Chemistry 2019 v1.3

IA2 high-level annotated sample response

August 2018

Student experiment (20%)

This sample has been compiled by the QCAA to assist and support teachers to match evidence in student responses to the characteristics described in the instrument-specific marking guide (ISMG).

Assessment objectives

This assessment instrument is used to determine student achievement in the following objectives:

2. apply understanding of chemical equilibrium systems or oxidation and reduction to modify experimental methodologies and process primary data
3. analyse experimental evidence about chemical equilibrium systems or oxidation and reduction
4. interpret experimental evidence about chemical equilibrium systems or oxidation and reduction
5. investigate phenomena associated with chemical equilibrium systems or oxidation and reduction through an experiment
6. evaluate experimental processes and conclusions about chemical equilibrium systems or oxidation and reduction
7. communicate understandings and experimental findings, arguments and conclusions about chemical equilibrium systems or oxidation and reduction.

Note: Objective 1 is not assessed in this instrument.

Queensland Government
Queensland Curriculum & Assessment Authority
180963

Instrument-specific marking guide (ISMG)

Criterion: Research and planning

Assessment objectives

2. apply understanding of chemical equilibrium systems or oxidation and reduction to modify experimental methodologies and process primary data
5. investigate phenomena associated with chemical equilibrium systems or oxidation and reduction through an experiment

The student work has the following characteristics:	Marks
• informed application of understanding of chemical equilibrium systems or oxidation and reduction to modify experimental methodologies demonstrated by – a considered rationale for the experiment – justified modifications to the methodology • effective and efficient investigation of phenomena associated with chemical equilibrium systems or oxidation and reduction demonstrated by – a specific and relevant research question – a methodology that enables the collection of sufficient, relevant data – considered management of risks and ethical or environmental issues.	5–6
• adequate application of understanding of chemical equilibrium systems or oxidation and reduction to modify experimental methodologies demonstrated by – a reasonable rationale for the experiment – feasible modifications to the methodology • effective investigation of phenomena associated with chemical equilibrium systems or oxidation and reduction demonstrated by – a relevant research question – a methodology that enables the collection of relevant data – management of risks and ethical or environmental issues.	3–4
• rudimentary application of understanding of chemical equilibrium systems or oxidation and reduction demonstrated by – a vague or irrelevant rationale for the experiment – inappropriate modifications to the methodology • ineffective investigation of phenomena associated with chemical equilibrium systems or oxidation and reduction demonstrated by – an inappropriate research question – a methodology that causes the collection of insufficient and irrelevant data – inadequate management of risks and ethical or environmental issues.	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Analysis of evidence

Assessment objectives

2. apply understanding of chemical equilibrium systems or oxidation and reduction to modify experimental methodologies and process primary data
3. analyse experimental evidence about chemical equilibrium systems or oxidation and reduction
5. investigate phenomena associated with chemical equilibrium systems or oxidation and reduction through an experiment

The student work has the following characteristics:	Marks
• appropriate application of algorithms, visual and graphical representations of data about chemical equilibrium systems or oxidation and reduction demonstrated by correct and relevant processing of data • systematic and effective analysis of experimental evidence about chemical equilibrium systems or oxidation and reduction demonstrated by – thorough identification of relevant trends, patterns or relationships – thorough and appropriate identification of the uncertainty and limitations of evidence • effective and efficient investigation of phenomena associated with chemical equilibrium systems or oxidation and reduction demonstrated by the collection of sufficient and relevant raw data.	5–6
• adequate application of algorithms, visual and graphical representations of data about chemical equilibrium systems or oxidation and reduction demonstrated by basic processing of data • effective analysis of experimental evidence about chemical equilibrium systems or oxidation and reduction demonstrated by – identification of obvious trends, patterns or relationships – basic identification of uncertainty and limitations of evidence • effective investigation of phenomena associated with chemical equilibrium systems or oxidation and reduction demonstrated by the collection of relevant raw data.	3–4
• rudimentary application of algorithms, visual and graphical representations of data about chemical equilibrium systems or oxidation and reduction demonstrated by incorrect or irrelevant processing of data • ineffective analysis of experimental evidence about chemical equilibrium systems or oxidation and reduction demonstrated by – identification of incorrect or irrelevant trends, patterns or relationships – incorrect or insufficient identification of uncertainty and limitations of evidence • ineffective investigation of phenomena associated with chemical equilibrium systems or oxidation and reduction demonstrated by the collection of insufficient and irrelevant raw data.	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Interpretation and evaluation

