2014 Examination Report

GENERAL COMMENTS

The 2014 VCE Chemistry examination was based on the key knowledge and key skills for both Units 3 and 4.

In Section A, the most challenging questions were Question 11, which required students to balance a skeleton equation for a redox reaction by considering the half-equations, and Question 30, which related to an experimental context less familiar to students. Students were expected to apply their knowledge in familiar and unfamiliar contexts.

Other areas that require improvement included:
- differences in solutions of weak acids and strong acids (Question 3)
- the distinction between acid strength and concentration (Question 5)
- titration curves and dependence of titration endpoint on acid/base strength (Question 6)
- chemical formula of calcium hydroxide (Question 7)
- conversion between concentration units (Question 17)
- identifying the appropriate analytical technique for a specific analysis (Question 18)
- systematic nomenclature rules (Question 19)
- interpretation of the formula $CH_4.6H_2O$ (Question 23)
- use of electrochemical series to check the possibility of a redox reaction (Question 26)
- predictions based on electrochemical series assuming standard conditions (Question 27)
- role of half-equations in electrochemistry calculations (Question 29).

In Section B, student performance varied markedly depending on the type of question asked. Some questions related directly to electrochemistry and required descriptive responses and overall performance on these questions was quite low. Question 9 in particular revealed concerns with effective reading of question information, the use of appropriate states and arrow notations in half-equations, and the use of accurate chemical language.

When asked to produce graphs on supplied grids, performance was stronger on energy profiles (Question 1a.) than concentration time graphs (Questions 6bi. and 6bii.).

Question 3a. was notable for the variety of valid solution techniques adopted by students. Students are reminded that the most obvious or common solution method is not necessarily the only option.

Students were required to provide accurate structural or semi-structural formulas in Questions 2a., 2c., 3ci., 4cii. and 5a. The instruction to 'show all bonds' in structures is very clear in its expectation. However, the bond between O and H in hydroxyl and carboxyl groups was often not shown. The structure in Question 4cii. posed a different challenge in that it was deduced from supplied spectroscopy data. Students were expected to realise that in IR spectroscopy (Question 4a.), the O-H (acid) bond absorbs across a broad band of values and across a different band of values to O-H (alcohol). Students were asked to deduce a semi-structural formula in Question 3ci. but many did not make the link between biodiesels and the ester functional group.

Questions 7bii, 7biii. and 7biv. revealed a need for greater appreciation of the scope of the key knowledge point 'chemical bonding – primary, secondary and tertiary structures of proteins', particularly with respect to amino acid side chains and the bonds between them. In Question 7c. the link between structure changes and enzyme activity was often superficial.

Questions 9, 10 and 11 revealed a need for greater attention to detail on a range of areas of electrochemistry. Questions 9a., 10a., 10d., 10f., 11a., 11b. and 11d. required students to write equations and these were mostly half-equations. Significant issues such as inappropriate states and arrows (Question 9a.), inability to provide an oxidant half-equation for an alkaline H_2-O_2 fuel cell (Question 10d.) or an equation for the decomposition of water (Question 11d.) proved to be challenging for some students. Where students were required to write equations in an unfamiliar context (Questions 11a. and 11b.), information preceding the questions was often overlooked.

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 errors resulting in a total more or less than 100 per cent.
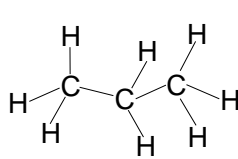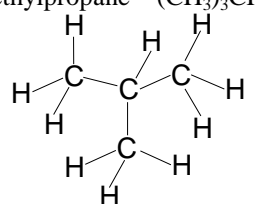
Section A – Multiple-choice questions

