

Investigating the Effect of Temperature on the Rate Constant of the Decomposition of Aqueous Hydrogen Peroxide.

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IB Chemistry HL
Internal Assessment

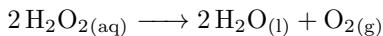
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1 Introduction

The reaction of hydrogen peroxide, H_2O_2 , decomposes to form oxygen gas and water. Although this reaction is thermodynamically favourable to the products side, it will proceed at an extremely-slow rate at room temperature, unless catalyzed:



In this investigation, potassium iodide (KI) was used as a catalyst so that the reaction (specifically, the formation of oxygen gas) inside the system can occur at a measurable rate within a practical time frame. This investigation aims to explore how temperature impacts the rate constant for the catalyzed decomposition reaction of aqueous hydrogen peroxide. The rate of the reaction is observed indirectly by measuring the initial rate of increase in gas pressure inside a sealed flask, as oxygen gas ($\text{O}_{2(\text{g})}$) builds up.



1.1 Background Concepts

Increasing temperature increases particles' kinetic energy and the fraction of collisions with energy $\geq E_A$, so the rate constant is expected to increase. The temperature dependence of a rate constant can be modelled by the Arrhenius equation:

$$k = A \cdot e^{-\frac{E_A}{RT}} \quad (2)$$

where A is the frequency factor, E_A is the activation energy, $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$, and T is the temperature (K).

Linearizing gives:

$$\ln K = -\frac{E_A}{RT} + \ln A \quad (3)$$

Where the slope of the linear graph is $-\frac{E_A}{R}$, and the y-intercept is $\ln A$.

As $\text{O}_{2(\text{g})}$ is produced in a sealed flask of approximately constant gas volume, the pressure increases (ideal gas approximation):

$$PV = nRT \quad (4)$$

With H_2O_2 concentration and catalyst amount constant, changes in k_{app} can be compared across temperature levels.

¹Value obtained from IB Chemistry Data Booklet, version 1.0 (first assessment 2025).

* * *

As a result, the research question for this investigation is:

How does temperature affect the apparent rate constant for KI-catalyzed H₂O₂ decomposition, measured by initial ΔP/Δt in a sealed flask?

1.2 Hypothesis

Given that the Arrhenius rate constant is dependent on the temperature, I hypothesize that increasing the temperature will cause the rate constant for the decomposition of aqueous hydrogen peroxide, H₂O₂, to increase exponentially.

2 Research Design

2.1 Variables

Independent variable: Temperature of the reaction system. The H₂O₂ in the sealed flask was equilibrated to the target temperature using a water bath and heat plate before the start of each trial. The temperature was monitored using a Vernier Temperature Probe before and during the trials. The trials were only started once the water bath temperature reached within 1 °C of the target temperature.

Dependent variable: Rate of the decomposition reaction of H₂O₂ and KI.

Controlled variable: Initial concentration of H₂O₂ (mol dm⁻³), total volume of gas space in the sealed flask, environmental conditions (temperature, humidity), time interval between pressure readings, the same apparatus setup (same Vernier pressure sensor used for all measurements), and data-collection settings.

2.2 Materials

- (1x) Bottle of 3% hydrogen peroxide, H₂O₂ (aqueous)
- (1x) Bottle of potassium iodide, KI (solid)
- (1x) Jug of distilled water
- (1x) 1000 mL beaker (waste beaker)
- (2x) 600 mL beakers
 - 1. (1x) for ice bath

2. (1x) for H₂O₂ solution

- (1x) 250 mL flask (for experiment, to be placed in water bath)
- (1x) 250 mL beaker (for H₂O₂ solution)
- (1x) 100 mL beaker (for KI solution)
- (1x) Glass bowl (for water bath)
- (1x) Rubber stoppers (with holes and pipes)
- (1x) Vernier Gas Pressure Sensor
- (1x) Vernier Stainless Steel Temperature Probe
- (1x) Vernier LabQuest
- (1x) 25 mL Pipette + suction bulb
- (1x) 10 mL graduated cylinder (for measuring distilled water)
- (1x) Digital balance
- (1x) Metal stick from ring stand
- (1x) Safety goggles
- (1x) Lab coat

2.3 Experimental Design

This experiment was designed to isolate the temperature of the water bath as the sole independent variable affecting the rate constant for the KI-catalyzed decomposition reaction of aqueous hydrogen peroxide. Oxygen gas produced during the reaction increased the pressure inside a sealed 250 mL flask. Thus, the increase in the rate of the initial pressure value was used to determine the rate constant at each temperature. A water bath (wide glass bowl on heat plate) was used to equilibrate the reaction system to within 1°C of the target temperature, with ice available in a beaker nearby to lower the temperature when required. The masses of KI were pre-measured and recorded before data collection, and sealed with plastic wrap and rubber band.

2.4 Procedure

2.4.1 Part I: Setup

1. Obtain safety goggles and lab coat.

2. Gather the required items from *section 2.2* to work station.
3. Assemble the pressure measurement setup:
 - Connect the Vernier Gas Pressure sensor to the LabQuest
 - Connect the airtight plastic tube to the pressure sensor.
 - Connect the plastic tubing to the rubber stopper.
 - Close the valve on the rubber stopper.
4. Secure the 250 mL flask on the ring stand using a ring clamp, so that it remains stable during the data collection.
5. Add 25 mL of distilled water to the 250 mL flask for setup purposes.
6. To prepare the water bath, place the glass bowl on the hot plate and add water to a level so that it just submerges the 25 mL water inside the flask. This will represent the hydrogen peroxide during the experiment.
7. Draw a horizontal line on the neck of the reaction flask using a marker to standardize the insertion depth of the rubber stopper in every trial.
 - **Note:** Before inserting the rubber stopper each time, add a few drops of water on fingers, and rub the sides of the rubber stopper to improve the sealing.
8. Ensure the temperature probe is not touching the bottom of the glass bowl or the sides of the flask. Secure the temperature probe using a ring clamp (to standardize the placement between trials)
9. Set the LabQuest to record at *5 samples / second*, for a total of *60 seconds* for each trial.

