CHEMISTRY INVESTIGATION

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

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°C, 35°C, 40°C, and 45°C 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°C, 35°C, 40°C, and 45°C.

clear outline of reaction mechanism, sourced.

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] ✓ Succinct and clear

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]

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

*An explanation for the delay, then sudden color change, would be appropriate here

demonstrates effective research for prior art in this field.

[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.

Sources are less reliable but appropriate - similar studies to this one.

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:

Evidence of connecting experiment with core-learning good.

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] all statements supported with sources. nice.

There is an approximate rule that for each 10°C 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." Clear.

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°C increased, the reaction time doubles:

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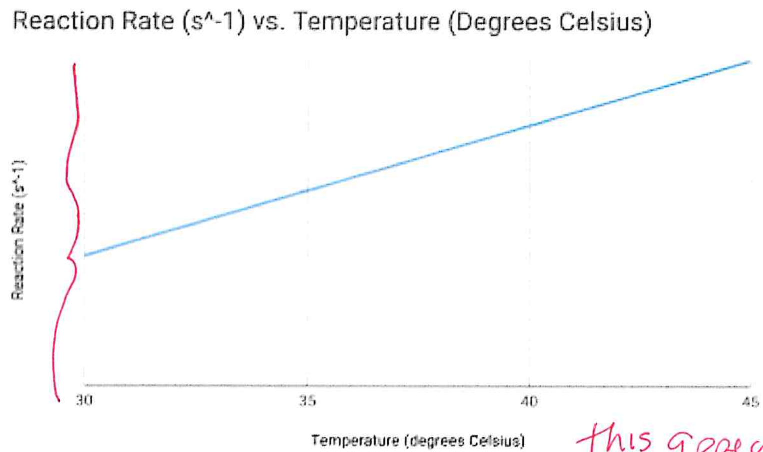
[8]Libretexts, "15.2: The Rate of a Chemical Reaction," Chemistry LibreTexts, February 23, 2019, accessed March 22, 2019, https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map:_Introductory_Chemistry_(Tro)/15:_Chemical_Equilibrium/15.02:_The_Rate_of_a_Chemical_Reaction.

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

evidence of research concerning relevant scientific topics. textbooks and university websites are appropriate here. - good.



Y axis lacks numbers.

this appears to be for illustrative purposes.

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°C, 35°C, 40°C, and 45°C. 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°C 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°C between each temperature for a more accurate graph:[10]

I wonder if H_2O_2 (aq) is thermally stable at 37°C.

[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,

Best to number all sources for consistency

This is a fascinating application of this research, and relevant: H_2O_2 solutions are used extensively in medicine, worldwide.

very interesting — a definition is perhaps needed here...

Name of Condition	Historic values	Experimental values
Moderate hypothermia	32°C	30°C
Normal body temperature	36.5°C	35°C
Hyperpyrexia	41.1°C	40°C ✓
Highest recorded body temperature	46°C yikes.	45°C

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.

all of this should be quantified

For example: all solutions were 1.00 M

- 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.

this should be specified

Demonstrates attention to relevant controls but qualitative only.

IV. EXPERIMENTAL METHOD

A. MATERIALS USED/APPARATUS

Good - shows how to make it. However better to simply say add "1.4M HCl (aq), 5.0 mL"

- 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 ✓

this is good - repeatable - but would help to include resulting mo

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https://www.npr.org/sections/goatsandsoda/2014/11/14/364060441/you-might-be-surprised-when-you-take-your-temperature.

number needed here

- Digital stopwatch
- Thermometer ✓

B. *EXPERIMENTAL PROCEDURE*

demonstrates a quantitative analysis of uncertainty

1. Place the 250mL Erlenmeyer flask water bath onto a hot plate. Heat the bath until it reaches 30°C 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°C, 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°C, 35°C, 40°C, and 45°C. ✓

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. (From 6M to ~1.4M)
- 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]

Demonstrates appropriate interpretation of risk. should discuss proper disposal

[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.

