Research Question: *To determine the activation energy of the iodine clock reaction between hydrogen peroxide, potassium iodide, and sodium thiosulphate by varying the temperature at which the reaction occurs*

I. Background Information

Iodine Clock Reactions

In 1886, Hans Landolt, a Swiss chemist, discovered the iodine clock reaction, also known as the Landolt reaction. In this reaction two colourless solutions are mixed together. Initially the resulting solution remains colourless; however, after a period of time it quickly experiences a colour change to dark blue.[1] There are many variations of the iodine clock reaction, although the underlying principle is the same in all of them. They are all complex reactions.
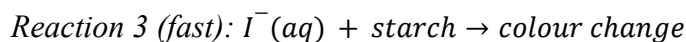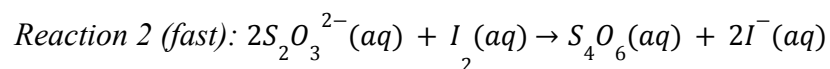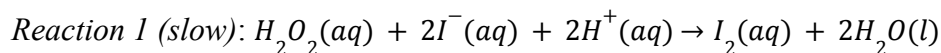
Complex reactions are multi-step reactions which occur in two or more elementary steps. Multi-step reactions can be expressed in reaction mechanisms which are a chronological series of elementary steps by which an overall chemical reaction occurs.[2] As explained by Jerry March, reaction mechanisms describe "which bonds are broken, in what order, how many steps are involved, the relative rate of each step, and so on."[3] The relative rate of each step can be described as either 'fast' or 'slow. The slowest elementary step in the mechanism is known as the rate determining step because it is the step which determines the rate equation of the overall reaction. The rate equation is the rate of the rate determining step excluding intermediates. Intermediates are products of one step which act as reactants in following steps and consequently they are not present in the balanced equation for the overall reaction.[4]

The iodine clock reaction which will be explored in this investigation involves hydrogen peroxide. In this variation, a solution of hydrogen peroxide and sulphuric acid is reacted with a solution of potassium iodide, sodium thiosulphate, and starch. There are 3 main reactions that compose the iodine clock reaction, each reaction has its own set of elementary steps.

The reaction that occurs is the reaction between hydrogen peroxide, iodide anions, and a hydrogen cation to form iodine and water. Iodide anions are present in the solution due to the strong electrolyte property of potassium iodide which essentially means that it completely dissociates in water: $KI(aq) \rightarrow K^+(aq) + I^-(aq)$. The hydrogen cation is present in the solution due to the weak acidic property of water which allows it to partially dissociate: $H_2O \Leftrightarrow H^+ + OH^-$.

In the second reaction, iodine is reduced back into iodide anions by its reaction with thiosulphate. The reducing agent, thiosulphate, is present in the solution due to the dissociation of sodium thiosulphate is water: $Na_2S_2O_3(aq) \rightarrow 2Na^+(aq) + S_2O_3^{2-}(aq)$.

The third and final reaction is between iodine anions and starch. The starch acts as an indicator, when it reacts with iodine anions the solution undergoes a colour change to dark blue.[5] This reaction occurs once all of the sodium thiosulphate is consumed.

$$Reaction\ 1\ (slow):\ H_2O_2(aq)\ +\ 2I^-(aq)\ +\ 2H^+(aq) \rightarrow I_2(aq)\ +\ 2H_2O(l)$$

$$Reaction\ 2\ (fast):\ 2S_2O_3^{\ 2-}(aq)\ +\ I_2(aq) \rightarrow S_4O_6(aq)\ +\ 2I^-(aq)$$

$$Reaction\ 3\ (fast):\ I^-(aq)\ +\ starch \rightarrow colour\ change$$

As the first reaction contains the rate determining step, the rate equation of its mechanism can be written as: $rate = k[H_2O_2]^x[I^-]^y[H^+]^z$ where k is the rate constant and the sum of x, y, and z represent the overall order of the reaction.

Rate of Reaction

The rate of reaction is defined as "the speed at which a reaction proceeds."[6] Therefore, it can also be expressed as the change in concentration of a reactant consumed in a period of time. In the case of this iodine clock reaction, $rate = \frac{\Delta[I^-]}{\Delta t}$.