2.4.2 Part II: Preparation of materials

1. Pour a large amount of aqueous H₂O₂ into a clean 600 mL beaker to use as the master solution for all trials. Excess can be poured back using a funnel.
2. Prepare potassium iodide portions for each trial:
 - (a) Using a digital scale, weigh 0.30 g of solid KI into individual plastic cups.
 - (b) Label each cup with its corresponding temperature level and trial number.
 - (c) Seal each cup using a piece of plastic film, and secure it with rubber band to reduce exposure to moisture from air.
3. Using another clean 600 mL beaker, fill with ice. This will be used to lower the temperature of the water bath for lower temperature levels.

2.4.3 Part III: Calibration

1. With the apparatus assembled, open the valve on the rubber stopper so that the pressure sensor is open to the atmosphere. Record the atmospheric pressure for 10 seconds and record the average pressure in kPa.
2. Rinse the 25 mL pipette with aqueous H₂O₂ to avoid contamination, then dispose into the waste beaker.

Note: An airtight-sealing calibration was not conducted because the experiment relies on finding the change in pressure over time. In the case of a minor leak, the pressure readings would be consistently lower than the actual pressure, which does not affect the rate of change in pressure and the rate constant.

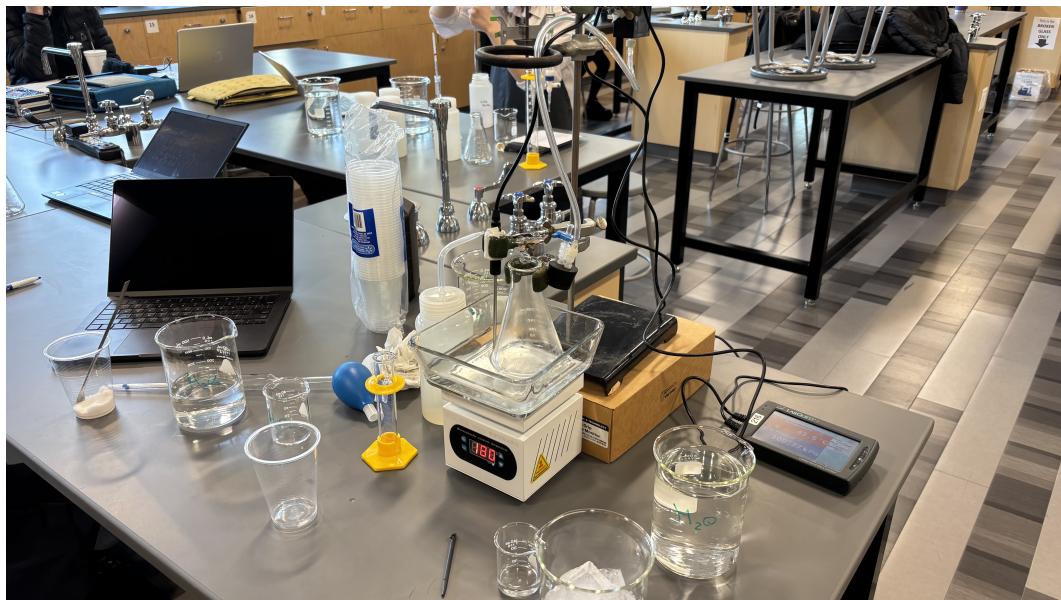


Figure 1: Apparatus setup.

2.4.4 Part IV: Experiment

1. Adjust the water bath temperature to the target temperature, either by using the hot plate or by adding ice (depending on temperature level).
2. Pipette 25 mL of H₂O₂ to a clean 250 mL beaker. Once the temperature of the water bath reaches within 1 °C of the target temperature, pour the H₂O₂ into the reaction flask. Keep the reaction flask in the water bath to maintain consistency.
3. Measure 5 mL of distilled water using a 10 mL graduated cylinder, and pour into the plastic cup containing the pre-weighed KI for the trial. Stir to dissolve the KI. Repeat twice, so that there is a total of 10 mL of KI solution.
4. Start the data collection and collect a 3 second baseline with the flask sealed. Then, remove the rubber stopper, and quickly add the KI solution into the reaction flask, and immediately seal the flask with the

- rubber stopper (with water on sides of flask to improve seal).
5. Swirl the flask gently for *5 seconds*, then keep the flask still for the remainder of the run.
 6. After data collection ends, save the run, and record the LabQuest run number in the data table with the corresponding trial.
 7. Dispose the solution into the waste beaker, and rinse the reaction flask once using tap water, then rinse again with distilled water.
 8. Repeat *steps 1-7* for each trial at each temperature level, for a total of *40 trials*.

2.4.5 Part V: Cleanup

1. Disconnect the gas pressure sensor and temperature probe from the LabQuest.
2. Save the file on the LabQuest, and download the data to a computer.
3. Neutralize the waste solution by adding a small amount of sodium thiosulfate, then dispose the waste solution down the drain with running water.
4. Return used glassware to the dirty bin, and return all equipment.

Note: If table turns yellow, wipe down with a paper towel, some water, and a few crystals of sodium thiosulfate.

3 Data Collection

3.1 Data Tables

Level	Trial	Target (°C)	Run #	Hot plate (°C)	Start temp (°C)	End temp (°C)	Mass of KI (g)
1	1	15	4	45	14.4	15.1	0.30
	2		5		15.4	16.0	0.29
	3		6		14.7	14.0	0.32
	4		7		14.9	15.3	0.32
	5		8		15.32	14.4	0.31
2	1	20	48	55	19.3	18.7	0.30
	2		9		21.4	20.5	0.28
	3		10		21.0	21.3	0.29
	4		11		19.7	19.4	0.31
	5		12		19.3	19.8	0.31
3	1	25	13	65	25.2	25.8	0.29
	2		14		25.3	25.8	0.29
	3		15		25.7	26.7	0.29
	4		16		24.7	24.6	0.28
	5		17		25.4	25.9	0.30
4	1	30	18	85	29.6	30.6	0.33
	2		19		29.1	28.5	0.30
	3		20		30.9	31.5	0.30
	4		21		30.0	30.4	0.30
	5		22		30.8	31.0	0.29
5	1	35	23	100	35.6	35.4	0.31
	2		24		35.3	35.8	0.31
	3		25		35.1	33.3	0.32
	4		26		34.7	35.3	0.31
	5		27		35.5	36.3	0.29
6	1	40	43	125	39.8	40.9	0.28
	2		44		41.3	41.1	0.28
	3		45		40.5	37.3	0.29
	4		46		40.0	41.0	0.28
	5		47		39.1	38.8	0.29
7	1	45	33	160	45.6	44.9	0.29
	2		34		44.5	43.2	0.30
	3		35		44.8	44.8	0.29
	4		36		44.5	44.7	0.29
	5		37		45.1	44.2	0.29
8	1	50	38	200	49.1	49.5	0.31
	2		39		49.8	49.0	0.28
	3		40		49.0	48.1	0.29
	4		41		49.2	49.7	0.29
	5		42		49.7	49.9	0.29

