SASTA OLIPHANT SCIENCE AWARDS

SOUTH AUSTRALIAN SCIENCE TEACHERS ASSOCIATION

Prize Winner

Scientific Inquiry

Year 11-12

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A Deeper Exploration of the Iodine Clock Experiment

Oliphant Science Awards Science Inquiry

Melson Shi, Year 12

Introduction

The iodine clock reaction is an experiment which is renowned for its dramatic and sudden colour change. It is often used to explore the effect of reagent or catalyst concentration on reaction rates. This investigation provides a deeper exploration to the reaction, exploring its underlying mathematical relationships in attempt to predict the reagent concentration required to yield a specific reaction time.

According to collision theory, the rate at which chemical reactions occur are influenced by their conditions. By adjusting the variables which affect rate of reaction, the total time taken for a reaction to complete can be manipulated accordingly. Total reaction time can be indicated by the appearance of a secondary product, which may manifest visually as a colour change. Following this theory, certain time intervals may be measured with the time elapsed by a corresponding chemical reaction.

The aim of this investigation is to measure a 15-second time interval using a reaction between an iodine species and a redox reagent in the presence of starch.

Background Chemistry

Rates of reaction

According to collision theory, chemical reactions occur when reactant particles collide with enough energy and at correct orientations to form activated complexes. Therefore, to increase the rate of reaction, the frequency of collisions and/or the energy of particles must increase.

One such way to increase the frequency of collisions is to increase the concentration of reactants; this increases the total number of reactant particles present in a given volume of solvent, thus increasing the number of potential collisions between any two particles. Resultantly, the frequency of successful collisions, and hence the overall reaction rate, both increase. Using these principles, this investigation adjusts the concentration of an iodine species to observe changes in the reaction rate.

Cycle of reactions

This investigation considers three different reactions. The first reaction (denoted R_1) occurs between hydrogen molecules, iodide ions, and hydronium ions, yielding water and iodine in solution.

$$R_1\text{: } \mathrm{H_2O_2}_{(aq)} + 2\mathrm{I^-}_{(aq)} + 2\mathrm{H^+}_{(aq)} \rightarrow \mathrm{H_2O}_{(l)} + \mathrm{I_2}_{(aq)}$$

In the second reaction (denoted R_2), the iodine molecules produced from R_1 react with thiosulfate ions to yield iodide and tetrathionate ions. This is the terminating reaction which determines the total reaction time.

$$R_2\text{: } 2\mathrm{S_2O_3}^{2-}{}_{(aq)} + \mathrm{I_2}_{(aq)} \rightarrow \mathrm{S_4O_6}^{2-}{}_{(aq)} + 2\mathrm{I^-}_{(aq)}$$

As shown, R_2 produces iodide ions – one of the reactants in R_1. But reciprocally, R_1 produces iodine molecules – one of the reactants in R_2. Hence, the two reactions occur simultaneously, constituting a cycle in which iodine and iodide are continuously renewed. As such, neither of the two are limiting reagents of either R_1 or R_2, regardless of how much substance was originally used, because both are sustained indefinitely.

Instead, the thiosulfate ion – the other reactant of R_2 – becomes the limiting reagent of the entire cycle. It is measured out to be proportionally less than the other two reactants of R_1, causing R_2 to terminate before R_1, and thereby breaking the cycle between the two. Subsequently, R_1 continues and produces an excess of iodine molecules which are not renewed into iodide ions.

The excess iodine no longer reacts as per R_2, but instead reacts with starch in a new reaction (denoted R_3).

$$R_3\text{: } \mathrm{Starch}_{(aq)} + \mathrm{I_2}_{(aq)} \rightarrow (\mathrm{Starch} \cdot \mathrm{I_2})_{(aq)} \quad \{\text{colour change}\}$$

Since R_3 occurs at a significantly lower rate of reaction, it does not occur while R_2 is still in progress; this is because the iodine reaction with thiosulfate is more spontaneously favourable compared to starch. Hence, the commencement of R_3 must be an indicator that R_2 has terminated.

As both R_1 and R_2 are colourless, R_3 may be uniquely characterised by a colour change. So, the time elapsed from the start of the reaction to the colour change of solution is taken as the total reaction time.

The entire reaction cycle is illustrated in a flowchart below (see *Figure 1*).

Effect of concentration

In this investigation, the concentration of hydrogen peroxide is increased in increments of 20%. In doing so, the reaction rate of R_1 increases, which, in turn, causes the concentration of iodine molecules (produced from R_1) to increase. Following the same principle,

the reaction rate of R_2 likewise increases, due to increased iodine concentration. Therefore, the thiosulfate in R_2 is depleted in less time, causing R_3 to begin sooner.

In summary, an increase in the concentration of hydrogen peroxide corresponds to a decrease in the total reaction time. Using this principle, a reaction time of 15 seconds can be matched to a particular concentration of hydrogen peroxide.