The rate of chemical reactions depends on many factors including temperature, pressure, the type of substances, and the type of chemical reaction. To understand how these factors affect the rate of reaction, one must understand collision theory.
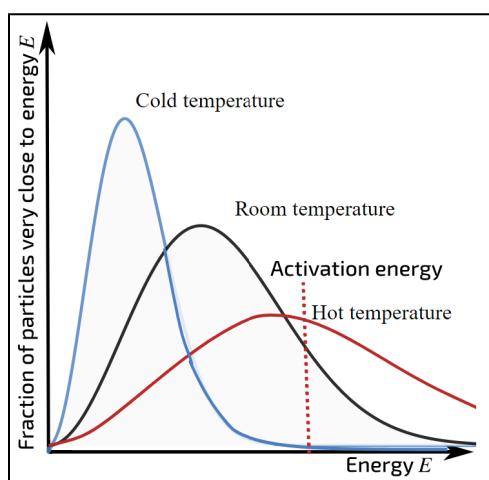
Collision theory was first introduced in the early 20th Century and it is based around the assumption that for a reaction to occur reactants must collide with a minimum amount of energy, called activation energy, and in the correct orientation.[7] As temperature is increased, reactant particles possess more kinetic energy and move at higher velocity. As a result of this, collisions occur more frequently and the number of successful collisions increases as more reactant particles possess enough energy for the reaction to take place. This concept is often illustrated in Maxwell-Boltzman distribution diagrams as shown in *figure 1*.

figure 1: Effect of temperature on the Maxwell-Boltzman curve[8]

Activation Energy

The aim of this investigation is to determine the activation energy of the iodine clock reaction by varying the temperature at which the reaction occurs. Activation energy is defined as "the minimum amount of energy that is required to activate atoms or molecules to a condition in which they can undergo chemical transformation."[9]

In 1889, Svante Arrhenius, a Swedish chemist, first used the term activation energy to describe this concept.[10] In the same year, Arrhenius formulated his formula called the Arrhenius equation after proving and explaining work done by J. Hood and J. Van't Hoff.[11] The Arrhenius

equation can be expressed as: $k = Ae^{\frac{-E_a}{RT}}$ where k is the rate constant, A is the frequency at which molecules collide in the correct orientation, E_a is the activation energy, R is the ideal gas constant which is equal to $8.31\ JK^{-1}mol^{-1}$, and T is the temperature of the reaction. This equation describes the relationship between temperature and activation energy; it will be used later in the investigation to ultimately calculate the activation energy of the reaction. The literature value for the activation energy of this iodine clock reaction is 56 ± 3 kJmol^{-1}.[12]

Formula Derivations

In this section, an expression for the activation energy of the reaction will be derived using formulas mentioned in the previous sections.

The rate equation can be expressed in two different ways:

$$rate = k[H_2O_2]^x[I^-]^y[H^+]^z \text{ and } rate = \frac{\Delta[I^-]}{\Delta t}$$

By equating these equations an expression for the rate constant, k, can be derived:

$$k[H_2O_2]^x[I^-]^y[H^+]^z = \frac{\Delta[I^-]}{\Delta t}$$

$$k = \frac{\Delta[I^-]}{\Delta t[H_2O_2]^x[I^-]^y[H^+]^z}$$

To simplify the equation, let $c = \frac{\Delta[I^-]}{[H_2O_2]^x[I^-]^y[H^+]^z}$. The expression for the rate constant becomes:

$$k = \frac{c}{\Delta t}$$

This expression can be substituted into the logarithmic form of the Arrhenius equation:

$$ln(k) = \frac{-E_a}{RT} + ln(A)$$

$$ln(\frac{c}{\Delta t}) = \frac{-E_a}{RT} + ln(A)$$

$$ln(c) + ln(\frac{1}{\Delta t}) = \frac{-E_a}{RT} + ln(A)$$

$$ln(\frac{1}{\Delta t}) = \frac{-E_a}{RT} + ln(A) - ln(c)$$

$$ln(\frac{1}{\Delta t}) = (\frac{-E_a}{R})(\frac{1}{T}) + ln(\frac{A}{c})$$

This expression is rearranged in the form of a line graph: $y = m \cdot x + c$ where the y values are equal to $ln(\frac{1}{\Delta t})$, the gradient is equal to $\frac{-E_a}{R}$, the x values are equal to $\frac{1}{T}$, and the y-intercept is equal to $ln(\frac{A}{c})$. Therefore, when the graph of $ln(\frac{1}{\Delta t})$ against $\frac{1}{T}$ is plotted, $m = \frac{-E_a}{R}$ and thus the activation energy, $E_a =- mR$.

