Investigating the Effect of Varying H_2O_2 Concentrations on the Reaction Rate of an Iodine Clock Reaction

I. Introduction and Background

An iodine clock reaction is well known for its dramatic colour change from colourless to dark blue in the blink of an eye. This fascinating, magic-like, sudden change in colour caught my curiosity and attention which lead to me studying this reaction and topic. There are various versions of this reaction, however, I will be using the ascorbic acid (vitamin C) variant for my experiment. This reaction involves two separate colourless solutions that react with each other once mixed. The first solution (Solution A) contains a mixture of ascorbic acid and iodine (I_2) in aqueous, while the second solution (Solution B) contains a mixture of hydrogen peroxide (H_2O_2) and a starch indicator in aqueous. In Solution A, the ascorbic acid breaks the iodine, in aqueous, into iodide ions (I^-) and acts as a proton donor, releasing acidic protons (H^+), making the solution colourless.

(fast) $$I_{2\,(aq)} + \text{Ascorbic Acid} \rightarrow I^-_{(aq)} + 2H^+$$ **Equation 1**

When mixed with Solution B, the hydrogen peroxide reacts with the newly formed iodide ions and acidic protons to produce iodine and water; the iodide essentially gets converted back into iodine. This is the slower reaction and is the rate-determining step (RDS) which determines the reaction rate of this reaction.

(slow, RDS) $$H_2O_{2\,(aq)} + 2I^-_{(aq)} + 2H^+ \rightarrow I_{2\,(aq)} + 2H_2O_{(l)}$$ **Equation 2**

These two reactions happen extremely quickly and instantaneously when the solutions are mixed. Iodine is constantly being reconverted to iodide due to ascorbic acid and oxidized back to iodine due to hydrogen peroxide. This competing reaction prevents the iodine produced from reacting with starch to trigger a colour change as it is continually being consumed by ascorbic acid as soon as it is formed. This process continues until the ascorbic acid is fully consumed and a sudden colour change occurs. This colourless to dark blue change is achieved by the formation of a triiodide (I_3) starch complex when excess iodine reacts with iodide ions in a redox reaction as electrons are transferred from iodide ions to iodine molecules.

$$I_{2\,(aq)} + I^-_{(aq)} \rightarrow I^-_{3\,(aq)} \xrightarrow{\text{Starch}} \text{Blue Starch Complex}$$ **Equation 3**

Figure 1: Iodine Clock Reaction Colour Change

Since a physical colour change is observed, the reaction rate can simply be determined by recording the time taken for the blue triiodide starch complex to appear. This can be achieved by using a stopwatch or video recording device. From chemical kinetics and the rate law, the concentration of the reactants affects the rate of reaction of a chemical reaction. Depending on the order of reaction, this change in concentration will result in different effects on the reaction rate with some being more drastic than others. Another factor that determines the rate of reaction would be the rate constant (*k*), however, as all trials will be performed under standard ambient conditions, the lab environment will remain at a constant temperature of 25℃ and thus the value of the rate constant will not change.

II. Research Question

For my experiment, I will be using the rate law to reach a definitive answer to my research question: **How does using different concentrations of H_2O_2 (3% ± 0.03, 6% ± 0.04, 9% ± 0.06, 12% ± 0.10, 15% ± 0.00) affect the rate of reaction of an iodine clock reaction?**

To answer my research question, I will be diluting a standardized solution of 15% hydrogen peroxide to the desired concentrations of 3% increments (3%, 6%, 9%, 12%, 15%). While keeping the concentration and volumes of the other reactants constant, in addition to a controlled environment, I will be using my phone to video record the reaction to obtain the time taken for the reaction to complete. With this, I will be able to analyze my findings to conclude results to answer my research question.

III. Hypothesis

As the order of reaction can only be determined experimentally, with a literature value for the rate constant (*k*) at 25℃ being unavailable on the internet, in addition to the many variables that can influence the reaction rate of an iodine clock reaction, a meaningful hypothesis statement is not possible. Despite this, according to the rate law and collision theory, an increase in the concentration of hydrogen peroxide should result in an increase in the reaction rate as more particles will have the needed kinetic energy to successfully collide with one another, given the correct geometry, and form products, thus, requiring less time for the iodine clock reaction to complete and change colour.

IV. Variables

Table 1: Independent and Dependent Variables

Type of Variable	Description
Independent	<u>The Concentration of H_2O_2 Used in Solution:</u> The concentration of hydrogen peroxide used was varied by a set interval of 3%. The concentrations used were 3% ± 0.03, 6% ± 0.04, 9% ± 0.06, 12% ± 0.10, and 15% ± 0.00 for a total of five data sets.
Dependent	<u>Reaction Rate of Iodine Clock Reaction:</u> Depending on the concentration of hydrogen peroxide, the time taken for the iodine clock reaction to complete and change colour will vary.