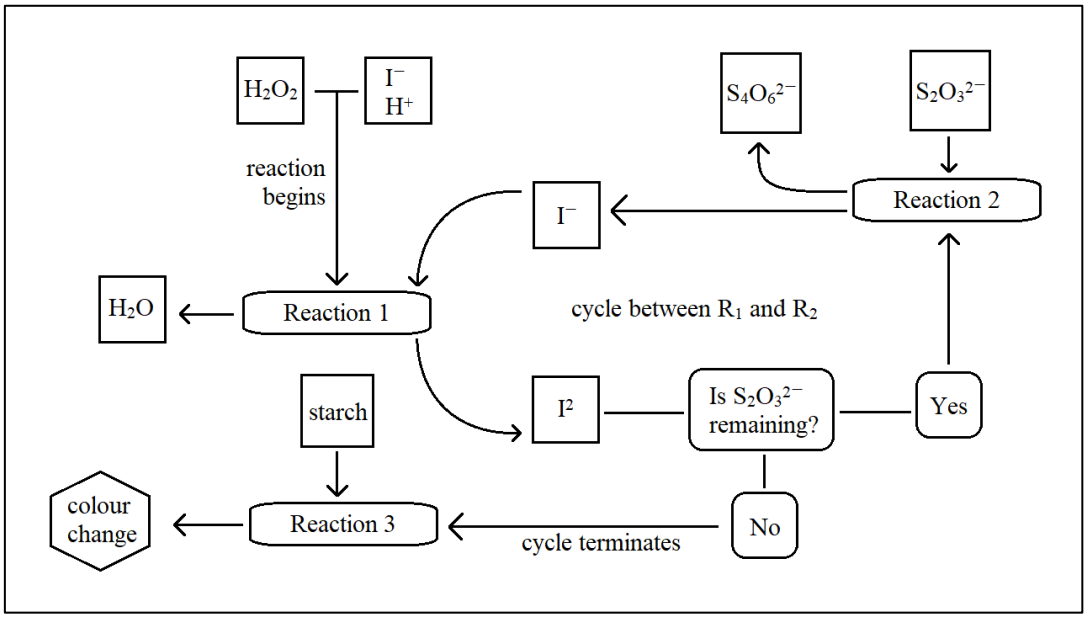

Figure 1: Flowchart of reaction cycle.

Hypothesis

As the concentration of hydrogen peroxide in solution increases, the total reaction time will decrease. There will exist some concentration value which corresponds to a 15-second reaction time.

Method

Using this background chemistry knowledge, an experimental method was developed and performed, whereby the three reactions are arranged to react in the format described above. This method included the alteration of hydrogen peroxide concentration ($[H_2O_2]$) across trials, as the independent variable. In summary, the procedure involved the measurement of reactant substances, followed by the mixing of them all together. The total reaction time was then recorded, as the dependent variable.

The equipment and method are presented below, with justifications in curly brackets and grey text.

Equipment

- 0.05M potassium iodide (KI) solution {in solution, KI dissociated to provide the iodide ions (I^-) required in R_1}
- 0.1M hydrochloric acid (HCl) solution {in solution, HCl dissociated to provide the hydronium (H^+) required in R_1}
- 1% concentrated starch solution {provided the starch required in R_3}
- 0.01M sodium thiosulfate ($Na_2S_2O_3$) solution {in solution, $Na_2S_2O_3$ dissociated to provide the thiosulfate ions ($S_2O_3{}^{2-}$) required in R_2}
- 3% concentrated hydrogen peroxide (H_2O_2) solution {used with water to form different concentrations of solution as the independent variable, affecting the rate of reaction in R_1}
- Distilled water (H_2O) {used to form different concentrations of hydrogen peroxide solution}
- $25mL$ beaker {container in which the substances were mixed, and the three reactions occurred}
- $10mL$ measuring cylinder {container in which the hydrogen peroxide solutions were prepared}
- Stopwatch {measuring instrument for the reaction time}
- Tray {platform on which the experiment was conducted}

Method (for initial data)

Set up (see *Figure 2*)

1. All bottles of chemicals were placed on the tray, with the beaker, measuring cylinder and stopwatch prepared nearby. {ensured a safe and appropriately set up space for the experiment}

Measurement of substances

2. In the beaker, drop size conversion (1mL ≡ 20 drops) was used to form a mixture of 2mL potassium iodide, 1mL hydrochloric acid, 0.5mL starch solution, and 0.5mL sodium thiosulfate. {using drop size removed the parallax error for the measurement of quantities, improving reliability. The volumes of each substance were determined to optimise the reaction conditions; notably, thiosulfate is measured to be a small amount because it is the limiting reagent}

3. The beaker was swirled gently before being placed on the tray. {swirling ensured the formation of a homogeneous mixture, rather than distinct layers. This prevented the rate of reaction from being affected from an uneven spread within the solution}
4. In the measuring cylinder, drop size conversion was used to measure a 5mL solution of hydrogen peroxide and water. 100% hydrogen peroxide concentration was measured first, and *Table 1* was followed in the subsequent trials to form different concentration levels. {as the independent variable, the concentration of hydrogen peroxide could be easily altered by using different amounts of hydrogen peroxide and water. This concentration was prepared in a separate container from the rest of the substances so that the beginning of the reaction can could be controlled}
5. The measuring cylinder was swirled gently before being placed on the tray. {again, this ensured a homogeneous mixture and minimised the effect of systematic error}

Reaction

6. The contents of the measuring cylinder were poured into the beaker. Once all the contents were transferred, the stopwatch begun timing. {this formed a new mixture in which hydrogen peroxide was colliding with the other reactants of R_1, thus beginning the reaction cycle. The stopwatch began timing here as it signified the start point of the reaction}
7. The contents of the beaker were observed closely, and the stopwatch was stopped as soon as a slight colour change emerged. The time value was recorded in a results table. {before R_3 commenced, the solution had a clear colour; therefore, the emergence of colour indicated that R_2 had terminated, signifying the end point of the reaction}

Repetition

8. Steps 1 to 7 were repeated twice, continuing to measure the same concentration of hydrogen peroxide solution. {repetition of the exact same reaction yielded additional values for total reaction time, which could be reconciled with one another through an average, minimising the effects of random error}
9. Steps 1 to 8 were repeated five times, but different concentrations of hydrogen peroxide (80%, 60%, 40%, 20%, 0%) were used by adding water according to *Table 1*. {variation enabled reaction time to be related with hydrogen peroxide concentration}

Following this, the initial raw data was collected in a table (see *Table 3*). From this, graphing technology was used to determine the corresponding concentration of hydrogen peroxide which yielded a 15-second reaction (see Results and Analysis section). This reaction was then performed using the same procedure as above, for verification.

