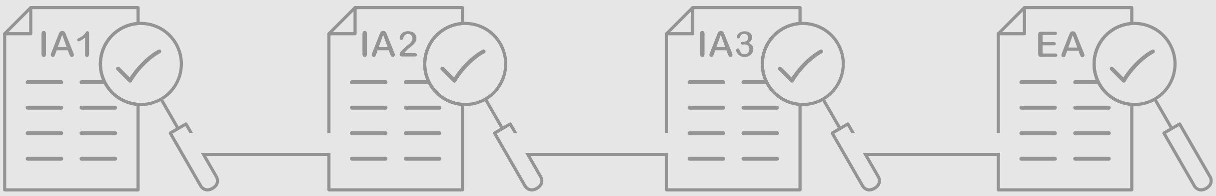
Chemistry subject report

2025 cohort

January 2026



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Queensland Curriculum & Assessment Authority

For all Queensland schools

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Contents

Introduction

The annual subject reports seek to identify strengths and opportunities for improvement of internal and external assessment processes for all Queensland schools. The 2025 subject report is the culmination of the partnership between schools and the QCAA. It addresses school-based assessment design and judgments, and student responses to external assessment for General and General (Extension) subjects. In acknowledging effective practices and areas for refinement, it offers schools timely and evidence-based guidance to further develop student learning and assessment experiences for 2026.

The report also includes information about:

- how schools have applied syllabus objectives in the design and marking of internal assessments
- how syllabus objectives have been applied in the marking of external assessments
- patterns of student achievement
- important considerations to note related to the revised 2025 syllabus (where relevant).

The report promotes continuous improvement by:

- identifying effective practices in the design and marking of valid, accessible and reliable assessments
- recommending where and how to enhance the design and marking of valid, accessible and reliable assessment instruments
- providing examples that demonstrate best practice.

Schools are encouraged to reflect on the effective practices identified for each assessment, consider the recommendations to strengthen assessment design and explore the authentic student work samples provided.

Audience and use

This report should be read by school leaders, subject leaders, and teachers to:

- inform teaching and learning and assessment preparation
- assist in assessment design practice
- assist in making assessment decisions
- help prepare students for internal and external assessment.

The report is publicly available to promote transparency and accountability. Students, parents, community members and other education stakeholders can use it to learn about the assessment practices and outcomes for senior subjects.

Subject highlights

423
schools offered Chemistry

82.45%
of students completed 4 units

6.76%
increase in enrolment since 2024

Subject data summary

Unit completion

The following data shows students who completed the General subject.

Note: All data is correct as at January 2026. Where percentages are provided, these are rounded to two decimal places and, therefore, may not add up to 100%.

Number of schools that offered Chemistry: 423.

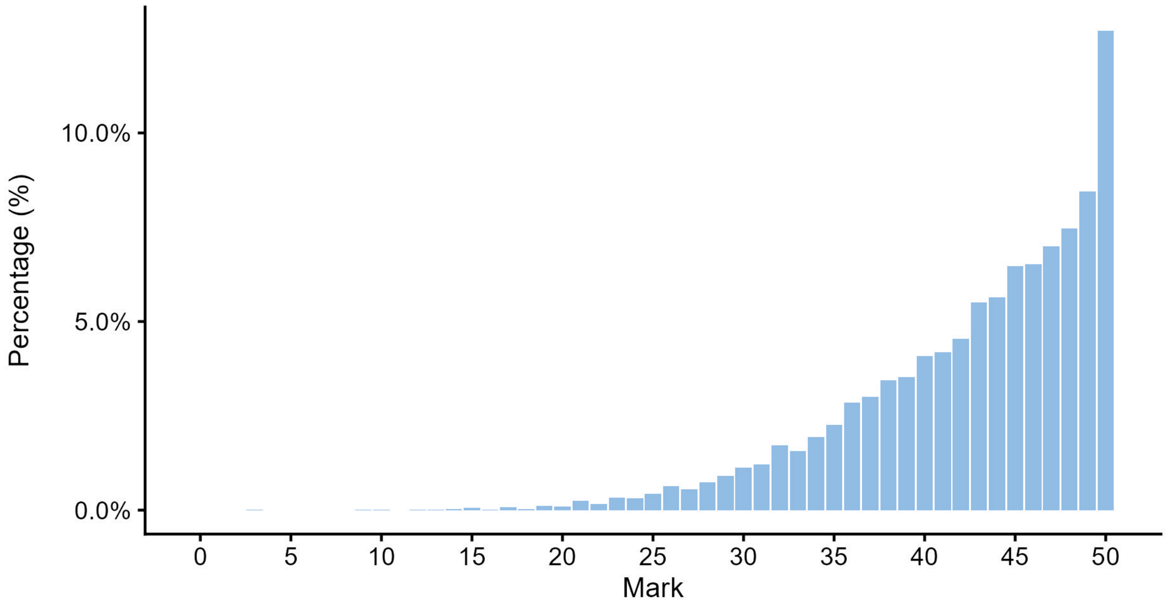
Completion of units	Unit 1	Unit 2	Units 3 and 4
Number of students completed	11,322	10,451	9,335

Units 1 and 2 results

Number of students	Unit 1	Unit 2
Satisfactory	10,707	9,825
Unsatisfactory	615	626

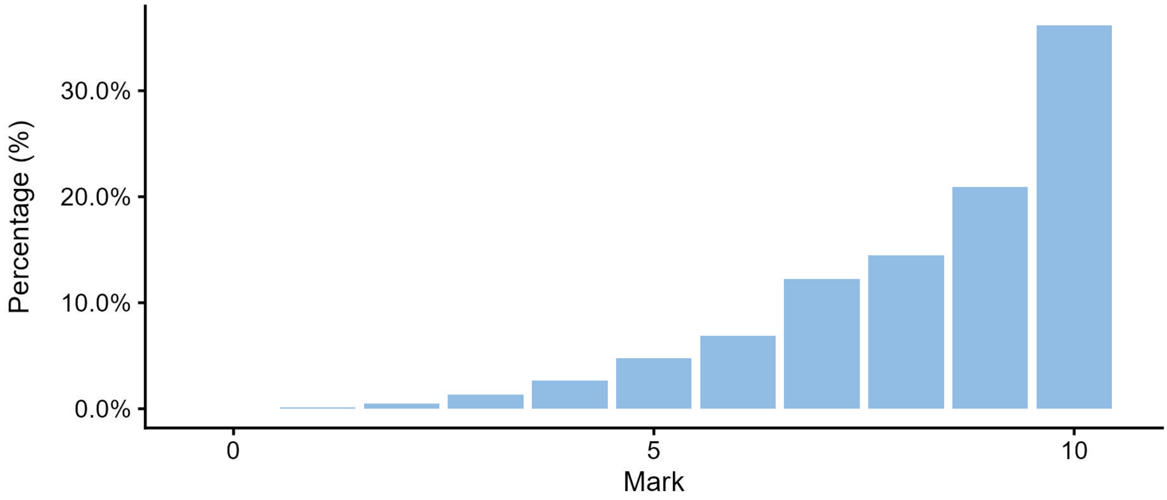
Units 3 and 4 internal assessment (IA) results