Table 2: Controlled Variables

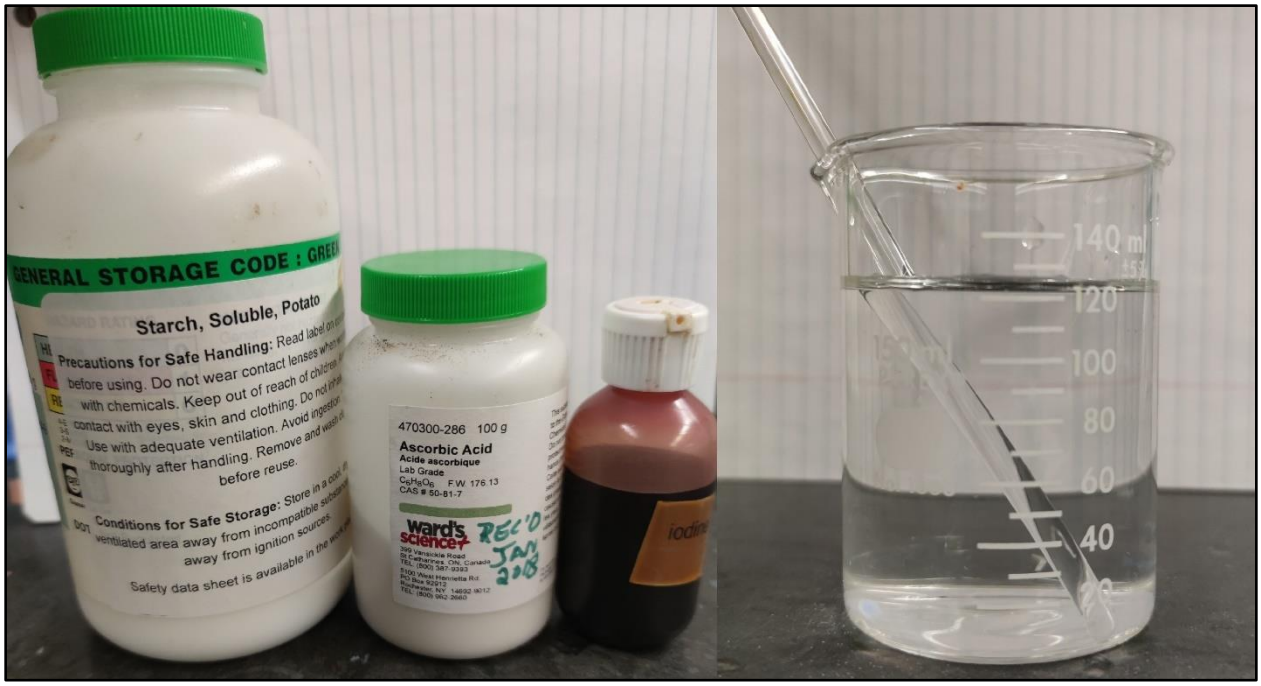
Controlled Variable	Significance	Method of Control
Distilled Water	Water directly from the tap may contain impurities such as dissolved ions which can interfere with the chemical reactions and results obtained.	For all solutions, distilled water is used instead of tap water. This removes the possibility of interference from the impurities found in tap water and ensures the accuracy of the experiment.
Source, Concentration and Volume of Solution A and Starch Solution Used	Using different sources of Solution A and starch solution may result in slight variations in the concentrations which can affect the resulting reaction time. From the rate law, the reactant concentrations do affect the reaction rate. Since only the concentration of hydrogen peroxide is being varied, all other reactants will have to be at a constant concentration.	To ensure the same concentration of Solution A and starch solution were used, one massive solution of Solution A ($750cm^3$) and starch solution ($525cm^3$) was prepared for this experiment. The same solution was used to source the identical volumes of Solution A ($50cm^3$) and starch solution ($35cm^3$) needed per trial.
Equipment Used	Using different equipment may result in a variation in the measurement uncertainties and integrity of measurements.	The same equipment was used to conduct each trial and rinsed with distilled water to ensure measurement uncertainties were kept consistent and to reduce the chance of random errors.
Lab Environment (SATP)	As the rate constant (k) is temperature dependant and will influence the rate of reaction of the experiment, this experiment was conducted in a lab environment under standard ambient conditions.	The lab was maintained at a constant room temperature of 25°C at 101kPa. To ensure that the temperatures of the solutions were constant per trial, all solutions were left on the lab counter to meet room temperature (25°C). An exception was made for hydrogen peroxide which was refrigerated when not being used to slow down its decomposition reaction.
Parallax Error	Due to the surface tension of most liquids in a narrow piece of glassware, a concave shape is created at the surface called a meniscus. As a result, a variation in volume readings can lead to systematic errors.	When observing the burette and graduated cylinder, all readings were conducted at eye level and perpendicular, not above or below, to ensure an accurate reading at the bottom of the meniscus.

V. Equipment and Materials

Table 3: Apparatus

Chemical	Equipment	Glassware
- 90cm^3 of 2% Iodine Tincture - 3000mg of Ascorbic Acid (Vitamin C tablets work) - 0.6g of Soluble Starch (Potato) - 45cm^3 of 3% H_2O_2 - 45cm^3 of 6% H_2O_2 - 45cm^3 of 9% H_2O_2 - 45cm^3 of 12% H_2O_2 - 45cm^3 of 15% H_2O_2 (135cm^3 of 15% H_2O_2 if diluting yourself with the instructions included in the procedure) - 1.5dm^3 Distilled Water	- Electronic Scale (± 0.001g) - Lab Scoop Spatula - Plastic Funnel - Filter Paper - Chemical Waste Container - Hot Plate - Safety Googles - Rubber Grip for Hot Beakers - Timer (smartphone and phone stand or stopwatch) - Retort Stand - Burette Clamp - Mortar and Pestle (if using Vitamin C tablets)	- 1x Glass Stirring Rod - 7x 150cm^3 Beaker (± 5%) - 1x 250cm^3 Erlenmeyer Flask (± 5%) - 1x 600cm^3 Beaker (± 5%) - 1x 1000cm^3 Beaker (± 5%) - 1x 10cm^3 Graduated Cylinder (± 0.1cm^3) - 2x 25cm^3 Graduated Cylinder (± 0.05cm^3) - 1x 100cm^3 Graduated Cylinder (± 0.5cm^3) - 1x 50cm^3 Burette (± 0.05cm^3)