Assessment objectives

4. interpret experimental evidence about chemical equilibrium systems or oxidation and reduction
6. evaluate experimental processes and conclusions about chemical equilibrium systems or oxidation and reduction

The student work has the following characteristics:	Marks
• insightful interpretation of experimental evidence about chemical equilibrium systems or oxidation and reduction demonstrated by justified conclusion/s linked to the research question • critical evaluation of experimental processes about chemical equilibrium systems or oxidation and reduction demonstrated by – justified discussion of the reliability and validity of the experimental process – suggested improvements and extensions to the experiment that are logically derived from the analysis of evidence.	5–6
• adequate interpretation of experimental evidence about chemical equilibrium systems or oxidation and reduction demonstrated by reasonable conclusion/s relevant to the research question • basic evaluation of experimental processes about chemical equilibrium systems or oxidation and reduction demonstrated by – reasonable description of the reliability and validity of the experimental process – suggested improvements and extensions to the experiment that are related to the analysis of evidence.	3–4
• invalid interpretation of experimental evidence about chemical equilibrium systems or oxidation and reduction demonstrated by inappropriate or irrelevant conclusion/s • superficial evaluation of experimental processes about chemical equilibrium systems or oxidation and reduction demonstrated by – cursory or simplistic statements about the reliability and validity of the experimental process – ineffective or irrelevant suggestions.	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Communication

Assessment objective

7. communicate understandings and experimental findings, arguments and conclusions about chemical equilibrium systems or oxidation and reduction

The student work has the following characteristics:	Marks
• effective communication of understandings and experimental findings, arguments and conclusions about chemical equilibrium systems or oxidation and reduction demonstrated by − fluent and concise use of scientific language and representations − appropriate use of genre conventions − acknowledgment of sources of information through appropriate use of referencing conventions.	2
• adequate communication of understandings and experimental findings, arguments and conclusions about chemical equilibrium systems or oxidation and reduction demonstrated by − competent use of scientific language and representations − use of basic genre conventions − use of basic referencing conventions.	1
• does not satisfy any of the descriptors above.	0

Task

Context
You have completed the following practicals in class: • Investigate factors that affect equilibrium. Simulations could be used (suggested practical). • Investigate the electrical conductivity of strong and weak acids and bases (simulation can be used) (suggested practical). • Acid-base titration to calculate the concentration of a solution with reference to a standard solution (mandatory practical). • Perform single displacement reactions in aqueous solutions (mandatory practical). • Construct a galvanic cell using two metal/metal-ion half cells (mandatory practical). • Use an electrolytic cell to carry out metal plating (suggested practical). • Carry out electrolysis of water or copper sulfate. Simulations could be used (suggested practical).
Task
Modify (i.e. refine, extend or redirect) an experiment in order to address your own related hypothesis or question. You may use a practical performed in class, a related simulation or another practical related to Unit 3 (as negotiated with your teacher) as the basis for your methodology and research question.

Sample response

Criterion	Marks allocated	Result
Research and planning Assessment objectives 2, 5	6	5
Analysis of evidence Assessment objectives 2, 3, 5	6	6
Interpretation and evaluation Assessment objectives 4, 6	6	6
Communication Assessment objective 7	2	2
Total	**20**	**19**

The annotations show the match to the instrument-specific marking guide (ISMG) performance-level descriptors.

Key: Research and planning Analysis of evidence Interpretation and evaluation Communication

Note: Colour shadings show the characteristics evident in the response for each criterion.

Research and planning [3–4]

a reasonable rationale for the experiment

The rationale shows sound application of scientific concepts to the research question. However, the rationale does not discuss the electrolytes in the original experiment and the modified methodology.

How does changing the concentration of the electrolyte (KOH) affect the time to produce 25 mL of hydrogen gas by electrolysis?

