

# 2015 VCE Chemistry examination report

## General comments

The 2015 VCE Chemistry examination was the third exam for the current *VCE Chemistry Study Design* and covered the designated key knowledge and key skills from Units 3 and 4.

Demonstrating skills and understanding of chemical ideas in examinations is dependent on thorough preparation and efficient examination technique. Responding well to all questions within the allocated time requires solid practice and students should ensure that they use reading time well. Students may benefit from the inclusion of reading time as part of written assessment tasks. Students are reminded that they should read through all parts of a question before beginning to frame their response.

Most students performed well in Section A. The most challenging questions, in decreasing order of performance, were:

- Question 29: Students seemed to assume what the question was asking and incorrectly selected the polarity of the cathode.
- Question 15: This question challenged students to use higher-order thinking skills and utilise the information and structures of isoleucine and glucose given in the data book as well as their understanding of fatty acids.
- Question 8: Students were assessed on their understanding of the relationship between the polarity of phases in chromatography and the type of bonding that occurs between the molecules in the mixture and the phases.
- Question 28: Students needed to check the electrochemical series to determine which metals are weaker reductants than copper and should not be allowed to be oxidised if pure copper is to be produced.
- Question 4: Many students did not use the mole ratio implicit in the equation.
- Question 22: Many students ignored the fact that  $[\text{OH}^-] = 2 \times [\text{Ba}(\text{OH})_2]$ .
- Question 23: This question assessed student understanding of the relationships between  $K_w$ , the self-ionisation of water, temperature,  $[\text{H}_3\text{O}^+]$  and pH.

Section B questions assessed students' ability to provide appropriate written responses across the four Areas of Study associated with Units 3 and 4.

- Organic chemical pathways provided the basis for Questions 1, 5 and 6, and parts of Questions 3c., 9c. and 9d. It was evident that improvement is required in drawing the structures of organic compounds.
  - In Question 1a. bond location was drawn inaccurately in many cases.
  - In Question 3c. many accurate chemical structures could not be rewarded because they were not consistent with the information provided on the spectra included in the question.
  - In Question 5b. 'the full structural formula of an isomer of butan-2-ol' proved challenging for some students. In full structural formulas containing a hydroxyl group, the O–H bond should be shown.
  - In Question 6a. responses revealed particular issues with identifying and drawing the structure of an amide link/peptide bond.
  - Responses to Question 9d. revealed difficulties in showing the structure of a triglyceride.
- Chemical analysis provided the basis for Questions 2, 3, 4, 10c. and 11.
  - In Question 2ci. many students struggled to accurately convert the  $n(\text{NH}_3)$  in a 20.00 mL aliquot of cloudy ammonia to a concentration, in  $\text{g L}^{-1}$  of  $\text{NH}_4\text{OH}$ . The appropriate use of the volume data is important. Question 2cii. asked for an explanation for the difference

between calculated and stated results, and students needed to accurately identify factors that lead to result discrepancies.

- Question 3 required students to deduce the structure of a molecule from IR, high resolution  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR spectra. While basic spectrum interpretation was well handled, the effective use of the splitting pattern information in arriving at an accurate structure proved challenging for many.
- Question 4 showed that while most students could interpret absorbance spectra and use a calibration curve effectively, Question 4c. was an effective performance discriminator. Students needed to check whether the supplied concentration fitted on the two calibration curves but made unnecessary assumptions about the absorbance(s) used to establish those curves.
- Question 10c., which involved application of the general gas equation, was notable for use of an incorrect molar mass for  $\text{H}_2$  and not converting grams to kilograms.
- Question 11 required students to critically analyse experimental technique and data. The challenge in such questions is to consider likely 'best practice' when identifying errors in procedure. Many responses suggested that there is room for further discussion in classes of procedures and associated calculations when considering experimental work. When describing errors in the experimental procedure, some students tended to apply 'learned errors' – for example, the need to weigh the filter paper – with many trying to use this for both experimental technique and calculation errors. When preparing for the examination, students may benefit from revisiting this question and formulating a detailed experimental procedure considering questions such as 'Was the beaker weighed or at least tared on the balance?', 'Was enough HCl added?', 'Should the rock have been crushed?', 'Should the solution be filtered before adding NaOH?' and 'Were soluble impurities removed when precipitate was collected?'. If students have used a technique in class – for example, using a Gooch crucible, which removes the need to use filter paper – they should be encouraged to compare the potential accuracy of the different techniques. Many students identified the inappropriateness of filter paper in the stated calculation,  $\% \text{ iron} = [(\text{mass of dried iron(III) oxide} + \text{filter paper}) / (\text{mass of ore sample})] \times 100/1$ , but did not identify the inappropriateness of iron(III) oxide.
- Industrial chemistry was the main reference for Questions 7 and 8.
  - Responses to Questions 7b. and 7c. showed significant inconsistencies in understanding of how a system moves to equilibrium and interpretation of a rate–time graph from a collisions theory perspective. In Question 7b. students needed to explain the relationship between the concentration fraction/reaction quotient and  $K_c$  and how, based on this information, the reaction must proceed to get to equilibrium. In Question 7c. many assumed that the graph was a concentration–time graph. Le Châtelier's principle was not relevant to Questions 7b. and 7c.
  - Question 8 required students to show understanding of links between equilibria involving weak acids and the significance of  $K_a$  values. There was a significant difference between performances on Question 8a. and Question 8b. The context of Question 8a. required appropriate explanations of the validity of the assumptions. In Question 8b., calculations that made use of assumptions associated with weak acids were done well. Question 8c., which utilised Le Châtelier's principle, was not answered well. There was evidence that some students assumed that the  $\text{HS}^-(\text{aq})$  added acted as an acid and did not consider its impact in both equilibria.
- Supplying and using energy was the main reference for Questions 9 and 10.
  - Question 9a. required students to refer to relevant bonding when justifying their substance selection. In Question 9b. the 'relative amounts' of the two esters was commonly overlooked. Question 9c. required the use of the difference in mass-to-charge ratios of the two methyl esters. The difference of 28 in these ratios implies that methyl ester B has two more  $\text{CH}_2$  groups than methyl ester A. Therefore,  $\text{CH}_3(\text{CH}_2)_{16}\text{COOCH}_3$  is the semi-structural formula for methyl ester B. A number of students who did this correctly then misspelled the name of the ester. Question 9d. revealed limited skills in representing the structure of a triglyceride. A number of responses that were fundamentally correct did not represent the 2:1 ratio between ester B and ester A and could not be awarded full marks.

- Question 9ei. was answered well overall, but Question 9eii. was characterised by unbalanced equations and  $\Delta H$  values not consistent with the equation stoichiometry.
- Question 10 related to electrochemistry. In Question 10a. most students correctly identified the fuel cell electrolyte polarity and the product released at the cathode. However, the cathode half-equation was less well done, with indications that some students were confused by the battery shown in the circuit. When describing the disadvantage of the fuel cell compared to the petrol engine, many students referred to the continuous supply of reactants used in comparing fuel cells to other cells, without referring to the basic requirement of a petrol engine. In identifying advantages, 'no greenhouse gases' was a common response, suggesting limited awareness of the role of water as a greenhouse gas. Question 10b. was generally answered well. Performance was mostly consistent in Questions 10bi., 10bii. and 10biii. Students are reminded that when they are instructed to give a response 'in the box provided', placing it elsewhere on the page is inappropriate; for example, in Question 10biii. some students did not show the direction of electron flow in the box provided. In Question 10biv., many students who correctly applied  $Q = It$  and  $Q = n(e^-) \times F$ , used an inappropriate molar mass. In Question 10c. fundamental errors such as using incorrect  $M(\text{H}_2)$  and failing to convert to kilograms occurred too frequently.

## 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.

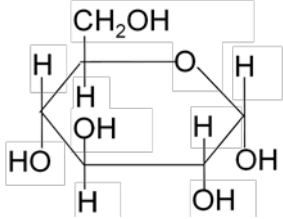
## Section A – Multiple-choice questions

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 |   |
|----------|-----|-----|-----|-----|-------------|---|
| 1        | 81  | 5   | 7   | 7   | 0           | When a base is added to an acid, the pH decreases and the biggest change in pH happens at the equivalence point. When a weak acid is added to a strong base, the pH at the equivalence point is $> 7$ due to the presence of the conjugate base of the weak acid.   |
| 2        | 5   | 6   | 82  | 6   | 0           | $2\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{s}) + 2\text{H}_2\text{SO}_4(\text{aq}) + \text{O}_2(\text{g}) \rightarrow 22\text{C}(\text{s}) + 2\text{CO}_2(\text{g}) + 24\text{H}_2\text{O}(\text{g}) + 2\text{SO}_2(\text{g})$ $n(\text{C}_{12}\text{H}_{22}\text{O}_{11}) \text{ reacting} = 50.0/342.0 = 0.146 \text{ mol}$ $n(\text{C}) \text{ produced} = 11 \times n(\text{C}_{12}\text{H}_{22}\text{O}_{11}) \text{ reacting} = 11 \times 0.146 = 1.61 \text{ mol}$ $m(\text{C}) \text{ produced} = 1.61 \times 12.0 = 19.3 \text{ g}$ |