Method (for 15-second clock)

Graphing

10. Using the raw data table, the average reaction time for each hydrogen peroxide concentration (denoted t) was calculated. {using average values minimised the effect of random error}
11. For each value of t, its reciprocal t^{-1} was calculated. Using graphing technology, a scatter plot displaying t^{-1} against hydrogen peroxide concentration was created, and fitted to linear regression function. {given that $t^{-1} \propto$ rate of reaction $\propto$ concentration of reactants, they are linearly related, and so a linear regression could be used to represent the trend. This then provided evidence either for or against the theoretical expectations}
12. A vertical line was plotted at $y = 1/15$, and the coordinates at which it intercepts the linear regression were determined. The x-coordinate indicated the concentration of hydrogen peroxide which should yield a 15-second reaction. {the intercept of $y = 1/15$ and the regression function could be interpreted as the coordinates on the regression function with a y-coordinate of $1/15$. As $1/15$ represented a time of 15 seconds, the corresponding x-coordinate represented the corresponding hydrogen peroxide concentration}

Reaction

13. Using drop conversion, the quantities of each reactant were measured by following steps 2-5. However, in the measuring cylinder, a hydrogen peroxide solution was prepared with the specific concentration determined in step 13. {recreated the conditions identical to that of all previous reactions, albeit the hydrogen peroxide concentration corresponded with a 15-second reaction time}
14. Steps 6 and 7 were repeated by beginning the stopwatch when reactants were mixed together, and stopping it when a colour change was observed. {recorded the actual reaction time which corresponded to the new concentration, as a comparison with the expectant reaction time of 15 seconds}
15. Steps 13 and 14 were repeated twice. {enabled averaging, hence minimising the effect of random error}

Table 1: Reactant quantities to be measured for different concentrations of hydrogen peroxide in solution.

Reactant	100% conc.	80% conc.	60% conc.	40% conc.	20% conc.	0% conc.
Potassium iodide (KI)	2mL					
Hydrochloric acid (HCl)	1mL					
Starch solution	0.5mL					
Sodium thiosulfate ($Na_2S_2O_3$)	0.5mL					
Distilled water (H_2O)	0mL	1mL	2mL	3mL	4mL	5mL
Hydrogen peroxide (H_2O_2)	5mL	4mL	3mL	2mL	1mL	0mL

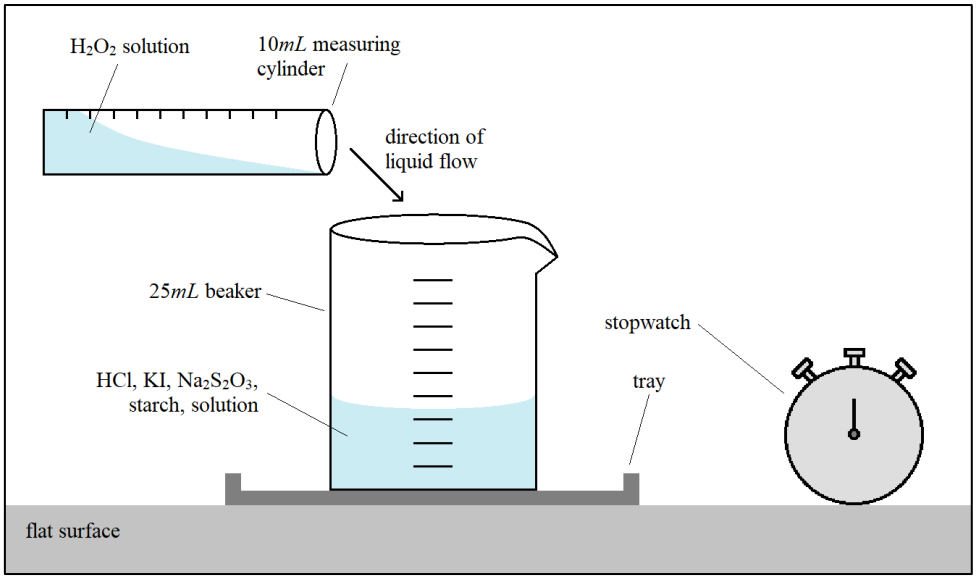

Figure 2: Diagram of experimental setup.

Aside from the method, safety considerations were made for the investigation (see *Table 2*).

Table 2: List of safety considerations.

Safety hazard	Hazard description	Prevention measures
Broken glass	Broken glass pieces are often sharp, and thus have the potential to pierce skin.	Exercise caution when handling glass. Keep glassware away from table edges.
Exposure to KI	Contact irritates skin and eyes [NCBI, 2023].	To prevent contact between substances and eyes, safety glasses should be worn at all times throughout the experiment. Minor contacts of substances with skin should be washed off with water, while major contacts should be addressed with treatment. Avoid direct contact with substances. Avoid inhalation or ingestion of substances.
Exposure to HCl	Contact irritates skin and eyes, and ingestion causes damage to internal organs [NCBI, 2023].	
Exposure to starch solution	Contact irritates skin and eyes, and ingestion causes damage to internal organs [NCBI, 2023].	
Exposure to $Na_2S_2O_3$	Contact irritates skin and eyes, and ingestion of large amounts causes intestinal irritation [NCBI, 2023].	
Exposure to H_2O_2	Contact irritates eyes and potentially burns skin, and ingestion causes damage to respiratory system [NCBI, 2023].	

Results and Analysis

Raw results

From the investigation, a table of raw data (see *Table 3*) was collected for three repetitions of six hydrogen peroxide concentrations. Aside from these quantitative measurements, qualitative observations were also made during the experiment (see *Table 4*).

Table 3: Raw data between hydrogen peroxide concentration [H_2O_2] and time of reaction t, across three trials.

Concentration [H_2O_2] (%)	Trial 1 reaction time t_1 (s)	Trial 2 reaction time (t_2) (s)	Trial 3 reaction time (t_3) (s)
0%	No reaction	No reaction	No reaction
20%	26.30	26.47	24.62
40%	15.29	17.33	15.57
60%	10.08	10.03	9.85
80%	6.70	6.73	6.87
100%	5.98	6.01	4.98

Table 4: Observations made during experiment.