Rationale

Electrolysis is a chemical change caused by passing an electric current through an electrolyte (Clark 2013). Pure water is not an electrolyte (Whitney 1903). Adding an ionic compound to water significantly enhances its conductivity, allowing it to act as an electrolyte. During electrolysis, reduction of hydrogen ions occurs at the cathode, resulting in the evolution of hydrogen gas.

$$2H^{+}_{(aq)} + 2e^{-} \rightarrow H_{2(g)} \qquad \text{(eq. 1)}$$

The electrical charge passed (Q, in coulombs) is equivalent to the product of current (I, in amps) and time (t, in seconds). Therefore, the volume of hydrogen gas evolved will be proportional to the quantity of electrical charge passed. One faraday of charge (F) is equal to 96 500 C (Purdue University 2017) and represents the electrical charge associated with one mole of electrons. Inspection of the reduction half-equation (eq. 1) shows that 2 moles of H+(aq) reacts with 2 moles of electrons to produce 1 mole of H2(g). The molar volume of hydrogen gas (Vm) occupies 22.4 L at STP (Lyon et. al. 2000).

Original experiment

The online simulation ‘Electrolysis Experiments’ (Crowley 2003) qualitatively examined how changing the electrolyte’s chemical composition affected the volume of hydrogen gas produced. The two electrolytes examined were acidified water and hydrochloric acid. These electrolytes have different concentrations of $H^{+}_{(aq)}$ available to undergo reduction to produce hydrogen gas. When compared with acidified water, hydrochloric acid produced double the volume of hydrogen gas. This led to the following research question being developed.

Research and planning [5–6]

a specific and relevant research question

The research question is clearly defined. The independent variable and the dependent variable are clearly stated.

The research question is connected to the rationale and enables effective investigation of oxidation and reduction.

Research question

How does changing the concentration of an electrolyte (KOH) affect the time to produce 25 mL of hydrogen gas by electrolysis?

Modifications to the methodology

justified modifications to the methodology

The response gives sound reasons for how the modifications to the methodology will refine, extend or redirect the original experiment.

To ensure that sufficient, relevant data was collected, the original experiment was:

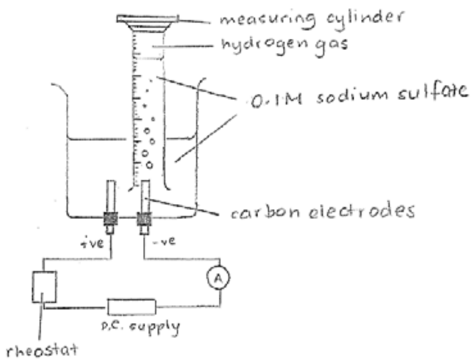
1. extended by
   a. introducing an ammeter (Figure 1) to quantify the current that passed through the electrolyte — this allowed the electrical charge, moles of electrons and moles of hydrogen gas to be calculated
   b. using a timer (± 0.05 seconds) to quantify the time that the current passed through the electrolyte — this allowed the rate of hydrogen production and moles of hydrogen gas produced to be determined (dependent variable)
   c. using five concentrations of KOH (0.2 M, 0.4 M, 0.6 M, 0.8 M and 1.0 M) to show the effect that the concentration of the electrolyte has on the time needed to produce the molar volume of hydrogen (independent variable). Each concentration will be tested three times
2. refined by
   a. using a 25.00 ± 0.25 mL measuring cylinder rather than a test tube (Figure 1) to quantify the volume of hydrogen gas produced
   b. using 100.0 ± 0.5 mL of solution for each trial (controlled variable)
   c. using a rheostat to reduce fluctuations in the current (controlled variable).

a methodology that enables the collection of sufficient, relevant data

The methodology shows careful and deliberate thought. It enables collection of adequate data so an informed conclusion to the research question can be drawn.

Three repeated measurements for each trial are planned to allow a mean to be calculated. Five variations of the independent variable are planned to allow trends and relationships to be analysed and graphs to be drawn.

Figure 1: Experimental setup



Research and planning [5–6]

considered management of risks and ethical or environmental issues

The response shows careful and deliberate identification and planning to handle risks and ethical or environmental issues in the experiment.

Analysis of evidence [5–6]

collection of sufficient and relevant raw data

The raw data is adequate for forming a conclusion and has direct bearing upon the research question. Five variations of the independent variable and three repetitions of each measurement are adequate.

Communication [2]

appropriate use of genre conventions

Raw data is recorded with the associated uncertainties and expressed consistently to the correct number of significant figures.

The response uses units and symbols correctly.