Figure 2: Some of the Chemicals and Glassware Used



VI. Safety Considerations

Table 4: Safety Considerations

Safety Concern	Reason of Concern	Method of Control
H_2O_2 and Iodine Tincture	Hydrogen peroxide can cause severe skin burns, and eye damage, and is toxic if ingested or inhaled, even at lower concentrations. Iodine can cause serious skin and eye irritation and is toxic to aquatic life.	Safety goggles should **always** be worn when handling these chemicals to protect the eyes from burning and irritation. Additionally, proper lab clothing and footwear should be worn. Handle the chemicals with care and wash your hands afterwards. If ingested or in the eyes, rinse the mouth or eyes. If on clothing or skin, remove contaminated clothing and wash the area with soap and warm water. Contact poison control or medical personnel. Refer to the MSDS of each chemical for further safety and first aid guidelines.
Hot Plate	This device is used for heating at high temperatures and can result in burning if used or handled improperly.	Do not touch the hot surface of the hot plate when in use. Allow the hot plate to cool down after use before moving or returning it to storage. Ensure the power cable is away from the hot plate surface and is turned off and unplugged when not in use.
Hot Beakers	When heating the starch solution, the beaker may get hot and can result in the burning of the fingers when handled.	Rubber gloves or mittens should be used when handling hot beakers to prevent the risk of burning the hand and fingers. In case of a burn, use cool (not cold) water and apply lotion or burn cream.
Glassware	Improper handling of glassware can lead to broken glass and spilled chemicals which can cut and irritate the skin, leading to injuries.	All glassware should be handled gently and with care. Ensure they are away from the edge of the lab countertops and will not get knocked accidentally.
Environmental Consideration	The chemicals and solutions used in this experiment are toxic and should not be released into the environment. Thus, they cannot be poured down the drain.	Disposal of all chemicals and solutions was done by pouring them into a Chemical Waste Container. Ensure to record the volume and concentrations of the chemicals so they can be properly disposed of in with accordance to local rules and regulations.
Ethics	The chemicals and solutions used in this experiment are harmful and costly.	By performing some pre-calculations, the exact quantity of each chemical and solution was determined beforehand resulting in only the necessary volumes of each solution being made to reduce the amount of harmful waste being created.

VII. Procedure

Preparing Solution A:

1. Measure 3000mg of ascorbic acid using an electronic scale and lab scoop spatula.
2. Put this into a 150cm^3 beaker and add 90cm^3 of distilled water by using a 100cm^3 graduated cylinder to measure. Note: if using vitamin C tablets there might be fizzing or bubbles when dissolving, additionally, there might be impurities which will have to be filtered out with filter paper and a plastic funnel.
3. Stir the ascorbic acid until it fully dissolves with the distilled water, making it colourless. If the dissolved ascorbic acid is not colourless or is slightly cloudy, consider filtering it with a plastic funnel and filtering paper when pouring the solution into a 250cm^3 Erlenmeyer flask.
4. After pouring this solution into a 250cm^3 Erlenmeyer flask, add 90cm^3 of 2% Iodine Tincture into the flask. Rinse the empty 150cm^3 beaker that did contain the dissolved ascorbic acid.
5. Swirl the Erlenmeyer flask so that the added iodine becomes colourless as it reacts with the ascorbic acid.
6. Transfer the solution from the Erlenmeyer flask by pouring it into a 1000cm^3 beaker. Rinse the empty Erlenmeyer flask for use later.
7. Fill up the 1000cm^3 beaker with the transferred solution to 750cm^3 by adding distilled water. Solution A is now complete and set it aside.

Making Starch Solution:

1. Measure roughly 0.6g of soluble starch with an electronic scale.
2. Add 525cm^3 of distilled water into a 600cm^3 beaker by filling the beaker to 500cm^3 and adding another 25cm^3 with a 25cm^3 graduated cylinder. Ensure the beaker and graduated cylinder are clean before use.
3. Add the measured amount of soluble potato starch to the beaker containing the distilled water.
4. Stir the solution and allow the starch to dissolve. Using a hot plate and heating the solution will help to speed up this process. Be sure to handle the heated beaker and hot plate with caution and use rubber gloves or mittens.
5. If the starch solution is of a greyish-cloudy colour, consider filtering the solution with a funnel and filter paper.
6. The starch solution for Solution B is now complete.

Calculations for Preparing Hydrogen Peroxide Dilutions:

As the concentration of hydrogen peroxide will be varied as the independent variable, I will need to dilute the standard 15% concentration that is provided into my various concentrations. To achieve this, I will need to perform some calculations to find the volumes of 15% H_2O_2 and distilled water needed to achieve each desired concentration. Since each trial requires 15cm^3 of H_2O_2, a total of 45cm^3 of each concentration is needed. A sample calculation, with uncertainty, to find the volumes needed for 3% H_2O_2 is shown in *Table 5* and my calculations are summarized below in *Table 6*.