Table 1: Raw temperature and setup data for all trials at each temperature level.

3.2 Sources of Uncertainty

To reduce random errors, 5 trials were conducted at each temperature level and averaged. Other variables, such as initial H₂O₂ concentration and volume, mass of KI, apparatus setup, and sealing method were all kept constant across all runs so that differences in the initial pressure-increase rate can be attributed primary to temperature.

4 Data Processing

4.1 Uncertainty Propagation

The uncertainty values for temperature and pressure were obtained from specifications of the equipment used, and the smallest scale on the digital balance was used as the uncertainty of mass: ± 0.01 g. A 25 mL volumetric pipette was used to obtain the H₂O₂ for all trials, but the exact volumes delivered were not confirmed with a graduated cylinder. Thus, the pipette's tolerance was used as the volume uncertainty: ± 0.06 mL. Time was recorded automatically by the LabQuest, so its uncertainty was assumed negligible relative to pressure variation throughout the experiment.

Tool	Uncertainty
Vernier Stainless Steel Temperature Probe	± 0.1 °C at 0 °C, ± 0.5 °C at 100 °C
Vernier Gas Pressure Sensor	± 4 kPa
Digital Balance	± 0.01 g
Volumetric Pipette (Class A TD)	± 0.06 mL

Table 2: Summary of uncertainties by tool.

Given that the Vernier documentation provides two uncertainty values for the temperature probe, linear interpolation was used for the uncertainty of the device:

$$\Delta T(x) = 0.20 + \frac{0.50 - 0.20}{100} \cdot x \quad (5)$$

Where x is the measured temperature obtained from the temperature probe (in Celsius), and ΔT is the uncertainty in Kelvin ².

4.1.1 Uncertainty in rate constant

The rate constant was calculated as the slope of a linear best-fit trendline to the pressure-time graph over a fixed *15 second* interval, starting at the first continuous rise in pressure after the rubber stopper was replaced ³.

²Uncertainty is not affected by the conversion between Celsius and Kelvin.

³**First continuous rise:** The first datapoint was counted as the start interval after a consecutive rise in the next adjacent 3 datapoints

The reaction rate equation for the decomposition reaction of hydrogen peroxide (H_2O_2) and potassium iodide (KI) can be expressed in the general form, where r is the reaction rate and k is the rate constant:

$$r = k[\text{H}_2\text{O}_2]^m[\text{I}^-]^n \quad (6)$$

Given that the moles of H_2O_2 and the amount of KI were held constant for all trials, the reaction rate is directly proportional to the rate constant k with temperature. Moreover, according to the ideal gas relationship ($PV = nRT$), pressure inside the sealed flask is proportional to the moles of O_2 produced:

$$P \propto n \quad (7)$$

Thus, an apparent rate constant k_{app} can be defined using the initial rate of pressure increase:

$$k_{app} = \frac{\Delta P}{\Delta t} \quad (8)$$

$$k_{app} \propto k \quad (9)$$

As there are 5 trials per temperature level, a mean apparent rate constant was calculated to represent the rate constant at each temperature::

$$\bar{k}_{app} = \left(\frac{1}{n}\right) \cdot \sum_{i=1}^n k_{app,i}, \quad (n = 5) \quad (10)$$

The random uncertainty in the mean k_{app} value was then calculated:

$$\Delta\bar{k}_{app} = \frac{\sigma}{\sqrt{n}} \quad (11)$$

Where σ is the standard deviation of the 5 k_{app} values, and n is the number of trials (5). This was included because random uncertainties (caused by small variations in, for example, plastic film sealing, mixing time, etc.) can be reduced by taking average, but systematic uncertainties (i.e. constant volumetric tolerance from using the same pipette for all trials) does not average out.

Note: As shown in *equation 8*, the apparent rate constant is the same as the initial rate of pressure increase.

4.1.2 Uncertainty in the Arrhenius plot

The vertical error bars (uncertainty in $\ln k_{app}$) was propagated using $\Delta \ln k_{app} = \frac{\Delta k_{app}}{k_{app}}$:

$$k_{app} \pm \Delta k_{app} = k_{app} \cdot (1 \pm \frac{\Delta k_{app}}{k_{app}}) \quad (12)$$

The logarithmic rule of addition was then used:

$$\ln(k_{app} \cdot (1 \pm \frac{\Delta k_{app}}{k_{app}})) = \ln(k_{app}) + \ln(1 \pm \frac{\Delta k_{app}}{k_{app}}) \quad (13)$$

$$\therefore \Delta \ln k_{app} = |\ln(1 \pm \frac{\Delta k_{app}}{k_{app}})| \quad (14)$$