Total marks for IA

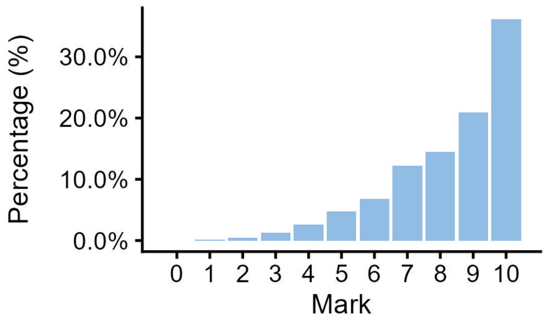


IA1 marks

IA1 total

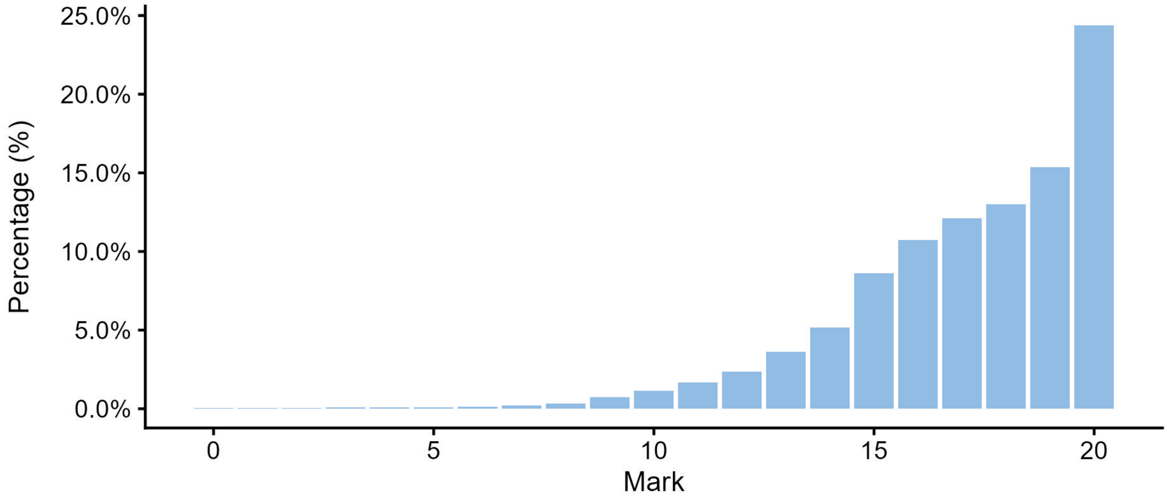


IA1 Criterion: Data test

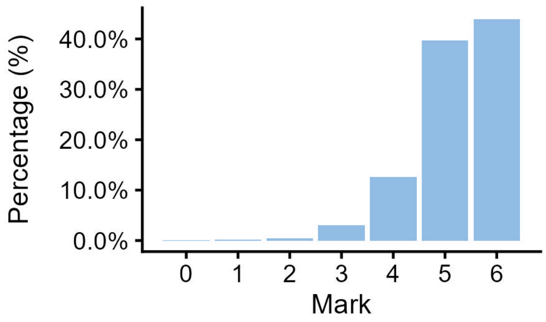


IA2 marks

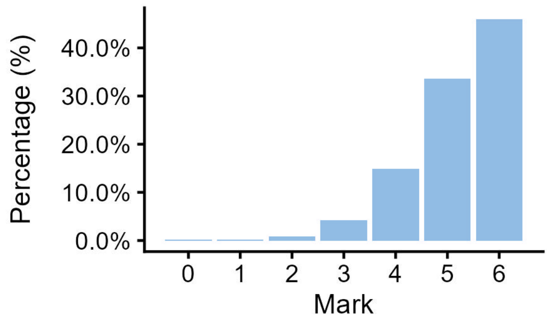
IA2 total



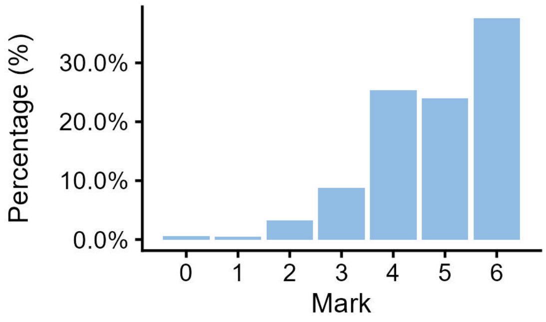
IA2 Criterion: Research and planning



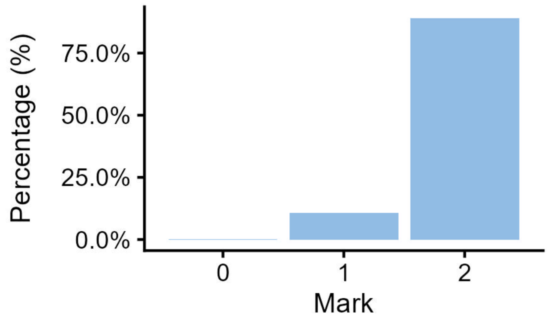
IA2 Criterion: Analysis of evidence



IA2 Criterion: Interpretation and evaluation

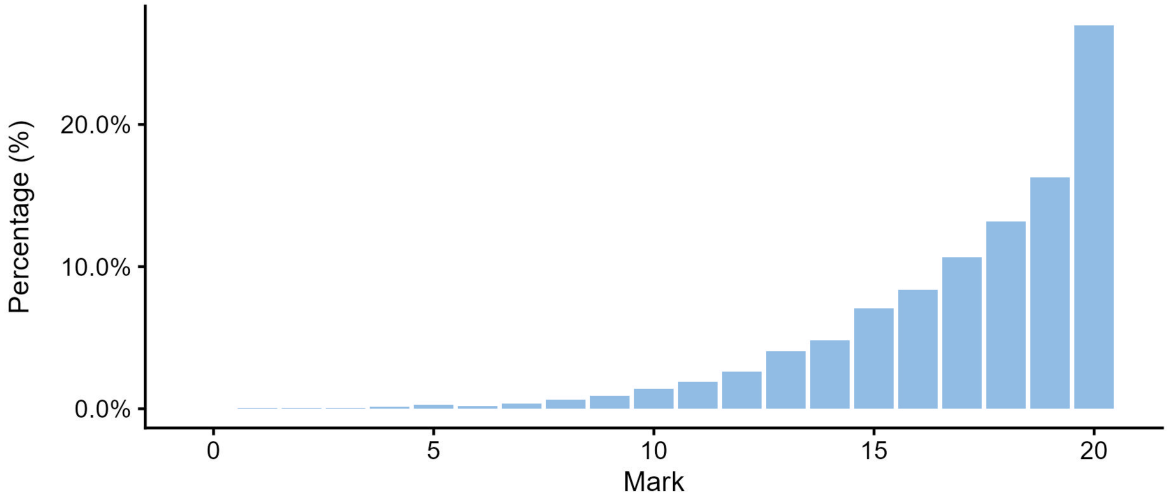


IA2 Criterion: Communication

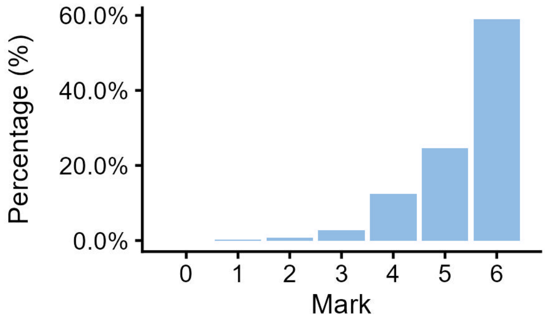


IA3 marks

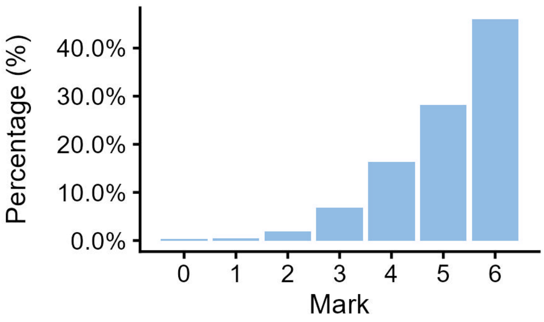
IA3 total



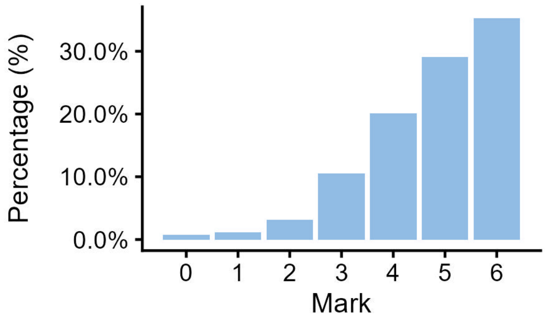
IA3 Criterion: Research and planning



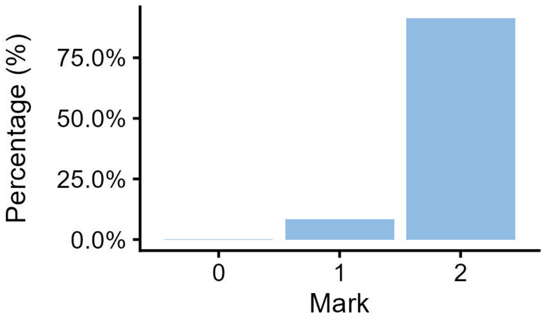
IA3 Criterion: Analysis and interpretation



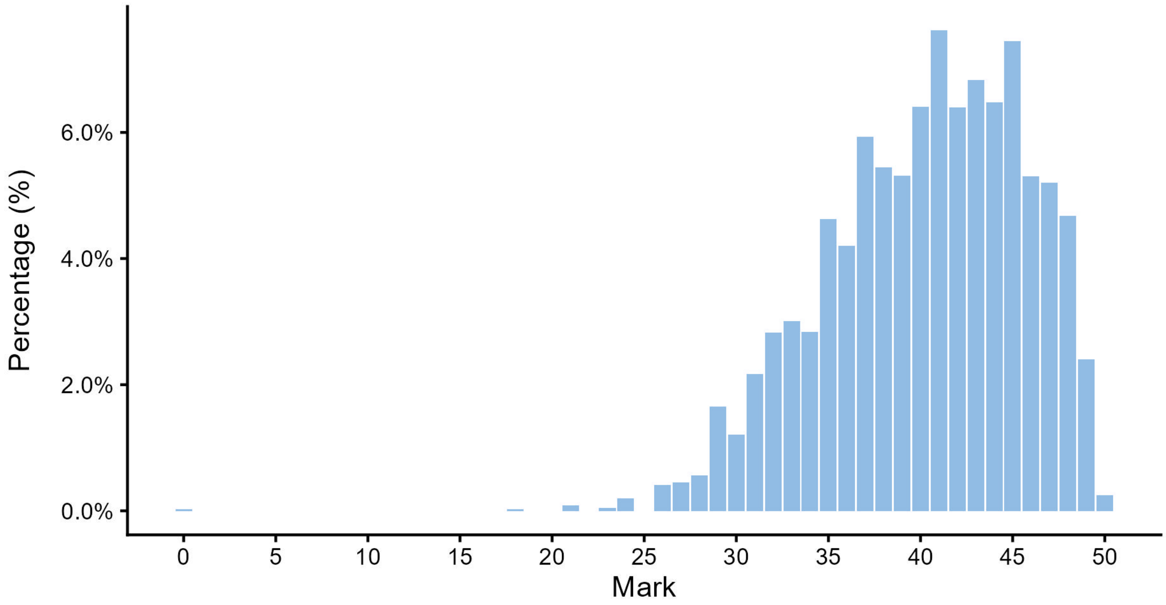
IA3 Criterion: Conclusion and evaluation