MSDS sources are appropriate for this assessment of risk.

V. DATA (RAW)

As a practical matter these uncertainties are only true for instantaneous color changes. In reality it is not so sharp, perhaps.

	Trial 1	Trial 2	Trial 3	Trial 4
Temperature of the hydrogen peroxide/HCl solution (°C) (±0.1°C)	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°C	8.80 ✓	8.40	6.85	8.18 ✓
35°C	5.04	5.86	5.26	5.23
40°C	4.65	4.96	2.33	4.90
45°C	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. This may be due to . . .

VI. DATA (PROCESSED)

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

45°C	$\frac{3.03+3.36+3.06+3.48}{4} = 3.23$	$\frac{1}{3.23} \approx 0.310$ ✓

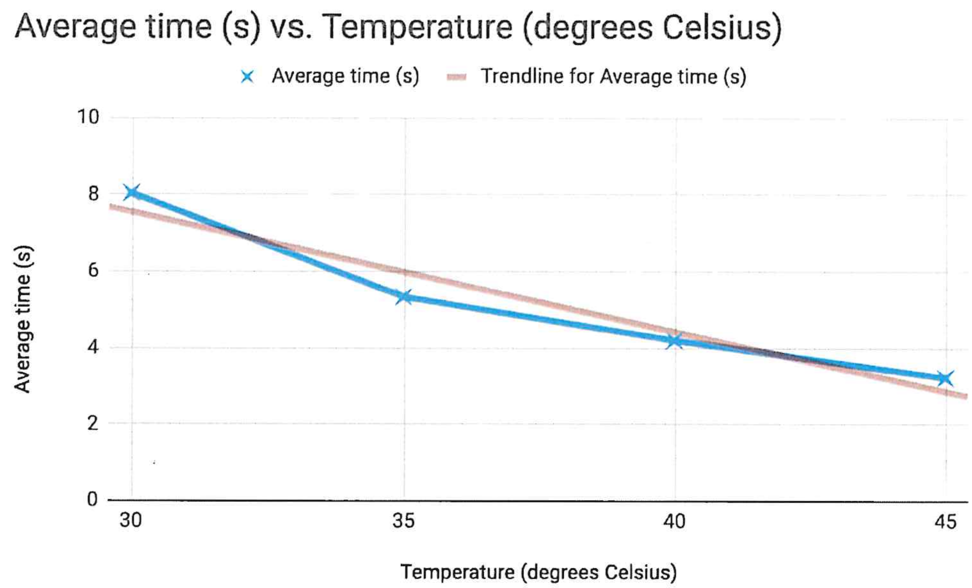
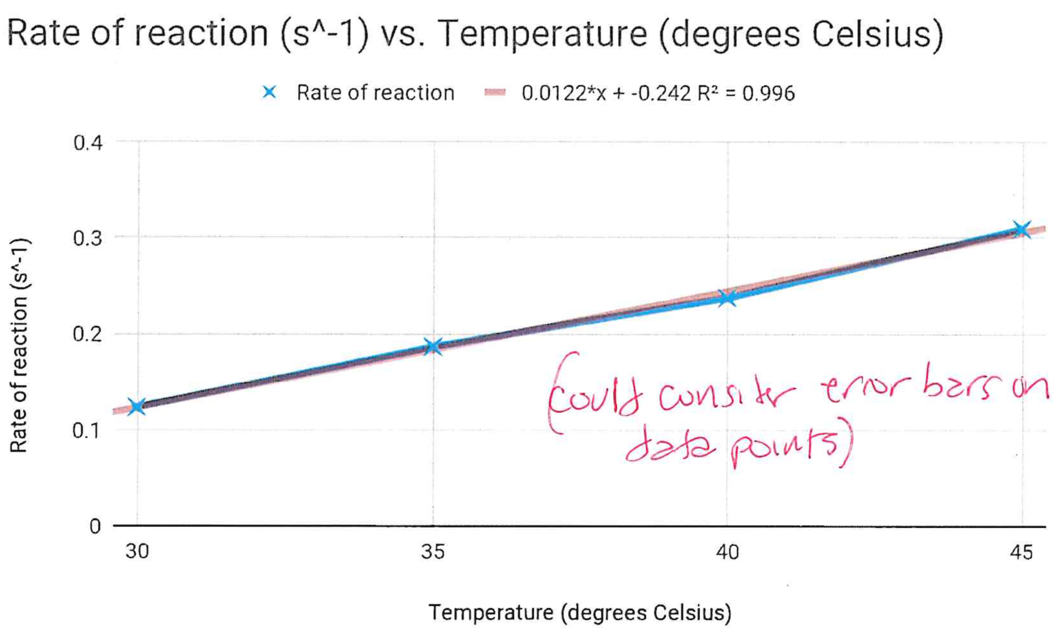