However, given the size of the uncertainty relative to the k_{app} values, the approximation $\ln(1 \pm x) \approx x$ for small x can be used, where $x = \frac{\Delta k_{app}}{k_{app}}$. Thus:

$$\Delta \ln(k_{app}) \approx \frac{\Delta k_{app}}{k_{app}} \quad (15)$$

4.2 Processed Data

Temp (°C)	Trial	Average temp (°C)	Average temp (K)	Mass of KI (g)	Start window (s)	End window (s)	Initial rate (kPa/s)	Avg. initial rate (kPa/s)	Initial rate SD (kPa/s)
15	1	14.75	287.90	0.30	26.6	41.6	0.00594	0.01023 ± 0.00194	0.00434
	2	15.70	288.85	0.29	40.4	55.4	0.00817		
	3	14.35	287.50	0.32	30.0	45.0	0.01237		
	4	15.10	288.25	0.32	30.0	45.0	0.01676		
	5	14.86	288.01	0.31	20.2	35.2	0.00792		
20	1	19.00	292.15	0.30	31.8	46.8	0.01397	0.01406 ± 0.00223	0.00498
	2	20.95	294.10	0.28	17.2	32.2	0.00864		
	3	21.15	294.30	0.29	25.8	40.8	0.01510		
	4	19.55	292.70	0.31	30.0	45.0	0.02171		
	5	19.55	292.70	0.31	24.0	39.0	0.01089		
25	1	25.50	298.65	0.29	19.0	34.0	0.01867	0.01782 ± 0.00315	0.00705
	2	25.55	298.70	0.29	20.0	35.0	0.02864		
	3	26.20	299.35	0.29	27.2	42.2	0.01631		
	4	24.65	297.80	0.28	24.0	39.0	0.01644		
	5	25.65	298.80	0.30	20.0	35.0	0.00904		
30	1	30.10	303.25	0.33	5.6	20.6	0.03811	0.03884 ± 0.00870	0.01944
	2	28.80	301.95	0.30	10.2	25.2	0.02327		
	3	31.20	304.35	0.30	11.0	26.0	0.06776		
	4	30.20	303.35	0.30	17.2	32.2	0.04581		
	5	30.90	304.05	0.29	11.4	26.4	0.01924		
35	1	35.50	308.65	0.31	8.0	23.0	0.06992	0.05442 ± 0.00600	0.01342
	2	35.55	308.70	0.31	16.8	31.8	0.05917		
	3	34.20	307.35	0.32	13.2	28.2	0.06227		
	4	35.00	308.15	0.31	6.2	21.2	0.04098		
	5	35.90	309.05	0.29	21.4	36.4	0.03975		
40	1	40.35	313.50	0.28	11.6	26.6	0.06090	0.04214 ± 0.00826	0.01847
	2	41.20	314.35	0.28	11.0	26.0	0.02914		
	3	38.90	312.05	0.29	9.6	24.6	0.02469		
	4	40.50	313.65	0.28	8.8	23.8	0.06334		
	5	38.95	312.10	0.29	10.0	25.0	0.03264		
45	1	45.25	318.40	0.29	6.6	21.6	0.04139	0.09427 ± 0.03053	0.06826
	2	43.85	317.00	0.30	16.2	31.2	0.06972		
	3	44.80	317.95	0.29	4.8	19.8	0.19417		
	4	44.60	317.75	0.29	8.0	23.0	0.13306		
	5	44.65	317.80	0.29	12.4	27.4	0.03301		
50	1	49.30	322.45	0.31	4.6	19.6	0.17295	0.10081 ± 0.02089	0.04672
	2	49.40	322.55	0.28	9.8	24.8	0.05932		
	3	48.55	321.70	0.29	11.4	26.4	0.07183		
	4	49.45	322.60	0.29	5.2	20.2	0.12192		
	5	49.80	322.95	0.29	11.2	26.2	0.07802		

Table 3: Processed data.

Note: Trial 5 of 15°C was removed from calculations because the source data could not be located on the LabQuest.

Run 8 from the LabQuest indicated a target temperature of 20°C.

4.3 Raw Data

Note: The original raw data file obtained from the LabQuest is 300 rows by 80 columns. Due to the size of this, the raw data file can be found in the appendix, *section A.1*.

Level	Trial	Target (°C)	Target (K)	Run # (LabQuest)	Start temp (°C)	End temp (°C)	Average temp (°C)	Volume of H ₂ O ₂ (mL)	Mass of KI (g)
1	1	15	288.15	4	14.4	15.1	14.75	25	0.30
	2			5	15.4	16	15.70		0.29
	3			6	14.7	14	14.35		0.32
	4			7	14.9	15.3	15.10		0.32
	5			8	15.32	14.4	14.86		0.31
2	1	20	293.15	48	19.3	18.7	19.00	25	0.30
	2			9	21.4	20.5	20.95		0.28
	3			10	21	21.3	21.15		0.29
	4			11	19.7	19.4	19.55		0.31
	5			12	19.3	19.8	19.55		0.31
3	1	25	298.15	13	25.2	25.8	25.50	25	0.29
	2			14	25.3	25.8	25.55		0.29
	3			15	25.7	26.7	26.20		0.29
	4			16	24.7	24.6	24.65		0.28
	5			17	25.4	25.9	25.65		0.30
4	1	30	303.15	18	29.6	30.6	30.10	25	0.33
	2			19	29.1	28.5	28.80		0.30
	3			20	30.9	31.5	31.20		0.30
	4			21	30	30.4	30.20		0.30
	5			22	30.8	31	30.90		0.29
5	1	35	308.15	23	35.6	35.4	35.50	25	0.31
	2			24	35.3	35.8	35.55		0.31
	3			25	35.1	33.3	34.20		0.32
	4			26	34.7	35.3	35.00		0.31
	5			27	35.5	36.3	35.90		0.29
6	1	40	313.15	43	39.8	40.9	40.35	25	0.28
	2			44	41.3	41.1	41.20		0.28
	3			45	40.5	37.3	38.90		0.29
	4			46	40	41	40.50		0.28
	5			47	39.1	38.8	38.95		0.29
7	1	45	318.15	33	45.6	44.9	45.25	25	0.29
	2			34	44.5	43.2	43.85		0.30
	3			35	44.8	44.8	44.80		0.29
	4			36	44.5	44.7	44.60		0.29
	5			37	45.1	44.2	44.65		0.29
8	1	50	323.15	38	49.1	49.5	49.30	25	0.31
	2			39	49.8	49	49.40		0.28
	3			40	49	48.1	48.55		0.29
	4			41	49.2	49.7	49.45		0.29
	5			42	49.7	49.9	49.80		0.29

Table 4: Temperature runs (raw data).