IA3 Criterion: Communication

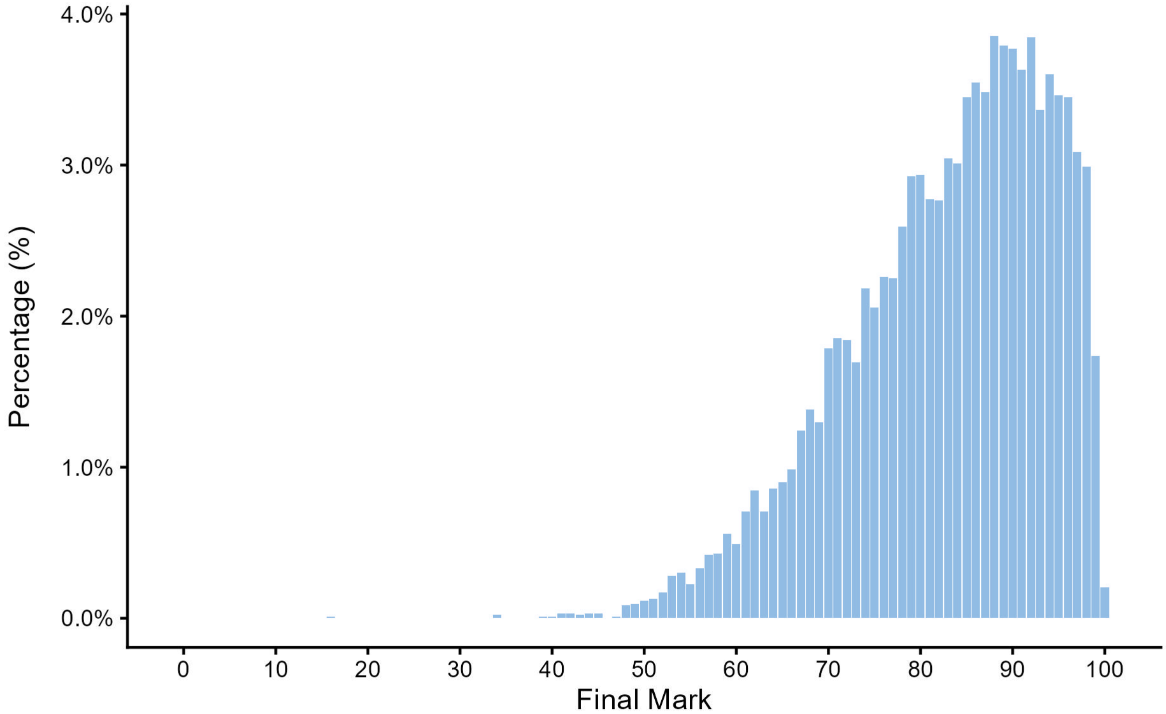


External assessment (EA) marks



Final subject results

Final marks for IA and EA



Grade boundaries

The grade boundaries are determined using a process to compare results on a numeric scale to the reporting standards.

Standard	A	B	C	D	E
Marks achieved	100–87	86–72	71–50	49–20	19–0

Distribution of standards

Number of students who achieved each standard across the state.

Standard	A	B	C	D	E
Number of students	4,132	3,671	1,495	36	1
Percentage of students	44.26	39.33	16.01	0.39	0.01

Internal assessment

This information and advice relate to the assessment design and assessment decisions for each IA in Units 3 and 4. These instruments have undergone quality assurance processes informed by the attributes of quality assessment (validity, accessibility and reliability).

Endorsement

Endorsement is the quality assurance process based on the attributes of validity and accessibility. These attributes are categorised further as priorities for assessment, and each priority can be further broken down into assessment practices.

Data presented in the Assessment design section identifies the reasons why IA instruments were not endorsed at Application 1, by the priority for assessment. An IA may have been identified more than once for a priority for assessment, e.g. it may have demonstrated a misalignment to both the subject matter and the assessment objective/s.

Refer to *QCE and QCIA policy and procedures handbook v7.0*, Section 9.5.

Percentage of instruments endorsed in Application 1

Internal assessment	IA1	IA2	IA3
Number of instruments	427	427	424
Percentage endorsed in Application 1	41	90	47

Confirmation

Confirmation is the quality assurance process based on the attribute of reliability. The QCAA uses provisional criterion marks determined by teachers to identify the samples of student responses that schools are required to submit for confirmation.

Confirmation samples are representative of the school's decisions about the quality of student work in relation to the instrument-specific marking guide (ISMG) and are used to make decisions about the cohort's results.

Refer to *QCE and QCIA policy and procedures handbook v7.0*, Section 9.6.

The following table includes the percentage agreement between the provisional marks and confirmed marks by assessment instrument. The Assessment decisions section for each assessment instrument identifies the agreement trends between provisional and confirmed marks by criterion.

Number of samples reviewed and percentage agreement

IA	Number of schools	Number of samples requested	Number of additional samples requested	Percentage agreement with provisional marks
1	419	2,977	0	100.00
2	419	2,968	6	78.28
3	419	2,956	14	83.77

Internal assessment 1 (IA1)

Data test (10%)

This assessment focuses on the application of a range of cognitions to multiple provided items.

Student responses must be completed individually, under supervised conditions, and in a set timeframe.

Assessment design

Validity

Validity in assessment design considers the extent to which an assessment item accurately measures what it is intended to measure and that the evidence of student learning collected from an assessment can be legitimately used for the purpose specified in the syllabus.

Reasons for non-endorsement by priority of assessment

Validity priority	Number of times priority was identified in decisions
Alignment	177
Authentication	0
Authenticity	3
Item construction	29
Scope and scale	69

Effective practices

Validity priorities were effectively demonstrated in assessment instruments that:

- contained questions that clearly cued students to respond by engaging and using qualitative and/or quantitative evidence from the dataset, rather than asking students to use theory related to Le Châtelier's principle to support their response, e.g. 'Deduce the position of the equilibrium using data to support reasoning'
- allocated marks consistently across questions and the associated marking scheme, and aligned marks to the scope and scale of the skills required to respond to the question, e.g. allocated 1 mark to the calculated value and 1 mark to the working for the question 'Calculate K_c for X. Show your working'.

Practices to strengthen

It is recommended that assessment instruments:

- use a variety of cognitive verbs to assess a range of knowledge and skills and ensure appropriate scope and scale, rather than repeatedly using a single cognitive verb to assess the same objective or skill, e.g. ask students to 'calculate the K_c for A' and provide the K_c value for B in the dataset rather than 'calculate the K_c for A and B', which repeats the calculation skill
- avoid part marks, which affect the scale and transparency of questions and can mislead students when planning their response, e.g. allocate 1 mark to correct deduction and 1 mark to appropriate reasoning, rather than a 1-mark allocation with 0.5 marks awarded for

deduction and 0.5 marks for reasoning, for the 2-mark question 'Deduce the change applied to the system'

- construct questions that clearly align the nature of the response to the objective being assessed and the cognitive verb being used, e.g. 'Predict the shift in chemical equilibrium using evidence' aligns to Assessment objective 4 (Interpret evidence).

Accessibility

Accessibility in assessment design ensures that no student or group of students is disadvantaged in their capacity to access an assessment.

Reasons for non-endorsement by priority of assessment

Accessibility priority	Number of times priority was identified in decisions
Bias avoidance	37
Language	81
Layout	27
Transparency	57

Effective practices

Accessibility priorities were effectively demonstrated in assessment instruments that:

- provided tables and/or graphs that were clear and unambiguous, e.g. graphs used appropriate scales and gridlines if students had to read an end point, pH value or concentration (mg/mL)
- limited the amount of theory and background information provided in the context of datasets, i.e. introductions to datasets were free from additional information and distractors
- provided clear and concise instructions that cued students to use qualitative and/or quantitative evidence to respond to questions without over-scaffolding, e.g. 'Use data to justify your response' rather than 'use the data from the graph in Dataset 1 to justify your response'.

Practices to strengthen

It is recommended that assessment instruments:

- are checked for appropriate formatting, e.g. using page breaks to ensure questions, headings and datasets are easily accessible
- align cognitive verbs with the objectives being assessed to clearly cue the expected responses identified in the marking scheme, e.g. *draw a conclusion*, *infer* or *predict* for Assessment objective 4 (Interpret evidence) items
- use correct scientific conventions for chemical formulas and equations, e.g. NH_3 instead of NH3
- are quality assured for spelling, grammar, punctuation and consistent textual features in questions and datasets.

Additional advice

When developing an assessment instrument for this IA, it is essential to consider the following key differences between the 2019 and 2025 syllabuses:

- perusal time has changed to 5 minutes

- the question specifications table has been revised (syllabus, p. 44). Instruments should be written in line with this table, so the focus of each question aligns to the relevant objective, e.g. the cognitive verb *compare* now aligns more closely to Assessment objective 3 (Analyse data) as it relates to the similarities and differences.

Assessment decisions

Reliability

Reliability refers to the extent to which the results of assessments are consistent, replicable and free from error.

Agreement trends between provisional and confirmed marks

Criterion number	Criterion name	Percentage agreement with provisional	Percentage less than provisional	Percentage greater than provisional	Percentage both less and greater than provisional
1	Data test	100.00	0.00	0.00	0.00

Effective practices

Reliable judgments were made using the ISMG for this IA when:

- percentage cut-offs were used appropriately to determine marks, e.g. 6/10 is 60% which is not greater than 60% and, therefore, is awarded a 6 rather than a 7
- student work clearly indicates where evidence in the student response matched the associated marking scheme, e.g. ticks indicated where evidence in the response aligned with the marking scheme, crosses indicated errors in the response and annotations clearly indicated where follow-through (FT) marks were awarded
- the marking scheme was used consistently across all responses and provided a detailed breakdown of marks awarded, including where part marks were used, to ensure the original scope and scale of the question was maintained.

Practices to strengthen

To further ensure reliable judgments are made using the ISMG for this IA, it is recommended that:

- uploaded student files are complete and checked to ensure that duplicate files are not uploaded and every page is scanned
- marking guides are updated at confirmation to ensure errors are corrected and alternative student responses are captured for quality assurance processes.

Additional advice

Schools should:

- ensure that comparable assessments, assessing similar subject matter to the endorsed instrument have been uploaded along with the corresponding marking scheme
- check that marks entered match the highlighted ISMG of the student sampled.

Samples

The following excerpts demonstrate the effective use of annotations on a student response to indicate where evidence matches the marking scheme. The Assessment objective 4 (Interpret evidence) question required students to determine the nature of an acid, using appropriate justification based on evidence in a graph from the dataset. The marking scheme awards 1 mark for the correct classification of the acid and 1 mark for an appropriate justification based on evidence, such as a description of the initial pH, the identification of a buffer zone, and a description of the vertical region of the graph at equivalence.

