CHEMISTRY INVESTIGATION

Confirmation of first-order kinetics for a hydrogen peroxide (H_2O_2) iodine clock reaction

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I. INTRODUCTION

This topic was examined for my investigation because, at first, I was interested in conducting further study on the role of catalysts. Since I wanted to investigate the role of catalysts in reactions that commonly occur in daily life, I decided to combine chemistry with my interest in biology and, initially, I decided to study how the common enzyme called catalase is able to decompose harmful hydrogen peroxide in the bloodstream into water and oxygen.[1] In fact, hydrogen peroxide can be so dangerous that researchers Michael S. Oberg, MD and Douglas Lindsey, MD, DrPH stated that "Our objection is to putting...hydrogen peroxide...onto living tissue."[2]

However, the initial investigation was modified due to difficulty locating a sufficient supply of catalase, so I researched other uses of hydrogen peroxide that could provide a similar experiment. This led to my realization that I could study an iodine clock reaction with hydrogen peroxide.

Wanting to connect this experiment with biology, I decided to investigate how changing temperature alters the activation energy needed to complete the reaction. The temperatures I decided to use were 30℃, 35℃, 40℃, and 45℃ because each represents a critical temperature of the human body, ranging from moderate hypothermia to the highest recorded human body temperature.[3]

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[1] "Exploring Enzymes," Scientific American, November 10, 2016, accessed March 22, 2019, https://www.scientificamerican.com/article/exploring-enzymes/.

[2] Michael S. Oberg, MD and Douglas Lindsey, MD, DrPH, "Do Not Put Hydrogen Peroxide or Povidone Iodine Into Wounds!" *Am J Dis Child* 141, no. 1 (January 1987): accessed March 21, 2019, doi:10.1001/archpedi.1987.04460010027015.

[3] Jennifer Huizen, "Hyperthermia: Symptoms, Treatment, and Causes," Medical News Today, accessed March 22, 2019, https://www.medicalnewstoday.com/articles/320226.php.;
"Profound Hypothermia," The Free Dictionary, accessed March 22, 2019, https://medical-dictionary.thefreedictionary.com/profound hypothermia.;
Eleanor Klibanoff, "You Might Be Surprised When You Take Your Temperature," NPR, November 22, 2014, accessed March 22, 2019, https://www.npr.org/sections/goatsandsoda/2014/11/14/364060441/you-might-be-surprised-when-you-take-your-temperature.

II. INVESTIGATION

A. REACTION STUDIED

I studied the three-step reaction for the creation of a starch-iodide complex:[4]

$$3I^- (aq) + H_2O_2 + 2H^+ (aq) \rightarrow I_3^- (aq) + 2\ H_2O\ (l)$$

$$I_3^- (aq) + 2S_2O_3^{2-} (aq) \rightarrow 3I^- (aq) + S_4O_6^{2-} (aq)$$

$$I_3^- (aq) + \text{starch} \rightarrow \text{starch-}I_3^- \text{ complex}$$

at 30℃, 35℃, 40℃, and 45℃.

B. BACKGROUND

An iodine clock reaction is used to measure the amount of time it takes in order for a certain number of moles of a blue-colored starch-I_3^- complex[5] to be formed when potassium iodide and an oxidizing agent are reacted. This oxidizing agent, for this investigation, will be hydrogen peroxide.[6]

In the first step of the reaction, the hydrogen peroxide reacts with the iodide ions found within potassium iodide to form triiodide ions. The H^+ results from any strong acid since acids act as H^+ donors. In this investigation, the strong acid is HCl:

$$3I^- (aq) + H_2O_2\ (l) + 2H^+ (aq) \rightarrow I_3^- (aq) + 2\ H_2O\ (l)$$

In the second step, the triiodide ions are reduced to iodide through the use of thiosulfate:

$$I_3^- (aq) + 2S_2O_3^{2-} (aq) \rightarrow 3I^- (aq) + S_4O_6^{2-} (aq)$$

In the final step, once all thiosulfate ions are consumed, the triiodide ions change the color of the starch, which serves as an indicator, and the colored starch-I_3^- complex appears:[7]

$$I_3^- (aq) + \text{starch} \rightarrow \text{starch-}I_3^- \text{ complex}$$

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[4] "Investigate the Kinetics of the Amazing Iodine Clock Reaction: Background," Science Buddies, accessed March 22, 2019, https://www.sciencebuddies.org/science-fair-projects/project-ideas/Chem_p091/chemistry/iodine-clock-reaction-kinetics#background.