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

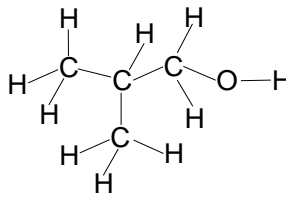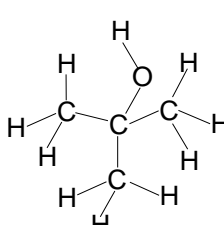| Question	% A	% B	% C	% D	% No Answer	Comments
1	68	31	0	1	0	Reverse reaction is: $CO_2(g) + 4H_2(g) \rightleftharpoons 2H_2O(g) + CH_4(g)$ for which $K = [H_2O]^2[CH_4]/\{[CO_2][H_2]^4\}$ Choice of alternative B, the equilibrium constant expression for the original reaction, indicates that students did not read the question carefully as the reverse reaction was required.
2	8	21	65	6	0	Addition of an inert gas has no effect on the concentration fraction – that is, $[CO][H_2]^4/[H_2O]^2[CH_4]$ – hence the system is not pushed out of equilibrium and so the $n(H_2)$ and $[H_2]$ do not change. Students who chose alternative B did not distinguish between the total pressure in the reaction vessel and the sum of the pressures exerted by the components of the equilibrium mixture. While adding the inert gas at constant volume does increase the total pressure in the reaction vessel, it does not affect the sum of the pressures exerted by – or the concentrations of – the components of the equilibrium mixture and has no effect on the position of equilibrium.
3	12	53	18	18	0	Since hydrochloric acid is a strong acid and ethanoic acid is a weak acid, the extent of ionisation in 0.10 M HCl is much greater than that in 0.10 M CH_3COOH. Consider the alternatives: **A.** Electrical conductivity depends on the total ion concentration in solution and so is significantly higher in 0.10 M HCl(aq). **B.** $n(NaOH)$ reacting $= 0.10 \times 10.0 \times 10^{-3} = 1.0 \times 10^{-3}$ mol This requires 1.0×10^{-3} mol HCl or 1.0×10^{-3} mol CH_3COOH for complete reaction. There is $0.10 \times 10.0 \times 10^{-3} = 1.0 \times 10^{-3}$ mol of both acids present, so both solutions will react completely with the NaOH. **C.** The reaction is $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + 2H^+(aq)$. The reaction will be faster with 0.10 M HCl(aq) since it has the higher $[H^+(aq)]$. **D.** The $[H_3O^+]$ is lower in the CH_3COOH(aq) solution since the weak acid is less ionised.
4	71	8	18	3	0	At 25 °C, pH 3 $\rightarrow [H^+] = 10^{-3}$ M, $[OH^-] = 10^{-11}$ M pH 6 $\rightarrow [H^+] = 10^{-6}$ M, $[OH^-] = 10^{-8}$ M The ratio $[H^+]$ in X$/[H^+]$ in Y $= 10^{-3}/10^{-6} = 10^3$ $= 1000$ Selection of alternative C suggests a lack of understanding of the information conveyed by pH values.
5	52	22	15	10	0	The pH of a solution is dependent on the $[H_3O^+]$ present in the solution. Since all four solutions were 0.10 M solutions of weak monoprotic acids, the solution with the lowest pH will have the highest $[H_3O^+]$ and this will be the strongest acid present – that is, the acid with the highest K_a value.

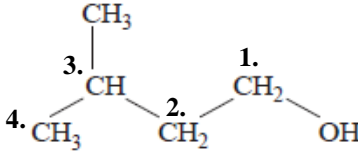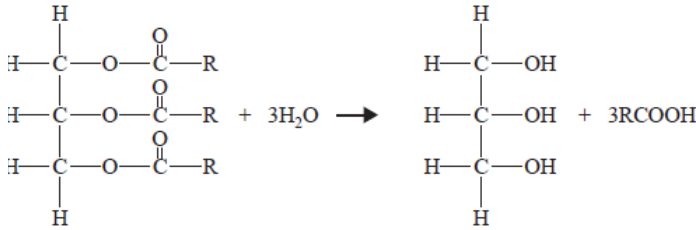| Question	% A	% B	% C	% D	% No Answer	Comments
						The selection of alternative B, ethanoic acid, may have been associated with students focusing on number of moles rather than concentration as the key factor. Selection of alternatives C or D was perhaps due to looking for the weakest acid rather than the strongest acid present.
6	53	20	15	12	0	The key characteristics of the titration curve given were: • initial pH just above 10 • equivalence point less than 7 • final pH just below 2. All of these support the titration of a weak base by a strong acid. Consider the acid and base reacting in each of the alternatives: **A:** HCl – strong acid; NH_3 – weak base **B:** HCl – strong acid; NaOH – strong base **C:** CH_3COOH – weak acid; NH_3 – weak base **D:** CH_3COOH – weak acid; NaOH – strong base. Students should be aware that $NH_4Cl(aq)$ contains $NH_4^+(aq)$ and $Cl^-(aq)$. Interpretation of the titration curve proved to be challenging for many students.
7	5	51	3	41	0	The equation for the reaction is: $2HCl(aq) + Ca(OH)_2(aq) \rightarrow CaCl_2(aq) + 2H_2O(l)$ $n[Ca(OH)_2]$ reacting $= 0.50 \times 40 \times 10^{-3}$ $= 0.020$ mol $n(HCl)$ required $= 2 \times 0.020$ $= 0.040$ mol $V(HCl)$ required $= 0.040$ mol/0.25 mol L^{-1} $= 0.16$ L $= 160$ mL Selection of alternative B indicates that most students did not pick up on the 2:1 mole ratio between HCl and $Ca(OH)_2$. An alternative approach, also requiring the correct chemical formula of calcium hydroxide, was to follow the calculation pathway: $n[Ca(OH)_2] \times 2 \rightarrow n(OH^-) \rightarrow n(H^+) \rightarrow n(HCl) \div c(HCl) \rightarrow m(HCl)$
8	7	18	9	66	0	$n(H_2S)$ produced $= 3 \times n(Al_2S_3)$ reacting $= 3 \times 0.200$ $= 0.600$ $V(H_2S)$ produced at SLC $= 0.600$ mol $\times 24.5$ L mol^{-1} $= 14.7$ L The choice of alternative B suggests ineffective reading of the question. Students should be able to distinguish between the given formulas of aluminium sulfide and hydrogen sulfide.
9	7	6	83	4	0	$n(C_3H_8)$ $= 2.80$ g/44.0 g mol^{-1} $= 0.0636$ mol $p(C_3H_8)$ $= nRT/V$ … temperature in kelvin, volume in litres $= 0.0636 \times 8.31 \times (60.0 + 273)/300.0 \times 10^{-3}$ $= 5.87 \times 10^2$ kPa
10	72	7	11	9	0	Since HCl was the common reactant in all four equations, in a redox reaction the oxidation number of H or Cl will change. In alternative A, the oxidation number of H decreases from +1 to 0, while the oxidation number of Fe increases from 0 to +2.

