

# 2016 VCE Chemistry examination report

## General comments

The 2016 Chemistry examination assessed students' ability to apply their understanding of relevant chemical concepts over a broad range of the key knowledge from Units 3 and 4 and included many questions with a strong experimental focus. In Section A many students answered most questions correctly. However, students struggled the most with Questions 20, 22, 25 and 27.

Section B provided students with the opportunity to demonstrate their understanding in a variety of contexts, incorporating descriptive responses and calculations appropriate to the key knowledge.

- Comparisons of chromatographic data in Question 1c. needed to include further detail. Most students assumed that retention time alone was enough to definitively conclude the presence of a specific compound in a mixture, overlooking the fact that such outcomes are only valid if made under identical conditions and where no other substance has the same retention time under those conditions.
- Questions 2, 3e., 9 and 10 provided a wide range of calculation focused questions. Stoichiometry was done well in Question 2a., but in Question 2b. many students stated that the precipitate should be dry even though 'heated until constant mass is achieved' was stated in the question. In responses to Question 3eii. many students struggled to effectively incorporate the density of ethanol into their calculations. Question 9bi. revealed a mathematical flaw in applying percentage in the calculation of  $n(\text{CO}_2)$ , which had a significant impact on the calculations in Question 9bii. Question 10, with two tables of data, strong focus on units, dependence of subsequent questions on previous answers and the need to incorporate information from the data book, was challenging for most students.
- Question 7, most of Question 3 and Question 4d. assessed the depth of students' knowledge of organic chemical pathways. Question 3b. emphasised the distinction between a double bond and a C=C double bond in classifying an acid as unsaturated. Question 3c. was challenging for many students. Students should know that biodiesel consists of fatty acid esters and that the alkyl group is bonded to an oxygen on the ester group. In Question 3d. many students struggled to identify an environmental advantage of biodiesel as a fuel compared to petrodiesel and provided renewable/non-renewable comparisons that lacked sufficient detail. Question 7a. related to a pathway from but-1-ene to butanoic acid and was mostly well handled. However, many students were challenged by the reactants reagent(s) required for the conversion of the alkene to the alcohol and the half-equation for the conversion of  $\text{Cr}_2\text{O}_7^{2-}$  to  $\text{Cr}^{3+}$ . Responses to Question 4d. revealed significant uncertainty about the structure of the amide group formed when amino and carboxyl groups react together as well as the number of amide groups in the repeating unit.
- Questions 4 and 6 focused mainly on qualitative and quantitative analysis utilising instrumental spectroscopy. Question 4a. assessed aspects of mass spectroscopy; however, many students confused the terms 'base' peak and 'principal' peak. The most common error was in accurately presenting the semi-structural formula of the base peak species. Students should be aware that all species that produce signals on a mass spectrum carry a positive charge. In Question 4b. several students overlooked the accurate evidence on the IR spectrum that was consistent with the compound and were attracted to the peak at around  $1600\text{ cm}^{-1}$ . Students should be aware that not every peak on an IR spectrum is identifiable from absorption bands given in Table 7 of the Data Book because it does not account for all vibrational modes. Responses to Responses to Question 4c. revealed superficial appreciation of  $^{13}\text{C}$  NMR spectra, with many students confused by what was probably a recorder blip. Most students made the point that

$\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$  has only one carbon environment, hence one spectral peak, but did not relate that to the symmetry of the structure. Question 6a. required students to read the calibration curve and determine the percentage by mass of copper in the sample. However, this proved challenging for some students, often because they assumed that the unit for  $\text{Cu}^{2+}$  concentration was  $\text{mol L}^{-1}$  event ( $\text{g L}^{-1}$ ) as given on the calibration curve. Question 6b. revealed significant misunderstanding relating to the volume of the sample prepared for analysis and the reliability of calibration curves. Most students could not effectively articulate that using 20 mL rather than 100 mL to dissolve the brass sample would increase the concentration by a factor of 5, and indicate that this was outside the range of the calibration curve and was therefore inaccurate.

- Question 5 assessed principles of rates and equilibrium. Questions 5a. and 5b. were generally well handled, although some students explained rate variations in terms of Le Chatelier's principle rather than collision theory. Responses to Question 5c. showed significant variation in students' ability to present accurate concentration–time graphs and adherence to simple principles, such as all species reaching equilibrium at the same time and relative concentration changes proportional to the mole ratios in the equilibrium equation.
- Question 8 assessed understanding of electrochemistry as it applied to the lithium-ion battery described in the stem of the question. Question 8b. was not answered well. Students should be aware that in a secondary cell the electrode that acts as the anode during discharge acts as the cathode during recharge. This being the case, the oxidation half-equation (provided in the question) at the anode during discharge is reversed to become the reduction half-equation at the cathode during recharge. Most students struggled to produce an acceptable explanation as to why lithium should not be in contact with water. Students should be aware that as the strongest reductant on the electrochemical series, lithium reacts readily with water and that the equation for the reaction can be deduced from the electrochemical series. Students should be able to identify, in the context of the question, the negative consequence of that reaction. Question 8d. saw most students default to a general characteristic of secondary cells rather than identify the design feature specific to the lithium-ion battery as was expected.
- Question 11 was challenging for most students. While most could identify a strength of the experimental design, many struggled to identify pertinent improvements and frame an appropriate comment on the conclusion drawn from the data collected. Progress in the question depended on the student's interpretation of 'Faraday's laws'. The investigation was focused on Faraday's first law, which in this context could be expressed as 'the mass of nickel deposited is proportional to the charge'. In many responses, it seemed that students considered the laws to be  $Q = It$  and  $Q = n(e^-) \times F$  and the focus was on the accuracy of the associated calculations.

Students should make effective use of the reading time. When completing questions with multiple parts, students should be encouraged to read all parts of a question carefully before beginning to frame a response.

## Specific information

This report provides sample answers or an indication of what answers may have included. Unless otherwise stated, these are not intended to be exemplary or complete responses.

The statistics in this report may be subject to rounding resulting in a total more or less than 100 per cent.

## Section A – Multiple-choice questions

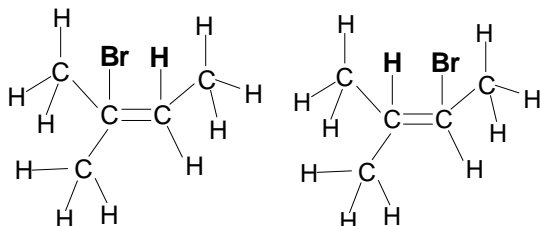
The table below indicates the percentage of students who chose each option. The correct answer is indicated by shading.

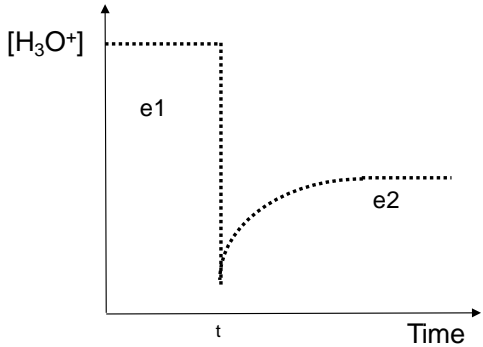
| Question | % A | % B | % C | % D | % No Answer | Comments  |
|----------|-----|-----|-----|-----|-------------|---|
| 1        | 61  | 13  | 7   | 19  | 0           | AAS, UV-Vis, GC and HPLC are well-recognised techniques by which the concentration of a substance can be determined. The key knowledge of the <i>VCE Chemistry Study Design</i> specifically refers to the use of a calibration graph to determine the amount of analyte.<br>TLC is a form of qualitative analysis. HPTLC (high-performance TLC), in which the different steps are automated, is used in quantitative analysis.<br><sup>1</sup> H NMR is a tool for structural analysis but qNMR (quantitative NMR) has been used to determine concentrations of some biochemicals. |
| 2        | 2   | 18  | 6   | 73  | 0           |   |
| 3        | 22  | 16  | 53  | 9   | 0           | According to oxidation states:<br>$\begin{array}{ccc} +1 & -1 & +1 & -2 & 0 \\ 2\text{H}_2\text{O}_2(\text{g}) & \rightarrow & 2\text{H}_2\text{O}(\text{l}) & + & \text{O}_2(\text{g}) \end{array}$ The oxidation number of oxygen has both decreased from $-1$ to $-2$ and increased from $-1$ to $0$ , as $\text{H}_2\text{O}_2$ has been:<br><ul style="list-style-type: none"> <li>oxidised to <math>\text{O}_2</math></li> <li>reduced to <math>\text{H}_2\text{O}</math>.</li> </ul>   |
| 4        | 54  | 28  | 10  | 8   | 0           | The most strongly absorbed dye moves the least distance from the origin.<br>$R_f = (\text{distance moved from origin}) / (\text{distance moved by solvent front from origin})$<br>$= (6 - 2) / (18 - 2) = 4/16$<br>$= 0.25$<br>Selection of option B was consistent with not measuring the distance moved from the origin.  |
| 5        | 6   | 84  | 9   | 1   | 0           | The base pairs in DNA are guanine-cytosine and adenine-thymine.<br>So for 180 guanine bases there will be 180 cytosine bases, 120 adenine bases and 120 thymine bases.  |