[5] Ibid.

[6] "How Does the Iodine Clock Reaction Work?" Write Charlie's iblog, accessed March 22, 2019, https://www.ibchem.com/faq/2008/09/25/how-does-the-iodine-clock-reaction-work/.

[7] "Investigate the Kinetics of the Amazing Iodine Clock Reaction: Background," Science Buddies, accessed March 22, 2019, https://www.sciencebuddies.org/science-fair-projects/project-ideas/Chem_p091/chemistry/iodine-clock-reaction-kinetics#background.

It is important to have an understanding of kinetic dependence, specifically collision theory, on temperature in order to predict the possible impact of temperature on the reaction.

Collision theory, in brief, is the concept that, in order for a reaction to occur, particles must complete three criteria:

1. Particles must collide with one another.
2. Particles must collide with sufficient energy to break old, pre-existing bonds.
3. Particles must collide with proper orientation.

Temperature's impact on collision theory is that as temperature is increased, particles' velocity is increased and the kinetic energy of each particle is subsequently increased. In general, since particles will collide more often under a high temperature condition, there is a greater chance that the collision will meet the three criteria and the reaction will occur.[8]

There is an approximate rule that for each 10℃ that a reaction's temperature is increased, the rate of reaction doubles.[9]

The hypothesis that will be evaluated is: "As the temperature of a hydrogen peroxide/dilute hydrochloric acid solution is increased, the rate of reaction will increase in a linear manner, indicating a first-order kinetic reaction."

C. CALCULATION METHOD

The rate of the reaction was found by recording the time needed to form the starch-I_3^- complex. When the reaction began, a stopwatch was started and once the distinctive color of the starch-I_3^- complex was observed, it was stopped.

$$rate = \frac{1}{t}$$

The equation above gives the average rate for the appearance of the starch-I_3^- complex and is commonly used to compare rates for reactions where color changes. The variable t is the average time recorded for the starch-I_3^- complex to appear, measured in seconds. This allows me to quantitatively compare the rates for different temperatures investigated.

I estimate that a graph of reaction rate will have a linear positive trendline because of the principle that for every 10℃ increased, the reaction time doubles:

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[8] Libretexts, "15.2: The Rate of a Chemical Reaction," Chemistry LibreTexts, February 23, 2019, accessed March 22, 2019, https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map:_Introductory_Chemistry_(Tro)/15:_Chemical_Equilibrium/15.02:_The_Rate_of_a_Chemical_Reaction.

[9] "Chemical Kinetics," Activation Energy, accessed March 22, 2019, http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch22/activate.php.

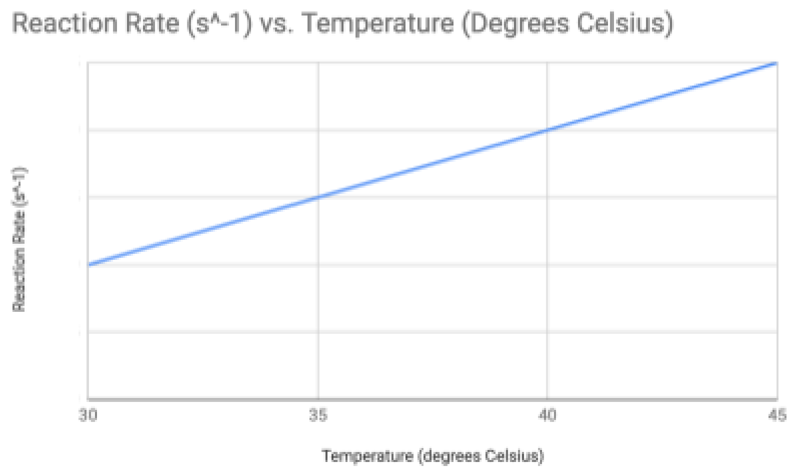

Figure 1: I estimate the trend to be positive and linear. The values of the y-axis is all real numbers (ℝ) with equal subintervals.