#	Time of observation	Observation
1	Measurement of substances – steps 2 and 4.	The number of drops were constant, but the apparent volume kept increasing.
2	Measurement of substances – after step 5.	Before the reactions began, the solutions were both homogeneous.
3	Reaction – during step 7.	The colour change of the substance, after the reaction cycle, was gradual.
4	Reaction – after step 7.	Colour change continued after the initial change, becoming darker gradually.
5	Repetition of measurement – steps 8 and 9.	After each reaction, the beaker had some liquid in it which was not cleaned.
6	Measurement – steps 2 and 4.	In each “pinch” of the bottles, about 15 drops were ejected, before regripping.

Photographs

A collection of photographs were also made, capturing the initial mixing of the solutions (see *Figure 3*), and the colour of the mixture at different times (see *Figure 4*).

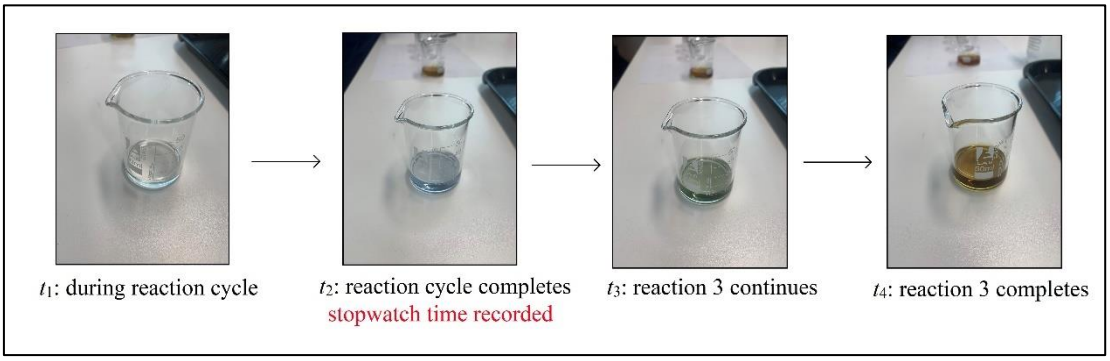

Figure 3 (left): Photograph of the initial mixing of solutions to begin reaction cycle.

Figure 4 (right): Collection of photographs depicting solution colour throughout reaction process.

Linear model analysis

Using this raw data, the average for each concentration (denoted t) was then calculated, using expression $t = (t_1 + t_2 + t_3) \div 3$. For example, for 20% concentration:

$$t = \frac{t_1+t_2+t_3}{3}$$

$$\therefore t = \frac{26.30+26.47+24.62}{3}$$

$$\therefore t \approx 25.80 \text{ seconds (4sf)}$$

Next, t-values were reciprocated to obtain t^{-1} values. Again, using 20% concentration as an exemplar:

$$t = 25.80$$

$$\therefore t^{-1} = 25.80^{-1}$$

$$\therefore t^{-1} = \frac{1}{25.80}$$

$$\therefore t^{-1} \approx 0.0388 \text{ (3sf)}$$

The same process was repeated for all hydrogen peroxide concentration values (see *Table 5*).

Table 5: Calculated t and t^{-1} values for each $[H_2O_2]$ value.

Concentration $[H_2O_2]$ (%)	Average reaction time t (s)	Reciprocated average reaction time t^{-1} (s^{-1})
0%	No reaction	No reaction
20%	25.8	0.0388
40%	16.1	0.0623
60%	9.99	0.100
80%	6.77	0.148
100%	5.66	0.177

Next, graphing software [Desmos, 2023] was used (see *Figure 5*) to create a scatter plot (denoted $t^{-1}_{[H_2O_2]}$). The horizontal axis represents concentration $[H_2O_2]$ and is unitless, while the vertical axis represents inverse reaction time t^{-1} and his units s^{-1}.

A linear regression function was also constructed to represent the trend of the scatter plot. It has the linear form $y = mx + c$, where m and c are constants that are determined by the regression technology (x, y represent $[H_2O_2], t^{-1}$ respectively). A vertical line at $t^{-1} = \frac{1}{15}$ and its intercept with the regression function are also plotted, representing the concentration required for a 15-second timer.

As mentioned before, a linear trend is appropriate in this context, because the concentration of a reactant is directly proportional to the rate of reaction. Note that a domain restriction of $\{x: 0 < x < 1\}$ applies, because it is invalid to consider less than 0% or more than 100% concentration.

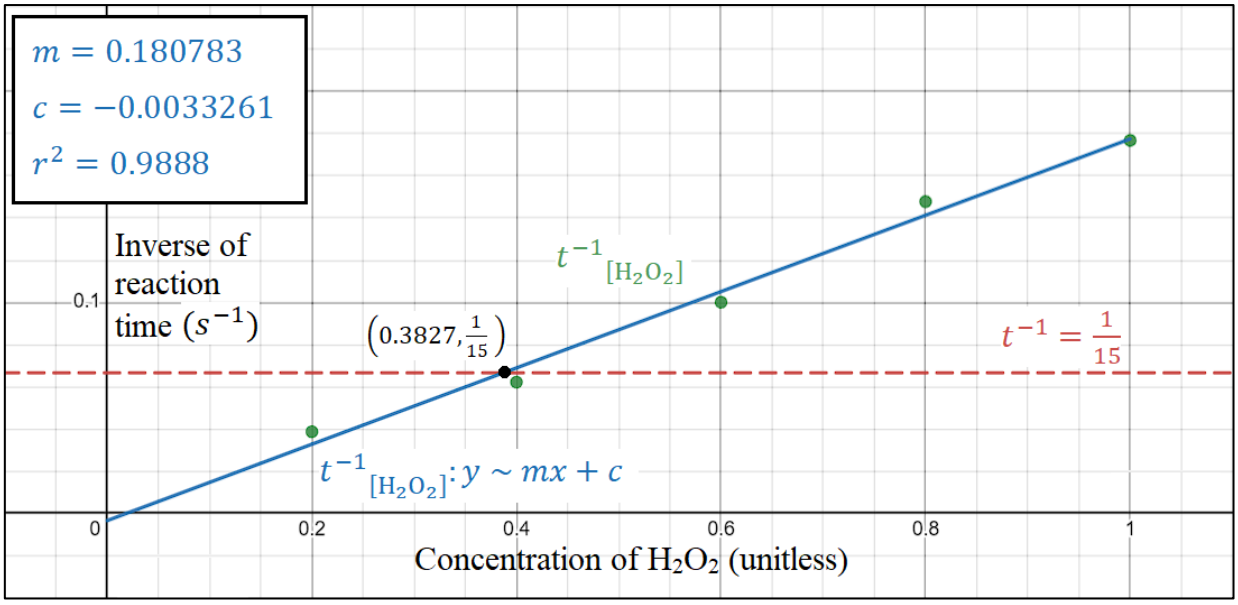

Figure 5: Rate of reaction (t^{-1}) fitted as a linear regression function of hydrogen peroxide concentration ($[H_2O_2]$) in an iodine clock reaction.