| Question | % A | % B | % C | % D | % No Answer | Comments   |
|----------|-----|-----|-----|-----|-------------|--|
| 6        | 15  | 23  | 3   | 59  | 0           | <p>Benzoic acid, <math>C_6H_5COOH</math>, is a weak acid, so the initial pH of the solution is <math>&gt; 1</math>. The pH at <math>25^\circ</math> is 2.6 (determined from <math>K_a</math>).</p> <p>The reaction occurring between this weak acid and the strong base, <math>NaOH(aq)</math> i.e.</p> $C_6H_5COOH(aq) + NaOH(aq) \rightarrow C_6H_5COONa(aq) + H_2O(l)$ <p>implies that the pH at the equivalence point will be <math>&gt; 7</math> because <math>C_6H_5COO^-(aq)</math>, the conjugate base of the weak acid, is a weak base.</p> <p>Beyond the equivalence point, the solution becomes increasingly alkaline because <math>NaOH(aq)</math> is in excess.</p> <p>Option D best represented the pH curve for the titration of weak acid with a strong base.</p>  |
| 7        | 7   | 86  | 5   | 2   | 0           | $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$ $n(NaOH) \text{ reacting} = 0.2450 \times 25.00 \times 10^{-3}$ $= 6.125 \times 10^{-3} \text{ mol}$ $n(HCl) \text{ in titre} = 6.125 \times 10^{-3} \text{ mol}$ $c(HCl) = 6.125 \times 10^{-3} / 13.49 \times 10^{-3}$ $= 0.4540 \text{ M}$  |
| 8        | 57  | 26  | 12  | 5   | 0           | <p>In terms of data recorded, any impact from rinsing techniques will appear in the titre, i.e. the <math>V(HCl)</math>.</p> <ul style="list-style-type: none"> <li>Option A: rinsing the burette with water will reduce the <math>c(HCl)</math> added and so increase the <math>V(HCl)</math> in the titre, leading to a lower calculated <math>c(HCl)</math>.</li> <li>Option B: rinsing the pipette with water will reduce the <math>c(NaOH)</math> in the aliquot and so decrease the <math>V(HCl)</math> in the titre, leading to a higher calculated <math>c(HCl)</math>.</li> <li>Option C: rinsing the conical flask with water has no impact on <math>n(NaOH)</math> in the flask, hence no effect on the calculated <math>c(HCl)</math>.</li> <li>Option D: leaving the funnel in the burette has no effect on titre volume, hence there is no effect on the calculated <math>c(HCl)</math> unless a drop of acid drops into the burette during the titration, thus decreasing the <math>V(HCl)</math> in the titre and leading to a higher calculated <math>c(HCl)</math>.</li> </ul> |

| Question | % A | % B | % C | % D | % No Answer | Comments   |
|----------|-----|-----|-----|-----|-------------|--|
| 9        | 20  | 6   | 5   | 69  | 0           | <p>The reaction occurring between the weak acid, <math>\text{C}_6\text{H}_5\text{COOH}</math>, and the strong base, <math>\text{NaOH}(\text{aq})</math> is <math>\text{C}_6\text{H}_5\text{COOH}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{C}_6\text{H}_5\text{COONa}(\text{aq}) + \text{H}_2\text{O}(\text{l})</math></p> <p>At the equivalence point the species present in the solution are <math>\text{C}_6\text{H}_5\text{COO}^-(\text{aq})</math> and <math>\text{Na}^+(\text{aq})</math>. Because <math>\text{C}_6\text{H}_5\text{COO}^-(\text{aq})</math>, as the conjugate base of a weak acid, is a weak base, the pH at the equivalence point will be <math>&gt; 7</math> (approximately 8.2).</p> <p>The indicator selected must include the equivalence point pH in its pH range for colour change.</p> <p>Phenol red (option D), pH range 6.8–8.4 (Data book Table 11), would be the most suitable, since none of the other options had <math>\text{pH} &gt; 7</math> in their colour change ranges.</p> |
| 10       | 80  | 7   | 10  | 2   | 0           | $E = VIt = 4.50 \times 1.50 \times 150$ $= 1.01 \times 10^3 \text{ J}$ $CF = E/\Delta T = 1.01 \times 10^3/5.35$ $= 189 \text{ J } ^\circ\text{C}^{-1}$  |
| 11       | 9   | 12  | 14  | 65  | 0           | <p><math>\alpha</math>-amino acids have the general structure <math>\text{H}_2\text{NCH}(\text{Z})\text{COOH}</math>.</p> <p>At low pH, i.e. in acidic solutions, basic <math>-\text{NH}_2</math> groups become protonated to form <math>-\text{NH}_3^+</math> groups. At low pH <math>-\text{COOH}</math> groups are unaffected.</p> <p>So, the correct structures for the terminal ends of met-enkephalin are <math>-\text{NH}_3^+</math> and <math>-\text{COOH}</math>.</p>   |
| 12       | 17  | 6   | 66  | 12  | 0           | <p>When 200 glucose molecules react to form a polysaccharide by condensation polymerisation, 199 water molecules are released.</p> <p><math>M(\text{polysaccharide})</math></p> $= 200 \times M(\text{C}_6\text{H}_{12}\text{O}_6) - 199 \times M(\text{H}_2\text{O})$ $= 200 \times 180.0 - 199 \times 18.0$ $= 32\,418 \text{ g mol}^{-1}$   |
| 13       | 7   | 89  | 3   | 1   | 0           | $\Delta H = H(\text{products}) - H(\text{reactants})$ $= 70 - 150$ $= -80 \text{ kJ mol}^{-1}$   |

| Question | % A | % B | % C | % D | % No Answer | Comments   |
|----------|-----|-----|-----|-----|-------------|--|
| 14       | 56  | 11  | 16  | 16  | 0           | <p>At the two-minute mark, the rate of change of all three concentrations – [CO], [Cl<sub>2</sub>] and [COCl<sub>2</sub>] – increases significantly and the system gets to equilibrium faster than it would have without the imposed change.</p> <p>The response to the imposed change is consistent with the injection of a catalyst into the reaction flask, i.e. option A.</p> <ul style="list-style-type: none"> <li>Option B – a volume increase would have caused an immediate increase on all three concentrations.</li> <li>Option C – an inert gas would have no effect as it does not impact on the reaction heading towards equilibrium.</li> <li>Option D – removal of some of the gas mixture would have caused an immediate decrease in all three concentrations.</li> </ul> |
| 15       | 12  | 12  | 14  | 61  | 1           | <p>At equilibrium, from concentration–time graphs</p> <p>[CO] = 0.05 mol L<sup>-1</sup><br/> [Cl<sub>2</sub>] = 0.05 mol L<sup>-1</sup><br/> [COCl<sub>2</sub>] = 0.15 mol L<sup>-1</sup><br/> <math>K = \frac{[\text{COCl}_2]}{[\text{CO}][\text{Cl}_2]}</math><br/> = 0.05/(0.05 × 0.15)<br/> = 6.7</p>  |
| 16       | 14  | 10  | 22  | 54  | 0           | <p><math>\text{CO(g)} + \text{Cl}_2\text{(g)} \rightleftharpoons \text{COCl}_2\text{(g)} \quad \Delta H = -108 \text{ kJ mol}^{-1}</math></p> <p>Heating the equilibrium system will favour the endothermic reaction. Since the forward reaction is exothermic, the reverse reaction will be favoured. This will cause the [COCl<sub>2</sub>] to decrease, the total gas pressure to increase, the equilibrium constant to decrease and the total number of gas molecules to increase.</p>   |
| 17       | 88  | 7   | 3   | 1   | 0           | <p><math>\text{C}_6\text{H}_{14}\text{(g)} + 9.5\text{O}_2\text{(g)} \rightarrow 6\text{CO}_2\text{(g)} + 7\text{H}_2\text{O(g)}</math><br/> <math>\Delta H = -4158 \text{ kJ mol}^{-1}</math></p> <p>Reverse equation</p> <p><math>6\text{CO}_2\text{(g)} + 7\text{H}_2\text{O(g)} \rightarrow \text{C}_6\text{H}_{14}\text{(g)} + 9.5\text{O}_2\text{(g)}</math><br/> <math>\Delta H = +4158 \text{ kJ mol}^{-1}</math></p> <p>Double equation</p> <p><math>12\text{CO}_2\text{(g)} + 14\text{H}_2\text{O(g)} \rightarrow 2\text{C}_6\text{H}_{14}\text{(g)} + 19\text{O}_2\text{(g)}</math><br/> <math>\Delta H = 2 \times +4158 \text{ kJ mol}^{-1}</math></p> <p><math>\Delta H = +8316 \text{ kJ mol}^{-1}</math></p>  |