Figure 2: This graph plots the average time for the starch-I_3^- complex to appear (s) for each temperature (degrees Celsius), shown in blue. The red line indicates its trend line, which is decreasing and indicates that the average time decreases as temperature increases.



very clear results: appropriate use of graphical analysis.

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. [needs explaining]

Temperature of the hydrogen peroxide/HCl solution (°C)	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°C	8.18 ± 0.01 = **8.18 ± 0.12%**	± 0.12%
35°C	5.23 ± 0.01 = **5.23 ± 0.19%**	± 0.19%
40°C	4.90 ± 0.01 = **4.90 ± 0.20%**	± 0.20%
45°C	3.48 ± 0.01 = 3.48 ± 0.29	± 0.29%

VII. EVALUATION

A. *CONCLUSION* [show]

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*

[seems likely that this also supports prior research (which is needed).]

It is preferable to show the degree of uncertainty first, and allow the reader to draw their own conclusions

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.

Excellent (although surprising) Demonstrates the importance of prior research in this field

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. This is also relevant and honest. The 3% H_2O_2 was not verified

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°C 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*. ✓

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perhaps a student next year could perform a quality control study of 3% H_2O_2.

VIII. BIBLIOGRAPHY

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Iodine clock reaction

IB Chemistry: The Internal Assesmment (this is taken directly from the IB chemistry guide)

General introduction

The internal assessment requirements are the same for biology, chemistry and physics. The internal assessment, worth 20% of the final assessment, consists of one scientific investigation. The individual investigation should cover a topic that is commensurate with the level of the course of study.

Student work is internally assessed by the teacher and externally moderated by the IB. The performance in internal assessment at both SL and HL is marked against common assessment criteria, with a total mark out of 24.

> **Note:** Any investigation that is to be used to assess students should be specifically designed to match the assessment criteria.

The internal assessment task will be one scientific investigation taking about 10 hours and the writeup should be about 6 to 12 pages long. Investigations exceeding this length will be penalized in the communication criterion as lacking in conciseness.

The practical investigation, with generic criteria, will allow a wide range of practical activities satisfying the varying needs of biology, chemistry and physics. The investigation addresses many of the learner profile attributes well. See section on "Approaches to the teaching of chemistry" for further links.

The task produced should be complex and commensurate with the level of the course. It should require a purposeful research question and the scientific rationale for it. The marked exemplar material in the teacher support materials will demonstrate that the assessment will be rigorous and of the same standard as the assessment in the previous courses.

Some of the possible tasks include:

- a hands-on laboratory investigation
- using a spreadsheet for analysis and modelling
- extracting data from a database and analysing it graphically
- producing a hybrid of spreadsheet/database work with a traditional hands-on investigation
- using a simulation provided it is interactive and open-ended.

Some tasks may consist of relevant and appropriate qualitative work combined with quantitative work.

The tasks include the traditional hands-on practical investigations as in the previous course. The depth of treatment required for hands-on practical investigations is unchanged from the previous internal assessment and will be shown in detail in the teacher support materials. In addition, detailed assessment of specific aspects of hands-on practical work will be assessed in the written papers as detailed in the relevant topic(s) in the "Syllabus content" section of the guide.