Table 5: Calculation to Find Volume of H_2O_2 and H_2O Needed for 3% H_2O_2

Dilution Calculations for 3% H_2O_2
$C_1V_1 = C_2V_2$ C_1 = concentration of 15% H_2O_2 standard V_1 = volume of 15% H_2O_2 to be found C_2 = target concentration of 3% H_2O_2 V_2 = total volume of 3% H_2O_2 needed
$V_1 = \frac{C_2V_2}{C_1}$ $V_1 = \frac{0.03 \cdot 45\text{cm}^3}{0.15} = 9\text{cm}^3$
$V_{\text{water}} = 45\text{cm}^3 - 9\text{cm}^3 = 36\text{cm}^3$ $\therefore$ 9cm^3 of 15% H_2O_2 and 36cm^3 of H_2O

Uncertainty = % H_2O_2 unc. + % H_2O unc. % H_2O_2 unc. = $\frac{0.1\text{cm}^3}{9.0\text{cm}^3} \cdot 100\% = 1\%$ % H_2O unc. = $\frac{0.05\text{cm}^3}{36.0\text{cm}^3} \cdot 100\% = 0.1\%$	Uncertainty = 1% + 0.1% = ± 1% = ± 0.03

Table 6: Hydrogen Peroxide Dilution Volume Calculations

H_2O_2 Concentration	15% Hydrogen Peroxide Needed (cm^3)	Distilled Water Needed (cm^3)
3% ± 0.03	9	36
6% ± 0.04	18	27
9% ± 0.06	27	18
12% ± 0.10	36	9
15% ± 0.00	45	0

Preparing Varying Concentrations of Hydrogen Peroxide:

1. Fill the burette to the 0cm^3 mark with distilled water. Ensure the burette is clean and the burette stop cork is in the closed position.
2. Using a 10cm^3, 25cm^3, or 100cm^3 graduated cylinder, pour the calculated amount of hydrogen peroxide needed from *Table 6* into a 250cm^3 Erlenmeyer flask. Ensure this graduated cylinder is clean before use.
3. Place the Erlenmeyer flask underneath the stop cork of the burette and pour the calculated amount of distilled water from the burette into the flask. Ensure you read the burette from the bottom of the meniscus.
4. Pour the diluted hydrogen peroxide into a 150cm^3 beaker and label its concentration. Place this aside.
5. Repeat steps 1 through 4 until all five varying concentrations of hydrogen peroxide have been created. Note: for the 15% concentration, no dilution is needed thus directly measure 45cm^3.

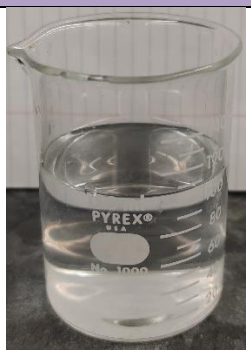
Conducting the Experiment:

1. Each trial consists of 50cm^3 of Solution A and 50cm^3 of Solution B. Solution B is composed of 35cm^3 of starch solution and 15cm^3 of hydrogen peroxide which has its concentration varied as the independent variable.
2. Measure 35cm^3 of starch solution with a 25cm^3 graduated cylinder and pour this into an empty 150cm^3 beaker. Ensure the graduated cylinder and beaker are clean before using.
3. Measure 15cm^3 of hydrogen peroxide of the desired concentration that is being experimented with another 25cm^3 graduated cylinder. Add the measured amount of hydrogen peroxide into the 150cm^3 beaker containing the 35cm^3 starch solution. This is Solution B, and it is complete.
4. Measure 50cm^3 of Solution A using the 100cm^3 graduated cylinder and pour this into another empty 150cm^3 beaker. Ensure this graduated cylinder and beaker are clean before using.
5. Set up the timing device. If using a smartphone and phone stand, ensure that the Solution B beaker is within the frame of the camera.
6. Begin recording or timing as soon as Solution A is poured into Solution B. Once the colourless solution mixture changes colour from colourless to dark blue or black, stop timing or video recording. Record the time taken for the reaction to complete along with the concentration of hydrogen peroxide used for that trial.
7. The trial is complete, dump the finished reaction into the Chemical Waste Container and rinse the two 150cm^3 beakers for the next trial.
8. Repeat steps 2 through 7 until all 15 trials are complete; three trials per independent variable which there are five for a total of 15.
9. When all trials have been successfully conducted, clean up the lab area and rinse all glassware and equipment. Wash your hands with soap and properly dispose of your waste container.

VIII. Raw Data

Qualitative Data:

Table 7: Qualitative Observations

Type	Description			
Colour Change	 Moments after mixing, the colourless solution is fully transparent and clear.	 Moments before reaction completion, the presence of blue triiodide starch complex starts to become visible.	 The solution goes from colourless to suddenly dark blue in a blink of an eye. Some spots of colourless solution are still visible.	 The reaction has completed, dark blue-blackish colour. No more colourless solution is present, and the solution is no longer transparent.
After both solutions were mixed, it appeared at first as if nothing was happening. However, in actuality, the iodine is constantly being converted to iodide and oxidized back to iodine as shown and discussed by *Equations 1 and 2* in the *Introduction and Background*. After some time, a sudden colour change occurs indicating that the reaction has completed.				

Quantitative Data:

Table 8: Raw Data Collected

Trial	$[H_2O_2]$	Start Time (± 0.01)	End Time (± 0.01)
1	3%	0:10.40	4:28.00
2	3%	0:05.10	4:41.00
3	3%	0:06.40	4:32.25
4	6%	0.06.30	1:49.30
5	6%	0:06.25	1:47.45
6	6%	0:04.20	1:51.50
7	9%	0:05.30	1:08.20
8	9%	0:06.40	1:11.10

Trial	$[H_2O_2]$	Start Time (± 0.01)	End Time (± 0.01)
9	9%	0:08.00	1:09.20
10	12%	0:11.45	0:57.25
11	12%	0:06.00	0:46.15
12	12%	0:07.20	0:53.00
13	15%	0:06.40	0:41.10
14	15%	0:16.35	0:47.50
15	15%	0:04.00	0:36.50

IX. Processed Data

Calculating the Reaction Time Taken (Δt)

The time taken for the iodine clock reaction to complete, as indicated by a sudden colour change, can be achieved by calculating the difference in time between the starting and ending times by subtracting the end time from the start time. Since my video recording was performed at 60 frames per second (FPS), an extra calculation is required to convert the frames to milliseconds. This can be done by dividing the remaining frames by the number of frames per second, in my case, 60.