Management of risks

0.1 M potassium hydroxide solution may irritate the eyes and skin. Eye protection will be worn and any solution that touches the skin will be washed off immediately. Waste materials will be returned to the prep room.

There is a very small risk of explosion from the hydrogen and oxygen released in the electrolysis. No naked flames will be used while passing the current through the apparatus. The electrolysis will be carried out in a well-ventilated room.

Qualitative observations

During the electrolysis process, there were only slight variations in the rates of gas evolution at both electrodes, attributed to small fluctuations in circuit resistance. These were minimised by use of the rheostat.

Raw data

Table 1: Time taken for the passing of 0.600 ± 0.001 A to collect 25.00 ± 0.25 mL of H_2

Concentration (mol/L)	Time (± 0.5 s)*		
	Trial 1	Trial 2	Trial 3
0.2	359.5	368.5	364.5
0.4	360.0	345.5	327.5
0.6	325.5	339.5	333.5
0.8	343.5	307.0	327.5
1.0	307.0	339.5	326.5

**Human reaction time when operating the timer.*

Operating temperature of the apparatus = 26.0 °C = 299.0 K

Pressure in the lab = 101 kPa

Processing of data

Raw data was processed to determine the molar volume of hydrogen using the equations shown in Table 2. The researched molar volume hydrogen at STP (22.4 dm^3/mol) was converted into a ‘true’ value at laboratory conditions. This value was compared with the experimental volume produced to determine the accuracy of the experimental results and, therefore, the validity of the experimental process.

The measurement uncertainty was converted to percentage uncertainty and propagated to determine the precision of the experimental results and, therefore, the reliability of the experimental process. A spreadsheet program was used to graph the experimental results to allow patterns to be examined.

Analysis of evidence [5–6]

correct and relevant processing of data

Raw data is manipulated accurately to provide evidence that is applicable to the research question.

thorough and appropriate identification of the uncertainty and limitations of evidence

Measurement uncertainty is appropriately propagated through numerical calculations associated with processed data to determine the total uncertainty for the experimental results.

Communication [2]

appropriate use of genre conventions

Processed data is consistent with raw data and expressed to the correct number of significant figures.

The response uses units and symbols correctly.

Table 2: Sample calculation 1.0 M KOH

Formula used to process data	Sample calculations for 1.0 M KOH
Average time = $\frac{\text{trial 1 + trial 2 + trial 3}}{3}$	Average time = $\frac{307.0 + 339.5 + 326.5}{3}$ = 324.3 ± 16.3 seconds
Uncertainty for the mean = ± $\frac{\text{range}}{2}$	Uncertainty for the mean = ± $\frac{(339.5 - 307.0)}{2}$ = ± 16.3 seconds
Percentage uncertainty (%) = $\frac{\text{absolute uncertainty}}{\text{measurement value}} \times \frac{100}{1}$	Percentage uncertainty (%) = $\frac{16.3}{324.3} \times \frac{100}{1}$ = 5%
Electrical charge (Q) = current (I) × time (t)	Q = 0.600 A ± 0.2% × 324.3 s ± 5% = 195 C ± 5.2% = 195 C ± 5%
Moles of electrons passed (n) = $\frac{Q}{F}$	$n\,(e^-) = \frac{Q}{F}$ = $\frac{195 \pm 5\%}{96\,500}$ = 0.00202 ± 5% = 2.02 × 10^{-3} mol ± 5%
Inspecting the balanced chemical equation to find the reacting ratio of electrons to hydrogen gas, $2H^+_{(aq)} + 2e^- \rightarrow H_{2\,(g)}$ indicates a ratio of 2:1. 2 moles of electrons produce 1 mole $H_{2(g)}$.	$n\left(H_{2(g)}\right) = \frac{n\,(e^-)}{2}$ = $\frac{2.02 \times 10^{-3} \text{ mol} \pm 5\%}{2}$ = 1.01 × 10^{-3} mol ± 5%
Rate of $H_{2(g)}$ production = $\frac{\Delta \text{ volume (cm}^3\text{)}}{\text{time (s)}}$	Rate of $H_{2(g)}$ production = $\frac{25.00 \pm 1\% \text{ cm}^3}{324.3 \pm 5\% \text{ s}}$ = 0.0771 $cm^3\,s^{-1}$ ± 6%
The researched molar volume of hydrogen is 22.4 L/mol at 0 °C and 101 kPa of pressure. Theoretical value adjusted for 26.0 °C. Molar volume at 26.0 °C ($V_{m\,26}$) = $\frac{V_m \times T_{experimental}}{T_{stp}}$	$H_{2(g)}$ ($V_{m\,26}$) = $\frac{22.4 \times 299}{273}$ = 24.5 L Theoretical $n\left(H_{2(g)}\right)$ in 25 cm^3 = $\frac{0.025}{24.5}$ = 1.02 × 10^{-3} mol
Percentage error (%) = $\frac{\lvert\text{experimental} - \text{theoretical}\rvert}{\text{theoretical}}$ × 100%	Percentage error (%) = $\frac{\lvert 1.01 \times 10^{-3} - 1.02 \times 10^{-3} \rvert}{1.02 \times 10^{-3}}$ × 100% = 1.0%

