Chemistry 2019 v1.3

IA2 mid-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.

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	4
Analysis of evidence Assessment objectives 2, 3, 5	6	4
Interpretation and evaluation Assessment objectives 4, 6	6	4
Communication Assessment objective 7	2	2
Total	**20**	**14**

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 relevant research question

The research question is connected to the rationale and allows the effective investigation of oxidation and reduction. However, the response does not specifically identify the independent variable or the dependent variable.

How does changing the nature of the electrolyte affect the molar volume of hydrogen gas produced by electrolysis?

Research question

How does changing the nature of the electrolyte affect the hydrogen gas produced 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, as shown in the equation:

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

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.

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 the reacting ratio of electrons to molecules of $H_{2(g)}$ atoms is 2:1. Therefore, it follows that 2 x 96 500 C = 193 000 C will be required to produce one mole of $H_{2(g)}$. The molar volume of hydrogen gas (V) should occupy 22.4L at STP (Lyon et. al. 2000).

The online simulation 'Electrolysis Experiments' (Crowley 2003) has been modified to investigate whether changing the electrolyte will affect the experimental molar volume obtained by electrolysis.

Methodology

feasible modifications to the methodology

The modifications can be achieved. However, the response does not justify how the modifications will refine, extend or redirect the original experiment.

Original experiment

The online simulation was used to investigate electrolysis on 25 March 2017. Each of the available simulated electrolytes were selected in turn. The connection to DC power supply was clicked and observations of each electrode reaction, together with the ratio of gases produced at the cathode and anode, were recorded.

Modifications

- To quantify the volume of gas collected from the cathode, the test tube in the original experiment was replaced by a 25 mL measuring cylinder.
- An ammeter was introduced to the circuit, as shown in Figure 1.
- A rheostat was introduced to ensure that fluctuations in current were eliminated as much as possible.
- A timer was used to record how long the experiment ran.
- Five different concentrations of potassium hydroxide were used.

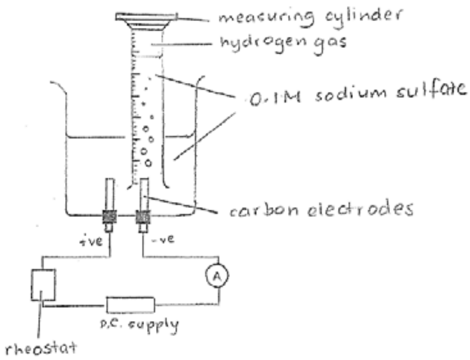
Research and planning [5–6]

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: Modified experimental setup



Procedure

The apparatus was assembled as shown in Figure 1.

The experiment was repeated three times for each concentration. Five different concentrations of potassium hydroxide were used: 1.0 M, 0.8 M, 0.6 M, 0.4 M and 0.2 M.

Research and planning [5–6]	

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.

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 should 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.

Results

Qualitative observations

During the passing of current through each electrolyte, the gas given off at the cathode was identified as hydrogen by testing a small sample using a burning taper (resulting in a squeaky pop). Also, the gas given off at the anode was identified as oxygen in each case through testing a small sample with a glowing taper (resulting in the taper relighting).

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.

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.

Raw data

Table 1: Time taken for the passing of 0.600 ± 0.001A to collect 25.00 ± 0.25mL 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 has been taken to equal 0.5 s. Therefore, the times have been recorded to the nearest half second. This results in an uncertainty of ± 0.5 s.

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

Pressure in the lab = 101 kPa

Control of variables

In each trial, the volume of hydrogen gas collected in the measuring cylinder was 25.00 ± 0.25 mL and the current remained constant at 0.600 ± 0.001 A.

