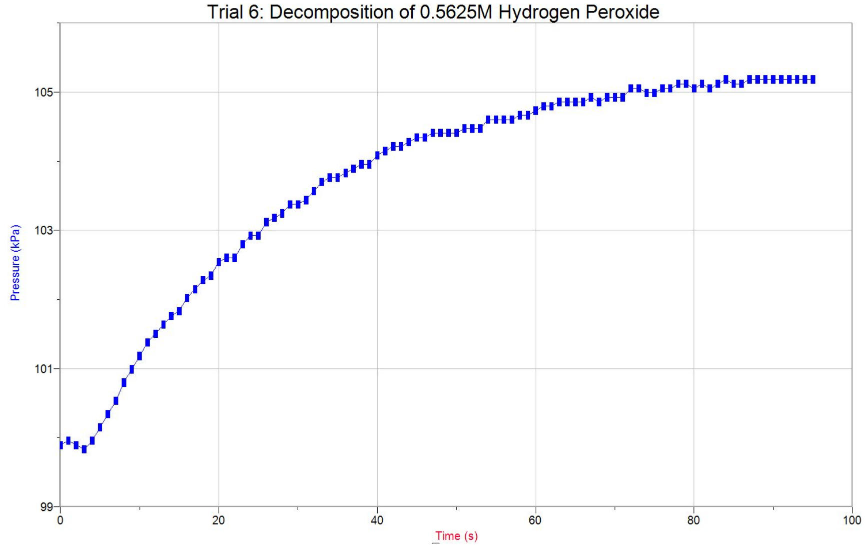
Trial 6:

$[H_2O_2]$= 0.5625M

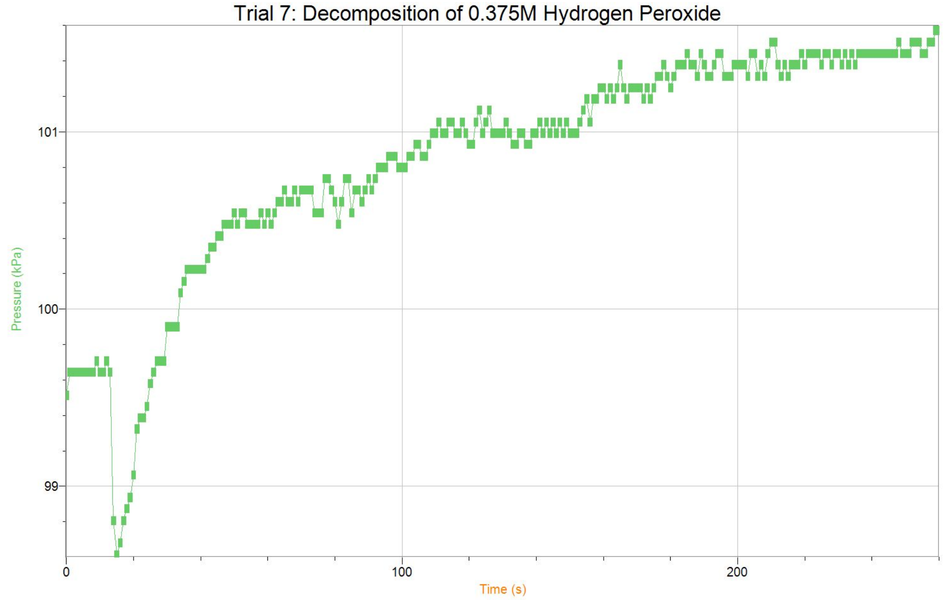
Initial Pressure= 99.89 kPa

Final Pressure= 105.18 kPa

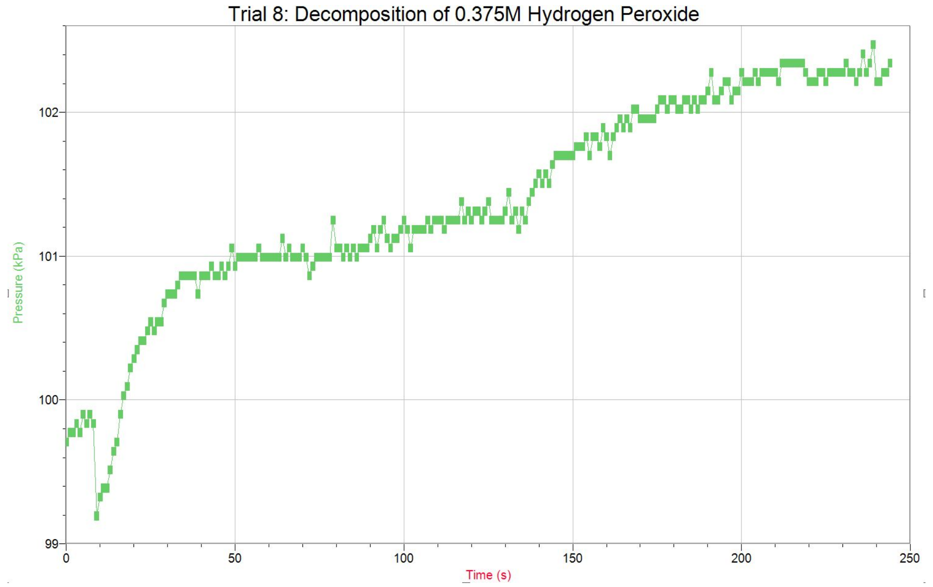
Final Time= 95 seconds



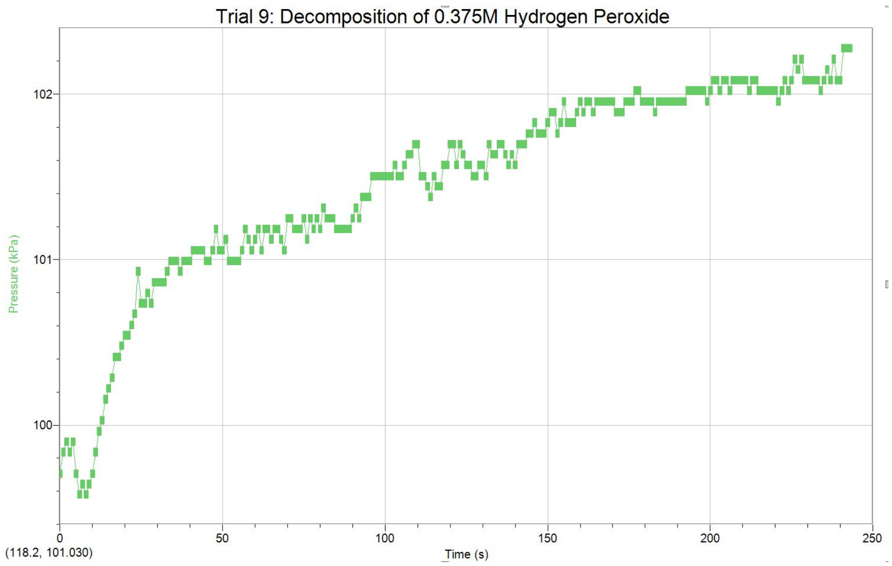
Trial 7:
$[H_2O_2]$= 0.375M
Initial Pressure= 99.51 kPa
Final Pressure= 101.57 kPa
Final Time= 260 seconds



Trial 8:
$[H_2O_2]$= 0.375M
Initial Pressure= 99.71 kPa
Final Pressure= 102.34 kPa
Final Time= 244 seconds

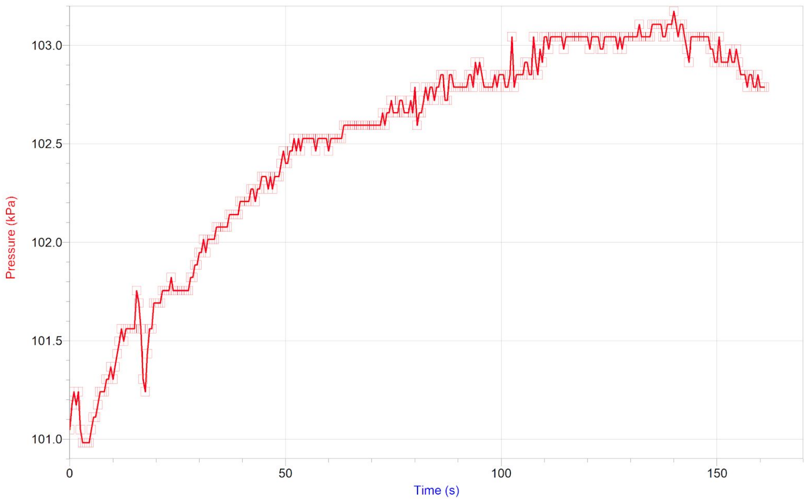


Trial 9:
$[H_2O_2]$= 0.375M
Initial Pressure=99.71 kPa
Final Pressure= 102.28 kPa
Final Time= 243 seconds