Analysis of evidence [5–6]

thorough identification of relevant trends, patterns or relationships

The identification of relationships is not superficial or partial. The relationships are applicable to the research question.

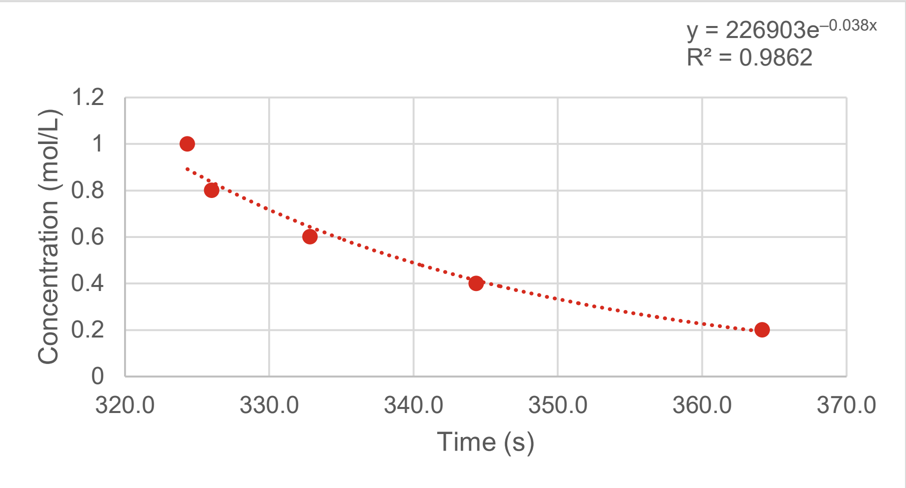
Table 3: Moles of hydrogen produced per 25 mL of gas collected

Concentration (mol/L)	Average time (s)	Electrical charge (Q)	Moles electrons $n(e^{-1})$ (1×10^{-3})	Moles $H_{2(g)}$ $n(H_{2(g)})$ (1×10^{-3})	% error
0.2	364.2 ± 1%	219 ± 1%	2.27 ± 1%	1.14 ± 1%	12%
0.4	344.3 ± 5%	207 ± 5%	2.15 ± 5%	1.08 ± 5%	6%
0.6	332.8 ± 2%	200 ± 2%	2.07 ± 2%	1.04 ± 2%	2%
0.8	326.0 ± 6%	196 ± 6%	2.03 ± 6%	1.02 ± 6%	0%
1.0	324.3 ± 5%	195 ± 5%	2.02 ± 5 %	1.01 ± 5%	1%

Table 4: Rates of hydrogen gas production per mL and per mole

Concentration (mol/L)	Average time (s)	Rate (mL/s)	Moles $H_{2(g)}$ $n(H_{2(g)})$ (1×10^{-3})	Rate (mol/s) (1×10^{-6})
0.2	364.2 ± 1%	0.0686 ± 2%	1.14 ± 1%	3.13 ± 2%
0.4	344.3 ± 5%	0.0726 ± 6%	1.08 ± 5%	3.13 ± 10%
0.6	332.8 ± 2%	0.0751 ± 3%	1.04 ± 2%	3.13 ± 4%
0.8	326.0 ± 6%	0.0767 ± 7%	1.02 ± 6%	3.13 ± 12%
1.0	324.3 ± 5%	0.0771 ± 6%	1.01 ± 5%	3.11 ± 10%