III. VARIABLES

Dependent variable: Time in seconds.

The reason this is the dependent variable is because the equation seen in part "C. Calculation Method" requires a measurement of time in order to determine the average rate. The recorded time for the starch-I_3^- complex to appear is dependent on the independent value: the temperature of the H_2O_2 and dilute HCl solution.

Independent variable: Temperature in degrees celsius.

The tested temperatures were 30℃, 35℃, 40℃, and 45℃. The reason as to why four different temperature values were selected is because the reliability of collected data was improved since more data points could be plotted on a graph and a more accurate view of the relationship between time and temperature could be recorded.

30℃ was selected as the lowest temperature because, although the human body has been recorded at a lower temperature, I did not want to use a temperature below room temperature in order to maintain a consistent method of changing the temperature of the H_2O_2 and dilute HCl solution in a hot water bath. Also, I rounded the scientific body temperatures, as seen in the table below, in order to maintain consistent intervals of 5℃ between each temperature for a more accurate graph:[10]

[10]Jennifer Huizen, "Hyperthermia: Symptoms, Treatment, and Causes," Medical News Today, accessed March 22, 2019, https://www.medicalnewstoday.com/articles/320226.php.;
"Profound Hypothermia," The Free Dictionary, accessed March 22, 2019, https://medical-dictionary.thefreedictionary.com/profound hypothermia.;
Eleanor Klibanoff, "You Might Be Surprised When You Take Your Temperature," NPR, November 22, 2014, accessed March 22, 2019, https://www.npr.org/sections/goatsandsoda/2014/11/14/364060441/you-might-be-surprised-when-you-take-your-temperature.

Name of Condition	Historic values	Experimental values
Moderate hypothermia	32℃	30℃
Normal body temperature	36.5℃	35℃
Hyperpyrexia	41.1℃	40℃
Highest recorded body temperature	46℃	45℃

A. CONTROL

The following variables were controlled over the course of the experiment:

- Reactant concentration/amount of reactant

Concentration and amount of each reactant was kept the same for each trial in order to ensure that the only factor for changes in the time for the colored starch complex to appear was a change in temperature. I used precise and calibrated instruments, including a digital balance and graduated cylinders, in order to ensure that these measurements remained consistent.

- H^+ concentration

A high concentration of H^+ may have impacted the experiment by forcing the reaction to completion at a faster rate. As a precaution to this, I diluted the HCl, which was the donor of H^+ ions as seen in the original equation for the reaction, to the same volume each trial.

IV. EXPERIMENTAL METHOD

A. MATERIALS USED/APPARATUS

- 3% H_2O_2 (hydrogen peroxide) solution
- 1.3 mL 6M HCl diluted with H_2O to a total volume of 5 mL
- Solution of 0.1g KI, 0.1g potato starch, and 0.1g $Na_2S_2O_3$ (Sodium thiosulphate) in 5 mL H_2O
- Water bath in a 250mL Erlenmeyer flask
- Hot plate
- Test tube
- Pipette
- Digital balance
- Digital stopwatch
- Thermometer