Question	% A	% B	% C	% D	% No Answer	Comments
11	64	10	23	3	0	The unbalanced equation indicates that the reaction is a redox reaction – Hg is oxidised to Hg^{2+} while $Cr_2O_7^{2-}$ is reduced to Cr^{3+}. The equation is most effectively balanced via the two half-equations: $Hg(l) \rightarrow Hg^{2+}(aq) + 2e^-$ $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$ In order to obtain the balanced overall equation, the oxidation half-equation is multiplied by 3 then added to the reduction half-equation to give: $3Hg(l) + Cr_2O_7^{2-}(aq) + 14H^+(aq) \rightarrow 3Hg^{2+}(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$ The selection of alternative A by most students suggests that they focused on the fact that Hg was balanced on both sides but did not consider that the equation must be balanced for all elements present. The most effective way to balance the equation for a redox reaction is to consider the relevant half-equations.
12	62	17	8	12	0	Since all the alkanols have a single hydroxyl (-OH) group, the determining factor in their relative attractions to the stationary phase is the length of their hydrocarbon chain and hence their molar masses. The higher the molar mass, the stronger the attraction to the stationary phase and the higher the retention time. The order of highest to lowest molar mass is the same at the order of highest to lowest retention time – that is, V, U, T, S. Selection of alternative B indicates lack of understanding of the difference in information conveyed by peak area and retention time.
13	8	5	8	79	0	The peak at the highest mass/charge ratio, $m/z = 60$, indicates that compound T has a relative molecular mass of 60. butan-1-ol, $C_4H_9OH \rightarrow M_r = 74.0$ ethanol, $C_2H_5OH \rightarrow M_r = 46.0$ methanol, $CH_3OH \rightarrow M_r = 32.0$ propan-1-ol, $C_3H_7OH \rightarrow M_r = 60.0$
14	31	64	3	1	0	$R_f = \dfrac{\text{(distance moved by compound \underline{from origin})}}{\text{(distance moved by solvent front \underline{from origin})}}$ $= (16 - 2)/(20 - 2)$ $= 14/18$ $= 0.78$ Students who selected alternative A did not reference their measurements to the origin. Students should be familiar with the R_f definition.
15	7	11	64	17	0	According to the ^{13}C NMR spectrum the compound has three different carbon environments. Consider the alternatives: **A.** propane – $CH_3CH_2CH_3$ **B.** 2-methylpropane – $(CH_3)_3CH$ 2 carbon environments ... 2 carbon environments

Question	% A	% B	% C	% D	% No Answer	Comments
						C. 2-methylpropan-1-ol $(CH_3)_2CHCH_2OH$ **D.** 2-methylpropan-2-ol $(CH_3)_3CHOH$ 3 carbon environments 2 carbon environments When determining the number of carbon (or hydrogen) environments, students should consider the molecular structure of the compound and equivalent carbon (or hydrogen) environments.
16	16	10	71	3	0	A calibration curve is most accurate between the limits of the concentrations of the standard solutions used during the calibration, in this case between 1.0 mg L^{-1} and 4.0 mg L^{-1}.
17	12	12	49	28	0	The solution to this question required the conversion of mg L^{-1} to mol L^{-1}, i.e. converting milligrams to grams and then grams to moles. According to the calibration curve absorbance 0.40 → c(Cu) $= 2.5$ ppm $= 2.5$ mg L^{-1} $= 2.5 \times 10^{-3}$ g L^{-1} $= 2.5 \times 10^{-3}/63.5$ mol L^{-1} $= 3.9 \times 10^{-5}$ mol L^{-1} Selection of alternatives A and D suggested issues with interpretation of the question, since neither suggested any attempt at conversion to mol L^{-1} as well as lack of attention to the detail in the information preceding the calibration curve. Selection of alternative B is consistent with not converting mg to g.
18	16	5	24	55	0	Excess molybdovanadate was added to convert the phosphate into a form that will absorb light in the **UV-visible** region of the spectrum. The wavelength at which phosphate treated with excess molybdovanadate absorbs strongly would be determined from the UV-visible absorption spectrum. A set of standards of known phosphate concentration treated with excess molybdovanadate is made up and their absorbances at the chosen wavelength measured to establish the relationship between absorbance and phosphate concentration (calibration curve). The absorbance of the sample is then measured at the same wavelength and the concentration of phosphate in the water determined. Chromatography may be used in phosphate determination; however, it is ion chromatography **not** GC or HPLC that is used. Atomic absorption spectroscopy is most commonly associated with the determination of specific metal content.