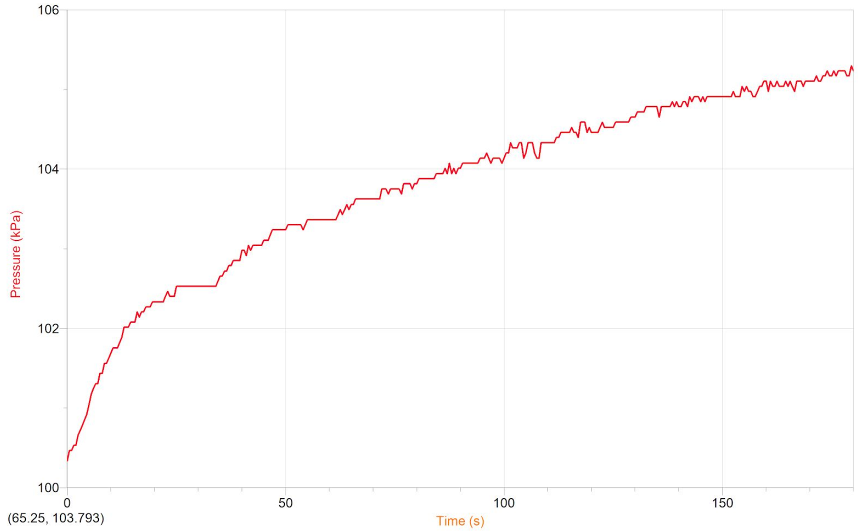


Part 4: KI Catalyzed decomposition of H_2O_2

At approximately 30℃
Trial 1:
Temp: 30.1℃
Initial pressure:101.15 kPa
Final Pressure: 103.4 kPa



Trial 2:
Temp: 29.0℃
Initial pressure:101.32Kpa
Final Pressure: 105.23Kpa



Calculations:

Part 2 :

Rate = k $[H_2O_2]^x[\text{catalyst}]^y$

Trial #	Concentration Catalase	Concentration H_2O_2 (mol/L)	Initial Rate of each Trial (kPa/s)	Average Initial Rate (kPa/s)
1	Constant	[0.75]	0.163	$\frac{0.163+0.178+0.159}{3} \approx 0.167$
2			0.178	
3			0.159	
4		[0.5625]	0.104	$\frac{0.104 + 0.138 + 0.133}{3} \approx 0.125$
5			0.138	
6			0.133	
7		[0.375]	0.110	$\frac{0.110+0.109+ 0.112}{3} \approx 0.110$
8			0.109	
9			0.112	

Rate = k $[Catalase]^0[H_2O_2]^1$
Rate = k $[H_2O_2]^1$

Concentration H_2O_2 (mol/L): [0.75]
Rate = k $[H_2O_2]^1$
0.167 = k $[0.75]^1$
k = 0.22

Concentration H_2O_2 (mol/L): [0.5625]
Rate = k $[H_2O_2]^1$
0.125 = k $[0.5625]^1$
k = 0.22

Concentration H_2O_2 (mol/L): [0.375]
Rate = k $[H_2O_2]^1$
0.110 = k $[0.375]^1$
k = 0.29

Average of 3 concentrations:

$\frac{0.22+0.22+0.29}{3} \approx 0.24$

k≈ 0.24

<u>Part 3:</u>

Activation Energy: $\ln(\frac{k2}{k1}) = -\frac{Ea}{R}(\frac{1}{T2} - \frac{1}{T1})$
Rate 1 = 0.3251 kPA/s
Temperature 1 = 16.3 C + 273 K = 289 K

Rate 2 = 0.2589 kPa/s   0.001170
Temperature 2 = 32.0 C + 273 K = 305 K

$- Ea = (8.1345) x \ln(\frac{k2}{k1}) \div (\frac{1}{305} - \frac{1}{289})$
$- Ea = (8.1345) x \ln(\frac{0.2589}{0.3251}) \div (\frac{1}{305} - \frac{1}{289})$
-Ea= -10203.62 J/mol
Ea= 10203.62 J/mol
Ea= 10.20 KJ/mol

Part 4:

Concentration of H_2O_2 is 0.1 M
Volume of H_2O_2 used is 2 mL

Temperature (K)	Initial Rate
288.15	0.09
302.7	0.165
318.25	0.225

For 288.15K
Rate = $k[H_2O_2]^1$
k = Rate/$[H_2O_2]$
k = 0.09(Kpa/s)/0.1M
k = 0.9

For 302.7K
Rate = $k[H_2O_2]^1$
k = Rate/$[H_2O_2]$
k = 0.165(Kpa/s)/0.1M
k = 1.65

For 318.25K
Rate = $k[H_2O_2]^1$
k = Rate/$[H_2O_2]$
k = 0.225(Kpa/s)/0.1M
k = 2.25

m= -3633.607 (Determined from logger pro)

m = $-E_a/R$
E_a = -m*R
E_a = 3633.607*8.3145 L*kPa/mol
E_a= 30.21 KJ/mol

Discussion:

For the first part of the experiment we were able to successfully extract the catalase from the lettuce. However there were some complications while using the blender to liquify the lettuce. It took many tries for the lettuce to fully liquify, which took up a lot of our time that we had to complete the rest of the lab. When calculating for the equilibrium constant, the value of "k" was the same for the concentration of H_2O_2 , proving that the order of the reaction is first order.