As indicated by the positive slope of the above trendline, an increase in concentration corresponds to a proportional increase in the t^{-1} value. This observation can be explained by collision theory. As $[H_2O_2]$ increases, the number of hydrogen peroxide moles within the solution increases. Resultantly, there is an increased frequency of collisions between hydrogen peroxide molecules and other reactant molecules (given by R_1). Therefore, the frequency of successful collisions – where reactants are in the correct orientation and have sufficient energy to form the activated complex – also increases. This increases the frequency at which reactants react to form products; the rate of reaction (t^{-1}) increases.

Aside from exhibiting trends, the experimental data in *Figure 5* can also be used to create the 15-second timer. As shown, the vertical line at $t^{-1} = 1/15$ intercepted the linear regression function at coordinates $(0.3827, 1/15)$. Therefore, 38% is approximately the hydrogen peroxide concentration which corresponds to a reaction time of 15 seconds.

To form a solution of this concentration, the volumes and number of drops for water and hydrogen peroxide are calculated:

$$V_{\text{total}} = 5\text{mL}$$

$$V_{H_2O_2} = 5(0.38) = 1.9\text{mL}$$

$$\text{Drops}_{H_2O_2} = 1.9 \div 0.05 = 38 \text{ drops} \qquad \{1 \text{ Drop } \equiv 0.05\text{mL}\}$$

$$V_{H_2O} = 5(1 - 0.38) = 3.1\text{mL} \qquad \{[H_2O] = 1 - [H_2O_2]\}$$

$$\text{Drops}_{H_2O} = 3.1 \div 0.05 = 62 \text{ drops} \qquad \{1 \text{ Drop } \equiv 0.05\text{mL}\}$$

Linear model results

Now, to verify the accuracy of the 15-second timer, the reaction procedure was repeated using the new concentration of 38%. The results are shown below (see *Table 6*).

Table 6: Total reaction time across three trials for a 38% concentrated hydrogen peroxide solution.

Concentration $[H_2O_2]$	Trial 1 time (s)	Trial 2 time (s)	Trial 3 time (s)	Average time (s)
38%	20.15	18.32	24.44	20.97

As shown in *Table 6*, the was a significant discrepancy between the expected reaction time of 15 seconds and the observed average reaction time of 20.97 seconds. To quantify this discrepancy, a percentage error value can be calculated:

$$\% \text{ error} = \left|\frac{\text{oberserved} - \text{expected}}{\text{expected}}\right|$$

$$= \left|\frac{20.97 - 15}{15}\right|$$

$$= |0.3980|$$

$$= 0.3980 \text{ (4sf)}$$

$$= 39.80\% \text{ error}$$

This considerably high percentage error is indicative of some flaw within the investigation process. Usually, systematic errors affect accuracy, however, the small *c*-value in *Figure 5* suggests that the effect of systematic error was not significantly detrimental (this is further discussed later).

Instead, *Figure 5* exhibits an anomaly. The close-up below (see *Figure 6*) provides a focused view of the data point at 40% concentration (in green) and the intersection point between the two lines (in black). Although the intersection point has a lower concentration of 38.27%, it has a higher t^{-1} value. This contradicts the expectation that reaction rate (t^{-1}) should increase proportionally with concentration.

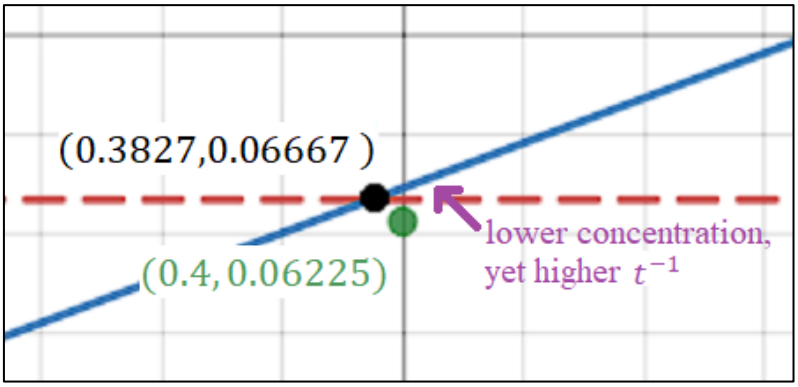

Figure 6: Close-up view of the 40% data point and intersection point of *Figure 5* to highlight anomaly.

Therefore, while the interpolation through the intersection point is statistically valid through the use of a regression function (indicated by the high $r^2 = 0.9888$ value), it is not reasonable from a conceptual perspective. This suggests that the discrepancy resulted from errors in the representation of data, rather flaws in the experiment itself. A possible cause is the conversion of raw data into t^{-1} values, rather than using the intrinsic trend of the data (reaction time against concentration).

Logarithmic model analysis

To address this discrepancy, a new relationship can be established between concentration $[H_2O_2]$ and reaction time t (instead of reaction rate t^{-1}). Using differential equations, it can be determined that for time as a function of concentration, the relationship is logarithmic (see *Appendix 1*).