| Question | % A | % B | % C | % D | % No answer |   |
|----------|-----|-----|-----|-----|-------------|---|
| 3        | 22  | 11  | 65  | 2   | 0           | <p>0.051 mol NaOH reacts with 0.017 mol C<sub>6</sub>H<sub>8</sub>O<sub>7</sub>, that is, in a 3:1 ratio.<br/> <math>3\text{NaOH}(\text{aq}) + \text{C}_6\text{H}_8\text{O}_7(\text{aq}) \rightarrow \text{Na}_3\text{C}_6\text{H}_5\text{O}_7(\text{aq}) + 3\text{H}_2\text{O}(\text{l})</math></p> <p>Students who selected alternative A may not have been familiar with the citric acid formula and so chose the most obvious balanced equation, without noting the data in the first sentence of the question.</p>   |
| 4        | 48  | 41  | 7   | 3   | 0           | <p><math>2\text{NaClO}_3(\text{s}) \rightarrow 2\text{NaCl}(\text{s}) + 3\text{O}_2(\text{g})</math><br/> <math>n(\text{O}_2) \text{ required} = pV/RT</math><br/> <math>= 76.0 \times 1.60 / (8.31 \times 292)</math><br/> <math>= 0.0501 \text{ mol}</math><br/> <math>n(\text{NaClO}_3) = (2/3) \times n(\text{O}_2) \text{ reacting}</math><br/> <math>= (2/3) \times 0.0501</math><br/> <math>= 0.0334 \text{ mol}</math><br/> <math>m(\text{NaClO}_3) \text{ required} = 0.0334 \times 106.5</math><br/> <math>= 3.56 \text{ g}</math></p> <p>The choice of alternative B is consistent with ignoring the NaClO<sub>3</sub>:O<sub>2</sub> mole ratio shown in the equation.</p>   |
| 5        | 5   | 4   | 7   | 83  | 0           | Renewable energy sources can be generated as fast as they are used.   |
| 6        | 4   | 9   | 17  | 69  | 0           | Students should be aware of the rules for assigning oxidation states, including that the oxidation state of monatomic ions is the same as the charge on the ion.  |
| 7        | 66  | 11  | 14  | 9   | 0           | Retention time of each species in the mixture depends on relative attraction to the stationary and mobile phases, and is independent of species concentration. Temperature, flow rate of carrier gas, the nature of the stationary phase and temperature all impact on the interactions of the species with the stationary phase and thus retention.  |
| 8        | 15  | 21  | 21  | 42  | 0           | <p>Polar molecules will be more attracted to the polar mobile phase by dipole-dipole attraction. Non-polar molecules will be more attracted to the non-polar stationary phase by dispersion forces. The polar molecules are more attracted to the polar solvent (mobile phase) and so will travel through the column faster than the non-polar molecules, which are more attracted to the non-polar stationary phase.</p> <p>The spread of selected alternatives suggests a significant lack of understanding of the link between chromatography and chemical bonding. Selection of alternatives B and C suggests issues with the nature of dipole-dipole attraction and/or dispersion forces, or a mistaken view of the relationship between the structure of the components and the polarity (or lack thereof) of the mobile and stationary phases.</p> |

| Question | % A | % B | % C | % D | % No answer |  |
|----------|-----|-----|-----|-----|-------------|--|
| 9        | 8   | 8   | 12  | 72  | 0           | <p>The molecules with two carbon environments have two peaks.</p> <ul style="list-style-type: none"> <li>• <math>\text{CH}_3\text{CBr}_2\text{CH}_3</math> – 2 peaks</li> <li>• <math>\text{CHBr}_2\text{CH}_2\text{CH}_3</math> – 3 peaks</li> <li>• <math>\text{CH}_2\text{BrCHBrCH}_3</math> – 3 peaks</li> <li>• <math>\text{CH}_2\text{BrCH}_2\text{CH}_2\text{Br}</math> – 2 peaks</li> </ul> <p>The number of carbon environments, hence peaks, can often be more easily identified by drawing the structures.</p>  |
| 10       | 9   | 10  | 15  | 65  | 0           | <p>The presence of the ethyl group, <math>\text{CH}_3\text{CH}_2-</math>, gives rise to a triplet (for the H atoms on <math>\text{CH}_3-</math>, caused by the H atoms on <math>\text{CH}_2</math>) and a quartet (for the H atoms on <math>\text{CH}_2-</math>, caused by the H atoms on <math>\text{CH}_3</math>).</p> <p>Peak splitting reflects the number of neighbouring H atoms and follows the <math>n + 1</math> rule.</p>  |
| 11       | 65  | 22  | 9   | 4   | 0           | <p>AAS – electrons promoted to higher energy levels<br/>           UV-Vis – electrons promoted to higher energy levels<br/>           IR – bond vibrations promoted to higher energy levels<br/>           Proton NMR – nuclear spin promoted to higher energy levels<br/>           MS – species ionised, electrons move to higher (beyond) energy levels</p> <p>Students should be aware of the energy transitions associated with absorption in the spectroscopies covered in the study design. The popularity of alternative B suggests that students are less familiar with the energy transitions in IR spectroscopy than in the other spectroscopies.</p> |
| 12       | 6   | 6   | 85  | 2   | 0           | <p>1,1,1-trichloropropane <math>\text{CH}_3\text{CH}_2\text{CCl}_3</math> – two hydrogen environments, a quartet and a triplet, in peak area ratio 2:3<br/>           1,2,3-trichloropropane <math>\text{CH}_2\text{ClCHClCH}_2\text{Cl}</math> – two hydrogen environments, a quintet and a doublet, in peak area ratio 1:4</p>   |
| 13       | 87  | 5   | 4   | 4   | 0           | <p><math>\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{CHClCH}_2\text{Cl}</math> – 1,2-dichlorobutane</p>  |
| 14       | 3   | 6   | 84  | 7   | 0           |  |

| Question | % A | % B | % C | % D | % No answer |   |
|----------|-----|-----|-----|-----|-------------|---|
| 15       | 16  | 14  | 30  | 40  | 1           | <p>Isoleucine: <math>\text{H}_2\text{N}-\text{CH}-\text{COOH}</math></p> $\begin{array}{c}   \\ \text{CH}_3\text{CHCH}_2\text{CH}_3 \end{array}$ <p>Each molecule has 10 C–H bonds, hence 40 C–H bonds in total.</p> <p>Lignoceric acid: Saturated fatty acid with 24 C atoms<br/> <math>\text{C}_{24}\text{H}_{48}\text{O}_2</math> or <math>\text{C}_{23}\text{H}_{47}\text{COOH}</math><br/> 47 C–H bonds</p> <p>Polyethene: <math>-(\text{CH}_2-\text{CH}_2)_{12}-</math><br/> <math>12 \times 4 = 48</math> C–H bonds</p> <p>Maltotetraose: 4 glucose residues<br/> Glucose, <math>\text{C}_6\text{H}_{12}\text{O}_6</math>, has 6 C–H bonds, as evident in:</p>  <p>4 glucose residues will provide <math>4 \times 6 = 24</math> C–H bonds</p> <p>The selection of alternative C may reflect the fact that it was the only option where the number of C–H bonds could be determined easily. Some students may also have selected the alternative with the greatest number of C–H bonds.</p> |
| 16       | 13  | 74  | 6   | 7   | 0           | <p>I – energy required to break reactant bonds (activation energy)<br/> II – energy released by forward reaction<br/> III – energy released during the formation of product bonds/activation energy for reverse reaction</p>  |
| 17       | 2   | 86  | 1   | 11  | 0           |   |
| 18       | 8   | 17  | 68  | 7   | 0           | <p>To get the equation <math>\text{N}_2\text{O}_4(\text{g}) \rightarrow 2\text{NO}_2(\text{g})</math><br/> Double the first equation:<br/> <math>\text{N}_2(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g}) \quad \Delta H = +60 \text{ kJ mol}^{-1}</math><br/> Reverse the second equation:<br/> <math>\text{N}_2\text{O}_4(\text{g}) \rightarrow \text{N}_2(\text{g}) + 2\text{O}_2(\text{g}) \quad \Delta H = -10 \text{ kJ mol}^{-1}</math><br/> Add the modified equations together:<br/> <math>\text{N}_2\text{O}_4(\text{g}) \rightarrow 2\text{NO}_2(\text{g}) \quad \Delta H = +50 \text{ kJ mol}^{-1}</math></p>  |
| 19       | 5   | 8   | 73  | 15  | 0           | <p>The observations recorded indicate that:</p> <ul style="list-style-type: none"> <li>the forward reaction is favoured by a temperature increase (blue colour)</li> <li>the reverse reaction is favoured by a temperature decrease (pink colour).</li> </ul> <p>So, the forward reaction is endothermic, and heating increases the equilibrium constant for the reaction.</p>  |