II. Setup and Methodology

Independent Variable: The temperature at which the reaction occurs.

The independent variable in this investigation is the temperature at which the reaction occurs. This value will be varied using a water bath to heat up the reactant solutions prior to the reaction. The temperature of the reactant solutions will be measured using a thermometer. Eight different temperatures will be used in this investigation: 10, 15, 22, 30, 35, 40, 45, and 50 degrees celsius. The uncertainty of this measurement is ± 1 degrees celsius.

Dependent Variable: The time for a colour change to appear.

The dependent variable in this investigation is the time taken for a colour change in the solution to appear. The value for time will be measured using a stopwatch. The stopwatch will start once the reactants have been reacted together. The stopwatch will stop once a colour change in the product solution is observed. The uncertainty of this measurement is ± 0.01 seconds.

Control Variables:

Control variable	Value of variable	Why and how variable is controlled
Volume and concentration of reactants in the rate determining step	10 cm³ of 0.5 mol·dm⁻³ hydrogen peroxide (H_2O_2) 10 cm³ of 0.5 mol·dm⁻³ potassium iodide (KI)	The volume and concentration of reactants must be kept constant throughout the investigation as they directly impact the rate of reaction and thus the time for the colour change to occur. If the volumes or concentrations of either hydrogen peroxide or potassium iodide are not kept constant the investigation will yield imprecise results. The volume of reactants will be kept constant by diligently measuring it using a volumetric pipette before the trial.
Volume of distilled water	40 cm³	The volume of distilled water used in each trial must be kept constant throughout the investigation. Distilled water further dilutes the reactants and if it is not kept constant the rate of reaction and thus the time for the colour change to occur will be affected. The volume of distilled water will be kept constant by diligently measuring it using a measuring cylinder before the trial.
Amount of starch solution added	5 drops	The amount of starch solution used in each trial must remain constant. The starch solution acts as an indicator and causes the solution to change colour in the presence of iodine. If the amount of starch solution is not kept constant the time for the colour change to occur will be affected.

Temperature of reactants at the start of each repeat	10, 15, 22, 30, 35, 40, 45, and 50 °C depending on trial	The temperature of the reactants must be kept constant for each repeat of the trial as it directly impacts the rate of reaction and thus the time for a colour change to occur. Moreover, the temperature of the reactants must be equal. If the temperature is not kept constant the investigation will yield imprecise results. The temperatures of the reactants will be measured using a thermometer before each repeat.
Point at which the timer is stopped due to the presence of a colour change	dark blue colour	The point at which the timer is stopped must be kept constant throughout the investigation. This point should be exactly when the solution experiences a colour change to a dark blue colour.

Apparatus

- ☐ 1 dm^3 of distilled water
- ☐ 1 dm^3 of 1 mol·dm^{-3} sulphuric acid, H_2SO_4
- ☐ 1 dm^3 of 0.5 mol·dm^{-3} hydrogen peroxide, H_2O_2
- ☐ 1 dm^3 of 0.5 mol·dm^{-3} potassium iodide, KI
- ☐ 1 dm^3 of 0.005 mol·dm^{-3} sodium thiosulphate, $Na_2S_2O_3$
- ☐ 10 cm^3 of 0.1 % starch solution
- ☐ 2 conical flasks
- ☐ 1 measuring cylinder (minimum volume of 40 cm^3)
- ☐ 1 volumetric pipette (minimum volume of 10 cm^3)
- ☐ 1 dropper
- ☐ 1 white tile
- ☐ 1 water bath
- ☐ 1 ice pack
- ☐ 1 thermometer
- ☐ 1 stopwatch