A new graph was constructed below (see *Figure 6*), with a scatter plot (denoted $t_{[H_2O_2]}$) and a logarithmic regression function in the form $y = a \ln x + k$ (x, y represent $[H_2O_2], t$ respectively). The vertical axis represents time t and has units s, while the horizontal axis represents concentration $[H_2O_2]$ and is unitless.

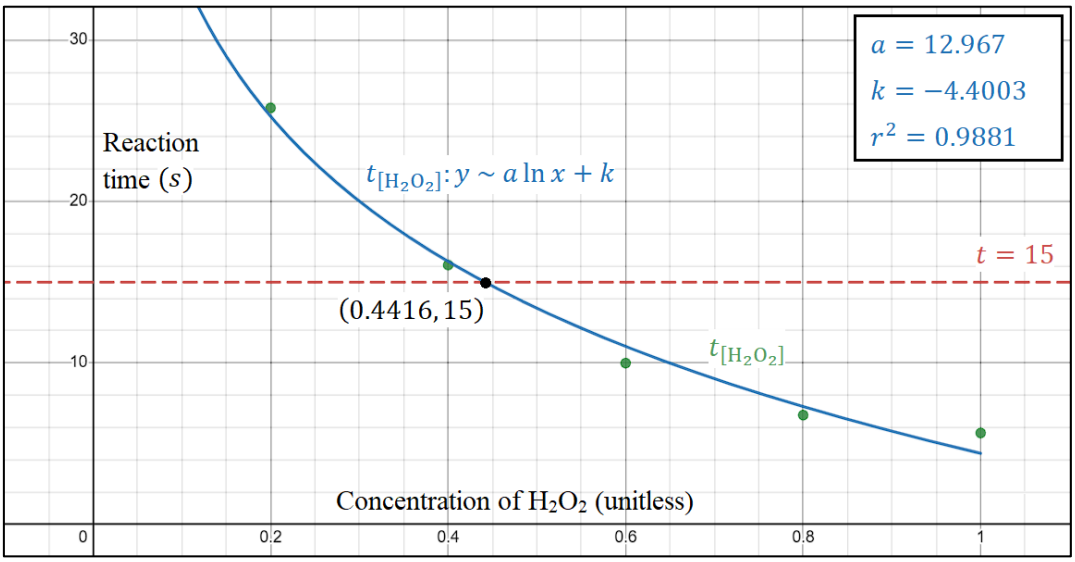

Figure 6: Reaction time (t) fitted as a logarithmic regression function of hydrogen peroxide concentration ($[H_2O_2]$) in an iodine clock reaction.

As indicated by the downwards trend of the above trendline, reaction time decreases as concentration increases. As previously explained, an increased concentration of hydrogen peroxide increases the frequency of collisions, which increases the frequency of successful collisions, which increases the reaction rate. Since more reactants are converted into products per time, the reactants are consumed in less time. This causes the observed decrease in total reaction time, albeit at a nonlinear rate.

Another notable feature of *Figure 6* is the asymptotic behaviour of the trendline. As concentration approaches zero ($[H_2O_2] \to 0^+$), the reaction time approaches infinity ($t \to \infty$). This observation can once again be inferred through collision theory – as

concentration decreases, the reaction time increases at an increasing rate, approaching infinity (no reaction) as concentration approaches zero (no product).

Figure 6 can also be used to interpolate a more accurate value for the concentration required in the 15-second timer. Given by the intersection $(0.4416, 15)$ between the two lines, the required concentration is approximately 44%. Repeating the previous calculations, this corresponds to 44 drops of H_2O_2 and 56 drops of distilled water.

Logarithmic model results

Repeating the reaction across three trails for the new 44% concentrated solution, reaction time values were obtained.

Table 7: Total reaction time across three trials for a 44% concentrated hydrogen peroxide solution.

Concentration $[H_2O_2]$	Trial 1 time (s)	Trial 2 time (s)	Trial 3 time (s)	Average time (s)
44%	15.15	14.81	14.89	14.95

With an average of 14.95 seconds, the new results in *Table 7* appear to be much closer to the expected time of 15 seconds, compared to the previous results (see *Table 6*). This can be quantified by calculating the percentage error:

$$\% \text{ error} = \left|\frac{\text{oberserved} - \text{expected}}{\text{expected}}\right|$$

$$= \left|\frac{14.95 - 15}{15}\right|$$

$$= |-0.00\bar{3}|$$

$$= 0.00\bar{3}$$

$$\approx 0.003333 \text{ (4sf)}$$

$$\approx 0.3333\% \text{ error}$$

This exceptionally low percentage error indicates the high accuracy of this investigation, generated by replacing the original linear model with a logarithmic model.

Evaluation

Throughout the investigation, the precision and accuracy of the results were impacted by various random and systematic errors. Evidence of these errors are found in the features of graphs, and can be explained by observations made during the investigation. These considerations are evaluated in *Table 8* below.

Table 8: Evaluation of errors.