| Question | % A | % B | % C | % D | % No answer |   |
|----------|-----|-----|-----|-----|-------------|---|
| 20       | 74  | 10  | 9   | 7   | 0           | <p>The solution turns blue (more blue) through any change that pushes the equilibrium to the right.</p> <p>Alternative A: Adding HCl increases <math>[Cl^-]</math>, so the reaction moves right to compensate.</p> <p>Alternative B: Adding <math>Ag^+(aq)</math> removes <math>Cl^-(aq)</math>, so the reaction moves left to compensate.</p> <p>Alternative C: A catalyst has no effect on the position of equilibrium.</p> <p>Alternative D: Adding water decreases overall concentration, so the reaction moves to the side with more particles to compensate.</p>  |
| 21       | 2   | 61  | 31  | 7   | 0           | <p>Increasing the temperature causes the system to favour the endothermic forward reaction. Since temperature changes are not instantaneous there is a gradual change in concentrations as the system moves to the higher temperature equilibrium. This was shown in both alternatives B and C.</p> <p>However, since 4 mol of <math>Cl^-(aq)</math> reacts for 1 mol of <math>Co(H_2O)_6^{2+}(aq)</math> to produce 1 mol of <math>CoCl_4^{2-}(aq)</math>, the decrease in <math>[Cl^-]</math> is much greater than the decrease in <math>[Co(H_2O)_6^{2+}]</math> and the increase in <math>[CoCl_4^{2-}]</math>. Also, the changes in <math>[Co(H_2O)_6^{2+}]</math> and <math>[CoCl_4^{2-}]</math> will be similar. This was best represented in alternative B.</p> <p>The changes shown in alternative C are not consistent with the equation mole ratio, particularly for <math>[CoCl_4^{2-}]</math>.</p> |
| 22       | 3   | 15  | 33  | 49  | 0           | <p><math>Ba(OH)_2(aq) \rightarrow Ba^{2+}(aq) + 2OH^-(aq)</math><br/> <math>[OH^-] = 2 \times [Ba(OH)_2]</math><br/> <math>= 2 \times 0.0500 \text{ M}</math><br/> <math>= 0.100 \text{ M}</math><br/> <math>[H_3O^+] = 10^{-14}/[OH^-]</math><br/> <math>= 10^{-13}/0.100</math><br/> <math>= 10^{-13} \text{ M}</math><br/> <math>pH = 13</math></p> <p>Alternative C did not allow for the fact that each 1 mol <math>Ba(OH)_2(aq)</math> releases 2 mol <math>OH^-(aq)</math>.</p>  |
| 23       | 12  | 55  | 20  | 13  | 0           | <p>The data provided showed that <math>K_w</math> increases as temperature increases.</p> <p>Hence, the equilibrium for the self-ionisation of water, <math>2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)</math>, shifts to the right at higher temperatures.</p> <p>As a consequence:</p> <ul style="list-style-type: none"> <li><math>[H_3O^+]</math> and <math>[OH^-]</math> increase with increasing temperature</li> <li>pH, which is based on <math>[H_3O^+]</math>, decreases with increasing temperature since pH decreases as <math>[H_3O^+]</math> increases.</li> </ul> <p>This question required that the link between <math>K_w</math> and the self-ionisation of water be recognised, and that as the equilibrium shifts to the right the concentrations of both <math>H_3O^+</math> and <math>OH^-</math> increase. Students should be aware that the pH of water is 7 only at 25 °C.</p>    |

| Question | % A | % B | % C | % D | % No answer |  |
|----------|-----|-----|-----|-----|-------------|--|
| 24       | 62  | 12  | 21  | 6   | 0           | <p>A check of oxidation states shows that <math>\text{H}_2\text{O}_2</math> is reduced as the oxidation state of O decreases from <math>-1</math> in <math>\text{H}_2\text{O}_2</math> to <math>-2</math> in <math>\text{H}_2\text{O}</math>.<br/>(Oxidation state of N increases from <math>-3</math> in <math>\text{NH}_4^+</math> to <math>0</math> in <math>\text{N}_2</math>.)<br/>The reduction half-equation is:<br/><math>\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})</math>.</p>   |
| 25       | 6   | 67  | 15  | 11  | 0           | <p>From the electrochemical series:<br/> <math>\text{Cl}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-(\text{aq}) \quad E^0 = 1.36 \text{ V}</math><br/> <math>\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s}) \quad E^0 = 0.34 \text{ V}</math><br/> <math>\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s}) \quad E^0 = -0.76 \text{ V}</math><br/> <math>\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg}(\text{s}) \quad E^0 = -2.34 \text{ V}</math><br/> <math>\text{Na}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Na}(\text{s}) \quad E^0 = -2.71 \text{ V}</math></p> <p><math>\text{Zn}(\text{s})</math>, a reductant, may only be predicted to react spontaneously with an oxidant higher on the electrochemical series, in this case <math>\text{Cu}^{2+}(\text{aq})</math>, hence only <math>1 \text{ M CuCl}_2</math> will react with <math>\text{Zn}</math> powder.</p> |
| 26       | 18  | 9   | 61  | 12  | 0           | <p>The two half-cells are shown in the electrochemical series as:<br/> <math>\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq}) \quad E^0 = 0.77 \text{ V}</math><br/> <math>\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s}) \quad E^0 = 0.34 \text{ V}</math></p> <p>Half-reactions:<br/> Cu electrode: <math>\text{Cu}(\text{s}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-</math><br/> Pt electrode: <math>\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightarrow \text{Fe}^{2+}(\text{aq})</math><br/> Electrons flow from the Cu electrode to the Pt electrode.<br/> Cell voltage: <math>0.77 - 0.34 = 0.43 \text{ V}</math></p>   |
| 27       | 13  | 65  | 13  | 9   | 0           | <p>The reactions occurring in fuel cells and primary cells, and the discharge phase of secondary galvanic cells, are spontaneous reactions. Electroplating, an electrolysis process, is non-spontaneous.</p>   |



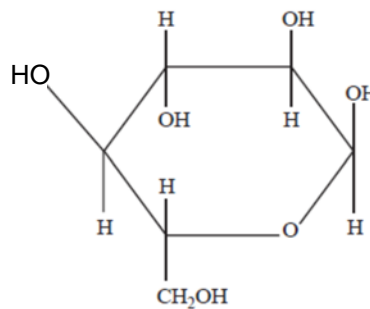
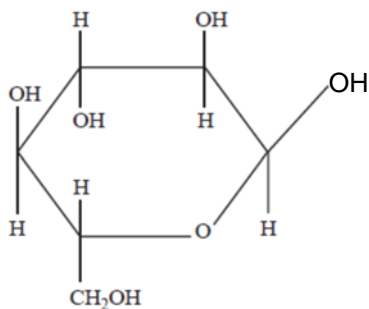
| Question | % A | % B | % C | % D | % No answer |  |
|----------|-----|-----|-----|-----|-------------|--|
| 28       | 11  | 30  | 10  | 48  | 0           | <p>The relative positions in the electrochemical series of the metals present in the impure Cu was a key reference in this question:</p> $\text{Au}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Au}(\text{s}) \quad E^0 = 1.68 \text{ V}$ $\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s}) \quad E^0 = 0.80 \text{ V}$ $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s}) \quad E^0 = 0.34 \text{ V}$ $\text{Ni}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni}(\text{s}) \quad E^0 = -0.23 \text{ V}$ $\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s}) \quad E^0 = -0.28 \text{ V}$ $\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s}) \quad E^0 = -0.44 \text{ V}$ $\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s}) \quad E^0 = -0.76 \text{ V}$ <p>Since pure copper is deposited at Electrode II it must be the site of reduction, i.e. <math>\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})</math><br/> At Electrode I, Cu, and any metals that are stronger reductants than Cu (Zn, Co, Ni and Fe) will be oxidised; half-equation <math>\text{Cu}(\text{s}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-</math><br/> Metals that are weaker reductants than Cu (Ag and Au) will not be oxidised and will collect under Electrode I in the sludge. It is essential that Ag and Au are not oxidised at Electrode I, because their ions would be reduced in preference to <math>\text{Cu}^{2+}(\text{aq})</math> and would impact on the purity of the Cu collected at Electrode II.</p> <p>The selection of alternative B ignores the fact that Co, Ni and Fe cannot be present as solids if Cu(s) has been oxidised because they are stronger reductants than Cu and, under a voltage high enough to oxidise Cu, would also be oxidised.</p> |
| 29       | 31  | 12  | 38  | 18  | 0           | <p>Electrorefining is an electrolytic process, so electrons move from the (+) electrode to the (-) electrode. Since the electrons are moving from Electrode I, the site of oxidation, to Electrode II, the site of reduction, the electrode signs are:<br/> Electrode I – positive, Electrode II – negative.<br/> The reaction at the cathode, the site of reduction, must be <math>\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})</math> because copper is deposited there.</p> <p>Selection of alternative C suggested that students considered the question to be asking for the sign of the electrode at which the reduction reaction occurred. Electrode I was either ignored or assumed to be the cathode. This emphasises the importance of effective and accurate reading of questions.</p>   |
| 30       | 9   | 83  | 4   | 4   | 0           | <p>Since the metals in the electrode are oxidised, its mass must decrease with time.</p>   |

## Section B – Short-answer questions

### Question 1

#### 1a.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 55 | 45 | 0.5     |



This question required students to convert the ether O group into hydroxyl OH groups. However, many students presented inaccurate representations of bonding linkages and were not awarded the mark.

#### 1b.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 21 | 79 | 0.8     |

Glucose

#### 1c.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 17 | 83 | 0.9     |

Condensation reaction

#### 1d.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 36 | 64 | 0.7     |

Ether link/glycosidic link

Most errors involved the use of ester rather than ether or incorrect spelling of 'glycosidic'.

## Question 2

## 2a.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 15 | 85 | 0.9     |

$$\begin{aligned}
 n(\text{HCl}) \text{ initially added (250.00 mL flask)} &= c(\text{HCl}) \times V(\text{HCl}) \\
 &= 0.5866 \times 100.00 \times 10^{-3} \\
 &= 0.05866 \text{ or } 5.866 \times 10^{-2} \text{ mol}
 \end{aligned}$$

## 2b.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 34 | 30 | 36 | 1       |

$$\begin{aligned}
 n(\text{HCl}) \text{ in excess in 20.00 mL aliquot} &= n(\text{NaOH}) \text{ in titre} \\
 &= c(\text{NaOH}) \times V(\text{NaOH}) \\
 &= 0.1194 \times 22.75 \times 10^{-3} \\
 &= 0.002716 \text{ or } 2.716 \times 10^{-3} \text{ mol}
 \end{aligned}$$

It was important that the correct number of significant figures be included in the response. It was also important to understand that the HCl(aq) in the 20.00 mL aliquot from Step 5 reacted with NaOH(aq) in the titration.