Table 9: Trial 1 - Calculating Reaction Time Taken

Step	Trial 1 Calculations	Uncertainty Calculations
Calculating Δt: $\Delta t = t_{\text{end}} - t_{\text{start}}$	Δt = 4:28.00 – 0:10.40 = 4:17.20	Unc. for Δt = 0.01 + 0.01 = 0.02s % Unc. for $\Delta t = \frac{0.02\text{s}}{257.33\text{s}} \cdot 100\% = 0.008\%$
Converting to Seconds:	4 · 60s + 17s = 257s	
Converting 60FPS to Seconds: $\text{s} = \frac{\text{Remaining Frames}}{0.60}$	$\text{s} = \frac{0.20}{0.60} = 0.33$	
Final:	$\Delta t = 257.33\text{s} \pm 0.02$	

By repeating the process above and using the values from *Table 8*, the following data table is created.

Table 10: Processed Reaction Time Taken Data

Trial	$[H_2O_2]$	Δ Time (s) ± 0.02
1	3%	257.33
2	3%	275.83
3	3%	265.75
4	6%	103.00
5	6%	101.33

Trial	$[H_2O_2]$	Δ Time (s) ± 0.02
6	6%	107.50
7	9%	62.83
8	9%	64.50
9	9%	61.33
10	12%	45.67

Trial	$[H_2O_2]$	Δ Time (s) ± 0.02
11	12%	40.25
12	12%	45.67
13	15%	34.50
14	15%	31.25
15	15%	32.83

Using the findings from *Table 10*, the average reaction time for each varying concentration of hydrogen peroxide can be calculated and then graphed to determine a relationship between the concentration of hydrogen peroxide and the reaction rate of an iodine clock reaction.

Table 11: Averaging Reaction Time for 3% H2O2 Concentration

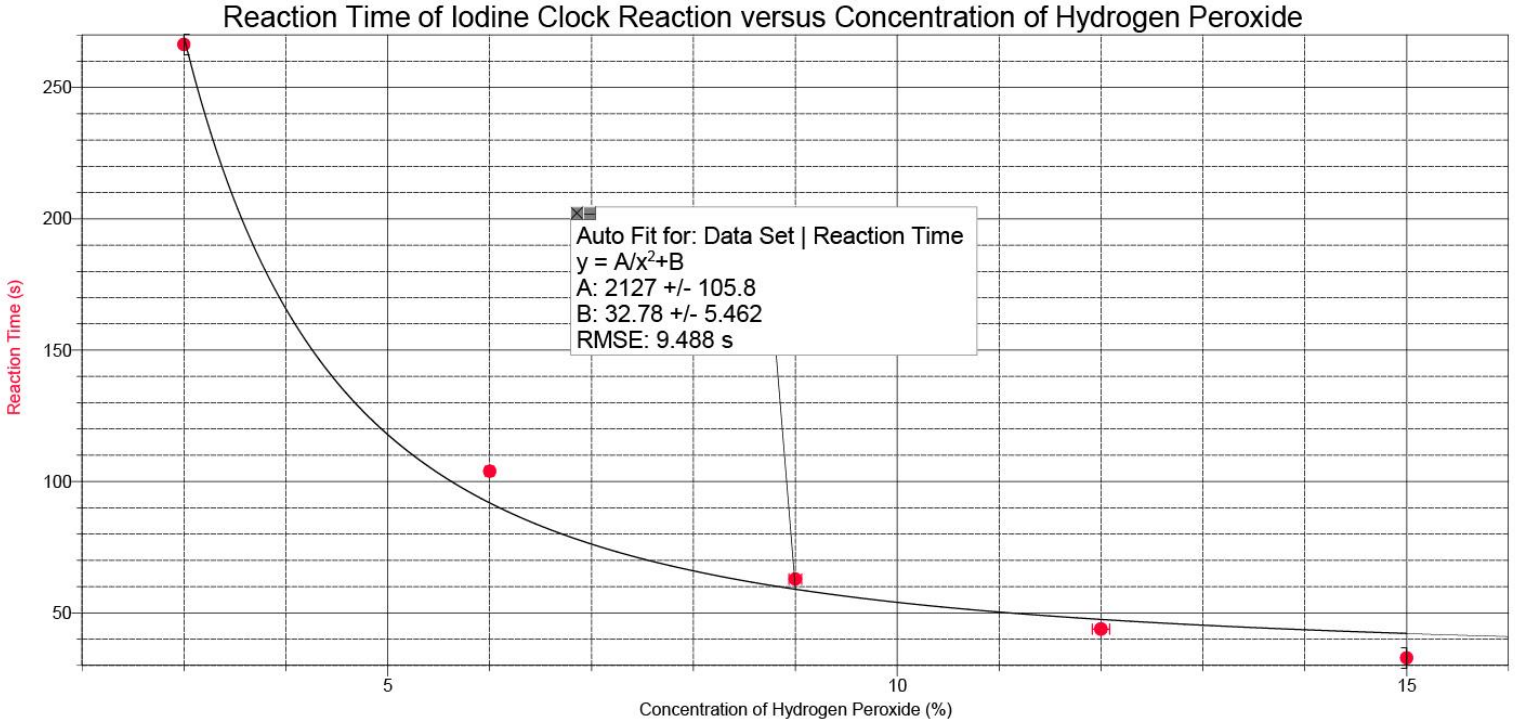
Calculations	Uncertainty Calculations
Averaging Reaction Time: $\overline{\Delta t} = \frac{257.33s + 275.83s + 265.75s}{3} = 266.30s$	Since there is a consistent uncertainty of ± 0.02s in the time taken for the reaction to complete, the average reaction time uncertainty is 0.02s · 3. $\therefore \overline{\Delta t}$ Unc. = ± 0.06s
Final:	$\overline{\Delta t} = 266.30s \pm 0.06$

By repeating the process above and using the values from *Table 10*, the following data table and graph are created.