Error	Evidence of error	Explanation of error	Effect on data
Random: Liquid leftover in cylinder	In graph of *Figure 5*, the individual scatter points did not lie exactly on the linear regression function. In particular, the data point at 80% concentration lay above the trendline.	The offset of this singular data point above the trendline indicates that the recorded reaction rate was higher than expected (because it represents a higher t^{-1} value). A plausible cause for this error is provided in Observation 5 of *Table 4*; after each reaction, there appeared to be small amounts of liquid remaining within the measuring cylinder. Because the cylinder was not cleaned after each trial, this liquid contaminated the following solution, thus it offset the hydrogen peroxide concentration from its intended value. The 80% data point suggests the leftover liquid for its trials was hydrogen peroxide, because the concentration of the solution would increase, justifying the increase in observed reaction rate.	The offset of the singular 80% data point changed the overall configuration of the scatter plot, which in turn changed the linear regression function, either through an increased slope or an upwards translation. The overarching effect is that the calculated concentration for the 15-second timer becomes lower than its actual value, due to the offset intersection between the regression function and the vertical line ($t^{-1} = 1/15$). However, because other data points were also affected, they oscillated somewhat randomly about the trend line; therefore, little net effect should have affected the regression function. Hence, although reproducibility is decreased, the overall effect on data was not detrimental.
Random: Drop size within the same bottle	In the raw data provided by *Table 3*, the individual reaction time values sometimes exhibited outliers. In particular, for the three reactions at 20% concentration, the times of 26.30*s* and 26.47*s* contrast with the third time of 24.62*s* – a considerably lower value.	These variations between individual reactions may be caused by the inconsistency of droplet size. According to Hewitt et al. [2001], droplet size is not always consistent, but depends on a variety of factors, notably, spray angle and fluid pressure. As stated in Observation 6 of *Table 4*, neither of these two factors were held constant for every drop; no precautions were made to conserve the angle, and fluid pressure changed as drops were released. Resultantly, the true concentration of hydrogen peroxide and/or sodium thiosulfate may have been offset, affecting the total reaction time. The 24.62*s* value indicates either a higher hydrogen peroxide or a lower sodium thiosulfate concentration than intended – both of these imbalances would have caused the observed decrease in reaction time.	For 20% concentration, the lower outlier of 24.62*s* caused the average reaction time to become lowered to 25.80*s*, therefore increasing the corresponding t^{-1} value. This causes the 20% data point in *Figure 5* to be located above the trendline, and affects the entire regression function, as explained above. However, this effect was likely to be negated by the repetition and averaging of results. Every data point is affected somewhat similarly by this error, so random oscillations of the scatter plot are likely to be negated. Moreover, the oscillations themselves were not significant, as indicated by the high correlation coefficient of $r^2 = 0.9888$. Therefore, although reproducibility is decreased, there is little overall effect on the results.
Systematic: Drop size across different bottles	The linear regression function of *Figure 5* had a nonzero y-intercept, at $y = -0.0033261$. This indicates that the line does not pass through the origin, but rather, vertically below it. This feature is not scientifically plausible, as it implies that there exists a negative reaction rate for some corresponding concentration.	According to Observation 1 of *Table 4*, the measurements for hydrogen peroxide were consistently above the markings on the measuring cylinder (see Observation 1 of *Table 4*). This indicates a flaw in the use of drop size conversion as a means for measurement. According to Zytynski et al. [n.d.], droplet size depends on viscosity, surface tension, and specific gravity of fluid. These properties are specific to the liquids themselves, implying that the droplets of different liquids do not equate to the same volume. This offset the quantities of each reactant from their intended values. In particular, it is likely that the quantity of sodium thiosulfate was proportionally higher than intended, as this would prolong reaction times, decreasing reaction rates and causing the negative y-intercept.	The negative y-intercept is, in effect, a downward vertical translation of the regression function. This changes the intersection point with the vertical line ($t^{-1} = 1/15$). Once again, this decreases the accuracy of the calculated concentration for the 15-second timer. Nonetheless, the impact of this on accuracy is a comparatively small amount, at only 0.33261%. Therefore, this systematic error moderately hinders validity.
Systematic: Delayed recording of reaction times	Same as above.	Another plausible explanation for this systematic error is the delays which reaction time measurements were subject to. Because the measurements were completed manually with a stopwatch, they depended upon human perception of a colour change. However, the reaction with starch was a gradual reaction, (see Observation 3 of *Table 4*), so there always existed some interval between the depletion of thiosulfate and the colour change – the indicator that the reaction had terminated. Therefore, all reaction time measurements were recorded to be higher than their actual values. Resultantly, all reaction rate values are offset downwards, thus offsetting the entire trend line downwards.	Same as above.

Conclusion

By recording the reaction times of five different hydrogen peroxide concentrations reacting with other substances, the corresponding reaction rates were calculated and represented in a graph. Through graphical analysis involving a linear regression function, the required concentration for a 15-second reaction was determined to be 38%, but yielded an average time of 20.97*s* (39.80% error) when tested. Subsequently, using a refined logarithmic approach with reaction time instead of rate, a new concentration of 44% yielded an average time of 14.95*s* (0.3333% error). The hypothesis, which stated that reaction time should increase with concentration, was correct. Therefore, the investigation was of high validity and achieved its aim.

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Word Count: 2183

(excludes tables, figures, and citations)

Logbook

23 February 2023

Today, after investigating the effect of reagent concentrations on reaction rate, my chemistry class briefly conducted the iodine clock experiment. I find this experiment interesting, as the primary reaction process itself is not actually visible – it is the final subsequent reaction with starch which is visible and induces the colour change. This is a clever way to clearly show the full reaction time; if the primary reaction induced a colour change, then it would be impossible to distinctly determine the beginning and end points of the reaction.

27 February 2023

Class explored the theory of the iodine clock reaction. Again, the cycle of reactions, all interacting with one another, is what makes the experiment unique. I find it interesting how the reaction between iodine and thiosulfate is always "more spontaneous" than the reaction between iodine and starch, such that the latter simply cannot begin until the former terminates.

More importantly, however, I realised some potential in exploring this experiment in further detail. Using the data collected from the original experiment, where different H_2O_2 concentrations yielded different concentration times, it may be possible to predict the concentration at which a certain reaction time will occur. This is essentially "working backwards" on the iodine clock reaction – setting a desired reaction time and working towards it, as opposed to simply leaving it as a completely dependent variable.

28 February 2023

By analysing the previous data using a linear equation, I determined that an exact H_2O_2 concentration of 38.27% should yield a reaction time of exactly 15 seconds. That is, if an approximately 38% solution of hydrogen peroxide is used in the iodine clock reaction, I should see a colour change after 15 seconds.

30 February 2023

I conducted the clock reaction with a 38% concentration H_2O_2 solution. Unfortunately, this yielded an average reaction time of 20.97 seconds. To me, this is surprising result. Such a large deviation from the expected 15 seconds is strange – it indicates the presence of systematic error. Furthermore, since all three trials were around this 20 second range, this result is unlikely to be due to random error – this means something is wrong with the process itself, somewhere.