## 2ci.

| Marks | 0  | 1  | 2  | 3  | 4  | Average |
|-------|----|----|----|----|----|---------|
| %     | 35 | 16 | 18 | 17 | 15 | 1.7     |

The titration flask contained, prior to titration, a 20.00 mL aliquot of the 250.00 mL of solution remaining after cloudy ammonia had been added to excess HCl(aq). Two solution strategies were accepted. Students could access marks from the aspect of ' $n(\text{HCl})$  reacting in 250.00 mL' or ' $n(\text{HCl})$  reacting in 20.00 mL' from  $n(\text{HCl})$  initially –  $n(\text{HCl})$  in excess.

Based on the procedure as described:

- $n(\text{HCl})$  in excess 250.00 mL =  $n(\text{HCl})$  in excess in 20.00 mL aliquot (b)  $\times$  (250/20)  
 $= 0.002716 \times (250/20)$   
 $= 0.03395 \text{ mol}$   
 $n(\text{HCl})$  reacted =  $n(\text{HCl})$  initially added (a) –  $n(\text{HCl})$  in excess in 250.00 mL  
 $= 0.05866 - 0.03395$   
 $= 0.02471 \text{ or } 2.471 \times 10^{-2} \text{ mol}$   
 $n(\text{HCl})$  reacted = ( $[\text{Question 2a.}] - ([\text{Question 2b.}] \times 250/20)$ )
- $n(\text{NH}_3)$  pipetted =  $n(\text{HCl})$  reacting  
 $= 0.02471 \text{ or } 2.471 \times 10^{-2} \text{ mol}$
- $n(\text{NH}_4\text{OH})$  in 20.00 mL sample =  $n(\text{NH}_3)$  pipetted  
 $= 0.02471 \text{ mol}$   
 $m(\text{NH}_4\text{OH})$  in 20.00 mL =  $0.02471 \times 35.0$   
 $= 0.8647 \text{ g}$   
 $c(\text{NH}_4\text{OH})$  in  $\text{g L}^{-1}$  =  $0.8647 \times (1000/20)$   
 $= 43.2 \text{ g L}^{-1}$

Based on  $n(\text{HCl})$  reacting in a 20.00 mL aliquot:

- $n(\text{HCl})$  in excess 20.00 mL =  $0.05866 \times (20/250)$   
 $= 0.0046928$   
 $n(\text{HCl})$  reacted =  $0.0046928 - 0.002716$   
 $= 0.001977$  or  $1.977 \times 10^{-2}$  mol  
 $n(\text{HCl})$  reacted =  $(\text{[Question 2a.]} \times (20/250)) - \text{[Question 2b.]}$
- $n(\text{NH}_3)$  pipetted =  $n(\text{HCl})$  reacting in 250.00 mL  
 $= 0.001977 \times 250/20$   
 $= 0.02471$  or  $2.471 \times 10^{-2}$  mol
- $n(\text{NH}_4\text{OH})$  in 20.00 mL sample =  $n(\text{NH}_3)$  pipetted  
 $= 0.02471$  or  $2.471 \times 10^{-2}$  mol  
 $m(\text{NH}_4\text{OH})$  in 20.00 mL =  $0.02471 \times 35.0$   
 $= 0.8647$  g  
 $c(\text{NH}_4\text{OH})$  in  $\text{g L}^{-1}$  =  $0.8647 \times (1000/20)$   
 $= 43.2$   $\text{g L}^{-1}$

One mark each was awarded for:

- accurately calculating  $n(\text{HCl})$  from the answers to Questions 2a. and 2b.
- indicating  $n(\text{NH}_3) = n(\text{HCl})$
- correctly using the  $M(\text{NH}_4\text{OH})$
- correctly converting from amount in 20.00 mL to amount in one litre.

Responses needed to be given using the appropriate units; for example, multiplying  $n(\text{NH}_4\text{OH}) \times (1000/20)$  and giving the answer as  $\text{g L}^{-1}$ .

**2cii.**

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 84 | 16 | <b>0.2</b> |

Acceptable explanations for the students' results being slightly lower than the manufacturer's claim were those that would lead to a higher titre and the calculation of more HCl in excess, less HCl reacting with  $\text{NH}_4\text{OH}$  and less  $\text{NH}_3$  in the aliquot of cloudy ammonia. These included:

- some  $\text{NH}_3$  evaporating prior to the titration with NaOH
- burette rinsed with water
- titration flask rinsed with Solution A
- endpoint of the titration was overshot.

Many students found it difficult to provide a reasonable response for the difference between the manufacturer's claimed value and the calculated value. Many students stated 'the pipette was rinsed with water', but this was not considered specific enough. It would be expected that 20.00 mL pipettes would have been used for the aliquot of cloudy ammonia and the aliquots of Solution A, and a pipette may have been used for the 100.00 mL of HCl added to the cloudy ammonia.

The impact of rinsing the pipette used to transfer aliquots of Solution A with water would probably have no effect. The titre for the first aliquot would be higher than it should be, but since the same pipette would be used for subsequent aliquots and concordant titres were achieved, the first titre would probably not be used in calculating the mean titre.

## Question 3

## 3a.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 23 | 26 | 50 | 1.3     |

Ester due to the lack of the broad O–H (acid) absorption band (stretch) at 2500–3300  $\text{cm}^{-1}$

One mark each was awarded for:

- determining that the molecule was an ester
- explaining why OH(acid) was not present.

Many students who correctly identified the molecule as that of an ester did not adequately explain how that was deduced from the IR spectrum. It was not sufficient to simply state 'no OH'.

## 3b.

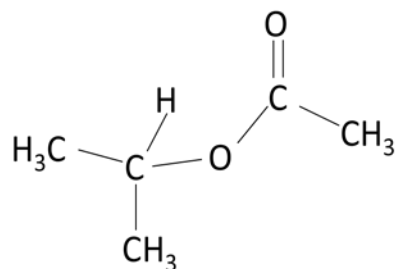
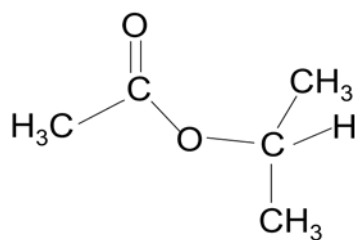
| Marks | 0 | 1  | 2  | Average |
|-------|---|----|----|---------|
| %     | 8 | 39 | 53 | 1.5     |

|  |   |
|--|---|
| Number of different chemical environments for hydrogen | 3 |
| Number of different chemical environments for carbon   | 4 |

There were three sets of peaks on the  $^1\text{H}$  NMR spectrum and four distinct peaks on the  $^{13}\text{C}$  NMR spectrum. Students should be aware that the TMS peak is a reference peak for chemical shift and is not used in determining the number of H or C environments.

## 3c.

| Marks | 0  | 1 | 2  | Average |
|-------|----|---|----|---------|
| %     | 70 | 1 | 29 | 0.6     |



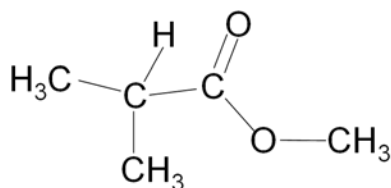
The  $^1\text{H}$  NMR shows:

- a septet – consistent with six neighbouring H atoms on two  $\text{CH}_3$  groups
- a doublet – consistent with one neighbouring H atom
- the septet and doublet combination is consistent with the presence of  $-\text{CH}(\text{CH}_3)_2$
- a singlet – consistent with no neighbouring H atoms
- a chemical shift around 5 for the septet, suggesting that the signal is for the H atom(s) on a C atom bonded to an O atom on the ester group
- a chemical shift around 2 for the singlet, suggesting that the signal is for the H atom(s) on a C atom bonded to the C atom on the ester group.

This data, in conjunction with three hydrogen environments, four carbon environments and the molecular formula,  $\text{C}_5\text{H}_{10}\text{O}_2$ , suggests  $-\text{CH}(\text{CH}_3)_2$  is attached to an O atom on the ester group, that is,  $\text{OCH}(\text{CH}_3)_2$ , and  $\text{CH}_3$  is attached to the C atom of the ester group – that is,  $\text{CH}_3\text{CO}$ .

The semi-structural formula is  $\text{CH}_3\text{COOCH}(\text{CH}_3)_2$ .

Another structure consistent with all the data except the chemical shift values is:



Expanded structures (showing all bonds correctly) were accepted.

#### Question 4

4a.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 37 | 13 | 50 | 1.2     |

Approximately 630 nm (600–650 was accepted)

At 630 nm only Solution B absorbs strongly/Solution B absorbs strongly with no significant absorbance by Solution A.

One mark each was awarded for:

- identifying the wavelength to be used
- indicating that only Solution B must absorb at that wavelength.

It appeared that some students misread the question and selected a wavelength at which the absorbance of both Solutions A and B could be measured, rather than one at which Solution B could be absorbed without interference from Solution A.

4b.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 24 | 38 | 38 | 1.2     |

$$\begin{aligned}
 c[\text{Co}(\text{NO}_3)_2] &= 10 \text{ mM} \\
 &= 10 \times 10^{-3} \text{ mol L}^{-1} \\
 &= 10 \times 10^{-3} \times 182.9 \\
 &= 1.8 \text{ g L}^{-1} \\
 &= 1.8 \times 10^3 \text{ mg L}^{-1}
 \end{aligned}$$

One mark each was awarded for:

- accurately obtaining the concentration from the calibration curve
- accurately multiplying by correct molar mass and giving answer in  $\text{mg L}^{-1}$ .