The theoretical activation energy for the catalase catalyzed reaction is 8KJ/mol. The experimental value calculated in the lab was 10.20 KJ/mol. This is very close to the theoretical, the experimental may have been slightly higher due to the fact that it was kept in ice and had a lower energy to start with.

The theoretical activation energy for the KI catalyzed reaction is 56.5 KJ/mol. Our result obtained experimentally for the activation energy was 30.209KJ/mol, which is approximately 26.3KJ/mol less than expecting, which is half the expected value. Considering the catalase is an organic enzyme used by living organisms this is not a healthy catalase because it will make a reaction proceed to fast for a living organism. The reason this occured is due to the error of this experiment. During this experiment we heated up the water but the temperature did not stay constant because the hotplate would either cause the temperature to rise to high or fall too low.

Conclusion:

In conclusion, the partial order of catalase is 0 and the partial order of hydrogen peroxide is 1. The activation energy of the catalase-catalysed is 10.20 kJ/mol while the activation energy of the potassium iodide catalyzed decomposition of hydrogen peroxide is 30.21 kJ/mol. Since the activation energy of the Catalase catalyzed decomposition of hydrogen peroxide is lower than that of the potassium iodide catalyzed reaction: the catalase is the more efficient catalyst.

Raw data:

Experiment 5:

Procedure:

Nov 28th, 2018

1) Extract catalse from the lettuce (no organic solvents)
- using blender, blend the lettuce until fully liquify
- Pour blended lettuce into a J-cloth and funnel that goes into volumetric flask
- place a stopper on the volumetric flask with the catalase and put flask in ice throughout Experiment

catalase

WATER 1

H_2O_2

2 trials

2) Determine the partial order with respect to the peroxide, in the prescence of the catalyst catalase, in the rate law
- using a graduated cylinder measure 10 mL of catalase and place it in Erlenmeyer flask
- Place a vial with 2mL of hydrogen peroxide into flask using forceps
- connect gas pressure sensor to labquest and place the gas pressure sensor into the Erlenmeyer flask
- close flask with stopper
- when pressure stabilizes, start recording pressure using labquest and shake flask for reaction to occur
- when pressure stabilizes again after the reaction is complete, stop recording pressure and save to USB
- clean equipment used
- Repeat part 2 of procedure two more times with different concentrations of hydrogen peroxide (i.e. adding 2 more mL of diluted water to vial)

3) Determine the activation energy for the catalase - catalyst decomposition of hydrogen peroxide
- using graduated cylinder, measure 10 mL of catalase and place it into the Erlenmeyer flask

- Measuring with a thermometer, heat the flask using a hot plate to a temperature of 35°C
- place a vial with 2 mL of hydrogen peroxide into flask using forceps
- connect the gas pressure sensor to LabQuest and place the gas pressure sensor into Erlenmeyer flask
- close flask with a stopper
- when the pressure stabilizes, start recording pressure using LabQuest and shake for reaction to occur
- when the pressure stabilizes again after reaction is complete, stop recording and save data onto USB
- Repeat part 3 two more times using different temperatures for the contents of the flask (ie, 40°C, 45°C)

4) Determine the activation energy for the KI-catalysed decomposition of hydrogen peroxide

- using graduated cylinder, measure 10 mL of Potassium iodide and place it within Erlenmeyer flask
- Measuring with a thermometer, heat flask using a hotplate to a temperature of 30°C
- place a vial with 2 mL of hydrogen peroxide into flask using forceps
- connect ~~LabQuest 2~~ gas pressure sensor to LabQuest and place the gas pressure sensor within Erlenmeyer flask
- close flask with stopper
- when pressure stabilizes, record pressure using LabQuest while shaking the flask
- when pressure stabilizes, ~~start recording pressure~~ again, stop recording pressure and save data onto USB

- Repeat part 4 of procedure 2 more times using different temperatures for the contents of the flask (i.e. 33°C, 36°C)

Trial 2-4 → 2 mL H_2O_2
Trial 5 → 0.5 mL H_2O
Trial 6 → 0.5 mL H_2O
Trial 7 → 0.5 mL H_2O