4.4 Example Calculation

Consider the first trial of the first temperature level, 15°C as an example (marked as red, in *table 3*). For this trial, the average temperature (taken from the start + end temperature) was 14.75°C:

$$T = 14.75^\circ\text{C} + 274.15 = 287.9\text{K} \quad (16)$$

Given that the analysis window for the pressure-time graph is 15 seconds starting at the first continuous rise after the rubber stopper was replaced, using the data helper I programmed ⁴, the selected interval was:

$$t_{\text{start}} = 26.6 \text{ s}, \quad t_{\text{end}} = 41.6 \text{ s} \quad (17)$$



Figure 2: Data helper.

A linear regression was then fitted to the 76 datapoints in the selected window, using the linear trendline formula $P = mt + b$ in Excel, where the slope m is the initial rate (or apparent rate constant k_{app}):

⁴To speed up data processing for all 40 trials, I programmed a helper that loaded all data and automatically generated graphs and stats using *Python* and the *Plotly.js* library.

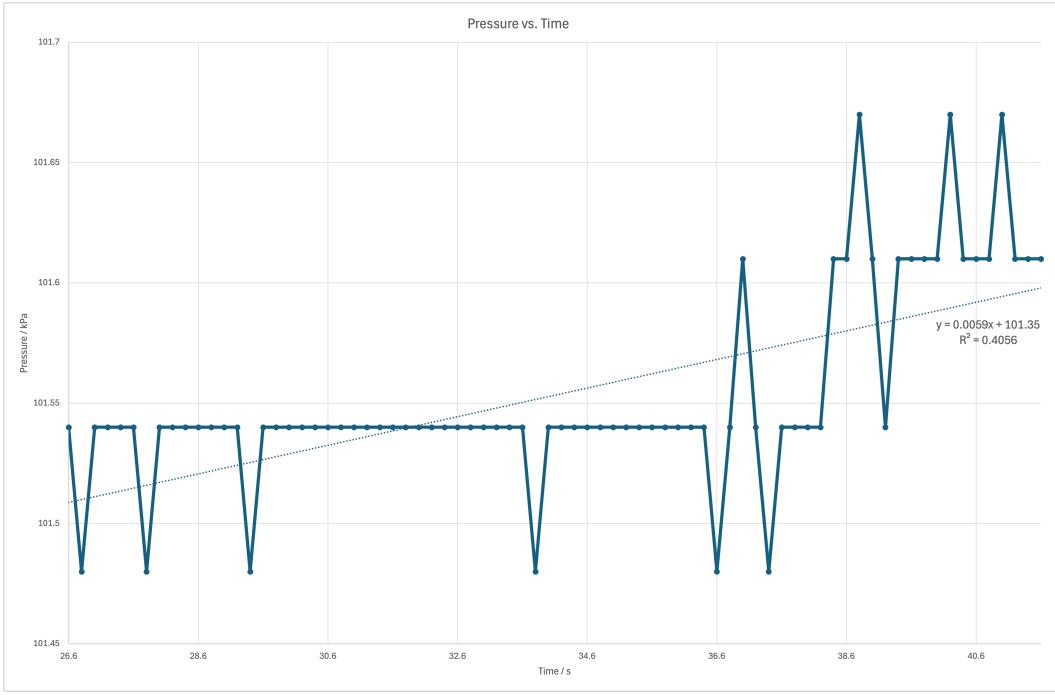


Figure 3: 15-second snapshot.

As shown in the graph above, the slope value over the time interval 26.6 s to 41.6 s was $0.0059 \text{ kPa s}^{-1}$. This matches the value reported for 15°C , *trial 1* in *table 3*. The average apparent rate constant can then be calculated:

$$\overline{k_{app}} = \frac{0.00594 \text{ kPa s}^{-1} + 0.00817 \text{ kPa s}^{-1} + 0.01237 \text{ kPa s}^{-1} + 0.01676 \text{ kPa s}^{-1} + 0.00792 \text{ kPa s}^{-1}}{5} \quad (18)$$

$$\overline{k_{app}} = \frac{0.05116 \text{ kPa s}^{-1}}{5} = 0.010232 \text{ kPa s}^{-1} \quad (19)$$

The standard deviation of the five trials is 0.00434:

$$\sigma = \sqrt{\frac{1}{5}(-0.004292)^2 + (-0.002062)^2 + (0.002138)^2 + (0.006528)^2 + (-0.002312)^2} \quad (20)$$

$$\sigma = 0.004234 \text{ kPa s}^{-1} \quad (21)$$

The random uncertainty in the mean can then be calculated:

$$\Delta \overline{k_{app}} = \frac{0.00434 \text{ kPa s}^{-1}}{\sqrt{5}} = 0.00194 \text{ kPa s}^{-1} \quad (22)$$

Thus, the initial rate for the first trial of 15°C is:

$$k_{app} = 0.01023 \pm 0.00194 \text{ kPa s}^{-1} \quad (23)$$

* * *

The approach from above was used to calculate the apparent rate constant for the other 8 temperature levels:

Temperature level ($^{\circ}\text{C}$)	Temperature level (K)	Apparent rate constant, k_{app} (kPa s $^{-1}$)
15	288.15	0.01023 ± 0.00194
20	293.15	0.01406 ± 0.00223
25	298.15	0.01782 ± 0.00315
30	303.15	0.03884 ± 0.00870
35	308.15	0.05442 ± 0.00600
40	313.15	0.04214 ± 0.00826
45	318.15	0.09427 ± 0.03053
50	323.15	0.10081 ± 0.02089

Table 5: Apparent rate constant.