| Question | % A | % B | % C | % D | % No Answer | Comments  |
|----------|-----|-----|-----|-----|-------------|---|
| 18       | 10  | 51  | 22  | 17  | 0           | <p>Since HBr adds across the C=C double bond there are only two possible products of the reaction.</p>    |
| 19       | 23  | 56  | 17  | 4   | 1           | <p><math>\text{Cr}_2(\text{SO}_4)_3 \rightarrow 2\text{Cr}^{3+}(\text{aq}) + 3\text{e}^-</math></p> <p>So the plating half-equation is <math>\text{Cr}^{3+}(\text{aq}) + 3\text{e}^- \rightarrow \text{Cr}(\text{s})</math></p> <p><math>n(\text{e}^-) = 3 \times 0.0192</math><br/> <math>= 0.0576 \text{ mol}</math></p> <p><math>Q = n(\text{e}^-) \times F</math><br/> <math>= 0.0576 \times 96500</math><br/> <math>= 5.56 \times 10^3 \text{ C}</math></p> <p><math>t = Q/I</math><br/> <math>= 5.56 \times 10^3 / 5.00</math><br/> <math>= 1.11 \times 10^3 \text{ secs (1110)}</math></p> |

| Question | % A | % B | % C | % D | % No Answer | Comments   |
|----------|-----|-----|-----|-----|-------------|--|
| 20       | 29  | 34  | 26  | 10  | 0           | <p>The ionisation of lactic acid in aqueous solution, i.e.</p> $\text{HC}_3\text{H}_5\text{O}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{C}_3\text{H}_5\text{O}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ <p>increases during dilution. Adding water decreases the overall concentration (although <math>[\text{H}_2\text{O}]</math> is constant) and so the system moves to partially compensate and increase the overall concentration by favouring forward reaction.</p> <p>The <math>[\text{H}_3\text{O}^+]</math> decreases – due to volume increase – then increases as the system moves to the right at the new equilibrium is lower, and the pH is higher, than before the dilution, as represented in the concentration–time graph.</p>  <p>Overall, the pH increases and the percentage ionisation increases.</p> |
| 21       | 11  | 10  | 65  | 12  | 1           | $K_a = \frac{[\text{NH}_3][\text{H}_3\text{O}^+]}{[\text{NH}_4^+]}$ <p>Applying standard weak acid assumptions:</p> $[\text{NH}_4^+]_{\text{eqm}} = 0.200 \text{ M and } [\text{NH}_3] = [\text{H}_3\text{O}^+]$ $K_a = \frac{[\text{H}_3\text{O}^+]^2}{0.200}$ <p>From Table 12 in the data book,</p> $K_a(\text{NH}_4^+) = 5.6 \times 10^{-10}$ $5.6 \times 10^{-10} = \frac{[\text{H}_3\text{O}^+]^2}{0.200}$ $[\text{H}_3\text{O}^+]^2 = 0.200 \times 5.6 \times 10^{-10}$ $[\text{H}_3\text{O}^+] = \sqrt{(1.12 \times 10^{-10})}$ $= 1.06 \times 10^{-5} \text{ M}$  |



| Question | % A | % B | % C | % D | % No Answer | Comments   |
|----------|-----|-----|-----|-----|-------------|--|
| 22       | 56  | 12  | 30  | 2   | 0           | <p><math>\text{CH}_2=\text{CH}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow \text{CH}_2\text{ClCH}_2\text{Cl}(\text{g})</math></p> <p>This is an addition reaction because <math>\text{Cl}_2</math> has <b>added</b> across the <math>\text{C}=\text{C}</math> double bond, but it is also a redox reaction.</p> <p>The redox nature of the reaction can be verified by considering oxidation states.</p> <p>The oxidation state of Cl decreases from 0 in <math>\text{Cl}_2(\text{g})</math> to <math>-1</math> in <math>\text{CH}_2\text{ClCH}_2\text{Cl}</math>.</p> <p>In <math>\text{CH}_2=\text{CH}_2</math>, the oxidation state of each H is <math>+1</math>, which means that the oxidation state of each C is <math>-2</math>.</p> <p>In <math>\text{CH}_2\text{ClCH}_2\text{Cl}</math>, the oxidation states are H: <math>+1</math>, Cl: <math>-1</math>, C: <math>-1</math>.</p> <p>The oxidation state of C has increased (from <math>-2</math> to <math>-1</math>) and the oxidation state of Cl has decreased from 0 to <math>-1</math>, so the reaction between <math>\text{CH}_2\text{CH}_2</math> and <math>\text{Cl}_2</math> is a redox reaction as well as an addition reaction.</p> |
| 23       | 94  | 3   | 2   | 1   | 0           |  |
| 24       | 30  | 40  | 23  | 7   | 1           | <p>According to the thermochemical equations supplied:</p> <p><math>2 \text{ mol CH}_3\text{OH} \rightarrow 1450/2 = 725 \text{ kJ of heat energy}</math></p> <p><math>32.0 \text{ g CH}_3\text{OH} \rightarrow 725 \text{ kJ}</math></p> <p><math>1 \text{ g CH}_3\text{OH} \rightarrow 725/32.0 = 22.7 \text{ kJ}</math></p> <p>So, option B was correct.</p> <p><math>1 \text{ mol C}_8\text{H}_{18} \rightarrow 10900/2 = 5450 \text{ kJ of heat energy}</math></p> <p><math>114.0 \text{ g C}_8\text{H}_{18} \rightarrow 5450 \text{ kJ}</math></p> <p><math>1 \text{ g C}_8\text{H}_{18} \rightarrow 5450/114.0 = 47.8 \text{ kJ}</math></p> <p>Octane, <math>\text{C}_8\text{H}_{18}</math>, releases approximately twice (<math>47.8/22.7 = 2.1</math>) as much energy per gram as methanol, <math>\text{CH}_3\text{OH}</math>.</p> <p>If oxygen supply is limited, combustion of methanol will be incomplete and less energy will be released.</p>  |

| Question | % A | % B | % C | % D | % No Answer | Comments  |
|----------|-----|-----|-----|-----|-------------|---|
| 25       | 18  | 25  | 35  | 21  | 0           | <p>On the electrochemical series,</p> $\text{Br}_2(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-(\text{aq}) \quad E^\circ = 1.09 \text{ V}$ $\text{I}_2(\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{I}^-(\text{aq}) \quad E^\circ = 0.55 \text{ V}$ $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s}) \quad E^\circ = 0.34 \text{ V}$ <p>Since <math>\text{Br}_2(\text{aq})</math> is a stronger oxidant than <math>\text{I}_2</math>, the accidental use of bromine solution in place of the iodine solution could not explain the 'no apparent change' observation.</p> <p>Slow reaction, equilibrium and a greasy surface, which would prevent effective electrolytic conduction in the electrolyte, could all explain the 'no apparent change' observation.</p> |
| 26       | 6   | 44  | 30  | 19  | 1           | <p>Additional pressure due to the production of <math>\text{CO}_2(\text{g})</math> in the reaction depends on <math>n(\text{CO}_2)</math> produced, in a 2.0 L vessel, at 24.1 °C</p> $n(\text{CO}_2) = n(\text{Na}_2\text{CO}_3)$ $= 0.142 \text{ mol}$ $p(\text{CO}_2) = n(\text{CO}_2) \times RT/V$ $= 0.142 \times 8.31 \times (24.1 + 273.0)/2.00$ $= 175 \text{ kPa}$   |