Risk Assessment

Risk	Hazard	Precautions
Injuries such as cuts or lacerations	Direct contact with broken glass caused by dropping, hitting, and breaking glassware	Before starting the investigation check the glassware to ensure it has no cracks or damages. If gloves are worn they must be slip-resistant to prevent the glassware from being dropped. In the case of broken glassware, handle with caution and do not directly contact the glass instead using a broom and dustpan for the safest removal.[13]
May irritate eyes and skin	Direct contact with 1 mol·dm-3 sulphuric acid (H_2SO_4)	Wash hands after handling. Avoid contact with skin using gloves and contact with eyes using safety goggles.[14]
Harmful in contact with skin and if inhaled, even dilute solutions will stain the skin	Direct contact with 0.5 mol·dm3 potassium iodide (KI)	Wash hands after handling. Avoid contact with skin using gloves and contact with eyes using safety goggles. Avoid inhaling iodine vapour by using a fume cupboard.[15]
Injuries such as skin burns	Direct contact with heated water in the water bath	Wear heat resistant gloves or tongs when moving glassware into or out of a water bath.[16]

In addition to assessing the risks of potential hazards, it is also important to consider the environmental concerns. Environmental concerns arise when handling the disposal of chemical substances especially as iodine is significantly toxic to aquatic life.[15] Therefore, it should be noted that chemical substances labelled hazardous should be prevented from reaching drains, sewers, or other bodies of water. However, chemical substances can become non-hazardous at certain concentrations meaning that diluting to non-hazardous levels and disposal through the drain is allowed, this is the case for chemicals such as sulphuric acid. Furthermore, reacting oxidising agents with reducing agents to neutralise the substance allows for their disposal through the drain, this is required when disposing of hydrogen peroxide.[17]

Method

In this section a step-by-step procedure will thoroughly describe how the investigation will be carried out. All required equipment can be found in the list of *Apparatus*. All risks with their hazards and precautions can be found in the *Risk Assessment*.

Prior to the investigation a preliminary experiment was conducted in preparation. In which, the method was refined and improved. During the preliminary experiment the rates of reaction were too fast. Consequently, water was added to the reactants in order to decrease their concentration and rate of reaction. After a few preliminary trials, it was concluded that 40 cm^3 of distilled water was ideal. It was also during this preparation where the best values for temperature were chosen. These values were chosen based on limitations introduced by the waterbath and ice pack.

1. Using the measuring cylinder, measure out 40 cm^3 of distilled water and add it to the first conical flask.
2. Measure out 10 cm^3 of sulphuric acid using the volumetric pipette and add it to the first conical flask.
3. Measure out 10 cm^3 of hydrogen peroxide using the volumetric pipette and add it to the first conical flask.
4. Measure out 10 cm^3 of potassium iodide using the volumetric pipette and add it to the second conical flask.
5. Measure out 10 cm^3 of sodium thiosulphate using the volumetric pipette and add it to the second conical flask.
6. Using the dropper, add 5 drops of starch solution to the second conical flask.
7. Place the first conical flask on top of the white tile.
8. Pour the contents of the second conical flask into the first conical flask and immediately start the stopwatch.
9. Stop the stopwatch once the solution experiences a colour change to dark blue.
10. Record the reading on the stopwatch.
11. Repeat steps 1-10 five times with the same temperature to reduce random errors and to increase the precision of the collected data.
12. Repeat steps 1-11 using different temperatures: 10, 15, 22, 30, 35, 40, 45, and 50 degrees celsius. To increase the temperature, heat up the reactant solutions using a water bath set to 60 °C. To decrease the temperature, cool the reactant solutions by placing them on top of the ice pack. The thermometer should be used to determine that the reactant solutions are at the correct temperature before the reaction.
13. Calculate the values of 1/temperature.
14. Calculate the mean time for the colour change to appear.
15. Calculate values of ln(1/time).
16. Calculate the percentage uncertainties present within the data.
17. Plot the graph of ln(1/time) against 1/temperature with a line of best fit, error bars, and a line of worst fit. The gradient of the line of best fit, $m = \frac{-E_a}{R}$.
18. Calculate the activation energy of the reaction, $E_a =- m \cdot R$.