Graph 1: Concentration of KOH vs. time taken to collect 25.0 mL of H2 gas

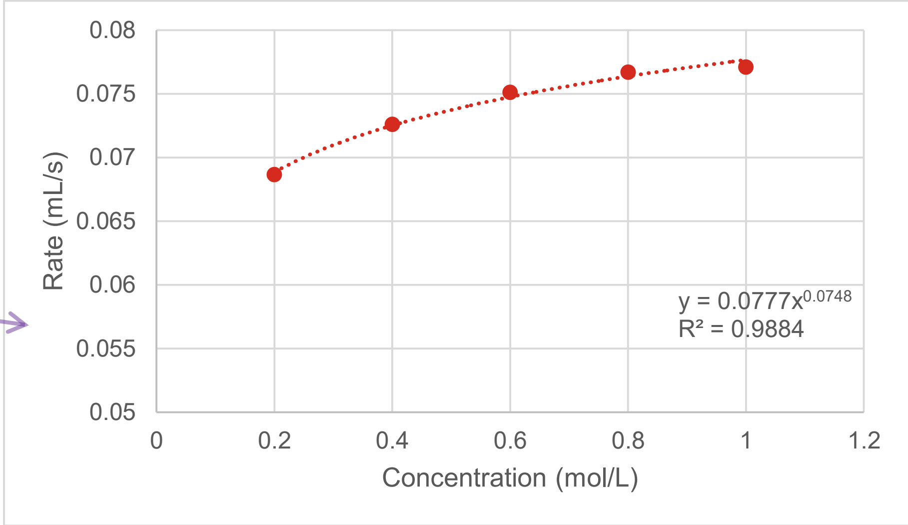


Communication [2]

fluent and concise use of scientific language and representations

The response represents data clearly so that the trends, patterns and relationships can be easily identified.

Graph 2: Rate of hydrogen gas production

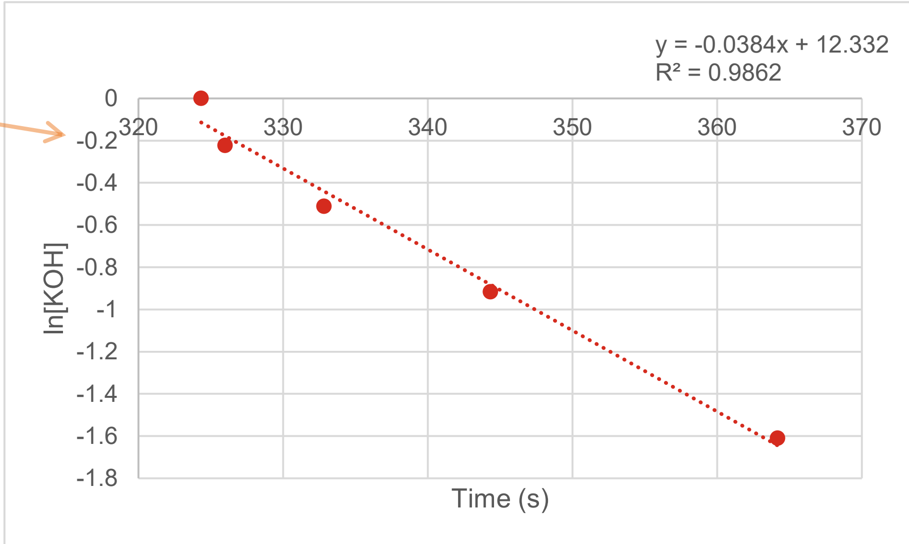


Analysis of evidence [5–6]

thorough identification of relevant trends, patterns or relationships

The identified trends, patterns and relationships are not superficial and allow a justified conclusion to the research question to be drawn.

Graph 3: ln [KOH] showing first-order reaction



Trends, patterns and relationships

Graph 1 indicates that as the concentration of the electrolyte (KOH) increased, the time taken to produce 25 mL of hydrogen gas decreased. This appears to be an exponential relationship, which suggests that there is a first-order relationship between concentration of the electrolyte and rate of hydrogen production.

Graph 2 supports this relationship and shows that as the concentration of KOH increased, the rate at which hydrogen was produced also increased. The shape of this graph suggests that the relationship between hydrogen production and concentration is a first-order reaction.