| Question | % A | % B | % C | % D | % No Answer | Comments   |
|----------|-----|-----|-----|-----|-------------|--|
| 27       | 12  | 20  | 21  | 46  | 0           | <p>The mass–time graphs show that:</p> <ul style="list-style-type: none"> <li>more CO<sub>2</sub> is produced in Trial 2 (the overall decrease in the mass of the flask is greater than in Trial 1)</li> <li>the initial rate of reaction is higher in Trial 2 (the gradient of the mass–time graph is steeper than in Trial 1)</li> </ul> <p>The larger m(CO<sub>2</sub>) produced in Trial 2 could be due to a higher m(CaCO<sub>3</sub>) or a higher c(H<sup>+</sup>). The reaction can be simplified to</p> $\text{CaCO}_3(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$ <p>For more CO<sub>2</sub> to be produced, the n(CaCO<sub>3</sub>) or n(H<sup>+</sup>) reacting has to increase.</p> <p>In trial 1</p> $n(\text{CaCO}_3) = 20/100.1 = 0.20 \text{ mol}$ $n(\text{H}^+) = 0.5 \times 0.100 = 0.05 \text{ mol}$ <p>CaCO<sub>3</sub> is in excess since 0.20 mol CaCO<sub>2</sub> requires 0.40 mol H<sup>+</sup>(aq) for complete reaction.</p> <p>Both options B (200 mL of 0.5 M HCl) and C (100 mL of 0.5 M H<sub>2</sub>SO<sub>4</sub>) provide more H<sup>+</sup>(aq), 0.1 mol in both cases, to react with CaCO<sub>3</sub> and so more CO<sub>2</sub>(g) is produced and the mass of the flask decreases.</p> <ul style="list-style-type: none"> <li>Option A: heating the 0.5 M HCl increases the reaction rate of the reaction but has no effect on m(CO<sub>2</sub>) produced.</li> <li>Option B: doubling the volume of HCl does not affect the rate of reaction, because the c(H<sup>+</sup>) is not altered, although it does increase the m(CO<sub>2</sub>).</li> <li>Option C: using 0.5 M H<sub>2</sub>SO<sub>4</sub> increases both the rate of reaction – the c(H<sup>+</sup>) is doubled – and the m(CO<sub>2</sub>) produced – the n(H<sup>+</sup>) is doubled.</li> <li>Option D: using crushed CaCO<sub>3</sub> increases the rate of reaction, due to the greater surface area, but has no effect on the m(CO<sub>2</sub>) produced.</li> </ul> |

| Question | % A | % B | % C | % D | % No Answer | Comments   |
|----------|-----|-----|-----|-----|-------------|--|
| 28       | 58  | 20  | 5   | 17  | 0           | $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightarrow 2\text{HI}(\text{g}) \quad \Delta H < 0$ <ol style="list-style-type: none"> <li>Adding <math>\text{H}_2(\text{g})</math> favours the forward reaction increasing the <math>m(\text{HI})</math>.</li> <li>Decreasing temperature favours the forward (exothermic) exothermic reaction increasing the <math>m(\text{HI})</math>.</li> <li>Adding <math>\text{Ar}(\text{g})</math> has no effect on the equilibrium or <math>m(\text{HI})</math> since <math>\text{Ar}</math> has no effect on the equilibrium ratio <math>[\text{HI}]^2 / \{[\text{H}_2][\text{I}_2]\}</math>.</li> <li>Decreasing the volume has no effect on the equilibrium or <math>m(\text{HI})</math> since although the pressure decreases the system is not thrown out of equilibrium since the equilibrium ratio <math>[\text{HI}]^2 / \{[\text{H}_2][\text{I}_2]\}</math> is not affected due to 'same number of particles on both sides'.</li> </ol> |
| 29       | 15  | 15  | 47  | 23  | 0           | <p>The relevant half-equations on the electrochemical series are:</p> $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g}) \quad E^\circ = 0.0 \text{ V}$ $\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s}) \quad E^\circ = -0.44 \text{ V}$ <p>Half-reactions in this galvanic cell will be:</p> <p>At Fe rod – anode (-): <math>\text{Fe}(\text{s}) \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^-</math></p> <p>At Pt electrode – cathode (+): <math>2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})</math></p> <p>Electrons move from the Fe electrode (anode) to the Pt electrode (cathode).</p> <p>The pH at the platinum electrode increases as the <math>c(\text{H}^+)</math> decreases due to its reduction to <math>\text{H}_2(\text{g})</math>.</p>   |
| 30       | 10  | 12  | 28  | 49  | 1           | <p>According to cell chemistry (from Question 29 solution above)</p> <p>At Fe rod – anode (-): <math>\text{Fe}(\text{s}) \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^-</math></p> <p>At Pt electrode – cathode (+): <math>2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})</math></p> <ul style="list-style-type: none"> <li>Bubbles (of <math>\text{H}_2</math>) would appear on the surface of the Pt electrode (not Fe).</li> <li>The <math>\text{Fe}^{2+}</math> solution becomes a darker green colour as the <math>c(\text{Fe}^{2+})</math> increases due to the half-equation <math>\text{Fe}(\text{s}) \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^-</math>. This being the case there will not be a deposit of iron crystals.</li> </ul>   |

## Section B

### Question 1a.

| Marks | 0 | 1  | Average |
|-------|---|----|---------|
| %     | 4 | 96 | 1       |

71 seconds

### Question 1b.

| Marks | 0  | 1 | 2  | Average |
|-------|----|---|----|---------|
| %     | 19 | 5 | 76 | 1.6     |

Compound: P

Evidence: it has the highest retention time/takes the longest time to elute from the column.

Students needed to provide a valid explanation/interpretation of how the evidence available (i.e. the chromatogram provided) supported P being the compound with the highest molecular mass.

### Question 1c.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 62 | 16 | 22 | 0.6     |

No, because there is no evidence that the 'same conditions' (temperature/carrier gas/column length, etc.) were used or there may be another compound(s) in the perfume that has a retention time of 53 seconds.

One mark each was awarded for:

- stating that it cannot be concluded that limonene was in the perfume
- an accurate statement as to why it cannot be concluded that limonene is one of the compounds.

The most common response suggested that limonene was present because the chromatogram showed a peak at the retention time of limonene. Students should be aware that a key requirement for comparison of chromatography data obtained in different tests is that the same conditions are used.

Overall performances on this question reflected good understanding of the basic information conveyed on a chromatogram but inadequate appreciation of the importance of conditions used when striving to identify experimentally whether a particular compound is present.

### Question 2a.

| Marks | 0  | 1 | 2  | 3  | 4  | 5  | Average |
|-------|----|---|----|----|----|----|---------|
| %     | 10 | 4 | 12 | 14 | 14 | 46 | 3.6     |

$$m(\text{BaSO}_4) \text{ collected} = 174.99 - 123.40$$

$$= 51.59 \text{ g}$$

$$n(\text{BaSO}_4) \text{ collected} = 51.59/233.4$$

$$= 0.2210 \text{ mol}$$

$$\begin{aligned} n(\text{FeS}_2) \text{ in sample} &= \frac{1}{2} \times 0.2210 \text{ mol} \\ &= 0.1105 \text{ mol} \end{aligned}$$

$$\begin{aligned} m(\text{FeS}_2) \text{ in sample} &= 0.1105 \times 120.0 \\ &= 13.26 \text{ g} \end{aligned}$$

$$\begin{aligned} \% \text{ FeS}_2 \text{ in sample} &= (13.26/14.3) \times 100 \\ &= 92.7\% \end{aligned}$$

One mark each was awarded for:

- accurately calculating  $m(\text{BaSO}_4)$
- accurately dividing  $m(\text{BaSO}_4)$  by 233.4
- accurately calculating  $n(\text{FeS}_2)$  from  $n(\text{BaSO}_4)$ , i.e. dividing  $n(\text{BaSO}_4)$  by 2
- multiplying  $n(\text{FeS}_2) \times 120.0$
- accurately calculating  $\%(\text{FeS}_2)$  from calculated  $m(\text{FeS}_2)$  and giving an answer to three significant figures.

This question was generally answered well. Some students proceeded to determine the % S or %  $\text{SO}_4^{2-}$  in the mineral sample. A significant number overlooked or inaccurately applied the 1:2 mole ratio between  $\text{FeS}_2$  and  $\text{SO}_4^{2-}$ .

#### Question 2b.

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 61 | 39 | <b>0.4</b> |

Acceptable responses included:

- All the sulfur is precipitated as  $\text{BaSO}_4$ .
- All the sulfur is converted to  $\text{SO}_4^{2-}$ .
- Precipitate was pure.
- $\text{FeS}_2$  is the only source of sulfur in fool's gold.
- No  $\text{BaSO}_4$  (precipitate) is lost (in washing, collection or transfer).
- $\text{BaSO}_4$  is the only precipitate.
- The filter paper had no moisture content.

Common incorrect responses included, 'the reaction between  $\text{Ba}^{2+}(\text{aq})$  and  $\text{SO}_4^{2-}(\text{aq})$  had gone to completion', 'excess  $\text{BaCl}_2$  was added' and 'all the  $\text{SO}_4^{2-}(\text{aq})$  was converted to  $\text{BaSO}_4$ '. These answers were not appropriate because they simply restated given or implied information from the stem of the question.

#### Question 3a.

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 31 | 69 | <b>0.7</b> |

Triglycerides/fats/lipids

Students should be able to readily distinguish between the three main biomolecules studied – proteins, fats (lipids) and carbohydrates by their distinctly different functional groups – peptide, ester and ether, respectively.

**Question 3b.**

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 44 | 56 | <b>0.6</b> |

One C=C double bond is present in each erucic acid molecule.

Many students incorrectly stated 'one double bond' in their explanation. Students should be aware that all fatty acids contain at least one double bond, namely the C=O double bond in the carboxyl functional group. However, only unsaturated fatty acids contain one or more C=C double bonds.