B. EXPERIMENTAL PROCEDURE

1. Place the 250mL Erlenmeyer flask water bath onto a hot plate. Heat the bath until it reaches 30℃ as measured by the thermometer.
2. Dilute 1.3 mL (±0.1 mL) of the 6M HCl with 4.7 mL H_2O (±0.1 mL) in order to produce a total volume of 5 mL diluted HCl (±0.2 mL).
3. Combine 10 mL (±0.1 mL) of the 3% H_2O_2 solution (measured with a graduated cylinder at the meniscus for accuracy, ±0.1 mL) with the diluted HCl in the test tube.
4. Place test tube into the water bath inside the 250mL Erlenmeyer flask. Move the thermometer into the test tube to record the temperature of the solution.
5. Once the internal temperature of the hydrogen peroxide/HCl solution reaches 30℃, stir the solution of 0.1g KI, 0.1g potato starch, and 0.1g $Na_2S_2O_3$ (Sodium thiosulphate) in 5 mL H_2O and add it to the test tube. At the precise moment that this solution reaches the hydrogen peroxide/HCl solution, begin the digital stopwatch.
6. Continue the stopwatch until a dark blue or brown color is observed. Immediately end the stopwatch at this moment.
7. Repeat steps 2-6 three additional times in order to create a complete set of trials and reduce the possibility of error.
8. Repeat steps 1-7 for the remaining temperatures: 30℃, 35℃, 40℃, and 45℃.

C. RISKS/SAFETY

The following substances used posed a potential risk. In order to adhere to safety, I wore goggles to protect my eyes. I also completed the experiment underneath a ventilation hood to remove hazardous fumes that may be formed.

- 6.0 mL hydrochloric acid can be corrosive and cause damage to the skin and especially to the eyes.[11] In addition to the goggles, I diluted it to make it safer to handle.
- Potassium iodide can cause harm if ingested, cause skin irritation, and eye damage.[12]
- Sodium thiosulfate can cause harm if ingested, cause skin irritation, eye damage, and respiratory issues.[13]

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[11] "Hydrochloric Acid Hazards & Safety Tips," MSDSonline, September 15, 2017, accessed March 22, 2019, https://www.msdsonline.com/2014/09/10/hydrochloric-acid-hazards-safety-tips/.

[12] *Potassium Iodide*. Label. Flinn Scientific, Batavia, IL, 2016.

[13] "Sodium Thiosulfate," National Center for Biotechnology Information. PubChem Compound Database, accessed March 22, 2019, https://pubchem.ncbi.nlm.nih.gov/compound/Sodium_thiosulphate#section=GHS-Classification.

V. DATA (RAW)

	Trial 1	Trial 2	Trial 3	Trial 4
Temperature of the hydrogen peroxide/HCl solution (℃) (±0.1℃)	Time taken for the colored starch-I_3^- complex to appear (s) (±0.01s)	Time taken for the colored starch-I_3^- complex to appear (s) (±0.01s)	Time taken for the colored starch-I_3^- complex to appear (s) (±0.01s)	Time taken for the colored starch-I_3^- complex to appear (s) (±0.01s)
30℃	8.80	8.40	6.85	8.18
35℃	5.04	5.86	5.26	5.23
40℃	4.65	4.96	2.33	4.90
45℃	3.03	3.36	3.06	3.48

I checked for outliers by calculating the standard deviation for each temperature. I did not find that any of the values were statistical anomalies.

A. OBSERVATIONS (QUALITATIVE)

The color at the end of each trial of the starch complex was a dark blue at first. However, I noticed that over time, the complex gained a more brown or black hue.

VI. DATA (PROCESSED)

Temperature of the hydrogen peroxide/HCl solution (℃)	Average time for the starch-I_3^- complex to appear (s)	Rate of reaction $rate = \frac{1}{t}$ in s^{-1}
30℃	$\frac{8.80+8.40+6.85+8.18}{4} = 8.06$	$\frac{1}{8.06} \approx 0.124$
35℃	$\frac{5.04+5.86+5.26+5.23}{4} = 5.35$	$\frac{1}{5.35} \approx 0.187$
40℃	$\frac{4.65+4.96+2.33+4.90}{4} = 4.21$	$\frac{1}{4.21} \approx 0.238$
45℃	$\frac{3.03+3.36+3.06+3.48}{4} = 3.23$	$\frac{1}{3.23} \approx 0.310$