Analysis of evidence [3–4] **basic processing of data** The response shows the fundamental steps involved in manipulating the raw data mathematically to produce the evidence. **basic processing of data** Raw data is manipulated to provide fundamental evidence that responds to the research question. However, volume has not been corrected for laboratory temperature and pressure. **Communication [2]** **appropriate use of genre conventions** Correct use of conventions of chemical equations, units and significant figures. **Analysis of evidence [3–4]** **basic identification of uncertainty and limitations of evidence** The response shows fundamental consideration of the impact of measurement uncertainty. However, measurement uncertainty has not been appropriately propagated through numerical calculations. The response shows fundamental consideration of the impact of error on the experimental results.	See below

Processing of data

Table 2: Algorithms used to calculate the molar volume of hydrogen

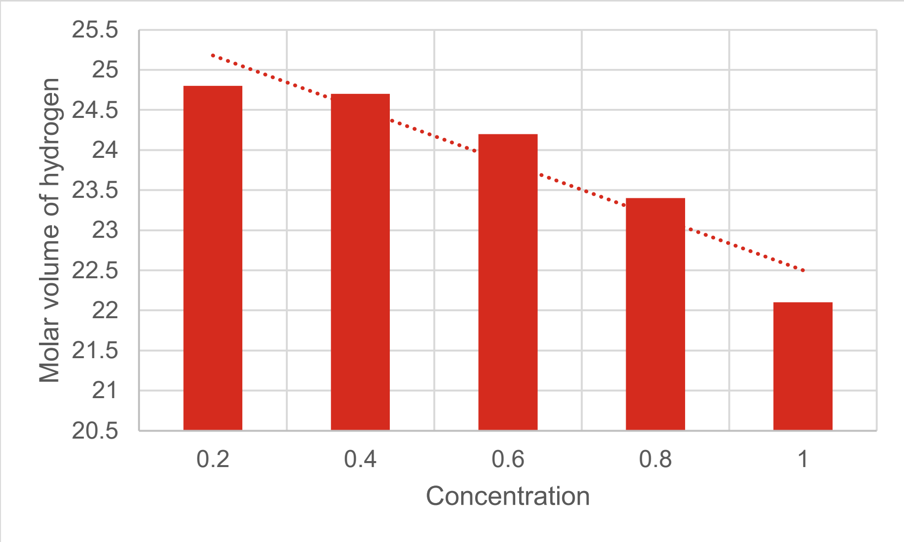
Equation 1: Q=It,
Equation 2: n=Q/F
Equation 3: V= v (25.00mL) / n
• Applying equation 1, the mean quantity of charge passed in each trial was calculated for each electrolyte. • Applying equation 2, the molar quantity of hydrogen was estimated for each electrolyte at the laboratory conditions. • Applying equation 3, the experimental molar volume can be calculated.

Table 3: Sample calculation 1.0 M KOH

Mean times, trials 1–3: = (307.0 + 339.5 + 326.5) /3 = 973.0 / 3 = 324.3 s
Mean charge passed (Q) = I x t = 0.600 A x 324.3 s = 195 C
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.
Using equation 2 to calculate the number of moles of electrons: n= Q / F = 195 C / 96500 C/mol = 2.02×10^{-3} mol of electrons 2.02×10^{-3} mol of electrons ↔ 1.01×10^{-3} mol of hydrogen gas 25.00 mL of hydrogen gas ↔ 1.01×10^{-3} mol of hydrogen gas
Experimental molar volume (V) = volume of gas collected (v) / quantity of hydrogen gas (n) = 25.00 mL / 1.01×10^{-3} mol = 24509 mL/mol = 24.5 L/mol
Uncertainty for time: Range of times across three trials = 339.5 – 307.0 = 32.6 s Uncertainty = ½ range = 32.6/2 = 16.3 s 16.3 s / 324.3 s = 5%
Uncertainty from measuring cylinder: 25.00 ± 0.25mL leads to an uncertainty of 0.25 mL/25.00 mL x 100 = ± 1.0%
Uncertainty for current: 0.001 A / 0.600 A = 0.17%

Table 4: processed data (all five electrolytes)