Note: The characteristic/s identified may not be the only time the characteristic/s occurred throughout a response.

Excerpt 1

Weak acid, as initial pH is ≈ 2
↳ Vertical part has a compressed nature

Excerpt 2

Acid B can be classed as a weak acid. This can be ~~seen in~~ determined by looking at the titration curve. It can be seen that there is a buffer region at around 1cm³ – 4.5cm³. The steep incline also is very compressed compared to Acid A, which is a strong titration.

Internal assessment 2 (IA2)

Student experiment (20%)

This assessment requires students to research a question or hypothesis through collection, analysis and synthesis of primary data. A student experiment uses investigative practices to assess a range of cognitions in a particular context. Investigative practices include locating and using information beyond students' own knowledge and the data they have been given.

Research conventions must be adhered to. This assessment occurs over an extended and defined period of time. Students may use class time and their own time to develop a response.

Assessment design

Validity

Validity in assessment design considers the extent to which an assessment item accurately measures what it is intended to measure and that the evidence of student learning collected from an assessment can be legitimately used for the purpose specified in the syllabus.

Reasons for non-endorsement by priority of assessment

Validity priority	Number of times priority was identified in decisions
Alignment	13
Authentication	15
Authenticity	3
Item construction	7
Scope and scale	1

Effective practices

Validity priorities were effectively demonstrated in assessment instruments that:

- maintained consistent conditions across the assessment task, e.g. where group work was indicated in the task specifications, strategies to authenticate individual student work were included
- included scaffolding that avoided leading students to a predetermined response (*QCE and QCIA policy and procedures handbook v7.0*, Section 8.2.3).

Practices to strengthen

It is recommended that assessment instruments:

- avoid repeating information in different sections of the task, e.g. task specifications in the scaffolding section
- provide checkpoints indicating that only one almost complete draft is to be submitted, consistent with the *QCE and QCIA policy and procedures handbook v7.0*, Section 8.2.5.

Accessibility

Accessibility in assessment design ensures that no student or group of students is disadvantaged in their capacity to access an assessment.

Reasons for non-endorsement by priority of assessment

Accessibility priority	Number of times priority was identified in decisions
Bias avoidance	1
Language	8
Layout	1
Transparency	1

Effective practices

Accessibility priorities were effectively demonstrated in assessment instruments that:

- were free from clerical errors and used appropriate language, grammar and punctuation
- were appropriately formatted, e.g. each checkpoint listed as a separate bullet point
- provided clear and concise instructions that matched the assessment specifications in the syllabus
- identified aspects that could be completed in groups, e.g. included asterisks (*) in the task description and a statement explaining the meaning of the asterisk.

Practices to strengthen

There were no significant issues identified for improvement.

Additional advice

When developing an assessment instrument for this IA, it is essential to consider the following key differences between the 2019 and 2025 syllabuses:

- The language in the task specifications has been revised to align to the mid performance-level descriptor in the ISMG

Assessment decisions

Reliability

Reliability refers to the extent to which the results of assessments are consistent, replicable and free from error.

Agreement trends between provisional and confirmed marks

Criterion number	Criterion name	Percentage agreement with provisional	Percentage less than provisional	Percentage greater than provisional	Percentage both less and greater than provisional
1	Research and planning	84.21	15.79	0.00	0.00

Criterion number	Criterion name	Percentage agreement with provisional	Percentage less than provisional	Percentage greater than provisional	Percentage both less and greater than provisional
2	Analysis of evidence	88.52	11.00	0.48	0.00
3	Interpretation and evaluation	88.52	11.24	0.24	0.00
4	Communication	99.52	0.00	0.48	0.00

Effective practices

Reliable judgments were made using the ISMG for this IA when:

- for the Analysis of evidence criterion
  - *correct and relevant* processing of raw data was conducted using algorithms and appropriate graphical representations for the data, e.g. mean cell potential, percentage uncertainties and percentage error were calculated to identify uncertainty; scatter graphs with appropriate lines of best fit and error bars were presented to identify trends
  - uncertainty and limitations were
    - *appropriate* for the data and correctly applied to enable systematic and effective analysis of the data, e.g. absolute uncertainties, percentage uncertainties and percentage error for mean cell potentials and error bars, gradients and R^2 values for graphical relationships
    - *thoroughly* identified through systematic and effective analysis of the evidence rather than discussing problems relating to methodology, e.g. precision, reliability and random error in the data
  - *sufficient* and *relevant* raw data was collected based on the independent and dependent variables to allow a meaningful analysis and draw a justified conclusion
- for the Interpretation and evaluation criterion
  - *justified* conclusions referred to the trends, patterns or relationships identified in the analysis of evidence rather than simply restating data, to consider how the evidence compared to the theoretical concepts identified in the rationale
  - *discussions* of validity and reliability were *justified* by referring to data, systematic and random errors in datasets and, where appropriate, accepted values for constants to consider
    - how specific aspects of the experimental design or data collection process impacted or improved the extent to which the experiment measured what was intended, i.e. validity
    - the likelihood that another experimenter would obtain the same results, i.e. reliability
  - extensions are *logically derived* when supported with reference to the limitations regarding the scope or applicability of the data collected and directly linked to validity of the experimental process, e.g. systematic errors related to the methodology and the accuracy of the results to the accepted/constant values from the rationale.

Practices to strengthen

To further ensure reliable judgments are made using the ISMG for this IA, it is recommended that:

- for the Forming criterion
  - a *specific* research question is developed to enable a response that is achievable within the required response length and directly linked to a justified conclusion, e.g. 'What is the relationship between the cell potential and the electrolyte concentration in a Daniell cell at 25 ^{o}C when one electrolyte concentration varies and the other is constant at 1M?'
  - a *considered* rationale demonstrates why the dependent and independent variables are chosen and how the research question is developed and linked to Unit 3 subject matter
  - modifications to the methodology are *justified* and explain how modifications to the original experiment improve the reliability and validity of the data collected, e.g. to improve reliability, change filter paper to a glass u-shaped salt bridge, as it allows for a more efficient ion transfer
- for the Finding criterion
  - the methodology enables the collection of
    - *relevant* data that measures variables (e.g. pH, concentration, temperature, time) rather than comparing products
    - *sufficient* data for appropriate trends, patterns or relationships and uncertainty and limitations of the evidence to be thoroughly identified, e.g. cell potential measured at five different concentrations of electrolyte
  - the impacts of hazards associated with the experiment and the subsequent management of risks are *considered* in how the methodology is performed.

Additional advice

It is essential to consider the following key differences between the 2019 and 2025 syllabuses:

- The alignment between criteria and characteristics of evidence within the student response has changed; however, teachers' judgments when determining the appropriate performance level for each characteristic remain the same.

Schools should also:

- clearly annotate the ISMG to indicate the characteristics evident (or the absence of evidence) in the student response and the mark awarded for each criterion (*QCE and QCIA policies and procedures handbook v7.0*, Section 9.6.1)
- use appropriate strategies to promote academic integrity and manage response length in student responses (*QCE and QCIA policy and procedures handbook v7.0*, Sections 8.1.1 and 8.2.6) and indicate on the student response where these have been applied.

Samples

The following excerpts have been included to show the clear and logical development of the research question in the rationale and how the scientific concepts unpacked in the rationale are used to justify the modifications to the methodology, leading to a justified conclusion.

Note: The characteristic/s identified may not be the only time the characteristic/s occurred throughout a response.

Excerpt 1

Rationale

A redox reaction involves the transfer of electrons between species in which one species is oxidised by losing electrons and the other is reduced by gaining electrons simultaneously (Redox Reactions & Oxidation Reduction, n.d.). An electrolytic cell facilitates the process of electrolysis which uses an external power source to fuel a non-spontaneous redox reaction (Briones, 2012).

Image redacted for copyright

Figure 1 - Components of an electrolytic cell (What is Electrolysis?, n.d.)

In the electrolysis of an aqueous solution containing Cu^{2+} ions, the competing reduction reactions at the cathode are (MHI, 2023):

$$Cu^{2+}{}_{(aq)} + 2e^- \rightarrow Cu_{(s)} \qquad E^{\circ}{}_{red} = +0.34V$$

$$2H_2O_{(l)} + 2e^- \rightarrow H_{2\,(g)} + 2OH^-{}_{(aq)} \qquad E^{\circ}{}_{red} = -0.83V$$

Generally, the reaction with the less negative standard electrode potential is dominant as it requires less energy to proceed (Holmes, et al., 2019). Here, the reduction of Cu^{2+} ions is dominant and solid copper deposits on the cathode.

The original experiment examined the effect of voltage on the amount of product formed during the electrolysis of 60mL, 0.5M $CuSO_4$ solution with a graphite anode and a paperclip cathode. After 30 seconds, a greater amount of copper deposit was observed at the cathode for 6V compared to 2V.

The experiment was extended to investigate the amount of product formed during the electrolysis of 60mL of $Cu(NO_3)_2$ for 5 increasing voltages (2V, 4V, 6V, 8V, 10V). Testing more voltages enabled a more accurate experimental relationship to be determined. The setup was further modified to use copper electrodes. The process was also refined to determine the amount of product formed by using an electronic balance to measure the mass loss at the anode. During the electrolysis of aqueous $Cu(NO_3)_2$ solution with copper electrodes, the competing oxidation reactions at the anode are (MHI, 2023):

$$Cu_{(s)} \rightarrow Cu^{2+}{}_{(aq)} + 2e^- \qquad E^{\circ}{}_{oxi} = -0.34V$$

$$2H_2O_{(l)} \rightarrow O_{2\,(g)} + 4H^+{}_{(aq)} + 4e^- \qquad E^{\circ}{}_{oxi} = -1.23V$$

Here, the oxidation of copper atoms is dominant. Hence, Cu^{2+} ions enter solution at the anode. This meant drying the anode would not affect results. However, copper deposit could be wiped off when drying the cathode. Hence, measuring the mass loss at the anode enabled effective drying which increased the method's validity in measuring the amount of product formed. Further, using an electronic balance enabled the collection of quantitative results which informed a more accurate, numerical relationship.