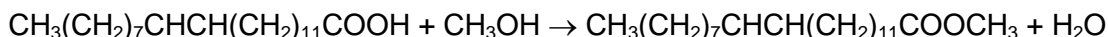
**Question 3c.**

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 57 | 43 | <b>0.5</b> |

- $\text{CH}_3(\text{CH}_2)_7\text{CHCH}(\text{CH}_2)_{11}\text{COOCH}_3$
- $\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_{11}\text{COOCH}_3$
- $\text{H}_3\text{COOC}(\text{CH}_2)_{11}\text{CH}=\text{CH}(\text{CH}_2)_7\text{CH}_3$

Overall performance on this question indicated significant issues with writing the semi-structural formula of an ester, particularly with the relative positioning of the ester and methyl groups.

Applying the general equation for ester production, i.e.  $\text{RCOOH} + \text{R}^1\text{OH} \rightarrow \text{RCOOR}^1 + \text{H}_2\text{O}$  to the formation of methyl erucate from erucic acid and methanol gives:

**Question 3d.**

| Marks | 0  | 1  | 2  | Average    |
|-------|----|----|----|------------|
| %     | 37 | 49 | 14 | <b>0.8</b> |

Possible responses included the following.

- There is a lower environmental impact of plant growth for biodiesel production compared to crude oil extraction (oil spills) and refining for petrodiesel production.
- Biodiesel combustion releases recently extracted  $\text{CO}_2$  back into the atmosphere, whereas petrodiesel adds to atmospheric  $\text{CO}_2$  levels.
- Biodiesel production is less harmful to marine life that is affected by oil spills during extraction and transport of crude oil for the production of petrodiesel.

One mark each was awarded for:

- an environmental advantage of biodiesel
- contrasting an environmental disadvantage of petrodiesel.

Most students did not adequately describe the environmental advantage/disadvantage and simply classified biodiesel as renewable and petrodiesel as non-renewable.

Some students were able to gain one mark for the renewable/non-renewable approach but few who took this line explained why the use of the biodiesel source is environmentally advantageous compared to the petrodiesel source.

Students should understand that renewable energy sources are those that are readily replenished, but that definition by itself does not indicate environmental advantage.

**Question 3ei.**

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 76 | 24 | 0.3     |

- $\text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) \rightarrow 2\text{C}_2\text{H}_6\text{O}(\text{aq}) + 2\text{CO}_2(\text{g}/\text{aq})$
- $\text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) \rightarrow 2\text{CH}_3\text{CH}_2\text{OH}(\text{aq}) + 2\text{CO}_2(\text{g}/\text{aq})$
- $\text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) \rightarrow 2\text{C}_2\text{H}_5\text{OH}(\text{aq}) + 2\text{CO}_2(\text{g}/\text{aq})$

Many students accurately identified the reactant and product formulas but assigned one or more states incorrectly. Many students included the correct chemical formulas for glucose and ethanol but either did not have  $\text{CO}_2$  as the other product or included a third incorrect product.

**Question 3eii.**

| Marks | 0  | 1 | 2  | 3  | Average |
|-------|----|---|----|----|---------|
| %     | 38 | 6 | 17 | 39 | 1.6     |

$$m(\text{C}_2\text{H}_6\text{O}) \text{ produced} = 0.785 \text{ g mL}^{-1} \times 1.00 \times 10^3 \text{ L}$$

$$= 785 \text{ g}$$

$$n(\text{C}_2\text{H}_6\text{O}) \text{ produced} = 785/46.0$$

$$= 17.07 \text{ mol}$$

$$n(\text{C}_6\text{H}_{12}\text{O}_6) \text{ required} = \frac{1}{2} \times 17.07 \text{ mol}$$

$$= 8.53 \text{ mol}$$

$$m(\text{C}_6\text{H}_{12}\text{O}_6) \text{ required} = 8.53 \times 180.0$$

$$= 1.54 \times 10^3 \text{ g}/1.54 \text{ kg}$$

One mark each was awarded for:

- accurately calculated  $n(\text{ethanol})$ , i.e.  $(d \times V/46.0)$
- accurately dividing  $n(\text{ethanol})$  by 2 – or a ratio consistent with the equation in Question 3ei
- accurately calculated  $m(\text{glucose})$ , i.e. multiplying  $n(\text{glucose})$  by 180.0 with the answer given in the appropriate unit.

**Question 4ai.**

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 48 | 52 | 0.5     |

Peak at  $m/z = 30$

On a mass spectrum, the most abundant species (most intense ion) is assigned an abundance of 100 and is known as the base peak.



**Question 4aii.**

| Marks | 0  | 1 | 2  | Average |
|-------|----|---|----|---------|
| %     | 24 | 9 | 68 | 1.5     |

$m/z = 60$

Acceptable justifications included

- $M_r(\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2) = 60$
- $M(\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2) = 60 \text{ g mol}^{-1}$
- Peak at  $m/z = 60$  is caused by its molecular ion  $[\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2]^+$

One mark each was awarded for:

- correct  $m/z$  ratio
- a justification linking 60 and the formula  $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ .

The principal peak in confirming the formula of the compound is the parent ion peak, which on this spectrum was shown at  $m/z = 60$ , consistent with the relative molecular mass of  $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ . Due to fragmentation, the molecular ion is unlikely to be the most abundant species in the spectrometer and so its peak is not the same as the base peak.

A significant number of students seemed to assume that the base peak identified in Question 4ai. was the principal peak in supporting the compound formula  $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ , based on the molecule symmetry. In a situation where the molecular ion peak did not appear on the spectrum due to complete fragmentation, not the case in the question, this argument may be applicable.

**Question 4aiii.**

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 60 | 40 | 1.5     |

$[\text{NH}_2\text{CH}_2]^+$

Students should be aware that the species associated with the peaks on a mass spectrum carry a single positive charge. Many students did not include the charge, while others did not give the semi-structural formula of the species.

**Question 4b.**

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 14 | 19 | 67 | 1.5     |

Yes, a peak in the absorption band characteristic of an N-H bond, i.e.  $3350\text{--}3500 \text{ cm}^{-1}$ , is evident.

One mark each was awarded for:

- answering 'Yes', but only if the explanation was based on the spectrum
- identifying the presence of a peak for the N-H bond.

Many students focused on the peak centred at  $1600 \text{ cm}^{-1}$  and argued that since this bond could not be identified from the data available or might have been due to C=C or C=O bond, consequently, despite the presence of the N-H bond, the spectrum was not consistent with the compound being  $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ . Despite this argument being flawed since bonds in  $\text{NH}_2$  groups on amines vibrate in bending mode through scissoring at  $1550\text{--}1650 \text{ cm}^{-1}$ , allowance in marking was made for the fact that students' previous interpretations of IR spectra would have been based on vibration frequencies in the stretching mode as per the data supplied in the Data Book.

**Question 4c.**

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 35 | 44 | 20 | 0.9     |

Yes, one peak on the spectrum is consistent with only one carbon environment.

$\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$  is a symmetrical molecule/both C atom have identical bonding environments.

One mark each was awarded for:

- recognition of the link between one peak and one C environment
- a valid explanation of one carbon environment.

Many students interpreted the spectrum as having two peaks. Students who chose this approach could still access the second mark through a valid discussion of why the  $^{13}\text{C}$  NMR spectrum of  $\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2$  should have one peak.

Several students simply stated that there was peak at around 46 ppm linked to  $\text{R}_3\text{CNH}_2$ . This was not enough to show that the spectrum was consistent with the structure.

**Question 4d.**

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 41 | 26 | 32 | 0.9     |

Acceptable responses included:



One mark each was awarded for:

- a correctly drawn amide bond (CONH or NHCO)
- a correctly drawn structure with an open bond at each end.

Many students did not represent the amide bond correctly, with many showing an O atom between the C and N atoms.

Students should be aware that repeating units of polymers show an open bond at both ends. This was overlooked in many responses.

**Question 5a.**

| Marks | 0  | 1  | 2  | 3  | 4  | Average |
|-------|----|----|----|----|----|---------|
| %     | 17 | 15 | 18 | 14 | 35 | 2.4     |

- Increasing temperature (constant volume)  
Increase  
Reasoning: Increasing temperature increases the (average) kinetic energy of reactant molecules so:
  - more collisions have energy greater than the activation energy
  - the proportion of collisions that are successful (fruitful) increases.

- Increasing pressure (constant temperature)  
Increase  
Reasoning: Increasing the pressure increases the closeness (concentration) of the reactant molecules and so the frequency (number) of collisions increases.

Several students tried, unsuccessfully, to apply Le Chatelier's principle to explain the effects of temperature and pressure changes on the rate of production of bromomethane.