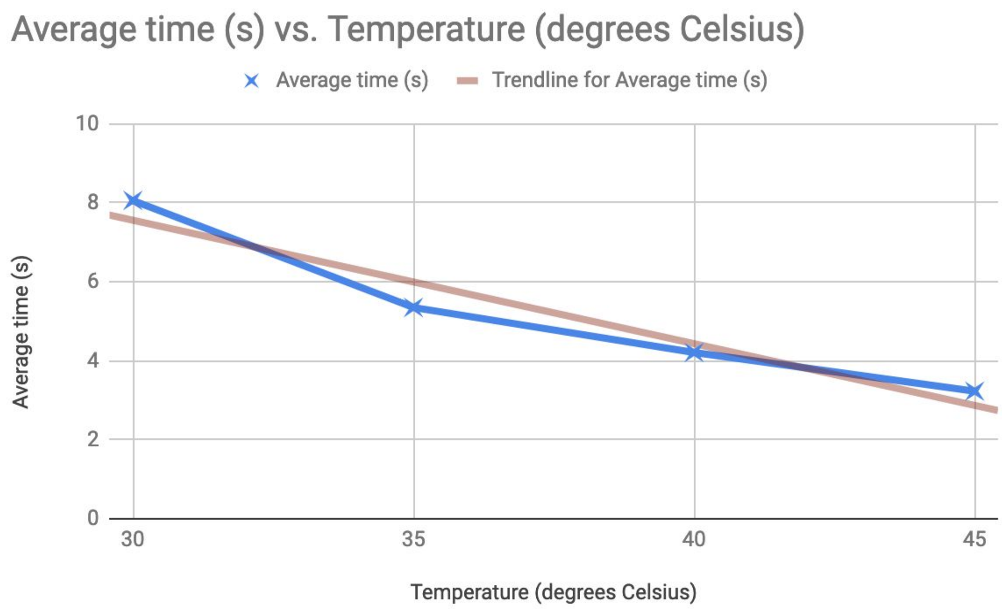

Figure 2: This graph plots the average time for the starch-I_3^- complex to appear (s) for each temperature (degrees Celsius), shown in blue. The red line indicates its trend line, which is decreasing and indicates that the average time decreases as temperature increases.