5 Data Analysis

Data from *table 3* and *table 5* were used to create an average initial rate (kPa s $^{-1}$) vs. temperature (K) graph:

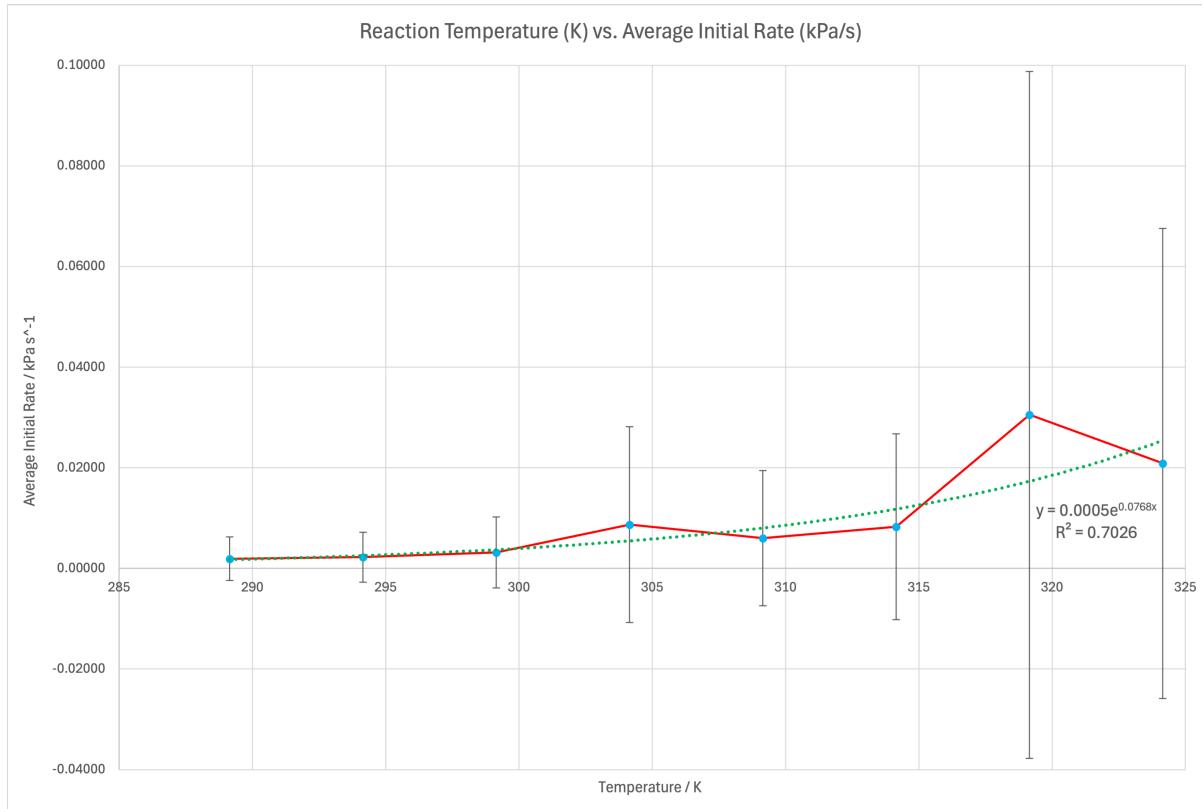


Figure 4: Graph of average initial rate (kPa s $^{-1}$) vs. temperature level (K).

As shown in *figure 4* above, there is an increasing exponential relationship between the apparent rate constant k_{app} and the temperature of the reaction:

$$f(x) = 0.0005e^{0.0768x} \quad (24)$$

The apparent rate constant k_{app} was defined in *section 4.1.1* to represent the initial rate of the reaction within the first 15 seconds after the reaction begins. Given that the initial amounts of H_2O_2 and I^- were held constant across all trials (with minor variations in the mass of KI), k_{app} is proportional to the actual rate constant k for the reaction, by a constant scale factor difference:

$$k_{app} = C \cdot k, \quad (25)$$

Where C is the constant scaling factor between the apparent rate constant and the true rate constant. As shown in *table 3* and *table 5*, the apparent rate constant increases from an average of $0.01023 \pm 0.00194 \text{ kPa s}^{-1}$ at 15°C (288.15K) to an average of $0.10081 \pm 0.02089 \text{ kPa s}^{-1}$ at 50°C (323.15K), which is an increase by a factor of 9.85. This supports my initial hypothesis that higher temperature increases the frequency of collisions and the fraction of molecules with energy $\geq E_A$.

To better model how the reaction temperature impacts the rate constant, the Arrhenius equation from *equation 2* was used to analyze the data, given that $k_{app} \propto k$:

$$k_{app} = A_{app} \cdot e^{-\frac{E_A}{RT}} \quad (26)$$

An Arrhenius plot of $\ln k_{app}$ vs. $\frac{1}{T}$ was created by taking the natural logarithms on both sides:

$$\ln k_{app} = -\frac{E_A}{R} \cdot \left(\frac{1}{T}\right) + \ln A_{app} \quad (27)$$

Recall from *section 1.1* that the slope of the Arrhenius plot is $-\frac{E_A}{R}$ and the y-intercept is $\ln(A)$. The Arrhenius equation can then be rearranged, where m is the slope of the Arrhenius plot, and b is the y-intercept:

$$\ln k_{app} = m \cdot \left(\frac{1}{T}\right) + b \quad (28)$$

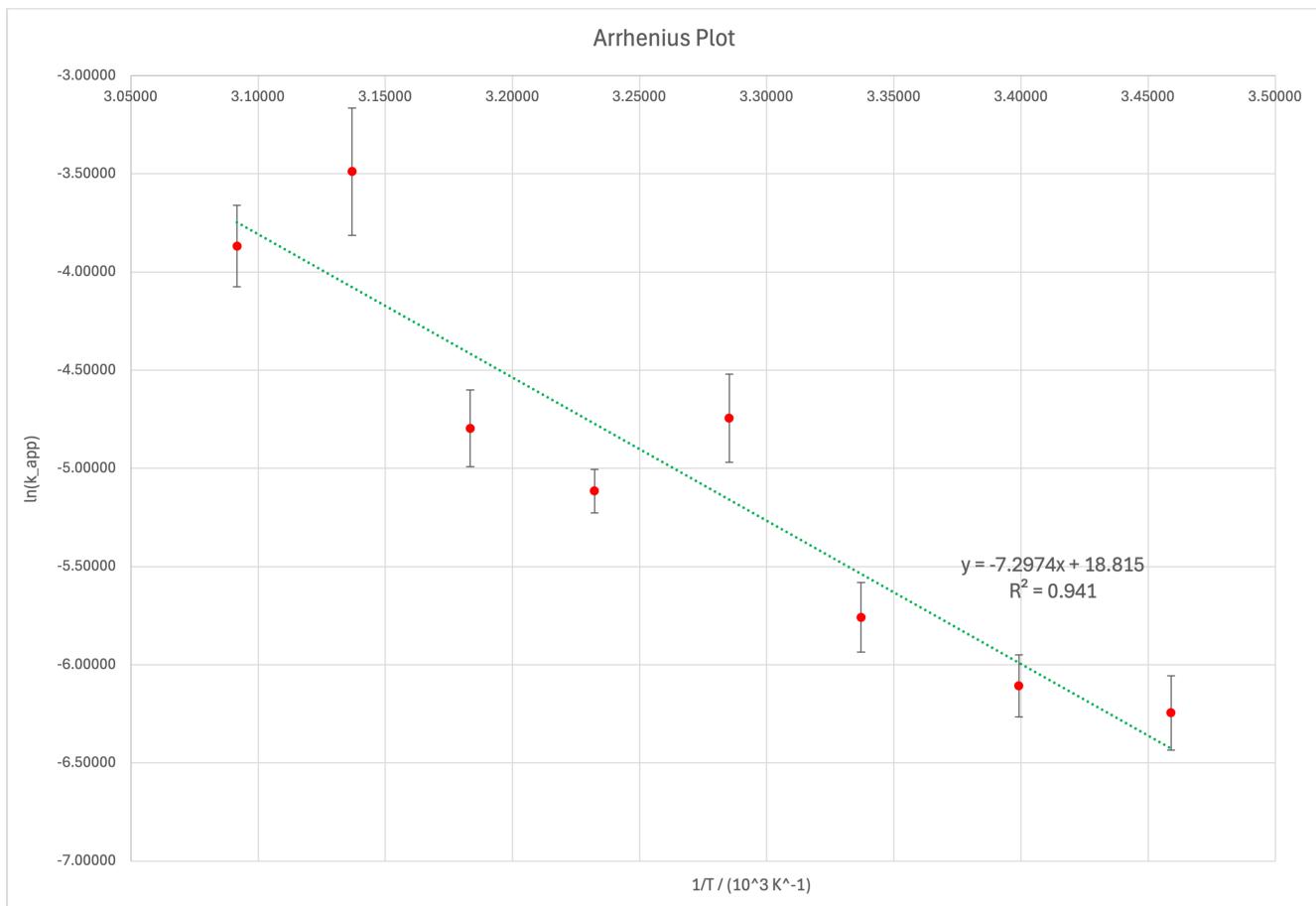


Figure 5: Arrhenius plot, graph of $\ln k_{app}$ vs. $\frac{1}{T} \cdot 10^3$.

However, because the x-axis of the graph uses $\frac{1}{T} \cdot 10^{-3}$ rather than $\frac{1}{T}$, the slope must be multiplied by 1000 to be correct:

$$\ln k_{app} = (m \cdot 1000) \cdot \left(\frac{1}{T}\right) + b \quad (29)$$

Plugging in the values from figure 5:

$$\ln(k_{app}) = (-7.2974 \cdot 10^3) \cdot \left(\frac{1}{T}\right) + 18.815 \quad (30)$$

Given that the slope $m = -\frac{E_A}{R}$, the activation energy E_A can be calculated using $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$ ⁵:

$$E_A = |-m \cdot R| = 7.2974 \cdot 10^3 \cdot 8.31 \text{ J K}^{-1} \text{ mol}^{-1} = 60641.4 \text{ J mol}^{-1} \quad (31)$$

$$\therefore E_A = 60.6 \pm 9.4 \text{ kJ mol}^{-1} \quad (32)$$

⁵Value obtained from IB Chemistry Data Booklet, version 1.0 (first assessment 2025).

Thus, the activation energy for the KI-catalyzed decomposition reaction is $60.6 \pm 9.4 \text{ kJ mol}^{-1}$. Note that the uncertainty for activation energy obtained from Excel's LINEST function.

A graph of the mass of KI vs. k_{app} was also plotted to check whether small variations in the mass of KI had an effect on the apparent rate constant. However, no clear relationship was observed, which shows that the small variations in the mass of KI was not the primary driver of the observed temperature dependence of k_{app} :