Concentration (mol/L)	Mean charge (C)	Molar volume of hydrogen, (L/mol) ± 1.0%	Percentage error (%)
0.2	219	24.5	1%
0.4	207	24.7	1%
0.6	200	24.2	1%
0.8	196	23.4	5%
1.0	195	22.1	10%

Analysis of evidence [3–4] **identification of obvious trends, patterns or relationships** The response identifies an easily recognised pattern that has some relevance to the research question.	**Graph 1: Molar volume of hydrogen** 
Interpretation and evaluation [3–4] **reasonable conclusion/s relevant to the research question** The conclusion is based on sound judgment and related to the research question, but is not explicitly justified using the evidence gathered during the experiment. **reasonable description of the reliability and validity of the experimental process** The response describes sources of random error. However, evidence has not been used to discuss the reliability or validity of the experimental process.	# Conclusion The data obtained supports the idea that the molar volume of hydrogen calculated via electrolysis increases as the concentration of the electrolyte decreases. All five concentrations of electrolytes provide a range of values for molar volume within 10% of the 'true' value, suggesting that the concentration of the electrolyte has some effect on the molar volume of hydrogen calculated. In three cases, the experimental value almost matches the 'true' value. The 'true' molar volume is concordant with the experimental values obtained from three concentrations of electrolyte, with a maximum discrepancy in the other two of about 10% (Table 4). The random errors in the experiment have been shown to equate to 4.3%, attributed to the limitations of the equipment used to measure current, volume and time. The values from 0.8 and 1.0 M solutions lie outside this, indicating that systematic errors are significant and that the experimental methodology may need some redesigning. The rheostat was used to ensure that current stayed at 600 mA throughout each trial. The digital multimeter used measured current to the nearest mA, equating to an uncertainty of less than 0.2%. The error in the measuring cylinder (the only analogue device used) contributed random error in each trial and accounted for about a quarter of the random uncertainty at ± 1.0%. The stopwatch had two decimal places but, in operating the device, human reaction time results in a significantly larger uncertainty than ± 0.01 s. Each trial has an uncertainty of ± 0.5 s allocated.

Interpretation and evaluation [3–4] reasonable description of the reliability and validity of the experimental process The response uses sound judgment to identify possible systematic errors. reasonable description of the reliability and validity of the experimental process The response identifies sensible sources of systematic and random error. However, it does not consider the impact of these errors on the reliability and validity of the experimental process. suggested improvements and extensions to the experiment that are related to the analysis of evidence The suggested modifications address systematic and random errors. However, the response does not use evidence to show that these modifications would improve the reliability and validity of this experiment. **Communication [2]** fluent and concise use of scientific language and representations The response is easily understood, avoids unnecessary repetition and meets the required length. acknowledgment of sources of information through appropriate use of referencing conventions The use of a referencing system fits the purpose of a scientific report.	See response text below.

Systematic errors are caused by problems in the setup of the experiment. These consistently result in a value that is inaccurate when compared with the 'true' value. Since three of the measured values were lower than that 'true' value, there may have been a systematic error in the method.

Evaluation of methodology

The experiment has been successful in generating data that can be used to answer the research question. However, the following modifications will improve the reliability of the data obtained and, therefore, the validity of the conclusions drawn:

Table 5: Experimental limitations and improvements

Limitation	Recommended improvements
Systematic error Difficulties in ensuring that no air is inside measuring cylinder before starting.	Perform the whole experiment in the Hoffman apparatus.
Systematic error Absorption of hydrogen by the porous carbon electrodes.	Use non-porous inert electrodes (e.g. silver or platinum). If these are not available, then run current prior to starting the experiment for long enough to ensure the carbon electrodes are saturated with gas.
Random error Volume of hydrogen per trial is small.	Increase the volume of gas to 50.00 mL, which would halve the uncertainty due to volume measurement.
Only five electrolytes were tested.	Test more concentrations of electrolyte.

Word count: 1545

Reference list

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