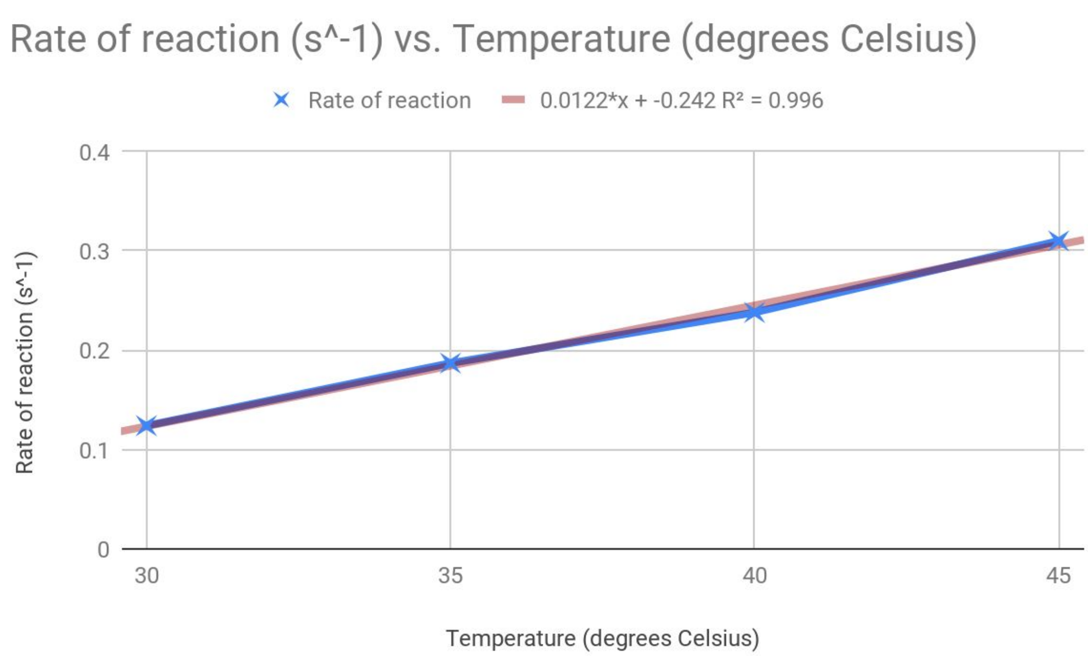

Figure 1: This graph plots the rate of reaction (s^{-1}) for each temperature (degrees Celsius). The red line indicates the trend line.

A. UNCERTAINTY

The table below shows my uncertainty calculation for the accuracy of recording the time taken for the colored starch-I_3^- complex to appear.

The uncertainty of the digital stopwatch and human reaction is ±0.01 seconds, as notated in the second column. The third column shows that there may have been only a 0.12-0.29% discrepancy possible from the collected data, although a larger uncertainty is possible.

Temperature of the hydrogen peroxide/HCl solution (℃)	Average time taken for the colored starch-I_3^- complex to appear (s) (±0.01s)	Total percent uncertainty in the average time taken for the colored starch-I_3^- complex to appear (s)
30℃	8.18 ± 0.01 = **8.18 ± 0.12%**	± 0.12%
35℃	5.23 ± 0.01 = **5.23 ± 0.19%**	± 0.19%
40℃	4.90 ± 0.01 = **4.90 ± 0.20%**	± 0.20%
45℃	3.48 ± 0.01 = 3.48 ± 0.29	± 0.29%

VII. EVALUATION

A. CONCLUSION

According to the data that was collected and processed, there is an evident linear positive trend when the temperature of a hydrogen peroxide and dilute hydrochloric acid is adjusted to different temperatures. The trendline of a linear graph should have the equation $y = mx + b$, where b is a constant. The equation of the trendline of the graph of the rate of reaction is $y = 0.0122x - 0.242$.

As the temperature of the solution of hydrogen peroxide and dilute hydrochloric acid is increased, the reaction rate increases in a linear fashion. This accepts the hypothesis.

B. STRENGTHS & WEAKNESSES

One strength of the investigation, as seen by the calculated uncertainty, the results are overall reliable. This is supported by the mostly linear relationship between each graphed data point; had the trials been inaccurate, the trendline would not have appeared linear. Also, the r^2 value, which measures how the data best fits the trendline, is 0.996. The most accurate r^2 value would be 1 and the approximate difference of 0.004 shows that the collected data is highly accurate.

On the other hand, limitations outside of possible human error do remain. During my researching of this investigation, I was unable to find comparable data for a hydrogen peroxide iodine clock at the temperatures I used. Therefore, I am unable to calculate the percent error for my investigation.

Also, since I used hydrogen peroxide from the same bottle for each day of experimentation, it is possible that a trace amount decomposed into oxygen gas and water between the two days, reducing its concentration; as a result, the first day of experimentation may have yielded the most accurate results, but only by a small amount (since no outliers were detected). In order to solve this issue, it would have been best to use fresh, unopened stock of hydrogen peroxide for each trial in order to have more accurate data collection.

Next, including more independent variable values (temperature values) would have resulted in more data points on the trend line and would have revealed a more accurate linear trend. I would have added points above and below 30℃ for a greater range of results.

C. FUTURE PROCEDURES

If this procedure was to be modified and re-evaluated, one change I would make would be to add a measurement of the change in concentration. Then, I would be able to find a more accurate rate of appearance of the colored starch-I_3^- complex by using the following equation, which would allow me to find the rate constant, k:

$$r = k(T)[A]^m[B]^n$$

This equation is different from the equation I used for my experiment because the equation I used is meant to be used to generally *compare* specific color-changing procedures, while the equation above would allow me to find the activation energy with the Arrhenius Equation by using *k*.

VIII. BIBLIOGRAPHY

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