III. Experimental Analysis

Raw data table: Measurements collected during trials

Temperature, T (± 1 °C)	Time for a colour change to occur, t (± 0.01 s)					
	Repeat 1	Repeat 2	Repeat 3	Repeat 4	Repeat 5	Mean
10	36.20	35.47	35.96	35.67	35.28	35.72
15	32.73	33.25	33.18	32.65	32.44	32.85
22	25.12	24.66	25.73	18.60*	25.35	25.22
30	18.23	19.25	19.86	18.68	19.03	19.01
35	13.92	14.71	13.58	14.54	14.12	14.17
40	10.23	11.00	10.64	9.97	10.10	10.39
45	8.83	7.89	8.25	7.90	8.47	8.27
50	5.03	5.31	4.96	5.46	5.12	5.18

* indicates anomalous results which are excluded from calculations

Processed data table: Temperature and time values for graph

Temperature, T_C (± 1 °C)	Temperature, T_K (± 1 K)	$1/T_K$ (K)	Mean time, t (± 0.01 s)	1/t (s)	ln(1/t) (s)
10	283	0.00353	35.72	0.0280	-3.58
15	288	0.00347	32.85	0.0304	-3.49
22	295	0.00339	25.22	0.0397	-3.23
30	303	0.00330	19.01	0.0526	-2.94
35	308	0.00325	14.17	0.0706	-2.65
40	313	0.00319	10.39	0.0963	-2.34
45	318	0.00314	8.27	0.1209	-2.11
50	323	0.00310	5.18	0.1932	-1.64

All example calculations are for the first row of the data table.

Example calculation - $1/T_K$: $\frac{1}{T_K} = \frac{1}{283.15} = 0.003531697 \approx 0.00353 \ K$

Example calculation - 1/t: $\frac{1}{t} = \frac{1}{35.72} = 0.0279955207 \approx 0.0280 \ s$

Example calculation - ln(1/t): $ln(\frac{1}{t}) = ln(0.028) = -3.575550769 \approx -3.58 \ s$

Uncertainty table 1: Concentration uncertainties

| Substance	Number of moles, n (± 0.01 mol)	Number of moles percentage uncertainty (%)	Volume, V (± 0.1 cm³)	Volume percentage uncertainty (%)	Concentration percentage uncertainty (%)
I^-	0.50	2.0	10.0	1.0	3.0
H_2O_2	0.50	2.0	10.0	1.0	3.0
H_2SO_4	1.00	1.0	10.0	1.0	2.0

Uncertainty table 2: Time uncertainties

Temperature, T (± 1 °C)	Time, t (± 0.01 s)		Mean time percentage uncertainty (%)	Percentage uncertainty in constant, c (%)	ln(1/t) percentage uncertainties (%)
	Mean	Range			
10	35.72	0.92	1.29		12
15	32.85	0.81	1.23		12
22	25.22	1.07	2.12		13
30	19.01	1.63	4.29		15
35	14.17	1.13	3.99	11	15
40	10.39	1.03	4.96		16
45	8.27	0.94	5.68		17
50	5.18	0.50	4.83		16

Example calculation (for the first row of the data table):

- Mean time percentage uncertainty: $\% \, Unc. = \frac{1}{2} \cdot \frac{range}{mean} \cdot 100\% = \frac{1}{2} \cdot \frac{0.92}{35.72} \cdot 100\% \approx 1.29 \, \%$

- Percentage uncertainty in $[I^-]$: $\%Unc. = \%Unc.(n) + \%Unc.(V) = (\frac{0.01 \cdot 100\%}{0.50} + \frac{0.1 \cdot 100\%}{10.0}) = 3 \, \%$

- Percentage uncertainty in $[H_2O_2]$: $\%Unc. = \%Unc.(n) + \%Unc.(V) = (\frac{0.01 \cdot 100\%}{0.50} + \frac{0.1 \cdot 100\%}{10.0}) = 3 \, \%$

- Percentage uncertainty in $[H^+] = [H_2SO_4]$: $\%Unc. = \%Unc.(n) + \%Unc.(V) = (\frac{0.01 \cdot 100\%}{1.00} + \frac{0.1 \cdot 100\%}{10.0}) = 2 \, \%$

- Percentage uncertainty in constant, c:
  $\%Unc. = 2 \cdot \%Unc.([I^-]) + \%Unc.([H_2O_2]) + \%Unc.([H^+]) = 2 \cdot 3 + 3 + 2 = 11 \, \%$