Most students accurately determined the concentration of Solution A, but few successfully converted the concentration to  $\text{mg L}^{-1}$  of  $\text{Co}(\text{NO}_3)_2$ .

The question stated that  $1 \text{ mM} = 10^{-3} \text{ M}$  and it was necessary to use this figure.

Many students read the wrong calibration curve.

## 4c.

| Marks | 0  | 1 | 2  | Average |
|-------|----|---|----|---------|
| %     | 65 | 9 | 25 | 0.6     |

Solution concentration  $1.5 \times 10^{-2} \text{ M} = 15 \text{ mM}$ . This is:

- on the calibration curve of Solution A, so the calibration curve can be used to determine solution concentration
- beyond the calibration curve of Solution B/calibration curve cannot be used for Solution B unless the solution is diluted to bring it within range/calibration curve for Solution B would have to be extrapolated and this is not reliable.

One mark each was awarded for:

- accurate explanation of why the graph can be used directly for Solution A
- recognition that the graph cannot be used directly for Solution B.

Many students assumed, incorrectly, that the same wavelength had been used to determine the calibration curves for both solutions, with minimal consideration given to the stated concentration.

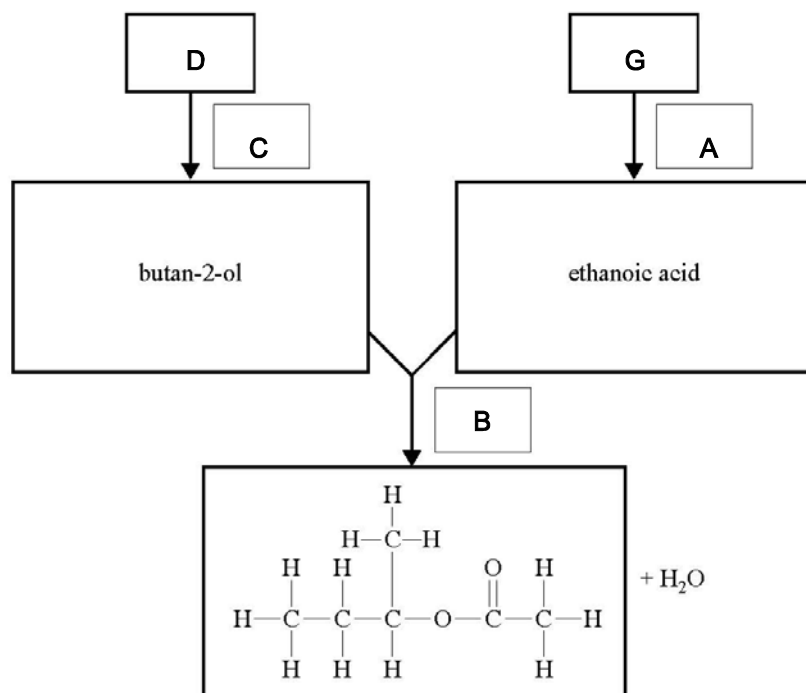
Students who presented only the argument that 'there is no suitable wavelength for analysis of A if B is in the mixture' were awarded one mark.

Students are reminded that they should be able to apply learning in familiar and unfamiliar contexts.

## Question 5

## 5a.

| Marks | 0 | 1 | 2  | 3  | 4  | 5  | Average |
|-------|---|---|----|----|----|----|---------|
| %     | 5 | 5 | 10 | 10 | 10 | 59 | 4       |



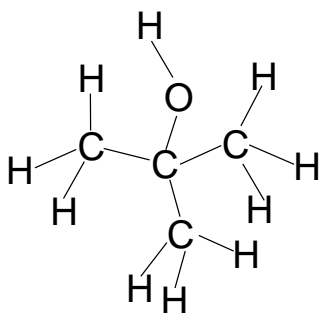
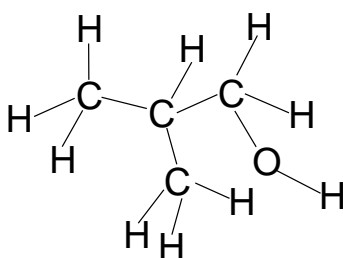
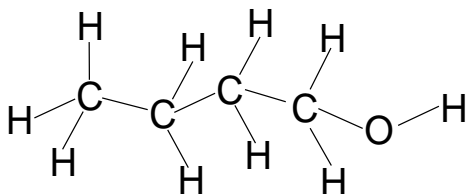
This question was related to basic organic chemical pathways covered in Unit 3 and was generally answered well.

However, some students did not follow the instruction to 'write the corresponding letter' in the boxes provided and instead included names and/or formulas. Incomplete detail such as writing 'H<sub>2</sub>SO<sub>4</sub>' rather than 'concentrated H<sub>2</sub>SO<sub>4</sub>' was also not awarded marks.

**5b.**

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 56 | 44 | <b>0.5</b> |

Acceptable structures included:



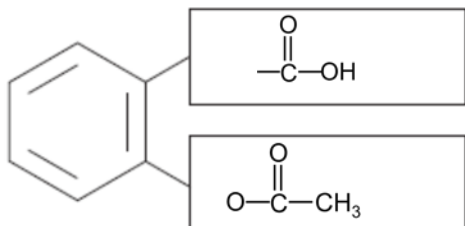
It was evident that many students read the question as the isomer butan-2-ol rather than a different compound that is isomeric with (has the same molecular formula as) butan-2-ol. The presence of butan-1-ol in the table as compound F was ignored by most students.

When asked to draw a full structural formula, students are reminded that all bonds including the O–H bond must be shown.



## 5ci.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 40 | 24 | 36 | 1       |



This question assessed students' understanding of the production of aspirin. Most errors resulted from the assumption that reaction with ethanoic anhydride occurs at the carboxyl group on salicylic acid rather than the hydroxyl group – the correct location. Some students who did select the correct reaction site mistakenly showed  $-\text{COOCH}_3$  as the result of the reaction rather than  $-\text{OOCCH}_3$  or  $-\text{O.COCH}_3$ .

## 5cii.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 24 | 42 | 34 | 1.1     |

The catalyst:

- decreases the activation energy by providing an alternative reaction pathway
- increases the proportion of successful (fruitful) collisions.

Students needed to refer to both activation energy and the increase in successful collisions. While students were well versed in the knowledge that catalysts provide an alternative reaction pathway with lower activation energy, most neglected to explain that this leads to a faster rate because of the associated increase in the proportion of collisions that are successful.

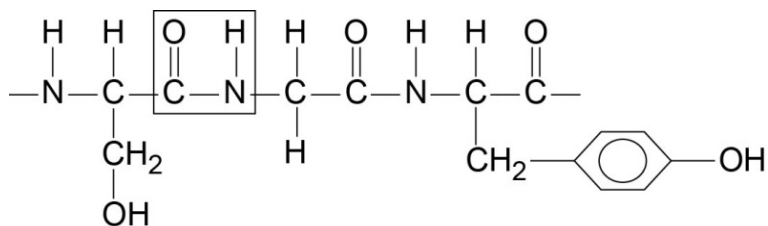
Students are encouraged to consider all factors that impact on reaction rate from the collision theory viewpoint.

Students should be aware that the presence of a catalyst does not change the amount of collisions but, because the alternative pathway it provides has lower activation energy, more of these collisions are successful (have energy equal to or greater than the activation energy).

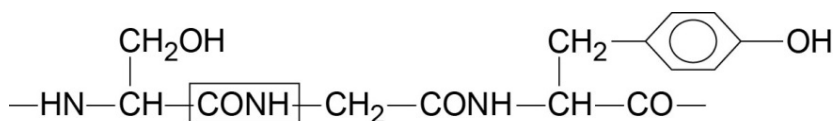
## Question 6

6ai.

| Marks | 0  | 1  | 2  | 3  | Average |
|-------|----|----|----|----|---------|
| %     | 20 | 27 | 36 | 16 | 1.5     |



or



One mark each was awarded for:

- three correct side groups in position,  $-\text{CH}_2\text{OH}$ ,  $-\text{H}$ ,  $-\text{CH}_2\text{C}_6\text{H}_4\text{OH}$
- two peptide groups only/correct backbone with open bonds at ends
- peptide group or amide link correctly indicated.

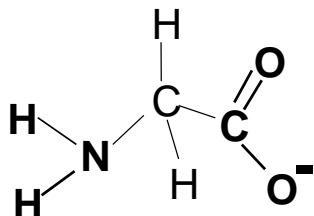
This question proved difficult for some students. The peptide group was often incorrectly shown, quite often with an O atom linked between C and N, and often the peptide group was either not or incorrectly circled/highlighted.

In a number of responses bonds were not left open at both ends, which is a requirement when representing part of the protein chain as shown in the -ser-gly-tyr- sequence.

Other errors included incorrect representation of the benzene ring when showing the tyrosine structure and selecting tryptophan rather than tyrosine as 'tyr'.

6aii.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 51 | 49 | 0.5     |



Students should be aware that in an alkaline solution, amino acids are deprotonated; the  $-\text{COOH}$  group is converted to  $-\text{COO}^-$ .

**6bi.**

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 11 | 89 | 0.9     |

–GTCGTC–

**6bii.**

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 13 | 29 | 59 | 1.5     |

Hydrogen bonding between base pairs is weaker than the (covalent) bonding between the components in a single strand of DNA.