Table 12: Average Reaction Time per Hydrogen Peroxide Concentration

H_2O_2 Concentration	Average Reaction Time (s) ± 0.06
3% ± 0.03	266.30
6% ± 0.04	103.94
9% ± 0.06	62.89
12% ± 0.10	43.86
15% ± 0.00	32.86

Graph 1: Average Reaction Time of Iodine Clock Reaction versus [H_2O_2]



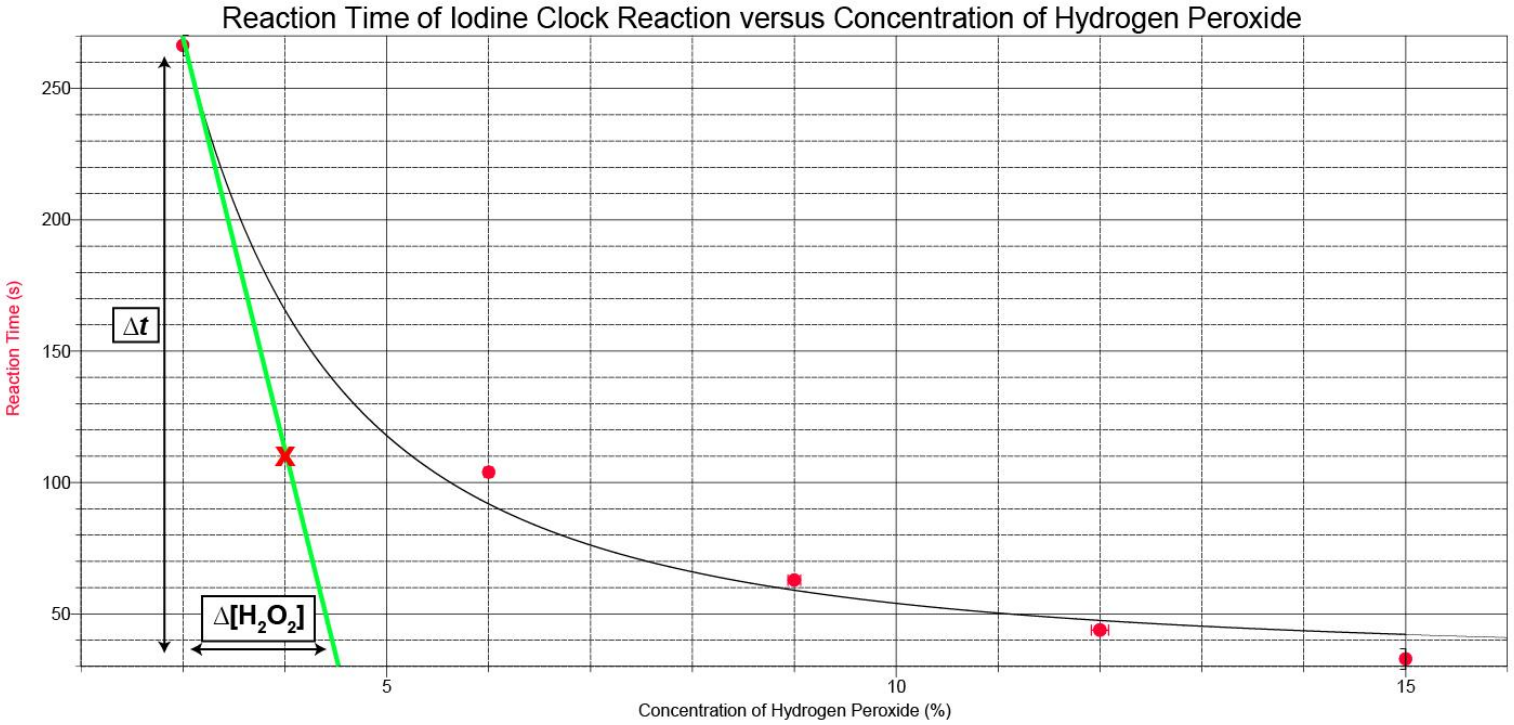
X. Data Interpretation

Upon observation of *Graph 1*, the reaction order with respect to H_2O_2 is most likely second order, however, to confirm this the following formula will be used to calculate the slope of the tangent at the varying concentrations of hydrogen peroxide. This formula will result in the rate of reaction at that concentration of hydrogen peroxide.

$$\text{Reaction Rate} = -\frac{\Delta[H_2O_2]}{\Delta t}$$

Calculating the Slope of Tangent (Rate of Reaction) at 3% H_2O_2

Graph 2: Reaction Time over Concentration Graph with Tangent Line



The slope of the tangent at 3% can be determined by drawing a straight line that is tangent to the curve at the 3% data point as illustrated in *Graph 2* above. With this, two points on the tangent line will be used to calculate the slope, $\frac{\text{rise}}{\text{run}}$. Due to the nature of my experiment, with concentration being the independent variable and time being the dependent variable, the axes are flipped compared to the typical method. For the slope of the tangent to represent the rate of reaction, the slope will have to be inversed. Thus, slope = $\frac{\text{run}}{\text{rise}}$. Since the concentration is given as a percentage, to convert this to molarity an assumption of 100g is made.

$$3\%\ H_2O_2\ \text{Concentration} = \frac{3.0\text{g}\ H_2O_2}{100\text{g Solution}\ (H_2O)} = \frac{\frac{3.0\text{g}}{34.01\text{gmol}^{-1}}}{0.100\text{dm}^3} = 0.882\text{moldm}^{-3}$$

With this, by using a second point at (4.0, 110.0), the slope of the tangent can be calculated.