The task will have the same assessment criteria for SL and HL. The five assessment criteria are personal engagement, exploration, analysis, evaluation and communication.

Internal assessment component

- Individual investigation
- This investigation covers assessment objectives 1, 2, 3 and 4.

Internal assessment criteria

The new assessment model uses five criteria to assess the final report of the individual investigation with the following raw marks and weightings assigned:

2	5	6	6	4	23
2 (8%)	6 (25%)	6 (25%)	6 (25%)	4 (17%)	24 (100%)

Levels of performance are described using multiple indicators per level. In many cases the indicators occur together in a specific level, but not always. Also, not all indicators are always present. This means that a candidate can demonstrate performances that fit into different levels. To accommodate this, the IB assessment models use markbands and advise examiners and teachers to use a **best-fit approach** in deciding the appropriate mark for a particular criterion.

Teachers should read the guidance on using markbands shown above in the section called "Using assessment criteria for internal assessment" before starting to mark. It is also essential to be fully acquainted with the marking of the exemplars in the teacher support material. The precise meaning of the command terms used in the criteria can be found in the glossary of the subject guides.

Personal engagement

This criterion assesses the extent to which the student engages with the exploration and makes it their own. Personal engagement may be recognized in different attributes and skills. These could include addressing personal interests or showing evidence of independent thinking, creativity or initiative in the designing, implementation or presentation of the investigation.

0	The student's report does not reach a standard described by the descriptors below.
1	**The evidence of personal engagement with the exploration is limited with little independent thinking, initiative or creativity.** The justification given for choosing the research question and/or the topic under investigation does not demonstrate **personal significance, interest or curiosity**. There is little evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation.

2	**The evidence of personal engagement with the exploration is clear with significant independent thinking, initiative or creativity.** Connection with biology The justification given for choosing the research question and/or the topic under investigation demonstrates **personal significance, interest or curiosity**. There is evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation. see oberg citation

Exploration

This criterion assesses the extent to which the student establishes the scientific context for the work, states a clear and focused research question and uses concepts and techniques appropriate to the Diploma Programme level. Where appropriate, this criterion also assesses awareness of safety, environmental, and ethical considerations.

0	The student's report does not reach a standard described by the descriptors below.
1–2	The topic of the investigation is identified and a research question of some relevance is **stated but it is not focused**. The background information provided for the investigation is **superficial** or of limited relevance and does not aid the understanding of the context of the investigation. The methodology of the investigation is only appropriate to address the research question to a very limited extent since it takes into consideration few of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of limited awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation***.
3–4	The topic of the investigation is identified and a relevant but not fully focused research question is described. The background information provided for the investigation is mainly appropriate and relevant and aids the understanding of the context of the investigation. The methodology of the investigation is mainly appropriate to address the research question but has limitations since it takes into consideration only some of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of some awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation.***
	temp. specific
5–6	The topic of the investigation is identified and a relevant and fully focused research question is clearly described. The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation. The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. NA The report shows evidence of full awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation.*** extensive could discuss safe disposal.

* This indicator should only be applied when appropriate to the investigation. See exemplars in TSM.

Analysis

This criterion assesses the extent to which the student's report provides evidence that the student has selected, recorded, processed and **interpreted** the data in ways that are relevant to the research question and can support a conclusion.