Students should be aware of the relative strengths of hydrogen and covalent bonds.

**6biii.**

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 27 | 32 | 41 | 1.2     |

The bases in a DNA strand are attached to deoxyribose by covalent bonding.

The popularity of hydrogen bonding in responses suggests that many students did not distinguish the bonds within the strands (covalent bonds) from the bonds between the strands (hydrogen bonds).

**Question 7****7a.**

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 18 | 82 | 0.8     |

- $K = [\text{NOBr}]^2/[\text{NO}]^2[\text{Br}_2]$
- $[\text{NOBr}]^2/[\text{NO}]^2[\text{Br}_2]$
- $1.3 \times 10^{-2} = [\text{NOBr}]^2/[\text{NO}]^2[\text{Br}_2]$

**7b.**

| Marks | 0  | 1  | 2  | 3  | Average |
|-------|----|----|----|----|---------|
| %     | 53 | 12 | 12 | 23 | 1.1     |

$$CF = [\text{NOBr}]^2/[\text{NO}]^2[\text{Br}_2] \text{ or } CF = [\text{NOBr}]^2/[\text{NO}]^2[\text{Br}_2]$$

$$= 10.0^2/(10.0^2 \times 5.0)$$

$$= 0.2$$

$CF(Q) > K_c$ , so system shifts to decrease the concentration fraction (at equilibrium  $Q = K_c$ ), and therefore the reverse reaction is favoured.

One mark each was awarded for

- correct calculation of the reaction quotient (concentration fraction)
- recognising that  $Q > K_c$  and  $Q$  will decrease
- stating reverse reaction is favoured (but not based on Le Châtelier's principle).

This question provided data to be used to calculate the concentration fraction to show the system was not at equilibrium, and so predict the direction in which the reaction would proceed. Many responses used Le Châtelier's principle, which overlooked the fact that it is used to explain the effect of changes to a system that is already at equilibrium. It was necessary to calculate the concentration fraction and compare it with the equilibrium constant.

Some students who correctly calculated the concentration fraction deduced that the reaction proceeded left but did not explain why.

Students need to be aware that explanation of how an initial mixture of reactants and products gets to equilibrium is not a reflection of Le Châtelier's principle.

## 7c.

| Marks | 0  | 1  | 2  | 3 | Average |
|-------|----|----|----|---|---------|
| %     | 36 | 34 | 22 | 8 | 1.1     |

| Time                    | Explanation  |
|-------------------------|--|
| between $t_0$ and $t_1$ | <ul style="list-style-type: none"> <li>The system is at equilibrium, so the rates of the forward and reverse reactions are equal; hence, the rate of formation of NOBr is constant.</li> <li>Frequency of successful collisions (between NO and Br<sub>2</sub>) is constant.</li> </ul>  |
| at $t_1$                | A volume decrease has the immediate effect of increasing all concentrations, and therefore increasing the frequency (number) of collisions between NO and Br <sub>2</sub> , so the rate of formation of NOBr increases.  |
| between $t_1$ and $t_2$ | <p>The rate of formation of NOBr decreases because:</p> <ul style="list-style-type: none"> <li>the forward reaction – formation of NOBr – is favoured, so as the reactant concentrations [NO] and [Br<sub>2</sub>] decrease, the frequency of collisions decreases and the rate of this reaction decreases</li> <li>as the [NOBr] increases due to the forward reaction being favoured, the rate of decomposition of NOBr (reverse reaction) increases, so the net effect is a decrease in the rate of formation of NOBr.</li> </ul> |

One mark each was awarded for explaining why the rate of formation:

- is constant between  $t_0$  and  $t_1$
- of NOBr increases at  $t_1$
- of NOBr decreases between  $t_1$  and  $t_2$ .

Interpretation of the rate–time graph for the formation of NOBr proved a challenge for most students. Many treated it as a concentration–time graph and were unable to provide appropriate collision-based explanations of the shape of the graph.

Students should be aware that reaction rate depends on the frequency of successful collisions between reactant particles and consider three stages of the graph from this viewpoint.

- Initially from  $t_0$  to  $t_1$ , the system is at equilibrium so the frequency of successful collisions between NO and Br<sub>2</sub> is constant and the reaction rate is constant as indicated by the horizontal line.
- At  $t_1$ , as a result of the volume decreases, the [NO] and [Br<sub>2</sub>] instantaneously increases as does the frequency of successful collisions and hence the reaction rate.
- From  $t_1$  to  $t_2$ , the system is compensating for the pressure increase (due to the volume increase) at  $t_1$  by moving to the side with fewer particles. The associated decrease in [NO] and [Br<sub>2</sub>] reduces the frequency of successful collisions and the reaction decreases as the system returns to equilibrium.

The rate of reaction when the system returns to equilibrium is higher than before the volume decreases because the system only partially compensates for the change when equilibrium is re-established. Therefore, the rate of formation of NOBr is still higher than prior to the imposed change because the final concentrations of NO and Br<sub>2</sub> are higher than at the original equilibrium.

**Question 8****8a.**

| Marks | 0  | 1  | 2  | Average    |
|-------|----|----|----|------------|
| %     | 64 | 21 | 16 | <b>0.5</b> |

Assumption 1:  $K_{a2}$  (second ionisation) is much smaller than  $K_{a1}$  (first ionisation), so the second ionisation has negligible impact on the  $[\text{H}_3\text{O}^+]$  and pH.

Assumption 2:  $K_{a1}$  (first ionisation) is very small and so the extent of ionisation of  $\text{H}_2\text{S}$  is very small and the change in  $[\text{H}_2\text{S}]$  is minimal.

**8b.**

| Marks | 0  | 1 | 2 | 3  | Average    |
|-------|----|---|---|----|------------|
| %     | 38 | 6 | 6 | 50 | <b>1.7</b> |

$$K_{a1} = \frac{[\text{HS}^-][\text{H}_3\text{O}^+]}{[\text{H}_2\text{S}]}$$

$$9.6 \times 10^{-8} = \frac{[\text{H}_3\text{O}^+]^2}{0.01}$$

$$[\text{H}_3\text{O}^+]^2 = 0.01 \times 9.6 \times 10^{-8}$$

$$[\text{H}_3\text{O}^+] = \sqrt{9.6 \times 10^{-10}}$$

$$= 3.1 \times 10^{-5} \text{ M}$$

$$\text{pH} = -\log_{10}(3.1 \times 10^{-5})$$

$$= 4.5$$

One mark each was awarded for:

- setting up equilibrium law
- accurate calculation of  $[\text{H}_3\text{O}^+]$
- accurate calculation of pH from  $[\text{H}_3\text{O}^+]$  calculated using equilibrium law.

As well as using the assumptions given in part a., students were also required to apply a standard assumption in weak acid calculations, that the contribution to the  $[\text{H}_3\text{O}^+]$  from the self-ionisation of water is negligible and so  $[\text{HS}^-] = [\text{H}_3\text{O}^+]$ .

Some students assumed that the  $[\text{H}_3\text{O}^+]$  was 0.01 M and calculated a pH of 2. However, to receive a mark for the pH calculation, it needed to be based on  $[\text{H}_3\text{O}^+]$  determined from the equilibrium law.

**8c.**

| Marks | 0  | 1 | 2  | Average    |
|-------|----|---|----|------------|
| %     | 61 | 9 | 30 | <b>0.7</b> |

Adding NaHS will increase the  $[\text{HS}^-]$ . This pushes the first ionisation equilibrium to the left (favouring reverse reaction), causing the  $[\text{H}_3\text{O}^+]$  to decrease and the pH to increase.

Students were expected to refer to the impact of the addition of  $\text{HS}^-(\text{aq})$  on the direction of the first equilibrium and the impact of the subsequent change in  $[\text{H}_3\text{O}^+]$  on pH. Some may have been confused by the presence of  $\text{HS}^-(\text{aq})$  in both equilibria and its addition pushing the second equilibrium to the right as well as the first equilibrium to the left. However, the relative size of the  $K_a$  values suggests that the first equilibrium will be impacted more.

One mark each was awarded for:

- effect of adding NaHS on the equilibrium position
- pH increase due to decrease in  $[\text{H}_3\text{O}^+]$ .

**Question 9****9a.**

| Marks | 0  | 1  | 2  | Average    |
|-------|----|----|----|------------|
| %     | 34 | 50 | 17 | <b>0.9</b> |

- glycerol soluble in water due to hydroxyl groups/hydrogen bonding
- methanol soluble in water due to hydroxyl groups/hydrogen bonding
- potassium hydroxide/potassium ions/hydroxide ions – soluble in water by ion-dipole bonding/all potassium compounds are soluble in water

This question was challenging for some students. In many cases the justification provided was superficial, and many responses simply stated that the substance was 'soluble in water'. Students needed to give a reason why the substance was soluble in water.

The instruction to 'name **one** substance' required students to give the name of the substance, not its chemical formula.

Students should know that fatty acid esters are non-polar and so would not be expected to be in the aqueous layer.

**9b.**

| Marks | 0  | 1  | Average    |
|-------|----|----|------------|
| %     | 56 | 44 | <b>0.5</b> |

There is approximately twice as much of methyl ester B as there is of methyl ester A or methyl ester A and methyl ester B are present in 1:2 ratio/[B] = 2 × [A].

Many students missed the link between chromatogram peak areas and relative amounts of components. Some focused more on the mass-to-charge ratios provided. Students need to be able to identify data relevant to the question being answered.