Table 13: Calculating the Rate of Reaction at 3% H_2O_2 Concentration

Step	Calculations	Uncertainty Calculations
Calculating H_2O_2 Concentration at 4%: $[H_2O_2] = \frac{H_2O_2\ \text{Mass}}{\frac{H_2O_2\ \text{Molar Mass}}{\text{Volume}}}$	*(Assuming 100g)* $[H_2O_2] = \frac{\frac{4.0\text{g}}{34.01\text{gmol}^{-1}}}{0.100\text{dm}^3}$ $[H_2O_2] = 1.176\text{moldm}^{-3}$	Unc. = % Unc. H_2O_2 + % Unc. Time % Unc. H_2O_2 = $\frac{0.06}{0.294} \cdot 100\% = 20\%$

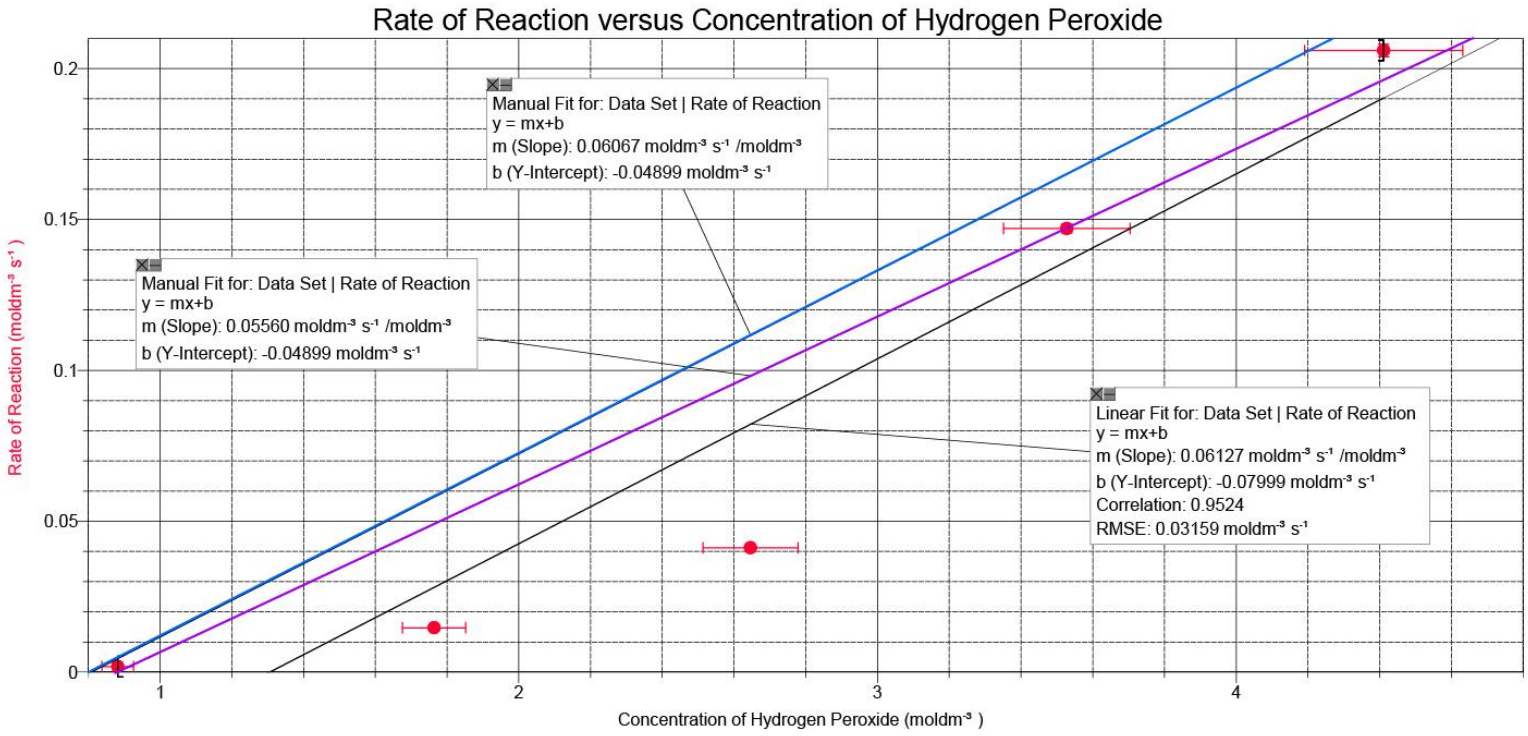
Step	Calculations	Uncertainty Calculations
Calculating Tangent Slope: $\text{Slope} = \frac{\text{run}}{\text{rise}} = -\frac{\Delta[H_2O_2]}{\Delta t}$	$r = -\frac{1.176-0.882}{110.0-266.3}$ $= -\frac{0.294 \text{moldm}^{-3}}{-156.3 \text{s}}$ $= 1.88 \times 10^{-3} \text{moldm}^{-3}\text{s}^{-1}$	% Unc. Time = $\frac{0.12}{156.3} \cdot 100\% = 0.1\%$ Unc. = 20% + 0.1% = 20% Absolute Unc. = 3.76×10^{-4}
Final:	Rate of Reaction = $1.88 \times 10^{-3} \text{moldm}^{-3}\text{s}^{-1} \pm 3.76 \times 10^{-4}$	

By repeating the process above, the following data table and graph are created.