The methodology was further refined by increasing the electrolyte's concentration to 1.0M and increasing the experiment's duration to 3 minutes. Increasing the concentration increased the number of ions and the electrical conductivity of solution which increased the rate of electron transfer (Gianchandani, Tabata, & Zappe, 2008). This along with increasing the experiment's duration allowed for a more significant mass loss at the anode which decreased percentage uncertainty of the electronic balance and increased the experiment's reliability.

With constant resistance, increasing voltage in an electrolytic cell supplies electrons with increased energy, resulting in faster electron flow and hence, an increased current. This relationship is given by (Online Learning College, 2022):

$$V = IR$$

$V = voltage\ (volts)$

$I = current\ (amperes)$

$R = resistance\ (ohms)$

$$\therefore I = \frac{V}{R} - ①$$

The amount of charge flowing through a circuit in a given time is given by (Gibbs, 2020):

$$q = I \times t$$

$q = total\ charge\ (coulombs)$

$I = current\ (amperes)$

$t = time\ (seconds)$

$$\text{Substitute ①}: \ q = \frac{Vt}{R} - ②$$

According to Faraday's law, the amount of product formed during electrolysis is proportional to the total charge flowing through the electrolytic cell (Marsden, n.d.).

$$product\ formed \propto q$$

$$\text{Substitute ②}: \ product\ formed \propto \frac{Vt}{R}$$

Therefore, assuming constant resistance, a positive, linear relationship between voltage and amount of product formed in 3 minutes, measured via the mass loss at the anode, is expected.

considered 5–6 RQ1

Research Question

How does increasing the voltage from 2V to 10V in 2V intervals affect the amount of product formed during the 3 minute electrolysis of 60.0mL, 1.0M $Cu(NO_3)_2$ using copper electrodes when measured by the mass loss at the anode (g)?

Spec + rel. 5–6

Excerpt 2

Conclusion

In general, the experimental results show that increasing the voltage, increases the mass loss at the anode linearly from $0.02g \pm 100\%$ at 2V to $0.07g \pm 34\%$ for 10V. In response to the research question, this means increasing voltage from 2V to 10V in 2V intervals results in a linear increase in the amount of product formed during the 3 minute electrolysis of 60.0mL, 1.0M $Cu(NO_3)_2$ using copper electrodes. This relationship is supported by the expected positive, linear relationship based on the determined constant resistance, which implies a proportional relationship between voltage, current and hence, charge and Faraday's law, which suggests a proportional relationship between charge and products formed (Marsden, n.d.). However, the electronic balance influenced highly imprecise results with uncertainties ranging from ±29% to ±100%. Despite results close to the theoretical, the observed counteracting errors of impurities falling into solution and oxygen evolution indicated that the method of measuring the product formed via the mass loss at the anode had low validity. Therefore, highly imprecise results, produced using a method which had low validity, limited confidence in answering the research question.

The following excerpt demonstrates a justified discussion of validity and reliability, linking the identified uncertainty and limitations to discuss their effect on the validity of the experiment and reliability of the results.

Note: The characteristic/s identified may not be the only time the characteristic/s occurred throughout a response.

Evaluation

From table 5, the uncertainties for the mean mass loss at the anode were large, ranging from ±29% to ±100%. The instrumental uncertainty was larger than the mean uncertainty for 2V, 6V and 8V and it contributed towards majority of the total uncertainty for 4V (±67% of ±83%) and 10V (±27% of ±34%). This was because mass changes were similar in magnitude to the electronic balance's limit of reading. The high uncertainty resulted in large, overlapping error bars which limit confidence in the positive, linear relationship. Therefore, random error associated with the electronic balance influenced imprecise results and ambiguity in the experimental relationship which reduced the experiment's reliability.

Two major sources of error observed during the experiment were the formation of a sludge below the anode and bubbles at the anode. The sludge suggested that the copper anode contained impurities which fell into solution as copper was oxidised. This systematic error would influence a higher mass loss than expected. The flaking impurities may also have disrupted the oxidation of copper, allowing for water to be oxidised instead.

$Cu_{(s)} \rightarrow Cu^{2+}{}_{(aq)} + 2e^-$ $\quad E^\circ{}_{oxi} = -0.34V$

$2H_2O_{(l)} \rightarrow O_{2\,(g)} + 4H^+{}_{(aq)} + 4e^-$ $\quad E^\circ{}_{oxi} = -1.23V$

Furthermore, although the oxidation of copper requires less energy, at higher voltages, the oxidation of water becomes competitive (MHI, 2023; CHEMEUROPE, n.d.). This results in oxygen gas which explains the observed bubbles. This systematic error would influence a lower mass loss than expected as oxidation of water does not result in mass loss at the anode. Oxygen evolution also explains the plateau in mass loss at the anode after 8V. However, as the errors were opposing, the experiment still produced relatively accurate results with percentage error under 12% for all but one voltage.

Bubbles were only observed from 4V. Thus, flaking impurities was initially the only error, resulting in a higher experimental y-intercept and the high percentage error of 42.6% for 2V. As voltage increased, the observed oxygen evolution was more significant. This inhibited the rate of increase in mass loss, resulting in a lower experimental gradient. The combination of these errors produced the decreasing then increasing pattern in error, the crossing trendlines and the fluctuation of datapoints above and below the theoretical in figure 3. Therefore, the method of measuring the anode's mass loss to determine the amount of product formed had low validity as it did not account for flaking impurities and was not able to measure oxygen produced by the oxidation of water.

The following excerpt demonstrates a justified modification of methodology, using a table to show the relationship between the extension or refinement and its effect on the reliability or validity of the investigation.

Note: The characteristic/s identified may not be the only time the characteristic/s occurred throughout a response.

Original experiment

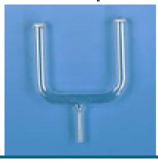
6 different galvanic cells were constructed from unique combinations of Cu^{2+}/Cu, Fe^{3+}/Fe^{2+}, I_2/I^-, and Zn^{2+}/Zn half-cells. By measuring the direction and magnitude of the EMF generated by each combination, the relative strengths of the reductant/oxidant pairs were ranked. In particular, the experimental voltage for the Cu/Zn cell created with 0.1M zinc nitrate and 0.1M copper(II) nitrate was 0.3V.

Table 1 – Modifications to original experiment

Modification	Justification
Redirection – instead of ranking oxidising/reducing agents, this investigation will explore the relationship between changing concentration of one electrolyte solution and the resulting cell voltage.	This means a range of independent variable values (0.2M, 0.4M, 0.6M, 0.8M, 1.0M) can be investigated. This allows the creation of a graph, so the validity and reliability of the experiment can be better evaluated.
Refinement – limit scope of experiment to two half-cells (Zn^{2+}/Zn and Cu^{2+}/Cu).	This permits an in-depth analysis of the reliability/validity of one specific relationship, whose findings should apply more broadly to other half-cell combinations.
Refinement – increase number of trials for each concentration from 1 to 3.	With only 1 trial originally, random errors would have significantly impacted results. Averaging multiple trials improves reliability of the data.
Refinement – use a digital Multimeter instead of an analogue galvanometer to measure cell voltage.	The original analogue galvanometer had an instrumental uncertainty of $\pm 0.1V$, while a digital Multimeter has an uncertainty of $\pm 0.01V$, significantly improving the precision of readings and overall reliability.
Refinement – always take voltage reading 5 seconds after connecting the half-cells.	As the cell reaction progresses, the concentration of products/reactants changes, which impacts the generated EMF. By keeping time of measurement constant, the consistency of data and thus reliability is improved.

The following excerpt has been included to demonstrate the connection between the uncertainty and limitations identified in the analysis of evidence, suggested improvements and extensions and their effect on validity and reliability.

Note: The characteristic/s identified may not be the only time the characteristic/s occurred throughout a response.

Analysis of Evidence/Source of Error	Suggested Improvement
Systematic/Human error: The initial filter-paper KNO_3 salt bridge was ineffective at preventing charge accumulation, thus producing poor voltage for all three trials of 0.1M and impacting the validity. Due to this, a filter-paper NaCl bridge was used for all following concentrations.	Use a reliable glass bridge that would effectively allow ion flow to improve the validity of the results. This was not available for the experiment. 
Random error: Temperature was recorded 25°C, however potential fluctuations may have occurred due to open windows, thus impacting both validity and reliability as the theoretical value comparisons will be incorrect if temperature had changed.	Ensure temperature remains constant throughout entire experiment by experimenting clear from external factors (open doors/windows) to improve validity and reliability.
Systematic and Human error: <u>Human:</u> ±1mL error on all measurements of electrolyte solutions due to unclear readings on the beaker, therefore human error impacted the validity of the data. <u>Systematic/human</u>: ±0.01 error on all voltage measurements due to voltmeter readings. The measurements were an approximate estimate; therefore human error impacted the validity of the data.	Use more precise measuring equipment to reduce random error and increase validity (e.g. digital voltmeter).
Human error: Salt residue from the salt bridge remained in the beakers, therefore reducing validity of the results. Electrodes were polished each concentration change; however buildup began to form after each trial.	Clean all equipment after every trial, not just when changes in concentration occurred. Polish electrodes after every trial to prevent buildup of oxidised/reduced layers on metal.
Random error: Lead crystals did not fully dissolve while creating the 3M $Pb(NO_3)_2$ solution, therefore trials likely had different true concentrations, therefore impacting validity of 3M results.	When creating concentrations, ensure crystals are fully dissolved in solution before using for experimentation.