Graph 3 produced a straight line, which shows that the relationship between concentration of the electrolyte and the production of hydrogen gas is a first-order reaction; that is, as [KOH] doubles, the time taken to produce the same volume of hydrogen is halved.

Annotations	Response
	Comparing the experimental number of moles calculated for each [KOH] (Table 4) with the theoretical moles of hydrogen gas allows the accuracy of the experimental results and, therefore, the validity of the experimental process to be evaluated. As the [KOH] increases, the accuracy of the results determined decreased.

Limitations of the evidence and reliability and validity of the experimental process

The limitations of the evidence and the evaluation of the experimental process are shown in Table 5.

Analysis of evidence [5–6]

thorough and appropriate identification of the uncertainty and limitations of evidence

The response suitably identifies uncertainty and limitations of the data in a way that is not superficial or partial. The response examines the uncertainty to determine if the evidence that will be used to draw a conclusion to the research question is reliable and valid.

Interpretation and evaluation [5–6]

justified discussion of the reliability and validity of the experimental process

The response uses evidence from the identification of uncertainties and limitations to support the consideration of the reliability and validity of the experimental process. The response identifies significant random and systematic errors.

Table 5: Limitations of the evidence

Limitations of the evidence		Reliability and validity of the experimental process
The time recorded for each trial is inconsistent and hence the average time is unreliable.	Varying times for collecting the same volume of hydrogen gas (Table 1) indicates that the raw data for time is inconsistent and, therefore, imprecise.	Percentage uncertainty for time equates to ± 0.2% (Table 1); however, total uncertainty for average time (Table 4) ranges from ± 1% to 6%, Therefore, the experimental process is unreliable due to random error.
The equipment used to measure the volume of hydrogen gas collected is imprecise.	Percentage uncertainties (precision) that arise from the equipment used to measure current (0.2%), volume (1%) and time (0.2%) equate to 1.4% (Table 3). Therefore, the measuring cylinder used to collect the gas contributes to the data being imprecise.	As the volume of hydrogen collected per trial is small and contributes 1% to the total random error (1.4%), the equipment used to collect the gas contributes to the experimental process being unreliable.
The volume of hydrogen gas collected is inaccurate.	Absorption of hydrogen by the porous carbon electrode results in some hydrogen gas not being collected. The hydrogen gas was collected over an aqueous solution, so the final volume of gas also contains water vapour. Therefore, the volume of hydrogen collected is inaccurate.	As all the hydrogen gas produced is not collected and the volume of gas collected is a mixture of gases rather than just hydrogen, the experimental process lacks validity due to a systematic error.

Interpretation and evaluation [5–6] justified conclusion/s linked to the research question The response uses sound reasons and evidence to support a conclusion that directly responds to the research question. The response uses an accepted value to draw a conclusion about the accuracy of the experimental results. **Communication [2]** acknowledgment of sources of information through appropriate use of referencing conventions The use of in-text referencing fits the purpose of a scientific report. **Interpretation and evaluation [5–6]** justified conclusion/s linked to the research question The response uses sound evidence and concepts, supported by scientific literature, to support the conclusion and relate results to the research question. The response uses analysis of evidence to support the decisions reached. The response provides sound reasons or evidence to support a statement in response to the research question.	**Conclusion** The results show that changing the concentration of KOH affects the time taken to produce 25 mL of hydrogen gas. As [KOH] increases, the corresponding time to produce 25 mL of hydrogen gas decreases (Graph 1). Therefore, increasing the concentration of $K^+_{(aq)}$ and $OH^-_{(aq)}$ ions, which act as electrolytes, increases the rate at which $H^+_{(aq)}$ ions in an aqueous solution are reduced to H_2(g). As the molar volume of any gas at STP is 22.4 L (Lyon et. al. 2000), the number of moles of hydrogen per 25 mL of gas produced is the same. The theoretical number of moles of H2(g) produced was 1.02 x10-3 moles (Table 2). The moles of hydrogen produced for each concentration of KOH, except 1.0 M, can be considered accurate as the accepted value for the moles of hydrogen produced falls within the experimental range of the results. However, the large total percentage uncertainties associated with these results indicates that the results, while accurate, may not be reliable. When an electric current is passed through a dilute aqueous solution of KOH, the concentration of ions (electrolytes) in the solution affects the amount of current that passes (Yuvaraj & Santhanaraj 2013). Increasing the concentration of ions increases the amount of current that can pass because it increases the number of effective collisions that can occur per unit of time and, therefore, increases the rate of hydrogen gas production (Yuvaraj & Santhanaraj 2013). Graph 1 and 2 support this relationship, which supports that the experimental results are valid. The reduction of H+(aq) to H2(g) is a first-order reaction with respect to rate (Santos, Sequeira & Figueiredo 2013). Graph 2 and 3 show that the rate of reaction to produce hydrogen is a first-order reaction with respect to [KOH], which further supports the validity of the experimental results. The uncertainty (random error) that arises from the limitations of the equipment equates to 1.4% (Table 3). However, the total uncertainty (random and systematic error) associated with time to produce the same volume of hydrogen gas for each concentration of KOH ranges from 1% to 6%. This indicates that the experimental process used contains random and systematic errors, which affected the reliability and accuracy of the experimental results obtained. Therefore, the experimental results are accurate and indicate that as the concentration of KOH increases, the time taken to produce 25 mL of hydrogen gas decreases. However, the large range of uncertainty associated with determining the time, rate of reaction and moles of $H_{2(g)}$ produced indicates that the data used to produce the results is unreliable and, therefore, the experimental process needs to be refined to improve the reliability of the results.