### Question 5b.

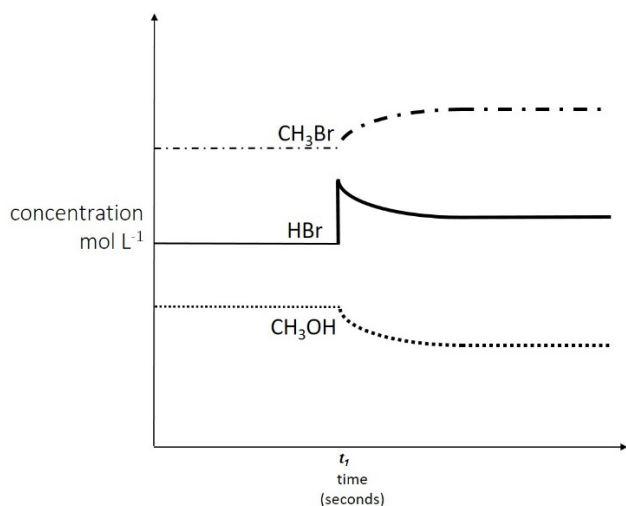
| Marks | 0  | 1  | 2  | 3  | 4  | Average |
|-------|----|----|----|----|----|---------|
| %     | 10 | 10 | 16 | 12 | 52 | 2.9     |

- Increasing pressure (constant temperature)  
No change  
Reasoning: The system cannot compensate for (partially oppose) the increase in pressure because there are the same number of particles (moles) on both sides of the equilibrium. The concentration fraction has not changed and the system remains at equilibrium.
- Continuously removing the product  $\text{CH}_3\text{Br}$  (constant volume and temperature)  
Increase  
Reasoning: System moves to compensate for (partially oppose) the removal of product by favouring the forward reaction (production of  $\text{CH}_3\text{Br}$ ) or removal of product reduces the rate of the reverse reaction and so the forward reaction is favoured.

Most students were able to produce appropriate responses explaining the effect of increasing pressure and removing product on the yield of bromomethane.

### Question 5c.

| Marks | 0  | 1  | 2  | 3  | Average |
|-------|----|----|----|----|---------|
| %     | 22 | 22 | 29 | 27 | 1.9     |



One mark each was awarded for:

- HBr – curve rises sharply vertically, then falls gradually and levels out clearly above its original concentration
- $\text{CH}_3\text{Br}$  rising gradually and levelling out and  $\text{CH}_3\text{OH}$  falling gradually and levelling out – close to mirror images

- all three graphs levelling out at the same time and the three concentration changes being the same.

Significant errors in responses included incorrect location of the HBr concentration on its return to equilibrium and large differences in the change in concentration during the return to equilibrium.

#### Question 5d.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 54 | 46 | 0.5     |

Appropriate responses included:

- breathing apparatus and full protective clothing required at all times
- clear handling instructions to avoid contamination with CH<sub>3</sub>Br
- exhaust extraction and capture system for HBr leaks
- appropriate warning system for detected HBr leaks.

Given the stated toxicity, lack of odour and lack of colour of bromomethane, simplistic responses such as 'wear a lab coat and gloves' were not appropriate. 'Wear a face mask' was a relatively common response that was not considered appropriate since the standard face mask that protects the eyes and face from contact with chemicals would not prevent inhalation. Another common response was 'wear a gas mask', which implied the prevention of inhalation of bromomethane.

#### Question 6a.

| Marks | 0  | 1  | 2  | 3  | Average |
|-------|----|----|----|----|---------|
| %     | 22 | 13 | 23 | 41 | 1.9     |

Absorbance 0.13 →  $c(\text{Cu}^{2+}) = 1.1 \text{ g L}^{-1}$  (acceptable range 1.05–1.1)

$$m(\text{Cu}^{2+}) \text{ in } 100 \text{ mL} = 0.11 \text{ g}$$

$$m(\text{Cu}^{2+}) \text{ in sample} = 0.11 \text{ g}$$

$$\begin{aligned} \% \text{ Cu}^{2+} \text{ in sample} &= (0.11/0.198) \times 100 \\ &= 56\% \end{aligned}$$

Several students assumed that the calibration graph reading was in  $\text{mol L}^{-1}$  (rather than the correct  $\text{g L}^{-1}$ ), which unnecessarily complicated their calculations as they struggled to deal with calculations yielding over 100 per cent.

#### Question 6b.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 69 | 14 | 18 | 0.5     |

Not making up the solution to 20.00 mL would have increased the  $c(\text{Cu}^{2+})$  by a factor of 5.

The solution becomes so concentrated that this would put the concentration and absorbance outside the range of the calibration curve.

It cannot be assumed that the calibration graph remains linear beyond the range of the known data.

One mark each was awarded for:

- recognising that  $c(\text{Cu}^{2+})$  increases by a factor of 5 or becomes too concentrated

- indicating why the result would be unreliable.

This question was not answered well. Many students did not realise the significance of the dilution to 20 mL rather than 100 mL and its effect on the concentration of  $\text{Cu}^{2+}$ . Many students suggested that since the amount of  $\text{Cu}^{2+}$  was not affected, the calibration curve remained reliable.

Students should be aware that calculations that require extrapolation beyond the range of the calibration curve cannot be reliable.

### Question 6c.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 39 | 61 | 1.6     |

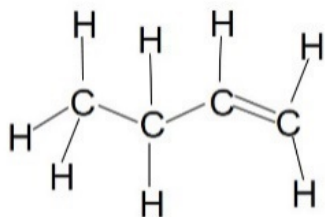
Appropriate responses included:

- UV-visible spectroscopy
- colorimetry/visible spectroscopy
- AES (atomic emission spectroscopy)
- gravimetric analysis
- volumetric analysis.

Chromatography (mainly TLC and HPLC) was a common incorrect response.

### Question 7ai.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 20 | 80 | 0.8     |



Most incorrect responses showed one C atom making 5 bonds.

### Question 7aii.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 71 | 29 | 0.3     |

$\text{H}_2\text{O}$  and  $\text{H}_3\text{PO}_4$  (acid catalyst)

There was a variety of incorrect responses to this question, including the omission of the acid catalyst and inappropriate alternatives to  $\text{H}_2\text{O}$ . Many students gave NaOH as their response, which suggested that many students simply applied knowledge from a remembered pathway from an alkane (via a haloalkane) to an alcohol.

**Question 7a.iii.**

|              |          |          |                |
|--------------|----------|----------|----------------|
| <b>Marks</b> | <b>0</b> | <b>1</b> | <b>Average</b> |
| <b>%</b>     | 46       | 54       |                |

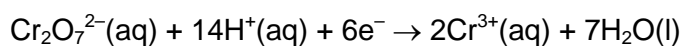
butan-1-ol/1-butanol

**Question 7a.iv.**

|              |          |          |                |
|--------------|----------|----------|----------------|
| <b>Marks</b> | <b>0</b> | <b>1</b> | <b>Average</b> |
| <b>%</b>     | 31       | 69       |                |

 $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ **Question 7a.v.**

|              |          |          |          |                |
|--------------|----------|----------|----------|----------------|
| <b>Marks</b> | <b>0</b> | <b>1</b> | <b>2</b> | <b>Average</b> |
| <b>%</b>     | 30       | 29       | 41       |                |

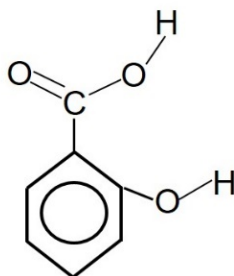


One mark each was awarded for:

- correct reactant and product formulas
- correct balancing.

**Question 7b.i.**

|              |          |          |                |
|--------------|----------|----------|----------------|
| <b>Marks</b> | <b>0</b> | <b>1</b> | <b>Average</b> |
| <b>%</b>     | 0        | 100      |                |

**Question 7b.ii.**

|              |          |          |                |
|--------------|----------|----------|----------------|
| <b>Marks</b> | <b>0</b> | <b>1</b> | <b>Average</b> |
| <b>%</b>     | 0        | 100      |                |

Ethanoic anhydride

**Question 8a.**

|              |          |          |                |
|--------------|----------|----------|----------------|
| <b>Marks</b> | <b>0</b> | <b>1</b> | <b>Average</b> |
| <b>%</b>     | 33       | 67       |                |

Negative (-)

Many students did not correctly apply two basic principles of electrochemical cells:

- electrons move spontaneously from the negative electrode to the positive electrode during discharge
- electrons move from the site of oxidation (anode) to the site of reduction (cathode).

#### Question 8b.

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 66 | 34 | <b>0.4</b> |



Responses to this question suggested that most students did not refer to the principle that the electrode that acts as the anode (site of oxidation) during discharge acts as the cathode (site of reduction) during recharging. This means that the oxidation half-equation ( $\text{LiC}_6 \rightarrow \text{Li}^+ + \text{e}^- + \text{C}_6$ ) during discharge is reversed to become the reduction half-equation ( $\text{Li}^+ + \text{e}^- + \text{C}_6 \rightarrow \text{LiC}_6$ ) during recharge.