0	The student's report does not reach a standard described by the descriptors below.
1–2	The report includes **insufficient relevant** raw data to support a valid conclusion to the research question. Some **basic** data processing is carried out but is either too **inaccurate or too insufficient to lead to a valid** conclusion. The report shows evidence of little consideration of the impact of measurement uncertainty on the analysis. The processed data is incorrectly or insufficiently interpreted so that the conclusion is invalid or very incomplete.
3–4	The report includes relevant but incomplete quantitative and qualitative raw data that could support a simple or partially valid conclusion to the research question. Appropriate and sufficient data processing is carried out that could lead to a broadly valid conclusion but there are significant inaccuracies and inconsistencies in the processing. The report shows evidence of some consideration of the impact of measurement uncertainty on the analysis. The processed data is interpreted so that a broadly valid but incomplete or limited conclusion to the research question can be deduced.
5–6	The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question. very high accuracy / low error Appropriate and sufficient data processing is carried out with **the accuracy** required to enable a conclusion to the research question to be drawn that is fully **consistent** with the experimental data. The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis. – extensive error analysis The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced. – expressed clearly in title

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation and the results with regard to the research question and the accepted scientific context.

0	The student's report does not reach a standard described by the descriptors below.

1–2	A conclusion is **outlined** which is not relevant to the research question or is not supported by the data presented. The conclusion makes superficial comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **outlined** but are restricted to an **account** of **the practical** or **procedural issues** faced. The student has **outlined** very few realistic and relevant suggestions for the improvement and extension of the investigation.
3–4	A conclusion is **described** which is relevant to the research question and supported by the data presented. A conclusion is described which makes some relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **described** and provide evidence of some awareness of the **methodological issues*** involved in establishing the conclusion. The student has **described** some realistic and relevant suggestions for the improvement and extension of the investigation.
5–6	A detailed conclusion is **described and justified** which is entirely relevant to the research question and fully supported by the data presented. A conclusion is correctly **described and justified** through relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are **discussed** and provide evidence of a clear understanding of the **methodological issues*** involved in establishing the conclusion. The student has **discussed** realistic and relevant suggestions for the improvement and extension of the investigation.

Conclusion is brief but entirely valid. Amply supported with graphs and data (raw + processed)

*See exemplars in TSM for clarification.

Communication

This criterion assesses whether the investigation is presented and reported in a way that supports effective communication of the focus, process and outcomes.

0	The student's report does not reach a standard described by the descriptors below.
1–2	**The presentation of the investigation is unclear, making it difficult to understand the focus, process and outcomes.** The report is not well structured and is unclear: the necessary information on focus, process and outcomes is missing or is presented in an incoherent or disorganized way. The understanding of the focus, process and outcomes of the investigation is obscured by the presence of inappropriate or irrelevant information. There are many errors in the use of subject specific terminology and conventions*.

3–4	**The presentation of the investigation is clear. Any errors do not hamper understanding of the focus, process and outcomes.** title states result: good. The report is well structured and clear: the necessary information on focus, process and outcomes is present and presented in a coherent way. Inverse plot is solid. The report is relevant and concise thereby facilitating a ready understanding of the focus, process and outcomes of the investigation. very. The use of subject specific terminology and conventions is appropriate and correct. Any errors do not hamper understanding. r² analysis/Kinetics terminology accurate.

*For example, incorrect/missing labelling of graphs, tables, images; use of units, decimal places. For issues of referencing and citations refer to the "Academic honesty" section.

Although the requirements for IA are centred on the investigation, the different types of practical activities that a student may engage in serve other purposes, including:

- illustrating, teaching and reinforcing theoretical concepts
- developing an appreciation of the essential hands-on nature of much scientific work
- developing an appreciation of scientists' use of secondary data from databases
- +developing an appreciation of scientists' use of modelling
- developing an appreciation of the benefits and limitations of scientific methodology.

The practical scheme of work (PSOW) is the practical course planned by the teacher and acts as a summary of all the investigative activities carried out by a student. Students at SL and HL in the same subject may carry out some of the same investigations.

Syllabus coverage

The range of practical work carried out should reflect the breadth and depth of the subject syllabus at each level, but it is not necessary to carry out an investigation for every syllabus topic. However, all students must participate in the group 4 project and the IA investigation.

Planning your practical scheme of work

Teachers are free to formulate their own practical schemes of work by choosing practical activities according to the requirements outlined. Their choices should be based on:

- subjects, levels and options taught
- the needs of their students
- available resources
- teaching styles.