Interpretation and evaluation [5–6]

suggested improvements and extensions to the experiment that are logically derived from the analysis of evidence

The response uses the analysis of the evidence to inform the suggested improvements and extensions to the experiment.

The response uses clear, sound reasoning to arrive at improvements and extensions that would improve the reliability and validity of the experimental process by reducing the impact of the identified random and systematic errors.

Suggested improvements and extensions

Suggested improvements and extensions to improve the reliability and validity of the experimental processes are outlined in Table 6.

Table 6: Analysis of evidence and suggested improvements and extensions

Analysis of evidence	Suggested improvements and extensions
Random error The average time to collect 25.00 mL of hydrogen gas for each electrolyte is imprecise.	Reduce random error by refining the experimental process to: • control the time used to collect the hydrogen gas • use a Hoffman's apparatus to determine when the final volume of gas is produced • repeat each trial until the time taken to produce a set volume of gas is consistent.
Random error The scale on the measuring cylinder contributes to the volume of hydrogen gas collected being imprecise.	Reduce random error by refining the experimental process to: • produce a larger volume of hydrogen gas • use equipment with a higher level of precision to collect the gas.
Systematic error The volume of hydrogen gas collected is inaccurate.	Reduce systematic error by extending the experimental process to: • include the measurement of atmospheric pressure and the temperature of the electrolyte solution to allow the volume of water vapour to be determined • use non-porous inert electrodes (e.g. silver or platinum) • run the current prior to starting the experiment for long enough to ensure the carbon electrodes are saturated with gas.
The molar volume of hydrogen gas is determined indirectly.	Redirect the experiment by producing hydrogen gas via a stoichiometric reaction (e.g. from the reaction of magnesium with hydrochloric acid) that determines the molar volume of hydrogen gas more directly, increasing validity.

Communication [2]

fluent and concise use of scientific language and representations

The response is easily understood, avoids unnecessary repetition and meets the required length.

Word count: 1931

Communication [2]

acknowledgment of sources of information through appropriate use of referencing conventions

The use of a referencing system fits the purpose of a scientific report.

Reference list

Clark, J 2013, 'Learning outcome 6(b)', *Chemguide: Support for CIE A Level Chemistry*, www.chemguideforcie.co.uk/section6/learningb.html.

Crowley, M 2003, *Electrolysis Experiments*, www.myweb.tiscali.co.uk/chemteach/swf/electrolysis2.swf.

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Purdue University 2017, *Electrolysis*, www.chem.purdue.edu/gchelp/howtosolveit/Electrochem/Electrolysis.htm.

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Whitney, WR 1903, 'Electrolysis of water', *The Journal of Physical Chemistry,* vol. 7, no. 3, pp. 190–193, www.dx.doi.org/10.1021/j150048a002.

Yuvaraj, AL & Santhanaraj, D. 2013, 'A systematic study on electrolytic production of hydrogen gas by using graphite as electrodes', *Material Research*, vol. 17, no. 1, pp. 83–87, www.dx.doi.org/10.1590/S1516-14392013005000153.