- ln(1/t) percentage uncertainty: $\% \, Unc. = \%Unc.(t) + \%Unc.(c) = 1.29 + 11 = 12.29 \approx 12 \, \%$

figure 2: A graph to show the relationship between temperature and the time for a colour change to occur in an iodine clock reaction
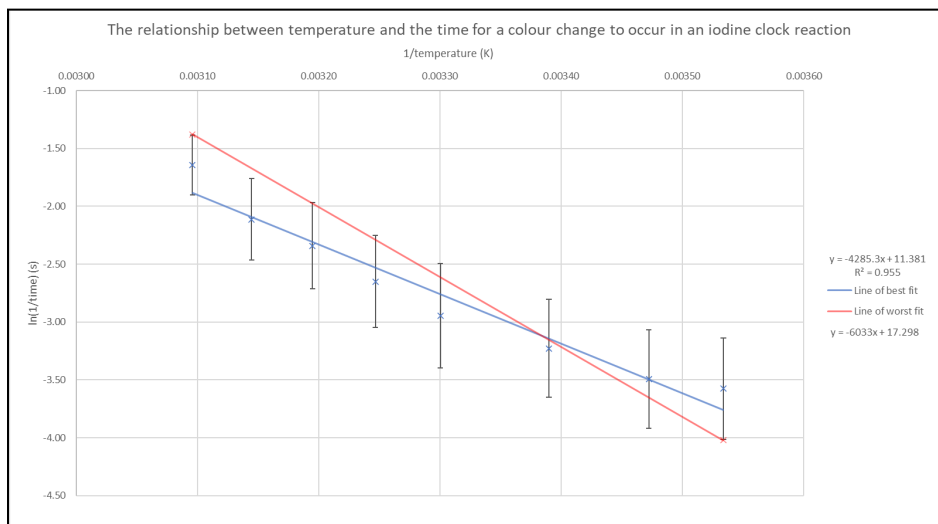
Analysis

The data of the mean time for the colour change to occur against the temperature of the reactants was plotted onto a graph (see *figure 2*). The equation for the linear line of best fit in *figure 2* is *y = -4285.3x + 11.381*. The negative gradient indicates that there is a negative correlation between the variables. In other words, as the temperature of the reactants increases, the time for the colour change to occur decreases. The activation energy is calculated as follows:

$$m = \frac{-E_a}{R} \rightarrow E_a = - m \cdot R = -(-4285.3) \cdot 8.31 = 35610.843 \, Jmol^{-1} \approx 35.6 \, kJmol^{-1}$$

To determine the reliability of the calculated value for activation energy, the percentage uncertainty of the gradient of the line of best fit must be calculated. For this reason, the steepest line of worst fit with the equation of *y = -6033x + 17.298* is plotted in red in *figure 2*. The percentage uncertainty of the gradient can be calculated as follows:

$$\% \, Unc.(m) = \left| \frac{m(LOBF) - m(LOWF)}{m(LOBF)} \cdot 100\% \right| = \left| \frac{-4285.3 - (-6033)}{-4285.3} \cdot 100\% \right| = 40.78360908 \, \% \approx 40.8 \, \%$$

Therefore this iodine clock reaction has an activation energy of 35.6 ± 14.5 kJmol⁻¹.

Another method to determine the reliability of the relationship is using the coefficient of determination (R^2), which is "a measure that assesses the ability of a model to predict an outcome in the linear regression."[18] In *figure 2*, the coefficient of determination is equal to 0.955.

Additionally, the results are considered reliable if the percentage uncertainty of the final value is greater than the percentage error. The percentage error can be calculated as follows:

$$\% \, error = \left| \frac{literature \, value - calculated \, value}{calculated \, value} \cdot 100\% \right| = \left| \frac{35.6 - 56}{56} \cdot 100\% \right| = 36.42857143 \, \% \approx 36 \, \%$$

Conclusion

The aim of this investigation is to determine the activation energy of the iodine clock reaction between hydrogen peroxide, potassium iodide, and sodium thiosulphate by varying the temperature at which the reaction occurs. At higher temperatures, the rate of reaction increases, this can be explained with collision theory. At higher temperatures, Reactant particles have more kinetic energy and consequently collisions occur more frequently. The number of successful collisions also increases as more reactant particles possess the activation energy. To determine the activation energy of the reaction, the Arrhenius equation is rearranged into a linear function and the graph of ln(1/time) against 1/temperature is plotted. The activation energy can ultimately be calculated using the gradient of the linear graph.