However, I can't figure out where the error must have originated from. I will continue reviewing my data to determine the error source. I have checked all my calculations and have certainty that they are accurate. However, there seems to be an anomaly in the graph, where a lower concentration is corresponding to a higher reaction rate at a particular point. This seems to be the cause of the problem; even though all calculations and results are reasonable, the resulting trendline from graphing is not reasonable.

2 March 2023

Began to investigate the mathematical side of reaction rates – I've actually always been interested in the mathematical side of reaction rates, as it is essentially rates of change (and thus, calculus) applied in a chemical context.

3 March 2023

After a day of thinking, I realised that since the rate of reaction (dc/dt) is proportional to concentration (c) itself, this constitutes a differential equation which can be solved into an exponent using integral calculus.

A problem, however, is that in the iodine clock investigation, the concentration was the independent variable, which means the rate of change of time with respect to concentration (dt/dc) is actually a more appropriate rate. To incorporate this, I have turned the equation into a logarithmic instead of an exponential – as they are inverses. This means that concentration will be the independent variable instead of time (along the x axis), matching the data which was collected.

4 March 2023

Through graphing of the logarithm, the new concentration is 44.16%. Hoping this will accurately yield a 15 second time when I conduct the experiment later. It is actually quite interesting that the same data was used, but analysed differently through two mathematical approaches, and yielded different results for each. I wonder if one is more valid that the other? I will explore this later; I suspect that the logarithm is more accurate as it directly addresses the rates of change.

7 March 2023

Today, I conducted the experiment using a 44% concentration. Results were excellent – it yielded an average of 14.95. Almost exactly 15 seconds!

10 March 2023

Used the collected data in a write-up for the experiment.

12 March 2023

Completed the evaluation of systematic and random errors. Drop size is another unique aspect of the experiment, and it would be interesting to see what results would have yielded without using drop size conversion.

29 June 2023

Completed some final refinements to the project.

Appendix

Appendix 1: Use of differential equations to determine the nature of the relationship between hydrogen peroxide concentration ($[H_2O_2]$) and total reaction time (t).

According to collision theory, rate of reaction $\left(\frac{dc}{dt}\right)$ is directly proportional to concentration (c) itself.

$$\frac{dc}{dt} \propto c$$

$$\therefore \frac{dc}{dt} = kc \quad \{\text{constant of proportionality}\}$$

This constitutes a differential equation which can be solved into an exponential function.

$$\frac{dc}{dt} = kc$$

$$\therefore \frac{1}{c}\frac{dc}{dt} = k$$

$$\therefore \int \frac{1}{c}\frac{dc}{dt}dt = \int k\, dt \quad \{\text{integration with respect to } t\}$$

$$\therefore \int \frac{1}{c}\, dc = \int k\, dt \quad \{\text{chain rule}\}$$

$$\therefore \ln c = kt + b \quad \{b \text{ is constant of integration}\}$$

$$\therefore e^{\ln c} = e^{kt+b}$$

$$\therefore c = e^{kt+b}$$

The above result indicates that when concentration (c) is a function of time (t), the relationship is exponential.

In this investigation, however, concentration is the independent variable. Therefore, time is a function of concentration instead. Therefore, the equation must be rearranged so that t is expressed in terms of c.

$$e^{kt+b} = c$$

$$\therefore \ln e^{kt+b} = \ln c$$

$$\therefore kt + b = \ln c$$

$$\therefore t = \frac{\ln c - b}{k}$$

$$\therefore t = \frac{1}{k}\ln c - \frac{b}{k}$$

$$\therefore t = a \ln c + k \quad \left\{\text{let } a = \frac{1}{k} \text{ and } k = -\frac{b}{k}\right\}$$

As shown, time as a function of concentration has a logarithmic relationship, in the form $t = a \ln c + k$. Therefore, a logarithmic regression function should be used.

End of *Appendix 1*.

OSA RISK ASSESSMENT FORM

for all entries in (✓) ☐ Models & Inventions and ☑ Scientific Inquiry

This must be included with your report, log book or entry. One form per entry.

STUDENT(S) NAME: ~~Unley~~ Melson Shi ID: 0750-017

SCHOOL: Unley High School

Activity: Give a brief outline of what you are planning to do.

Conduct an iodine clock experiment, using various chemicals in a solution. The experiment only involves the mixing of substance together, and no other ways of handling chemicals.

Are there possible risks? Consider the following:

- Chemical risks: Are you using chemicals? If so, check with your teacher that any chemicals to be used are on the approved list for schools. Check the safety requirements for their use, such as eye protection and eyewash facilities, availability of running water, use of gloves, a well-ventilated area or fume cupboard.
- Thermal risks: Are you heating things? Could you be burnt?
- Biological risks: Are you working with micro-organisms such as mould and bacteria?
- Sharps risks: Are you cutting things, and is there a risk of injury from sharp objects?
- Electrical risks: Are you using mains (240 volt) electricity? How will you make sure that this is safe? Could you use a battery instead? **Only batteries can be used for Models & Inventions entries*
- Radiation risks: Does your entry use potentially harmful radiation such as UV or lasers?
- Other hazards.

Also, if you are using other people as subjects in an investigation you must get them to sign a note consenting to be part of your experiment.

Risks	How I will control/manage the risk
Broken Glass Exposure to various chemicals (KI, H_2O_2, HCl, $Na_2S_2O_3$ and starch).	Exercise caution when handling glass. Keep glassware away from table edges. Wear safety glasses to prevent eyes from chemical contact. Avoid direct contact, inhalation or ingestion of substances. Wash off substances immediately if contacted with skin.

(Attach another sheet if needed.)

Risk Assessment indicates that this activity can be safely carried out

RISK ASSESSMENT COMPLETED BY (student name(s)): Melson Shi

SIGNATURE(S): mshi

☑ By ticking this box, I/we state that my/our project adheres to the listed criteria for this Category.

TEACHER'S NAME: Mehra Puthiyedathu

SIGNATURE: Mehra DATE: 30/06/23