**9c.**

| Marks | 0  | 1  | 2  | Average    |
|-------|----|----|----|------------|
| %     | 47 | 29 | 24 | <b>0.8</b> |

Name: Methyl stearate

Semi-structural formula:  $\text{CH}_3(\text{CH}_2)_{16}\text{COOCH}_3$

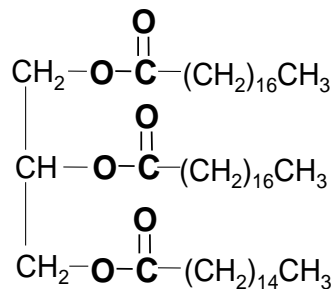
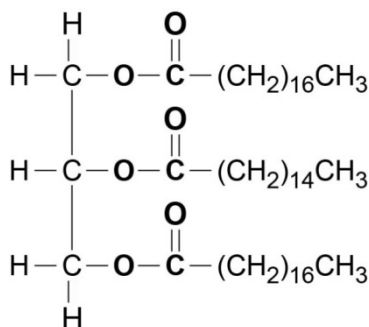
The mass-to-charge ratios provided in Question 9b. were the key to answering this question. Given the formula for methyl ester A,  $\text{CH}_3(\text{CH}_2)_{14}\text{COOCH}_3$ , methyl ester B, which according to the mass-to-charge ratios has a molar mass 28 higher than that of A, it must contain two extra  $\text{CH}_2$  groups ( $2 \times 14 = 28$ ).

Methyl ester B is  $\text{CH}_3(\text{CH}_2)_{16}\text{COOCH}_3$ . Using the formulas of some fatty acids in the data book, the ester is related to stearic acid and is named methyl stearate.

Just over half the students gave the correct semi-structural formula, but less than half of those were able to name it correctly. Chemical formulas and names of substances must be fully correct to gain marks.

## 9d.

| Marks | 0  | 1  | 2  | 3  | Average |
|-------|----|----|----|----|---------|
| %     | 48 | 13 | 20 | 19 | 1.1     |



One mark each was awarded for:

- correct fatty acid residues, with 2 × (CH<sub>2</sub>)<sub>16</sub> and 1 × (CH<sub>2</sub>)<sub>14</sub>
- accurate representation of the ester group
- accurate glycerol backbone including O.

The overall quality of structures drawn suggested that many students have had limited practice in drawing the structure of a triglyceride. The glycerol backbone and its link to the ester groups is common to all triglycerides. Some students did not allow for the 2:1 ratio in the stearate and palmitate.

## 9ei.

| Marks | 0  | 1  | 2  | 3  | Average |
|-------|----|----|----|----|---------|
| %     | 24 | 12 | 20 | 44 | 1.9     |

$$\begin{aligned}
 n(\text{C}_{17}\text{H}_{34}\text{O}_2) &= 2.28 \text{ g} / 270.0 \text{ g mol}^{-1} \\
 &= 8.44 \times 10^{-3} \text{ mol}
 \end{aligned}$$

$$\begin{aligned}
 \text{Energy released} &= 42.4 \text{ kJ } ^\circ\text{C}^{-1} \times 1.18 \text{ } ^\circ\text{C} \\
 &= 50.0 \text{ kJ}
 \end{aligned}$$

$$\begin{aligned}
 \Delta H_c &= 50.0 \text{ kJ} / 8.44 \times 10^{-3} \text{ mol} \\
 &= 5.93 \times 10^3 \text{ kJ mol}^{-1} / 5.93 \times 10^6 \text{ J mol}^{-1}
 \end{aligned}$$

One mark each was awarded for:

- accurately calculated  $n(\text{C}_{17}\text{H}_{34}\text{O}_2)$
- accurately calculated energy released
- accurately calculated  $\Delta H_c$  and correct units.

This was a standard calculation of molar enthalpy of combustion from calorimetry data.

Students should be familiar with the relationships ' $n = m/M$ ' and ' $\text{energy} = \text{calorimeter constant} \times \Delta T$ ', and know that 'molar enthalpy of combustion' is the energy released by one mole during combustion.

Since units were not specified in the question, they were an essential part of the final answer. Omitted or incorrect units were relatively common.

## 9eii.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 44 | 39 | 17 | 0.8     |

- $C_{17}H_{34}O_2(l) + 24.5O_2(g) \rightarrow 17CO_2(g) + 17H_2O(g)$ ,  $\Delta H = -5.92 \times 10^3 \text{ kJ mol}^{-1}$
- $2C_{17}H_{34}O_2(l) + 49O_2(g) \rightarrow 34CO_2(g) + 34H_2O(g)$ ,  $\Delta H = -1.18 \times 10^4 \text{ kJ mol}^{-1}$

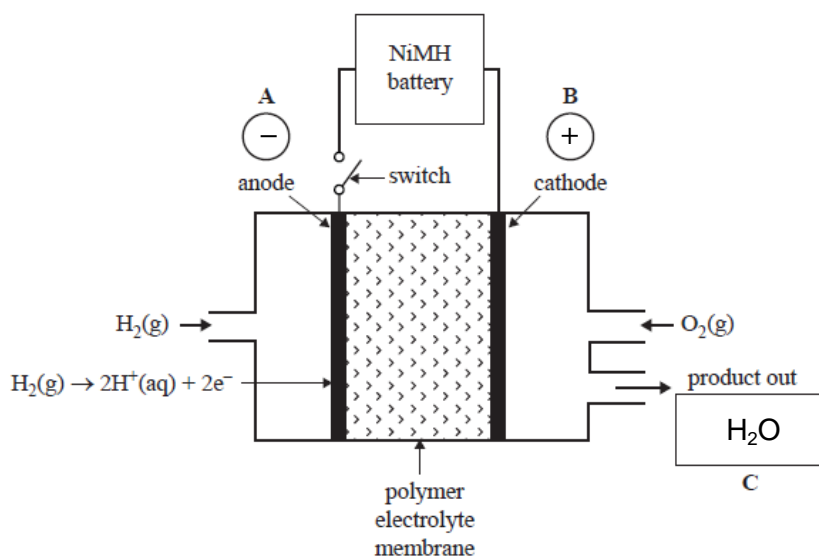
The most common errors were an incorrect coefficient for  $O_2$  and  $\Delta H$  value not consistent with the equation stoichiometry.

When balancing such combustion equations, students should balance C first, then H and then O, remembering to subtract the number of O atoms in the fuel from the total number of O atoms on the product side before determining the coefficient of  $O_2$ .

## Question 10

## 10ai.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 12 | 32 | 56 | 1.5     |



## 10aii.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 46 | 54 | 0.6     |

Cathode reaction:  $O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(g)$

Students should be aware that in a fuel cell the fuel is oxidised at the anode and oxygen is reduced at the cathode. The half-equation for the reduction of  $O_2$  in an acidic fuel cell can be deduced using the electrochemical series. However, when writing half-equations for specific cells, equilibrium arrows are not included. The electrochemical series shows the half-equations as reversible because the direction is determined by the other reacting species.

Whilst the half-equation provided in the electrochemical series in the data book shows  $H_2O(aq)$ , that was not appropriate in this question because the cell reaction given showed  $H_2O(g)$ .



## 10a.iii.

| Marks | 0  | 1  | 2  | Average |
|-------|----|----|----|---------|
| %     | 30 | 42 | 28 | 1       |

## Advantages

- highly efficient compared to petrol engine
- no CO<sub>2</sub> or other pollutants such as CO or unburnt hydrocarbons produced

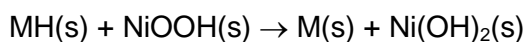
## Disadvantages

- relative cost
- difficulties in accessing and storing hydrogen
- risk of leaking hydrogen reacting explosively

Many students gave responses such as 'no greenhouse gases' as an advantage, and 'needs a constant supply of fuel' as a disadvantage. Such responses suggested students had a lack of awareness of the greenhouse gas nature of water vapour and a limited understanding of the role of the petrol tank in a common vehicle.

## 10bi.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 39 | 61 | 0.6     |



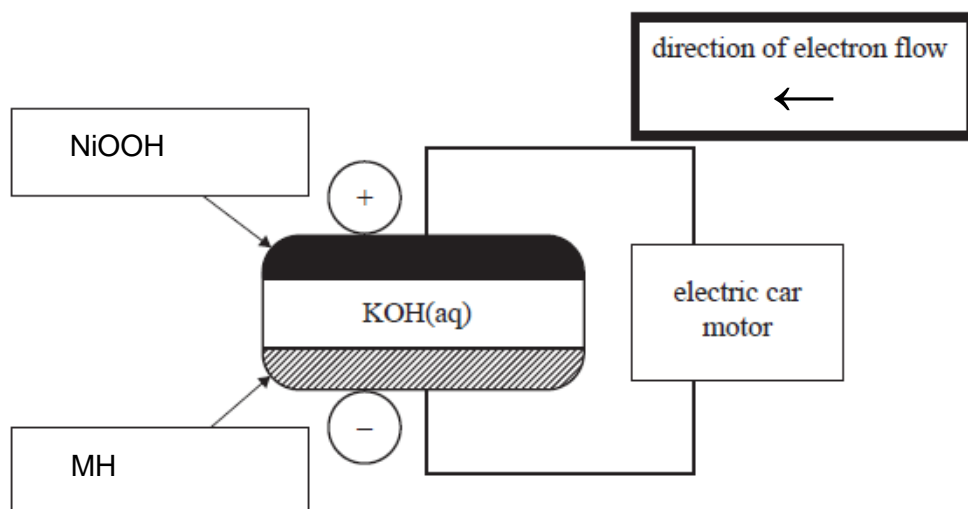
The equation for the discharging reaction was the reverse of the sum of the half-equations provided for the recharging reaction.