Table 14: Processed Reaction Rate Calculations

Data Set	H_2O_2 Concentration ($moldm^{-3}$)	Rate of Reaction ($moldm^{-3}s^{-1}$)
1 (3%)	0.882	$1.88\times10^{-3} \pm 3.76\times10^{-4}$ (± 20%)
2 (6%)	1.764	$1.47\times10^{-2} \pm 9.08\times10^{-4}$ (± 6%)
3 (9%)	2.646	$4.12\times10^{-2} \pm 2.90\times10^{-3}$ (± 7%)
4 (12%)	3.528	$1.47\times10^{-1} \pm 8.88\times10^{-3}$ (± 6%)
5 (15%)	4.411	$2.06\times10^{-1} \pm 9.23\times10^{-3}$ (± 5%)

Graph 3: Rate of Reaction versus Concentration of H_2O_2



Observing *Table 14*, when the concentration of hydrogen peroxide doubles from Data Set 1 to 2, the rate of reaction increases by a factor of 8. This suggests that the order of reaction, with respect to H_2O_2, is third order. Comparing the other data sets, 3 with 1 gives an order of 2.8, 4 with 2 gives an order of 3.3, 5 with 1 gives an order of 2.9, and 4 with 1 gives an order of 3.1, they all result in a reaction order of about 3. Thus, it is safe to conclude that the order of reaction of an iodine clock reaction, with respect to H_2O_2, is third order. Observing *Graph 3*, there is a positive relationship between the concentration of hydrogen

peroxide used in the iodine clock reaction with the rate at which the reaction happens as the correlation coefficient (*r*) is given as 0.95, which is pretty good. Upon further observation of the graph, a linear fit might not be appropriate as there are two data points significantly below the linear line. Perhaps a quadratic function would have been better suited to represent the relationship.

Calculating Mean Slope and Uncertainty

$$\text{Mean Slope} = \frac{|\text{maximum slope} + \text{minimum slope}|}{2} = \frac{|0.06127+0.05560|}{2} = 5.84\times10^{-2}s^{-1}$$

$$\text{Uncertainty} = \frac{|\text{maximum slope} - \text{minimum slope}|}{2} = \frac{|0.06127 - 0.05560|}{2} = 3.0\times10^{-3}$$

Thus, slope = $5.84\times10^{-2}s^{-1} \pm 3.0\times10^{-3}$ (% Unc. = 5%)

XI. Conclusion

With the gathered information from *Tables 12* and *14*, along with *Graphs 1* and *3*, it can be concluded that by increasing the concentration of hydrogen peroxide, the reaction rate of the iodine clock reaction does indeed increase. This is evident from the positive slope of *Graph 3*, $5.84\times10^{-2}s^{-1} \pm 3.0\times10^{-3}$, and that less time is needed for the reaction to complete as shown in *Table 12*, but that there is also an increase in the rate of reaction in *Table 14*. It is safe to conclude that the order of reaction with respect to H_2O_2 is third order as evaluated in the *Data Interpretation*. Although a literature value is unavailable via a rate constant (*k*) or rate of reaction for any of my concentration values, I believe my results are still valid due to the relatively low uncertainty of ±5% which is most likely attributed to the random and systematic errors of this experiment which will be discussed in the *Discussion* section below.

While there was no meaningful hypothesis statement for this experiment, the results from my experiment have shown that by increasing the concentration of hydrogen peroxide, the iodine clock reaction does complete faster. This makes chemical sense as, according to the rate law, the temperature and concentration of the reactants can influence the reaction rate of a reaction. Since this experiment was conducted at standard ambient conditions, the temperature was kept relatively constant. This means that the increase in reaction time is indeed attributed to the increase in hydrogen peroxide concentration and is backed up by the correlation coefficient (*r*) of 0.95 which suggests that there is a strong correlation between the independent variable, hydrogen peroxide concentration, and dependent variable, reaction time. This is because, according to collision theory, an increase in concentration increases the number of particles with the kinetic energy to meet the required activation energy of the reaction and successfully collide with one another to produce products.

XII. Discussion

Table 15: Strengths

Strength	Significance
Video Recording	By video recording, the uncertainty in the reaction time is greatly reduced as the implications of human reaction time is avoided.
Lower to Higher Concentration Trials	Starting with lower concentrations, the residue leftover has a smaller impact on the result of the next concentration interval as it is more diluted.

Strength	Significance
Three Trials per Independent Variable	Each experiment for the independent variables was repeated three times for consistency and to increase the precision of the raw data to provide an accurate result and conclusion.
Controlled Variables	By keeping the equipment, conditions of the lab environment, sources of Solution A, starch solution, distilled water, and hydrogen peroxide constant, the chances of random errors were reduced. Additionally, reading the burette perpendicularly from the bottom of the meniscus further limited random errors.

Table 16: Limitations and Improvements

Limitation	Significance	Improvement(s)
Assumed Density of H_2O_2 (Systematic)	As the concentration of hydrogen peroxide was given as a percentage, an assumption of 100g was made to convert the percent concentration to molarity as the density and mass of hydrogen peroxide were unknown.	Use concentrations of hydrogen peroxide already given in molarity to avoid assumptions.
Water Evaporation (Systematic)	When heating the starch solution to dissolve the soluble starch faster, some of the water evaporated as it was being heated. This would have reduced the volume of the solution as some of the solvent was evaporated into gas.	Use a lid or alternative to prevent the evaporated gas from escaping. This would allow the evaporated solvent to condense and turn back into liquid when cooled back down.

XIII. Extension

Further research could be conducted by calculating a value for the reaction constant (k) and comparing it to the reaction constant of the other concentrations and reaction rates. Since temperature did not change, this value of k should remain the same as it is only temperature dependent.

XIV. References

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