Extensions

Suggested Extension	Explanation and Justification
Explore a larger range of $Pb(NO_3)_2$ molar concentrations.	Concentrations were limited to 0.1M-0.5M, so extending an investigation to observe larger numbers of concentrations would allow for further identifications of trends and improved validity.
Investigate different temperatures and pressures.	While the effect of increasing concentration on voltage has been experimented, it would be valuable to investigate the effects of varying temperatures and pressures on cell potential, and observe which change causes the largest voltage difference.
Test different salt bridges.	Testing an array of salt bridge combinations (e.g. filter paper, glass tubes, KNO_3,agar gel) to find which combination is most efficient in neutralising charge would improve validity in future experiments.

Internal assessment 3 (IA3)

Research investigation (20%)

This assessment requires students to evaluate a claim. They will do this by researching, analysing and interpreting secondary evidence from scientific texts to form the basis for a justified conclusion about the claim. A research investigation uses research practices to assess a range of cognitions in a particular context. Research practices include locating and using information beyond students' own knowledge and the data they have been given.

Research conventions must be adhered to. This assessment occurs over an extended and defined period of time. Students may use class time and their own time to develop a response.

Assessment design

Validity

Validity in assessment design considers the extent to which an assessment item accurately measures what it is intended to measure and that the evidence of student learning collected from an assessment can be legitimately used for the purpose specified in the syllabus.

Reasons for non-endorsement by priority of assessment

Validity priority	Number of times priority was identified in decisions
Alignment	244
Authentication	23
Authenticity	4
Item construction	13
Scope and scale	9

Effective practices

Validity priorities were effectively demonstrated in assessment instruments that:

- provided claims that were clearly aligned to Unit 4 subject matter and allowed students to generate multiple research questions, e.g. 'Synthetic polymers are chemically superior'
- clearly and accurately identified which topics were being assessed to ensure consistency between the subject matter identified in the claims and the topics listed in the conditions section of the task, e.g. 'Molecular manufacturing has revolutionised chemical synthesis' would align with Topic 2: Chemical synthesis and design
- provided direct and simple claims that linked to only one context and avoided and/or options, e.g. 'Biofuels produced from waste materials are chemically green' rather than 'Biofuels from algae, oil seeds and wood waste are better than biofuels from waste oils'.

Practices to strengthen

It is recommended that assessment instruments:

- contain claims that directly cue students to analyse and interpret information relating to Unit 4 subject matter, e.g. avoid claims that have potential for redirection into biological, economic, environmental and/or ethical issues, or into Units 1–3 in Chemistry subject matter, as this may limit a students' ability to address all assessment objectives

- direct students to address all aspects of the task and align to the syllabus specifications.

Accessibility

Accessibility in assessment design ensures that no student or group of students is disadvantaged in their capacity to access an assessment.

Reasons for non-endorsement by priority of assessment

Accessibility priority	Number of times priority was identified in decisions
Bias avoidance	0
Language	11
Layout	0
Transparency	0

Effective practices

Accessibility priorities were effectively demonstrated in assessment instruments that:

- were free from formatting, spelling, punctuation and grammatical errors
- provide checkpoints indicating that only one almost complete draft is to be submitted, consistent with *QCE and QCIA policy and procedures handbook v7.0*, Section 8.2.5
- provided task information in each section in a format consistent with the syllabus, e.g. included a complete list of task specifications in the task section rather than in scaffolding.

Practices to strengthen

There were no significant issues identified for improvement.

Additional advice

When developing an assessment instrument for this IA, it is essential to consider the following key differences between the 2019 and 2025 syllabuses:

- The qualifiers used to describe each cognitive process in the task specifications have been revised.
- Examples of scientifically credible sources have been provided in the specifications to direct students to a wider variety of student-accessible sources.
- Group elements have been added to several Forming and Finding activities of the task.

Assessment decisions

Reliability

Reliability refers to the extent to which the results of assessments are consistent, replicable and free from error.

Agreement trends between provisional and confirmed marks

Criterion number	Criterion name	Percentage agreement with provisional	Percentage less than provisional	Percentage greater than provisional	Percentage both less and greater than provisional
1	Research and planning	91.17	8.35	0.48	0.00
2	Analysis and interpretation	94.03	5.73	0.24	0.00
3	Conclusion and evaluation	90.93	9.07	0.00	0.00
4	Communication	99.52	0.00	0.48	0.00

Effective practices

Reliable judgments were made using the ISMG for this IA when:

- for the Analysis and interpretation criterion
  - *relevant* trends, patterns or relationships in the evidence were used as the basis for *justified* scientific arguments
  - interpretation of research evidence was *justified* using scientific arguments linked to Unit 4 chemical concepts (i.e. properties and structure of organic materials or chemical synthesis and design) and supported with data from the sources
  - identification of limitations, such as methodological issues
    - were *appropriate* for the research question
    - *thoroughly* identified how or why each limitation made the evidence less effective in addressing the research question, e.g. by considering which aspect/s of the research question each piece of evidence addressed
- for the Conclusion and evaluation criterion
  - *justified* conclusions
    - discussed how the trends, patterns and relationships identified in the analysis of evidence directly addressed the research question rather than the claim
    - were supported by *justified* scientific arguments that clearly linked to the analysis and interpretation of credible evidence
  - *insightful discussions* about the quality of the evidence addressed the identified limitations and their impact on the ability to address the research question, rather than the credibility of the sources used as evidence
  - *relevant* improvements *considered* limitations of the evidence in addressing the claim and focused on ways to refine the research investigation to obtain more valid and/or reliable evidence
  - *relevant* extensions *considered* aspects of the claim not addressed by the research question, and further investigations or evidence required to make justified decisions about the claim.

Practices to strengthen

To further ensure reliable judgments are made using the ISMG for this IA, it is recommended that:

- for the Forming and Finding criterion
  - a *considered* rationale clearly connects the research question to Unit 4 subject matter and demonstrates how the research question was developed from the claim. The rationale should clearly articulate why the dependent and independent variables were chosen to be investigated and how these variables linked the research question to the claim and Unit 4 subject matter
  - a *specific* research question clearly identifies a direct link to Unit 4 subject matter and allows a justified conclusion to the research question to be reached within the specifications of the task, e.g. 'does the improved synthesis from ibuprofen's original route to its new green route result in less waste reactants and more useful products?'

Additional advice

It is essential to consider the following key differences between the 2019 and 2025 syllabuses:

- The alignment between criteria and characteristics of evidence within the student response has changed; however, teachers' judgments when determining the appropriate performance level for each characteristic remain the same.

Schools should also:

- support students through the research investigation process to develop a suitable research question related to the properties and structure of organic materials or chemical synthesis and design to ensure successful completion of the task within the scope of Unit 4
- clearly annotate the ISMG to indicate the characteristics evident (or the absence of evidence) in the student response and the mark awarded for each criterion (*QCE and QCIA policies and procedures handbook v7.0*, Section 9.6.1)
- use appropriate strategies to promote academic integrity and manage response length in student responses (*QCE and QCIA policy and procedures handbook v7.0*, Sections 8.1.1 and 8.2.6) and indicate on the student response where these have been applied.

Samples

The following excerpts illustrate considered rationales which lead to specific and relevant research questions. Both discuss relevant Unit 4 subject matter and directly link the chosen variables of the investigation to the properties and structures of their chosen organic molecules.

Note: The characteristic/s identified may not be the only time the characteristic/s occurred throughout a response.

Excerpt 1

How do polylactic acid (PLA) bioplastics compare from low-density polyethylene (LDPE) in terms of tensile strength (MPa) and biodegradability under simulated landfill conditions, measured in weight loss percentage overtime?

Claim

Bioplastics are better than conventional plastics.

Rationale

The purpose of this research investigation is to respond to the claim "Bioplastics are better than conventional plastics." With initial research, a broad question, "do bioplastics maintain durability, and are they more biodegradable and less impactful towards the environment compared to conventional plastics?" was developed based on the initial claim. Conventional plastics are synthetic materials developed from fossil fuels such as coal, natural gas and petroleum. Known for their affordability, adaptability and durability makes them commonly used in industries. However, they pose environmental issues due to their non-biodegradability and long decomposition times (BioPak, 2023). Low-Density Polyethylene, also known as LDPE, is a thermoplastic polymer formed from a petrochemical called ethylene. A polymer is a large molecule made from many subunits called monomers (Britannica, 2024). LDPE is a hydrocarbon polymer with non-polar $-CH_2-$ bonds produced from fossil fuels. Its fixed structure resists it from biological and chemical degradation, hence contributing to it being an environment issue (EuP Egypt, 2024). In comparison, bioplastics are made from renewable resources such as biomass instead of non-renewable resources like fossil fuels. These bioplastics can either be non- biodegradable or biodegradable, making them potentially more eco-friendly materials and they can be synthesised through chemical processes (Ashter, 2016). Polylactic acid, known as PLA, is a bioplastic polymer formed from organic sources such as sugar cane and corn starch (TWI, 2023). The bioplastic PLA is composed of an ester link. These links are receptive to both chemical and enzymatic hydrolysis which leads to the PLA degradation (Al-Tayyar et al., 2020). The chemical hydrolysis breaks down long polymer chains into smaller sections such as monomers (lactic acid) and then into smaller molecules which can be used as nutrients for microorganisms, contributing to its biodegradability (Al-Tayyar et al., 2020).