## 10bii.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 42 | 58 | 0.6     |

## 10biii.

| Marks | 0  | 1  | Average |
|-------|----|----|---------|
| %     | 40 | 60 | 0.6     |



During discharging, electrons flow from (-) to (+), from the oxidation of MH to the reduction NiOOH.

**10biv.**

| Marks | 0  | 1 | 2  | 3  | Average |
|-------|----|---|----|----|---------|
| %     | 22 | 6 | 13 | 59 | 2.1     |

$$\begin{aligned}
 Q &= It \\
 &= 1.15 \times 60 \times 60 \\
 &= 4.14 \times 10^3 \text{ C} \\
 n(\text{e}^-) &= Q/F \\
 &= 4.14 \times 10^3 / 96\,500 \\
 &= 0.0429 \text{ mol} \\
 n(\text{NiOOH}) &= 0.0429 \text{ mol} \\
 m(\text{NiOOH}) &= n(\text{NiOOH}) \times M(\text{NiOOH}) \\
 &= 0.0429 \times 91.7 \\
 &= 3.9 \text{ g}
 \end{aligned}$$

One mark each was awarded for:

- accurate calculation of charge
- accurate calculation of  $n(\text{NiOOH})$
- accurate calculation of  $m(\text{NiOOH})$ .

The most common error was using the molar mass of Ni rather than the required molar mass of NiOOH.

**10c.**

| Marks | 0  | 1 | 2  | 3  | Average |
|-------|----|---|----|----|---------|
| %     | 18 | 9 | 28 | 44 | 2       |

$$\begin{aligned}
 n(\text{H}_2) &= pV/RT \\
 &= 70.0 \times 10^3 \text{ kPa} \times 122.4 \text{ L} / (8.31 \times 298 \text{ K}) \\
 &= 3.46 \times 10^3 \text{ mol} \\
 m(\text{H}_2) &= n(\text{H}_2) \times M(\text{H}_2) \\
 &= 3.46 \times 10^3 \times 2.0 \\
 &= 6.92 \times 10^3 \text{ g} \\
 &= 6.9 \text{ kg}
 \end{aligned}$$

One mark each was awarded for:

- correct pressure and temperature units in gas equation
- accurate calculation of  $n(\text{H}_2)$
- accurate calculation of  $m(\text{H}_2)$  in kilograms.

The two most frequent errors were using the molar mass of H rather than the molar mass of  $\text{H}_2$ , and not converting to kilograms.

## Question 11

| Marks | 0  | 1 | 2  | 3  | 4  | 5 | 6  | Average |
|-------|----|---|----|----|----|---|----|---------|
| %     | 15 | 7 | 18 | 10 | 25 | 8 | 17 | 3.2     |

Acceptable responses included those indicated in the table below.

| Brief description of error  | Prediction and justification   |
|---|--|
| Experimental procedure error<br>The rock should be crushed to allow all the Fe in the ore to react with HCl(aq).                              | Prediction<br>% Fe calculated lower than true value.<br>Justification<br>Less Fe <sub>2</sub> O <sub>3</sub> collected, hence lower <i>m</i> (Fe) and lower % Fe calculated.   |
| Experimental procedure error<br>The 500 mL beaker should be weighed.  | Prediction<br>% Fe calculated lower than true value.<br>Justification<br>Higher <i>m</i> (ore) used in calculation of % Fe.  |
| Experimental procedure error<br>HCl(aq) should be in excess to ensure all the Fe in the ore is extracted.                                     | Prediction<br>% Fe calculated lower than true value<br>Justification<br>Less Fe <sub>2</sub> O <sub>3</sub> collected, hence lower <i>m</i> (Fe) and lower % Fe calculated   |
| Experimental procedure error<br>The solution should be filtered prior to adding NaOH.   | Prediction<br>Soluble impurities contribute to final mass. <i>m</i> (Fe <sub>2</sub> O <sub>3</sub> ) higher<br>Justification<br>% Fe calculated higher than true value  |
| Experimental procedure error<br>Excess NaOH(aq) should be added to ensure all the Fe <sup>3+</sup> (aq) precipitates as Fe(OH) <sub>3</sub> . | Prediction<br>% Fe calculated lower than true value<br>Justification<br>Less Fe <sub>2</sub> O <sub>3</sub> collected, hence lower <i>m</i> (Fe) and lower % Fe calculated   |
| Experimental procedure error<br>Fe(OH) <sub>3</sub> precipitate should be rinsed with distilled water to remove soluble impurities.           | Prediction<br>% Fe calculated higher than true value<br>Justification<br>Impurities present make it seem that more Fe <sub>2</sub> O <sub>3</sub> was collected, hence higher <i>m</i> (Fe) and higher % Fe calculated |

| Brief description of error  | Prediction and justification  |
|---|---|
| <p>Experimental procedure error</p> <p>The crucible should be heated to constant mass to ensure the <math>\text{Fe}_2\text{O}_3</math> collected is dry and all the <math>\text{Fe}(\text{OH})_3</math> has been converted to <math>\text{Fe}_2\text{O}_3</math>.</p> | <p>Prediction</p> <p>% Fe calculated higher than true value</p> <hr/> <p>Justification</p> <p>Water present makes it seem that more <math>\text{Fe}_2\text{O}_3</math> was collected, hence higher <math>m(\text{Fe})</math> and higher % Fe calculated</p>             |
| <p>Experimental procedure error</p> <p>Filter paper is not needed if a sintered crucible is used.</p>   | <p>Prediction</p> <p>% Fe calculated higher than true value</p> <hr/> <p>Justification</p> <p>Filter paper may not totally burn and would add weight to <math>\text{Fe}_2\text{O}_3</math> collected, leading to a higher <math>m(\text{Fe})</math> and higher % Fe</p> |
| <p>Experimental procedure error</p> <p>Filter paper (filter and crucible) should be weighed prior to adding precipitate.</p>  | <p>Prediction</p> <p>% Fe calculated higher than true value</p> <hr/> <p>Justification</p> <p><math>m(\text{Fe}_2\text{O}_3)</math> collected included filter paper, leading to a higher <math>m(\text{Fe})</math> and higher % Fe</p>                                  |
| <p>Calculation error</p> <p><math>m(\text{filter paper and dried } \text{Fe}_2\text{O}_3)</math> is not the same as the <math>m(\text{Fe})</math>:<br/> <math>\% \text{ Fe} = [m(\text{Fe})/m(\text{ore sample})] \times 100</math></p>                               | <p>Prediction</p> <p>% Fe calculated higher than true value</p> <hr/> <p>Justification</p> <p><math>m(\text{Fe}_2\text{O}_3)</math> collected included filter paper, leading to a higher <math>m(\text{Fe})</math> and higher % Fe</p>                                  |
| <p>Calculation error</p> <p><math>m(\text{Fe})</math> was not used in the calculation of % Fe.</p>  | <p>Prediction</p> <p>% Fe calculated higher than true value</p> <hr/> <p>Justification</p> <p><math>m(\text{Fe}_2\text{O}_3)</math> collected is higher than <math>m(\text{Fe})</math>, leading to higher % Fe</p>  |
| <p>Calculation error</p> <p>The number of significant figures should be consistent with the data.</p>   | <p>Prediction</p> <p>% Fe calculated higher than true value</p> <hr/> <p>Justification</p> <p>Data used in calculation leads to <math>m(\text{Fe}) = 4.06\%</math>. Expressed to two significant figures (4.1) increases % Fe</p>                                       |

Most students answered this question relatively well, although more practice is needed in the analysis of experimental techniques, recorded data and associated calculations.

Students' ability to discuss the appropriateness of practical procedures and associated calculations is related to their practical experience throughout VCE Chemistry. Responses to this question suggested that further discussion of procedures and associated calculations when considering experimental work is needed.

It is important that students respond as directed by the question. A number of students did not complete the 'Brief description of error' column and attempted to cover all aspects in the 'Prediction and justification' column, which resulted in confused responses.

Many of the procedure errors identified by students referred to weighing the 500 mL beaker and filter paper. Valid explanations as to why not weighing the beaker would lead to a lower % Fe in the ore, assuming that the recorded  $m(\text{ore})$ , 31.54 g, included the  $m(\text{beaker})$ , were accepted. However, the statement that 'The rock was weighed into a 500 mL beaker' may also suggest that the balance was tared with the beaker on it, prior to adding the rock. The recorded  $m(\text{ore sample})$ , 31.54 g, is unlikely to include the mass of a 500 mL beaker. The fact that the filter paper was not weighed was a common suggested error. However, marks were only awarded for one procedure or calculation error, not for both. While many students recognised that the calculation of the % Fe shown inappropriately included the  $m(\text{filter paper})$ , the incorrect use of  $m(\text{Fe}_2\text{O}_3)$  was less well recognised.

The procedure, to be effective and accurate, would need to include steps such as:

- crushing the rock to allow for effective reaction with  $\text{HCl}(\text{aq})$
- filtering to remove undissolved solids before adding  $\text{NaOH}(\text{aq})$
- testing to check if all  $\text{Fe}^{3+}$  has precipitated as  $\text{Fe}(\text{OH})_3$
- rinsing the  $\text{Fe}(\text{OH})_3$  to remove any soluble impurities
- heating the crucible to constant mass.

Using a sintered or Gooch crucible would have removed the need for filter paper. However, the crucible would need to be weighed appropriately.

A useful learning exercise for students may be writing a more detailed description of this experimental procedure.