The calculated value for the activation energy of this reaction is 35.6 ± 14.5 kJmol^{-1}, whereas the literature value is 56 ± 3 kJmol^{-1}. Considering the uncertainties in the values, the maximum calculated value is 50.1 kJmol^{-1} and the minimum literature value is 53 kJmol^{-1}. The calculated value is still 2.9 kJmol^{-1} less than the literature value. Reasons for this along with potential improvements of the method to reduce this difference are outlined in the *Evaluation*.

IV. Furtherance

Evaluation

To effectively evaluate the investigation, strengths and weaknesses in the method must be identified, assessed, and improved.

The most notable strength within the investigation is the relatively low individual uncertainty values for the measurements. For example, the percentage uncertainties of the concentrations of the substances were all 3 %. Low uncertainty values indicate the precise results as well as the absence of significant systematic errors. They also give direct feedback on the choice of equipment used to measure readings. In this case, the low uncertainty values verify that the appropriate equipment was used in the method. A further example of this is the uncertainties on the measurements for mean time which had a mean uncertainty of approximately 4 %. The low mean time uncertainties can be attributed to the stopwatch which had an absolute uncertainty of ± 0.01 seconds. Although, more importantly the range of these measurements is low which indicates only few random errors were present when acquiring these measurements. Random errors were present in determining when the colour change had occurred and in the reaction time of measuring this instance. Together, the mean overall uncertainty for ln(1/time) is approximately 15 %. These can be visualised on *figure 2* within the magnitude of the vertical error bars. The reason this uncertainty is higher is due to the many individual uncertainties that compose it. An improvement in the method to reduce this uncertainty is to take a video recording of the conical flask in which the reaction occurs and analyse the recording to determine the exact instance in which the colour change took place. This would eliminate the random errors associated with reaction time and reduce the percentage uncertainty of mean time.

Another strength in the investigation is the value for the coefficient of determination which is 0.955. This value is very high and falls within the accepted range where a maximum value of 1 indicates that the line of best fit perfectly fits the data.[19] Therefore, the line of best fit that represents the data is reliable. Furthermore, the results of the investigation are reliable as the percentage uncertainty of the final value (40.8 %) is greater than the percentage error (36 %).

However, this is contradicted as a high value of 40.8 % is calculated for the uncertainty of the gradient of the line of best fit. This is a clear weakness of the investigation as it indicates that the results could potentially be unpredictable. Although, it should be noted that the difference between the calculated value and literature value is relatively small at 2.9 kJmol^{-1} and therefore, the results remain precise and accurate. Nevertheless, as this value is based off of the worst possible outcome considering the uncertainties present, decreasing these uncertainties would in turn decrease the value. As an alternative improvement to video recordings, a greater number of repeats of the trials could be conducted to further increase the precision of the data.

An additional weakness in the investigation that is not accounted for in the uncertainties is temperature lost when opening the water bath to conduct the experiment as well as temperature lost when transferring the contents of the second conical flask into the first. This systematic error did not have a large impact, however, it still affected the results directly by causing the rate of reaction to decrease. Heat loss cannot be completely removed, although it can be significantly reduced by conducting the trial quicker to minimise the time heat can escape.

Overall, the investigation was a success as it yielded precise and accurate results as the difference between the calculated and literature values for the activation energy of the iodine clock reaction is small. This evaluation is supported by the value of the coefficient of determination of 0.955 and the low individual uncertainties. With the implementation of the suggested improvements, the results of the investigation will be further bolstered and the difference between the calculated and literature values will be decreased.

Further Discussion

To extend the research conducted in this investigation, it would be interesting to explore the effects of changing the pH at which the iodine clock reactions occur. This could be completed by adding a greater volume of sulphuric acid to increase the concentration of hydrogen cations or by adding sodium hydroxide to the solution to increase the concentration of hydroxide anions. This iodine clock reaction does require acidic conditions to occur, thus the decrease in pH could act as a catalyst for the reaction. Additionally, comparing and contrasting results between similar iodine clock reactions such as the iodate, persulphate, and chlorate variations would also be compelling.