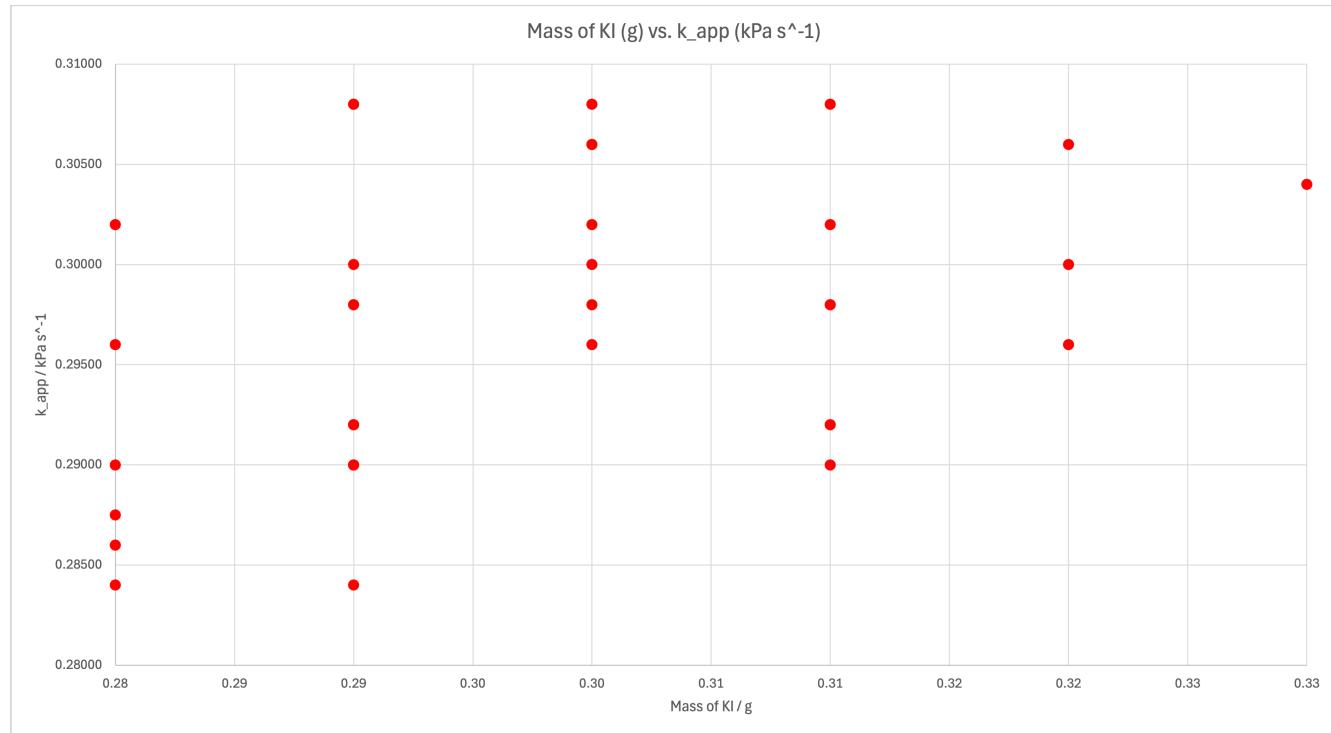


Figure 6: Graph of mass of KI vs. k_{app} for all trials.

6 Conclusion

This investigation aims to examine the relationship between reaction temperature and the initial rate of the KI-catalyze decomposition reaction of hydrogen peroxide, H_2O_2 , where the initial rate (k_{app}) was determined from the initial slope of pressure (kPa) vs. time (s) in a sealed flask. The experimental data showed that higher temperatures increase both the collision frequency and the fraction of molecules with kinetic energy $\text{KE} \geq E_A$, leading to a larger initial pressure-rise rate as oxygen is produced. The hypothesis in section 1.2 predicting an **exponential relationship** between temperature and the apparent rate constant was supported by the data.

Moreover, given that the apparent rate constant is proportional to the actual rate constant as apparatus setup and initial reactant amounts were held constant, the Arrhenius plot and graph was used, which produced an activation energy of $E_A = 60.6 \pm 9.4 \text{ kJ mol}^{-1}$ for the KI-catalyzed pathway. This value is consistent with accepted scientific values online: a lab published by MIT OpenCourseware and the Chemistry LibreTexts reports an uncatalyzed E_A of about 75 kJ mol^{-1} , while iodide catalysis lowers it to about 56 to 56.5 kJ mol^{-1} [1][2], which

is consistent with the experimental data within uncertainty.

Overall, increasing the reaction temperature does increase the measured rate constant for this reaction, as the KI provides an alternative reaction pathway that requires less energy.

7 Evaluation

7.1 Strengths

A key strength of this investigation was the control of experimental variables; same apparatus setup (flask, stopper, tubing, pressure sensor) was maintained throughout all trials, and the initial reactant amounts were held constant, so that changes in the reaction rate can be solely attributed to changes in temperature. Though there are minor fluctuations in the mass of KI, *figure 6* has proved the small variations to not be the primary impact on the apparent rate constant.

Another strength lies in replication and averaging. Learning from past mistakes in other IB Science investigations, conducting five trials per temperature level in this investigation and using mean values reduced the impact of random variations between trials and increased stability when a trial needs to be excluded (i.e. due to missing source data or other experimental errors), compared to relying on single or double trials per temperature level.

7.2 Weaknesses & Limitations

One major methodological limitation lies in the difficulty of maintaining the water bath temperature through the entire 60 seconds data collection period. While most trials started and ended within 1°C of the target temperature, the bath temperature could drift amidst the collection period due to heat loss to the surroundings. Moreover, from personal experience, the temperature probe may not have perfectly represented the temperature of the entire water bath; readings often drifted when blocks of ice drifted nearby. To reduce this limitation, a laboratory thermostatic water bath with internal circulation (i.e. Fisherbrand Isotemp General Purpose Deluxe Water Baths [3], Thermo Scientific Immersion Circulators [4], etc.) would provide a more uniform temperature control. However, the high cost of such equipment (\$1700 – \$4000) made it impractical for this investigation.



Figure 7: Fisherbrand Isotemp General Purpose Deluxe Water Baths



Figure 8: Thermo Scientific Immersion Circulators

A second major methodological limitation was in the control of the reaction temperature within the flask. While the temperature probe in the water bath reported temperatures within 1°C of the target temperature during data collection, the reacting solution inside the beaker may not have matched the bath temperature during the fitted interval due to the addition of the catalyst, especially when 10 mL of room-temperature water was mixed with solid KI before being added to the flask. Though this impact may be small, any mismatch in the temperature would directly increase the spread of data in k_{app} , as the reaction rate strongly depend on temperature. To reduce this source of error, the KI solution should be pre-equilibrated in the same water bath, and its temperature should be measured inside the flask, by using a 3-hole rubber stopper with a temperature probe inserted through a sealed port. Temperatures from within the flask would drastically improve the accuracy of the temperature assigned to each trial, and reduce variations in k_{app} , as well as bias caused by uneven water bath temperature.

Lastly, there's a limitation in the procedure in the addition of the catalyst. While the rubber stopper was re-placed to the flask as fast as possible, the reactions in higher temperatures may have already begun before the flask was sealed, which would lead to an underestimation of the initial rate. To reduce this variability, the catalyst should be added without opening the system, by injecting the catalyst using a syringe through a septum stopper, which would allow for a more consistent start time across trials and a better (and proper) seal on the rubber stopper.

By implementing these improvements in future iterations, a more complete characterization of how the reaction temperature influences the initial reaction rate of the decomposition reaction of hydrogen peroxide.

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A Appendix

A.1 Complete Raw Data

A.2 Source Code

All source code and raw data are open-source, available to view on GitHub.