Several students who applied this principle undermined the response by including (aq) as the state of  $\text{Li}^+$ , despite the inclusion of 'non-aqueous electrolyte' in the stem of the question.

#### Question 8c.

| Marks | 0  | 1  | 2  | 3 | Average    |
|-------|----|----|----|---|------------|
| %     | 45 | 29 | 18 | 8 | <b>0.9</b> |

Li is a strong reductant that reacts readily with water.

- $\text{Li(s)} \rightarrow \text{Li}^+(\text{aq}) + \text{e}^- / 2\text{H}_2\text{O(l)} + 2\text{e}^- \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$
- $2\text{Li(s)} + 2\text{H}_2\text{O(l)} \rightarrow \text{H}_2(\text{g}) + 2\text{LiOH(aq)}$

Hydrogen gas is explosive/Heat is generated/LiOH is a strong base/current does not flow.

One mark each was awarded for:

- appropriate reference to lithium's ready reaction with water
- both half-equations correctly balanced or a correctly balanced overall equation
- a significant consequence of lithium in contact with water

Responses to this question indicated that many students struggled to apply their understandings in this context. Many students focused on the battery itself rather than stating what happens when lithium is in contact with water and why is this an issue. Consequently, many students tried to frame responses around recharging problems that might arise if water was present in the battery.

Many students seemed to consider Li and  $\text{Li}^+$  to be interchangeable. Comments such as 'water is a stronger oxidant than lithium' or ' $\text{Li}^+$  will be oxidised by water' were common.

It was evident that many students did not read the question carefully and their answers were based on recharging problems that might arise if water were present. Other students thought that water would reduce in preference to  $\text{Li}^+$  during discharge.

#### Question 8d.

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 86 | 14 | <b>0.2</b> |

The movement of lithium ions into and out of the electrodes enables the reactions at the electrodes to be reversed.

Most students simply stated the general characteristic of secondary cells that products of discharge remain at the electrodes. The question was about the lithium-ion battery and the lithium ions are integral to the operation of cell in both discharging and recharging, so their movement into and out of the structure of the electrodes was the required design feature.

**Question 8e.**

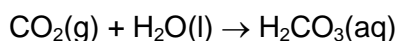
| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 25 | 75 | 0.8     |

Possible responses included:

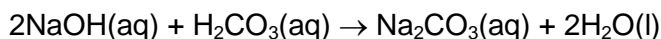
- A secondary cell is more convenient for on–off usage since it does not need a continuous external supply of reactants.
- A secondary cell can be recharged (electrically), whereas a fuel cell continuously needs fresh reactants.
- Secondary cells are usually cheaper than fuel cells.
- Secondary cells are more suitable for most of today’s electronic devices.
- Secondary cells are storage devices.

**Question 9ai.**

| Marks | 0 | 1  | Average |
|-------|---|----|---------|
| %     | 5 | 95 | 1       |

**Question 9aii.**

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 26 | 74 | 0.8     |

**Question 9bi.**

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 37 | 40 | 23 | 0.9     |

$$V(\text{air}) \text{ entering container} = 9.90 \text{ L}$$

$$\begin{aligned} n(\text{air}) \text{ entering container} &= pV / RT \\ &= 101.3 \times 9.90 / (8.31 \times 294.5) \\ &= 0.410 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{CO}_2) \text{ entering container} &= 0.0400\% \text{ of } n(\text{air}) \\ &= (0.0400/100) \times 0.410 \\ &= 1.64 \times 10^{-4} \text{ mol} \end{aligned}$$

Alternatively,

$$V(\text{CO}_2) \text{ entered} = (0.0400/100) \times 9.90$$



$$= 0.00396 \text{ L}$$

$$n(\text{CO}_2) \text{ entered} = pV/RT$$

$$= 101.3 \times 0.00396 / (8.31 \times 294.5)$$

$$= 1.64 \times 10^{-4} \text{ mol}$$

One mark each was awarded for:

- accurate use of the general gas equation using 9.90 L or 0.0396 L
- accurately calculating 0.400% of either 9.90 L, or  $n(\text{air})$  calculated from the general gas equation.

Many students seemed uncertain about the volume of air that entered the container, with 0.1 L and 10 L frequent responses. A common error that led to significant challenges later in the question was inaccurate application of the 0.0400% (v/v); many students converted this to a multiplier of 0.04 rather than the correct 0.0004.

#### Question 9bii.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 44 | 56 | 0.6     |

$$V(\text{NaOH}) \text{ in container} = 10.00 - 9.90$$

$$= 0.10 \text{ L}$$

$$n(\text{NaOH}) = c \times V$$

$$= 0.1000 \times 0.10$$

$$= 0.010 \text{ mol}$$

The most common error was the use of an incorrect  $V(\text{NaOH})$  – usually 9.90 or 10.00.

#### Question 9biii.

| Marks | 0  | 1  | 2  | 3  | Average |
|-------|----|----|----|----|---------|
| %     | 58 | 11 | 13 | 17 | 0.9     |

$$n(\text{NaOH}) \text{ reacting with absorbed CO}_2 = 2 \times n(\text{H}_2\text{CO}_3)$$

$$= 2 \times n(\text{CO}_2)$$

$$= 2 \times 1.64 \times 10^{-4}$$

$$= 3.28 \times 10^{-4} \text{ mol}$$

$$n(\text{NaOH}) \text{ remaining} = 0.0100 - 3.28 \times 10^{-4}$$

$$= 0.0097 \text{ mol}$$

$$c(\text{NaOH}) = 0.0097 / 0.10$$

$$= 0.097 \text{ M (} 0.097 \text{ mol L}^{-1}\text{)}$$

One mark each was awarded for accurately calculating:

- $n(\text{NaOH})$  reacting with  $\text{CO}_2$
- $n(\text{NaOH})$  remaining
- $c(\text{NaOH})$  from  $n(\text{NaOH})$ .

Several students who calculated the  $n(\text{CO}_2)$  in 9ai. to be  $1.62 \times 10^{-2}$  mol (i.e. did not apply the 0.0400% accurately) were able to show that the  $c(\text{NaOH})$  would be zero, based on the argument consistent with their data:

$$n(\text{NaOH}) \text{ required to react with } \text{CO}_2 = 2 \times 1.64 \times 10^{-2} = 0.032 \text{ mol}$$

However, only 0.010 mol NaOH is available for reaction, so the  $\text{CO}_2$  is in excess, and all the NaOH is consumed, so the  $c(\text{NaOH}) = 0 \text{ mol L}^{-1}$ .

Students should remember that consequential marks often apply in this type of question where subsequent parts use previously calculated data.

A relatively common error was use of an incorrect  $V(\text{NaOH})$  when calculating its concentration after absorbing  $\text{CO}_2$ .

#### Question 10ai.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 29 | 48 | 22 | 1       |

- $\text{C}_4\text{H}_{10}(\text{g}) + 6.5\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 5\text{H}_2\text{O}(\text{l}), \Delta H = -2874 \text{ kJ mol}^{-1}$
- $2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{l}), \Delta H = -5748 \text{ kJ mol}^{-1}$

One mark each was awarded for:

- a correct equation
- correct  $\Delta H$ .

Responses to this question indicated that a significant number of students either did not realise that thermochemical equations include the appropriate  $\Delta H$  value and/or that the molar enthalpy of combustion of butane was provided in Table 13 of the Data Book. Other significant errors included incorrect coefficients for  $\text{O}_2$  in the equation and not linking the  $\Delta H$  value with the coefficient of  $\text{C}_4\text{H}_{10}$ .

#### Question 10aii.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 35 | 15 | 50 | 1.2     |

$$m(\text{water}) \text{ in can} = 303.37 - 52.14 = 251.23 \text{ g}$$

$$\Delta T \text{ of water} = 32.7 - 22.1 = 10.6 \text{ }^\circ\text{C}$$

$$\text{Energy} = 4.18 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1} \times 251.23 \text{ g} \times 10.6 \text{ }^\circ\text{C}$$

$$= 1.113 \times 10^4 \text{ J}$$

$$= 11.1 \text{ kJ}$$

One mark each was awarded for:

- correct  $m(\text{H}_2\text{O})$  and  $\Delta T$
- accurate calculation of energy.

The most common errors were using an inaccurate mass of water and giving the answer in joules rather than kilojoules.

**Question 10aiii.**

| Marks | 0  | 1  | 2  | Average    |
|-------|----|----|----|------------|
| %     | 43 | 21 | 36 | <b>0.9</b> |

$$m(\text{butane}) \text{ reacted} = 260.15 - 259.79$$

$$= 0.36 \text{ g}$$

$$n(\text{butane}) \text{ reacted} = 0.36/58.0$$

$$= 0.0062 \text{ mol}$$

$$\text{Energy released per mol } \text{C}_4\text{H}_{10} = 11.13 \text{ kJ}/0.0062 \text{ mol}$$

$$= 1.8 \times 10^3 \text{ kJ}$$

$$\text{Molar heat of combustion} = -1.8 \times 10^3 \text{ kJ mol}^{-1}$$

One mark each was awarded for:

- accurately calculating  $n(\text{butane})$
- accurate calculation of heat of combustion.