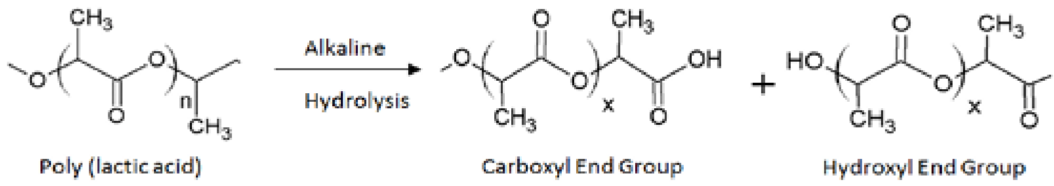


Figure 1: Chemical structure of PLA (Zuratul Hamid & Ismail, 2018)

To determine which plastic performs better, measurements such as tensile strength and biodegradability measured in weight loss can be used. Tensile strength is the plastics ability to withstand a maximum amount of tensile stress through pulling or stretching without breaking (Omnexus, 2025). It is a measurement indicating which plastic has a greater pulling force. Weight loss percentage provides a quantifiable and comparable metric for measuring the degradation of a plastic (Tomlins, 2008). Thus, leading to the development of the following research question, "How do polylactic acid (PLA) bioplastics compare from low-density polyethylene (LDPE) in terms of tensile strength (megapascals - MPa) and biodegradability under simulated landfill conditions, measured in weight loss percentage overtime?"

Research Question

How do polylactic acid (PLA) bioplastics compare from low-density polyethylene (LDPE) in terms of tensile strength (MPa) and biodegradability under simulated landfill conditions, measured in weight loss percentage overtime?

This investigation examined five different sources from Gajendiran et al., (2016) Ruggero et al., (2021), Boonmee et al., (2016), Djellali et al., (2013) and Samir et al., (2022) to determine the effectiveness of PLA bioplastics and its impact on tensile strength (MPa) and biodegradability under simulated landfill conditions, measured in % weight loss overtime. The outcomes from these sources will be reviewed to examine whether PLA is better in terms of tensile strength and biodegradability compared to LDPE.

Excerpt 2

Claim

The chemical structure of pesticides results in undesirable properties.

Rationale

The claim is: "The chemical structure of pesticides results in undesirable properties." This connects molecular structure to environmental behaviour, particularly persistence and toxicity — properties influenced by functional groups, bond types, polarity, and solubility (National Institute of Environmental Health Sciences, 2023).

Pesticides are synthetic chemicals used to control pests (US EPA, 2019). Chemical structure refers to the atomic arrangement within a molecule, determining its properties (Britannica, 2019). Undesirable properties refer to environmentally harmful outcomes of a pesticide's chemical structure including resistance to degradation which arise from features such as halogenation, low polarity, and bond stability (Decision et al., 2014).

The original question: *"How does the composition of different pesticides affect volatility, absorption, and solubility,"* was too broad, lacking chemical direction and tried to link unrelated variables.

The refined focus is on how structural features govern environmental persistence through degradation mechanisms. Halogenated, non-polar molecules typically resist hydrolysis and oxidation due to strong covalent bonds (e.g. C–Cl) and low solubility. In contrast, polar compounds with hydrolytically labile groups (e.g. esters, phosphates) degrade more readily via nucleophilic attack.

A direct comparison is made between DDT, a halogenated organochlorine with chlorine-substituted aromatic rings, and malathion, an organophosphate containing ester and phosphorothioate groups (Wrobel & Mlynarczuk, 2021). These differ in bond stability, polarity, intermolecular forces, and reactivity, making them ideal for investigation.

The refined research question is:
"How do the structural differences between the halogenated pesticide DDT and the organophosphorus pesticide malathion affect their chemical stability and environmental persistence?"

Research Question:

How do structural differences between the halogenated pesticide DDT and the organophosphorus pesticide malathion affect their chemical stability and environmental persistence?

Background:

A pesticide's persistence is determined by its molecular structure — including polarity, solubility, bond strength, functional groups, and lipophilicity (US EPA, 2013; NPIC, 2018). Non-polar molecules with strong covalent bonds resist degradation, while polar compounds with labile bonds are more reactive and biodegradable.

DDT (Figure 1), a halogenated organochlorine, contains chlorine-substituted aromatic rings and an ethane backbone (ACS, 2021). Its symmetrical, non-polar structure and strong C–Cl bonds (~338 kJ/mol) limit reactivity and solubility, resulting in high environmental persistence and bioaccumulation (Yin, 2022b).

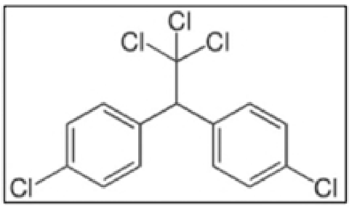


Figure 1:

In contrast, malathion (Figure 2) contains ester linkages and a phosphorothioate (P=S) group — both polar and hydrolytically unstable (PubChem, 2023). These groups enhance chemical reactivity and susceptibility to hydrolysis, promoting degradation.

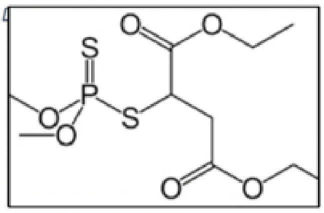


Figure 2: Malathion chemical structure

Lipophilicity, the affinity for lipid environments, is measured using Log K_ow. DDT's high Log K_ow (6.2) indicates strong fat solubility and low water interaction, increasing its accumulation in fatty tissues. Malathion's lower Log K_ow (2.75) reflects greater water affinity and mobility (NPIC, 2018).

Hydrolysis is a key degradation mechanism in which water acts as a nucleophile, often catalysed by acids, bases, or microbial enzymes (Western Oregon University, 2016). As shown in Figure 3, malathion undergoes hydrolysis readily due to its ester and phosphorothioate groups, forming more polar, less persistent products. DDT lacks these reactive sites and remains stable under similar conditions.

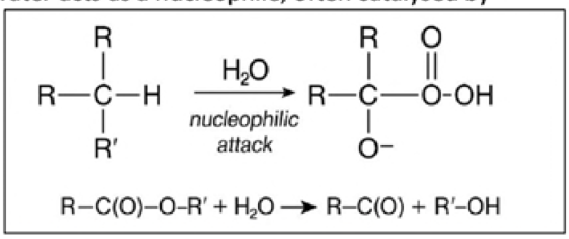


Figure 3: general mechanism cf ester hydrolysis vis nucleophilic attack by water (Western Oregon Univeristy, 2016)

The following excerpt demonstrates *justified* scientific arguments, using chemical structure and properties to justify the evidence identified in the analysis. The excerpt also includes the identification of limitations of evidence and a discussion of the quality of evidence, as it identifies the limitations and how these limitations affect the extent to which the data can be used to support the research question.

Note: The characteristic/s identified may not be the only time the characteristic/s occurred throughout a response.

PLA's increased tensile strength can further be explained due to its chemical structure. PLA is a semi-crystalline chemical structure, which means it has both ordered crystalline regions and disordered amorphous regions in its structure (Stacey, 2016). These crystalline contribute significantly to its increased tensile strength due to its closely packed and highly ordered molecules, which resists pulling (Ma et al., 2021). Combined with its strong intermolecular hydrogen bonding between its ester groups, it creates a strong polymer backbone (Djellali et al., 2013). In comparison to LDPE, where its branched molecular structure and decreased crystallinity results in weaker van der Waals interactions, which reduces its load capacity (VEM, 2022). A limitation to the data is that Samir et al., (2022) is a review article, which has gathered its information from multiple experiments. This reduces the reliability and validity of the data as each experiment may have differing methods to which they obtained the results, making comparison inconsistent and unreliable. Regardless, Samir et al., (2022) provided consistent and similar data when comparing to Djellali et al., (2013), Djellali et al., (2013) contains error in their results, (PLA: 64.1 $\pm$2.8, LDPE: 11.9 $\pm$1) reducing its reliability. Both sources provided relevant information to the claim as they provided data on the difference in tensile strength. Hence, the data is relevant to the research question. Both studies concluded that PLA has an increased tensile strength compared to LDPE.

References

Samir, A., Ashour, F. H., Hakim, A. A. A., & Bassyouni, M. (2022). Recent advances in biodegradable polymers for sustainable applications. *Npj Materials Degradation, 6*(1). https://doi.org/10.1038/s41529-022-00277-7

Djellali, S., Haddaoui, N., Sadoun, T., Bergeret, A., & Grohens, Y. (2013). Structural, morphological and mechanical characteristics of polyethylene, poly(lactic acid) and poly(ethylene-co-glycidyl methacrylate) blends. *Iranian Polymer Journal, 22*(4), 245–257. https://doi.org/10.1007/s13726-013-0126-6

The following excerpt illustrates the *extrapolation* of the findings to the claim. It evaluates the aspect of the claim addressed by the research question and identifies other aspects that would need to be investigated further before the claim can be fully answered.

Note: The characteristic/s identified may not be the only time the characteristic/s occurred throughout a response.

Extrapolation of findings to claim:

The claim "algae-based biofuels are more efficient than plant-based biofuels" can be evaluated, but to the constraints of this task. As the findings show that biodiesel from *Chlorella vulgaris* outperforms soybeans in terms of lipid content, CN and viscosity, it is more efficient. However, biodiesels can be derived from other plant-based sources such as castor or rapeseed, which can outperform certain microalgae species. Furthermore, this task only focused on biodiesels, a type of biofuel out of many such as bioethanol. Therefore, while investigation does support the claim

from the criteria stated, further investigation is required to fully support the claim of whether all algae-based biofuels are more efficient than plant-based biofuels.

External assessment

External assessment (EA) is developed and marked by the QCAA. The external assessment for a subject is common to all schools and administered under the same conditions, at the same time, on the same day. The external assessment papers and the EAMG are published in the year after they are administered.

Examination (50%)

Assessment design

The assessment instrument was designed using the specifications, conditions and assessment objectives described in the summative external assessment section of the syllabus.
The examination consisted of two papers:

- Paper 1, Section 1 consisted of multiple choice questions (20 marks)
- Paper 1, Section 2 consisted of short response questions (35 marks)
- Paper 2, Section 1 consisted of short response questions (55 marks).

Assessment decisions

Assessment decisions are made by markers by matching student responses to the external assessment marking guide (EAMG).

Multiple choice question responses

There were 20 multiple choice questions in Paper 1.

Percentage of student responses to each option

Note:

- The correct answer is **bold** and in a blue shaded table cell.
- Some students may not have responded to every question.