V. Bibliography

[1] Tennessee Tech (2016, March 10). *Iodine Clock Reaction*. Retrieved from: https://www.cae.tntech.edu/~dcashman/demos/demo_iodine-clock.html. Accessed: 26.10.22

[2] Khan Academy (2022). Reaction mechanism and rate law. Retrieved from: https://www.khanacademy.org/science/ap-chemistry-beta/x2eef969c74e0d802:kinetics/x2eef969c74e0d802:reaction-mechanisms/a/reaction-mechanisms. Accessed: 26.10.22

[3] March, J. (2007, January 16). *MARCH'S ADVANCED ORGANIC CHEMISTRY*. Hoboken, New Jersey: WILEY-INTERSCIENCE. Edition six

[4] LibreTexts Chemistry (2021, June 16). *Rate Determining Step*. Retrieved from: https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Kinetics/03%3A_Rate_Laws/3.02%3A_Reaction_Mechanisms/3.2.03%3A_Rate_Determining_Step. Accessed: 26.10.22

[5] Reynolds, T., Daniels, T. (2020, August 5). *Iodine Clock Reaction Explanation - Mechanism and Colour Change Explained*. Retrieved from: https://www.youtube.com/watch?v=uHX4JaSjkmE. Accessed: 26.10.22

[6] Britannica (2022, December 5). *reaction rate*. Retrieved from: https://www.britannica.com/science/reaction-rate. Accessed: 26.10.22

[7] Britannica (2022, August 25). *collision theory*. Retrieved from: https://www.britannica.com/science/collision-theory-chemistry. Accessed: 26.10.22

[8] University of Cambridge (2022). Maxwell-Boltzmann Distribution. Retrieved from: https://isaacphysics.org/concepts/cc_maxwell_boltzmann_distribution?stage=all. Accessed: 26.10.22

[9] Britannica (2021, April 16). *activation energy*. Retrieved from: https://www.britannica.com/science/activation-energy. Accessed: 26.10.22

[10] Raveendran B., (2022). *Activation Energy*. Retrieved from: https://byjus.com/jee/activation-energy/. Accessed: 26.10.22

[11] Britannica (2022, September 27). *Arrhenius equation*. Retrieved from: https://www.britannica.com/science/Arrhenius-equation. Accessed: 26.10.22

[12] Sweeney W., Lee J., Abid N., DeMeo S., (2014, August). *Efficient Method for the Determination of the Activation Energy of the Iodide-Catalyzed Decomposition of Hydrogen Peroxide*. Retrieved from: https://www.researchgate.net/publication/272135421_Efficient_Method_for_the_Determination_of_the_Activation_Energy_of_the_Iodide-Catalyzed_Decomposition_of_Hydrogen_Peroxide. Accessed: 27.10.22

[13] State Compensation Insurance Fund (2021, February 12). *Handle Glass Safely*. Retrieved from: https://www.safeatworkca.com/safety-articles/handle-glass-safely/. Accessed: 26.10.22

[14] CLEAPSS (2022). *Student safety Sulfuric (VI) acid*. Retrieved from: https://science.cleapss.org.uk/resource/sss022-sulfuric-vi-acid.pdf. Accessed: 26.10.22

[15] CLEAPSS (2022). *Student safety sheets - Iodine, including iodine solutions*. Retrieved from: https://science.cleapss.org.uk/Resource/SSS056-Iodine.pdf. Accessed: 26.10.22

[16] University of Manchester (2022). *RISK ASSESSMENT*. Retrieved from: https://www.hope-academic.org.uk/HandS/Risk%20assessments/waterbaths.htm. Accessed: 26.10.22

[17] CLEAPSS (2022). *Student safety sheets - Waste disposal*. Retrieved from: https://science.cleapss.org.uk/Resource/SSS099-Waste-disposal.pdf. Accessed: 26.10.22

[18] Michigan State University (2022). *Glossary: Constant of proportionality*. Retrieved from: https://connectedmath.msu.edu/families/glossary/. Accessed: 9.12.22

[19] Britannica (2022, October 4). *coefficient of determination*. Retrieved from: https://www.britannica.com/science/coefficient-of-determination. Accessed: 10.12.22

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