Many students missed the 'experimental value' instruction in the question and tried to use the molar enthalpy of combustion from the Data Book (i.e.  $-2874 \text{ kJ mol}^{-1}$ ).

**Question 10aiv.**

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 52 | 48 | <b>0.5</b> |

$$\% \text{ energy loss} = [(2874 - 1.8 \times 10^3)/2874] \times 100$$

$$= 37.4\%$$

High-scoring responses to this part of the question depended on the accurate combination of the answer to 10aiii. and the theoretical value of the enthalpy of combustion of butane from the Data book, Table 13. Many students seemed to confuse the terms 'theoretical' and 'experimental', endeavouring to combine their answers to 10a.ii. and 10a.iii. or use their answer to 10a.iii. with an incorrect molar enthalpy of combustion. A number used the  $\Delta H$  value (5748) from their equation in 10a.i., which contained 2 mol  $\text{C}_4\text{H}_{10}$  but did not realise that this was for 2 mol  $\text{C}_4\text{H}_{10}$  whereas their answer to 10a.iii. was for 1 mol  $\text{C}_4\text{H}_{10}$ .

**Question 10bi.**

| Marks | 0  | 1  | 2  | Average    |
|-------|----|----|----|------------|
| %     | 52 | 17 | 30 | <b>0.8</b> |

$$\Delta T \text{ water} = 34.9 - 28.5 = 6.4 \text{ }^\circ\text{C}$$

$$\text{Energy released into water} = 4.18 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1} \times 251.3 \text{ g} \times 6.4 \text{ }^\circ\text{C}$$

$$= 6.7 \times 10^3 \text{ J}$$

$$= 6.7 \text{ kJ}$$

$$m(\text{biscuit}) \text{ reacted} = 46.75 - 44.34$$

$$= 2.41 \text{ g}$$

$$\text{Energy per 100 g biscuit} = (6.7/2.41) \times 100$$

$$= 2.8 \times 10^2 \text{ kJ}/100 \text{ g}$$

One mark each was awarded for:

- accurately calculating energy released into water
- accurately calculating energy per 100 g of biscuit.

Many students made simple mistakes on this question. Students should be familiar with energy calculations using the specific heat capacity of water (given in Table 3 of the Data Book) and realise that  $4.18 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1}$  will give the energy in joules. Not converting to kJ was very common, as was overlooking the requirement to give the answer in kJ/100 g (biscuit). The ability to effectively interpret supplied experimental data is a fundamental requirement.

#### Question 10bii.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 67 | 33 | 0.4     |

A biscuit is not a pure substance/(is a mixture), so does not have a chemical formula or a molar mass.

This question was not answered well, with many superficial responses such as 'biscuits are not measured in moles/you can't have a mole of biscuits'. Students should be aware that only pure substances have molar masses. Responses such as 'contain more than one element' were unsatisfactory since this also describes a compound.

#### Question 10c.

| Marks | 0  | 1 | 2  | Average |
|-------|----|---|----|---------|
| %     | 79 | 7 | 13 | 0.4     |

% energy transferred to water =  $100 - 37.4 = 62.6\%$

$2.8 \times 10^2 \text{ kJ} = 62.6\%$  of energy content

$2.8 \times 10^2 = 0.626 \times \text{energy content}$

'Energy content' =  $2.8 \times 10^2 / 0.626$

=  $4.5 \times 10^2 \text{ kJ/100 g}$

One mark each was awarded for:

- accurately calculating percentage energy transferred
- calculating more accurate energy content.

Most students struggled with this question, with many not realising the need to use their answer from 10aiv. – percentage of energy lost to determine the percentage of energy transferred to the water – and then apply that to determine a more accurate energy content value.

#### Question 11

| Marks | 0  | 1 | 2  | 3  | 4  | 5  | 6 | 7 | Average |
|-------|----|---|----|----|----|----|---|---|---------|
| %     | 20 | 7 | 18 | 14 | 22 | 10 | 9 | 1 | 2.9     |

For this question, students needed to understand the experiment and analyse the results. Higher-achieving students were able to explain a strength of the experimental design, suggest and justify improvements and then comment on the validity of the conclusion. Acceptable strengths of the experimental design included the following.

| Strength                                  | Explanation   |
|---|---|
| Time was the same in all trials           | reduced the number of variables   |
| Each brass key was sanded before weighing | removes possible contaminants from the key's surface                    |
| Three trials were carried out             | allows for better verification of results/to test whether $m \propto Q$ |
| Nickel anode is used                      | maintains electrolyte concentration                                     |

Suggested improvements or modifications could have included two of the following.

| Improvement or modification  | Justification   |
|--|---|
| A suitable concentration of $\text{Ni}^{2+}(\text{aq})$ is used                          | The products of the electrolysis are dependent on the concentration of $\text{Ni}^{2+}(\text{aq})$ .  |
| Ensure the $\text{Ni}^{2+}(\text{aq})$ solution is pure/free of other metal ions         | Prevents other metals being deposited on the key.   |
| Ni electrode should be weighed before and after each experiment                          | This will enable a check of whether the amount of Ni oxidised at the anode is the same as the amount plated on to the key/give more accurate results.   |
| Ensure voltages are below 2.06 V   | High voltages may lead to water reacting depending on solution concentration. Results are unreliable due to possible $\text{O}_2$ and/or $\text{H}_2$ production.   |
| Maintain a constant voltage (without stating constant current)                           | Possible side reactions if voltage is too high/eliminates another variable.   |
| Use constant voltage and current   | Multiple trials for averaging (assuming first interpretation of aim, as mentioned above).   |
| Current should be measured at regular intervals during the plating not just at the start | Variations in current make it difficult to accurately calculate the amount of charge passing through the cell. By taking an average of current readings over the 20 minutes, a more accurate value is obtained. |
| Patting dry with paper towel is inaccurate   | The keys need to be dried to constant mass to ensure they are dry.  |
| Keys should have same shape and surface area   | Reduces variables that could affect results   |
| Use a pure Cu electrode sheet rather than brass keys                                     | Reduce possibility of side reactions. Other components of brass key may react with $\text{Ni}^{2+}$ in solution. The mass of the key would be less than predicted.  |
| Carry out more trials at different currents  | Get a more consistent set of results from which to draw conclusions/to obtain concordant results.   |
| Extend the time for electroplating   | Allows for greater mass to be deposited and hence weighing errors are less significant.   |
| Keep current constant and vary the time of electroplating                                | To investigate further the relationship between mass deposited and the amount of charge passed.   |
| Wash key after sanding/before weighing   | Remove fine particles/soluble impurities.   |
| Connect circuit before key added   | Avoid reaction between Zn in brass and $\text{Ni}^{2+}(\text{aq})$ .  |

Students could have included the following in commenting on the validity of a conclusion that referenced directly or indirectly one of Faraday's Laws.

- Results show limited consistency with Faraday's first law –  $m(\text{Ni})$  deposited should be proportional to charge passed and mass of Ni deposited is higher for the higher current
- Trials Y and Z reflect Faraday's first law – show mass is proportional to charge.  
For Y,  $m/\text{current} = 0.201/0.54 = 0.372$   
For Z  $m/\text{current} = 0.188/0.50 = 0.376$   
For Trial X –  $m/\text{current} = 0.256$  – hence more trials are needed to confirm relationship
- Although X and Y support this conclusion (for Faraday's first law), to some degree more trials in a more tightly controlled experimental setup, should be considered
- To test the validity of Faraday's first law – constant voltage – the same starting concentration and consistent electrode properties are needed. Then the effect of time and current on mass deposited needs to be tested
- The experiment only attempts to test Faraday's first law. To test his second law, electrolytes with ions of different charges need to be investigated. As this has not been done, a conclusion about Faraday's laws in general is not valid
- A logical consideration showing some appreciation of the link (or lack thereof) between the data collected and Faraday's laws

This question proved challenging for most students. The aim 'investigate whether Faraday's laws apply' assumed that students would know Faraday's laws. It was clear that many students considered them to be the relationships used in associated calculations, i.e.  $Q = It$  and  $Q = n(e^-)F$ .

Few students provided convincing explanations of the validity of the conclusion, with many simply commenting on the accuracy of the calculation of the mass of nickel deposited.

While most students could identify a strength in the experimental design, improvements or modifications proved challenging. Common suggestions for improvements were open-ended statements such as 'do more trials' and 'keep voltage and current constant', without explanation of how this would improve the investigation.

Students' ability to discuss the appropriateness of practical procedures and draw conclusions based on experimental data is related to their practical experience throughout VCE Chemistry and should always be a development area.