Question	A	B	C	D
1	**56.01**	16.23	12.54	14.89
2	3.15	24.33	**60.55**	11.74
3	17.83	27.32	8.22	**46.21**
4	6.27	7.96	**79.04**	6.57
5	9.30	19.06	**62.75**	8.15
6	8.46	13.94	20.18	**57.07**
7	7.39	7.05	**81.21**	4.13
8	29.55	8.07	**53.33**	8.75
9	5.57	36.34	27.20	**30.65**
10	11.83	**56.00**	21.15	10.58
11	**57.78**	8.99	17.41	15.63

Question	A	B	C	D
12	27.79	**32.42**	14.52	24.99
13	10.12	**71.68**	8.99	8.95
14	30.38	4.95	6.60	**57.85**
15	18.29	4.42	**75.05**	2.01
16	14.37	**68.15**	6.84	10.42
17	3.88	**93.62**	1.15	1.27
18	**84.43**	4.97	7.93	2.54
19	**43.87**	21.53	12.27	21.99
20	22.99	11.27	18.72	**46.76**

Effective practices

Overall, students responded well to:

- describe and explain questions that were based on redox and galvanic cell processes, and that used spectroscopic data to distinguish between functional groups such as ketones, aldehydes, and carboxylic acids
- questions that required application of chemical principles and procedures to calculate pH and pKa, determine oxidation states, and draw or name structural isomers with accuracy and appropriate use of chemical conventions
- scenarios where they analysed evidence to classify acids and organic molecules based on chemical and/or structural properties, and contrast the movement of ions and elections in a galvanic cell
- interpretation of data that required them to infer the nature of a reaction based on K_c values, energy change, and product formation, effectively integrating multiple data sources and justifying conclusions with scientific reasoning.

Practices to strengthen

When preparing students for external assessment, it is recommended that teachers consider:

- how students accurately communicate their knowledge when using chemistry conventions, e.g.
  - including ionic charges and states of matter in redox reactions
  - using equilibrium arrows to show partial dissociation of weak acids and reaction arrows to show full dissociation of strong acids
  - writing oxidation states with the charge before the number (i.e. +3) and writing ionic charges with the magnitude before the charge (i.e. 2+)
- teaching and learning opportunities for students to address all aspects of the question by understanding
  - the cognitive verb and the nature of the response required to answer the question
  - how to apply the number of marks to a suitable response, e.g. a question that requires a prediction and an explanation of reasoning for 3 marks would typically require a prediction and two points of explanation to support the prediction

- teaching and learning opportunities for students to develop a detailed understanding of specific reactions and their conditions, including
  - the electrolysis of dilute, concentrated and molten salt under different conditions
  - operation of a hydrogen fuel cell under acidic and alkaline conditions
  - organic pathways and the conditions under which reactions occur.

Samples

Short response

Question 27) from Paper 1

This question required students to determine the product formed at the cathode and the oxidation half-equation of the electrolysis of different concentrations of NaCl.

Effective student responses:

- determined $H_2(g)$ as a product at the cathode for concentrated (25%) NaCl(aq)
- determined the oxidation half-equation for the concentrated (25%) NaCl(aq)
- determined Ha(l) as the product at cathode for molten NaCl(l)
- determined the oxidation half-equation for molten NaCl(l).

This excerpt has been included:

- to demonstrate the clear communication of the products of electrolysis of different concentrations of NaCl
- to demonstrate the writing of half-equations, showing charges and states of matter for the reactants and products and using the forward reaction arrow.

Electrolyte	Cathode product	Oxidation half-equation
concentrated (25%) NaCl(aq)	$H_2(g)$	$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$
molten NaCl(l)	Na(l)	$2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$

Question 28c) from Paper 1

This question required students to determine whether the pH of equivalence point and the volume of HCl required to reach equivalence point would change if titrated with a strong base rather than a weak base. The question also asked students to explain their reasoning.

Effective student responses:

- determined the pH of the equivalence point is 7
- explained that the pH change in equivalence point would increase when a strong base is titrated with a strong acid

- determined the volume of HCl required to reach equivalence point has not changed
- explained that the moles of base to be neutralised remains the same.

This excerpt has been included:

- to demonstrate reasoning and supporting calculations to illustrate the relationship between concentration and volume.

The pH of the equivalence point: pH of equivalence point will increase (pH 7 instead of pH 5 currently), as the titration will be of a strong base (NaOH) and strong acid (HCl), instead of a weak base (BOH) and strong acid (HCl).

The volume of HCl required to reach the equivalence point: The same volume of HCl will be required (20mL), as the same number of moles are needed for neutralisation. $n(NaOH) = cV = 0.2 \times 0.01 = 0.002$ mol.

$\therefore HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O$

$\therefore$ 1:1 molar ratio of HCl : NaOH

$\therefore n(HCl) = n(NaOH) = 0.002$ mol

$\therefore V(HCl) = \frac{n}{c} = \frac{0.002}{0.1} = 0.02\,L = 20\,mL$

$\therefore$ same volume of HCl required.

Question 29b) from Paper 1

This question required students to evaluate three methods of the production of benzaldehyde, in terms of E-factor and atom economy and show reasoning.

Effective student responses:

- concluded that Na-MnO_x catalyst pathway has the best atom economy
- provided evidence to support atom economy conclusion
- Criegee oxidation pathway had the lowest environmental impact
- provided evidence to support environmental impact conclusion.

This excerpt has been included:

- to demonstrate the systematic evaluation of each method leading to a valid conclusion.

① $a \cdot e = \frac{2(106.13)}{(214.28 + (0.5 \times 32))} \times 100 = 92.17\%$ $E = 5.2$

② $a \cdot e = \frac{2(106.13)}{(214.28 + (22.99) + (126.90) + (4 \times 16))} \times 100 = 49.57\%$ $E = 13.9$

③ $a \cdot e = \frac{2(106.13)}{(214.28 + (207.2) + (16 \times 4) + (227.0 \times 4))} \times 100 = 15.23\%$ $E = 3.2$

While all produce 1 kg of the desired product, the production of benzaldehyde is the greenest for reaction 1, as it has the highest atom economy of 92.17% and second lowest E-factor of 5.2. While the third method has less of an environmental impact in terms of waste production (E = 3.2, the lowest) it has the lowest atom economy and is therefore not efficient enough in its conversion. Reaction 2 is the least green as it has the highest E-factor of 134 and ~~lowe~~ a moderately low atom economy of 49.57%.

END OF PAPER

Question 4a) from Paper 2

This question required students to describe the dissociation of HOCl(aq) and HCl(aq) using balanced chemical equations.

Effective student responses:

- accurately described the dissociation of HOCl(aq) using a reversible arrow
- accurately described the dissociation of HCl(aq) using a forward reaction arrow.

This excerpt has been included:

- to demonstrate a clear description of the dissociation of
  - HOCl(aq) using a balanced equation, showing all states of matter and ionic charges, and using a reversible arrow to accurately represent the partial dissociation of a weak acid
  - HCl(aq) using a balanced equation, showing all states of matter and ionic charges, and using a forward reaction arrow to accurately represent the full dissociation of a strong acid.

$HOCl_{(aq)} + H_2O_{(l)} \rightleftharpoons OCl^-_{(aq)} + H_3O^+_{(aq)}$

$HCl_{(aq)} + H_2O_{(l)} \rightarrow Cl^-_{(aq)} + H_3O^+_{(aq)}$

Question 5a) from Paper 2

This question required students to determine three amino acids represented by spots on an electrophoresis gel, and explain their reasoning.

Effective student responses:

- determined the identity of each amino acid
- explained the link between the buffer's pH and the pH of the isoelectric point of Arg and Glu
- explained the link between the charge of Arg and Glu and their positions in the gel
- explained the link between the buffer's pH and the pH of the isoelectric point of Cys and its position in the gel.

This excerpt has been included:

- to demonstrate clear explanations that support the identification of the spots on the electrophoresis gel with consideration to the properties of the different amino acids.

Glu has an isoelectric point at pH = 3.2. As this is below the buffer's pH of 5, it acts as an acid and donates H^+ from its COOH group to form COO^-, being an anion. Hence, its attracted to the positive electrode, so it must be P. P = Glu. Arg and Cys both have isoelectric points higher than 5, so they act as bases and accept H^+, as the NH_2 group becomes NH_3^+. Hence, they are cations and are attracted to the negative electrode. Thus, they are Q or R. Since Arg pI = 10.7, Cys PI = 5.1, Arg would become more positively charged as it accepts protons to a greater extent due to greater isoelectric point. This is due to Cys only having 1 NH_2 group, while Arg has 2.

Thus, Arg would be more attracted to ~~positive~~ negative electrode (closer), Cys would be less attracted to ~~positive~~ negative electrode. ~~R~~ (further). Hence, R is Arg, Q is Cys.

Question 8a) from Paper 2

This required students to determine the structural formulas and IUPAC names for compounds for two compounds.

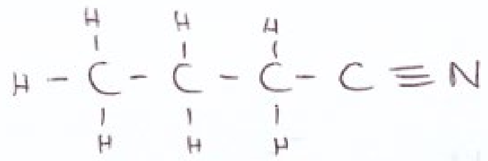
Effective student responses:

- drew a structural formula for Compound A and identified it as butanenitrile
- drew a structural formula for Compound D and identified it as 1-propanol.

This excerpt has been included:

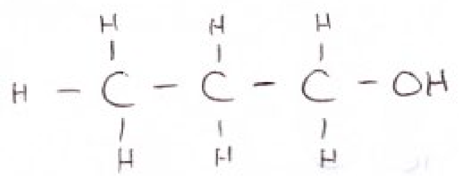
- to demonstrate an appropriate structural formula for the two compounds and the correct application of IUPAC nomenclature.

Compound A



IUPAC name: butanenitrile

Compound D



IUPAC name: propan-1-ol