Question	% A	% B	% C	% D	% No Answer	Comments
19	7	5	45	44	0	The alkanol that was oxidised to the acid has the hydroxyl, -OH, group on C1, since only primary alkanols can be oxidised to acids, so the chain of C atoms is numbered as shown below. With 4 C atoms in the chain and a methyl, CH_3, group on C3, the alcohol was 3-methylbutan-1-ol, and had the semi-structural formula $(CH_3)_2CHCH_2CH_2OH$. During oxidation the $–CH_2OH$ was converted to $–COOH$ to give 3-methylbutanoic acid, $(CH_3)_2CHCH_2COOH$. Selection of alternative C suggested that either, or both, of two expected understandings were overlooked: • only primary alkanols can be oxidised to acids • when determining the systematic name, the C atoms are numbered so that the functional group is on the lowest possible numbered C atom, within the constraint the C atoms must be numbered from one end of the chain to the other.
20	13	77	6	4	0	Thymine and adenine are paired, hence the wheat DNA contains 27% thymine and 27% adenine by number of bases. Cytosine and guanine are paired and make up the remainder of the bases, so the DNA contains 23% cytosine and 23% guanine by number of bases.
21	2	21	64	13	0	During the formation of one molecule of the trisaccharide, two molecules of water are released as hydroxyl groups on adjacent glucose molecules react to form ether (glycosidic) links. $3C_6H_{12}O_6 \rightarrow C_{18}H_{32}O_{16} + 2H_2O$ $M(\text{maltotriose}) = 3 \times M(C_6H_{12}O_6) - 2 \times M(H_2O)$ $= 3 \times 180 - (2 \times 18.0)$ $= 540 - 36.0$ $= 504 \text{ g mol}^{-1}$ Selection of alternative B is consistent with overlooking the fact that when 'n' glucose molecules link together to form a polysaccharide 'n-1' H_2O molecules are condensed out.
22	79	6	8	7	0	In hydrolysis of a triglyceride, H_2O reacts across each ester groups to it into a carboxyl, -COOH, and hydroxyl, -OH groups.
23	11	50	21	18	1	1 mol $CH_4.6H_2O \rightarrow$ 1 mol CH_4 + 6 mol H_2O $n(CH_4)$ extracted $= n(CH_4.6H_2O)$ $= m(CH_4.6H_2O)/M(CH_4.6H_2O)$ $= 1.00 \times 10^3 \text{ g}/(16.0 + 6 \times 18.0) \text{ g mol}^{-1}$ $= 1.00 \times 10^3/124.0$ $= 8.06 \text{ mol}$

Question	% A	% B	% C	% D	% No Answer	Comments
						$\Delta H_c(CH_4) = -889 \text{ kJ mol}^{-1}$ Energy released $= n(CH_4) \times \Delta H_c(CH_4)$ $= 8.06 \text{ mol} \times 889 \text{ kJ mol}^{-1}$ $= 7.17 \times 10^3 \text{ kJ}$ The choice of alternative C, which was six times the correct amount of energy, indicates that many students misinterpreted the formula $CH_4.6H_2O$ and assumed that $n(CH_4) = 6 \times n(CH_4.6H_2O)$, which was incorrect. The choice of alternative D was consistent with misinterpreting the sample size as 1.00 kg of CH_4 rather than 1.00 kg of $CH_4.6H_2O$.
24	14	4	7	75	0	Renewable energy sources are those that are readily replenishable. Natural gas, coal seam gas and methane hydrate are all non-renewable since their supplies once used up are **not** readily replenished. **Microbial decomposition** (of plant material) will continue to produce methane as long as plant material is available and so this is a **renewable** energy source.
25	7	15	71	6	0	$Ru^{2+}(aq)$ is an oxidant and so will react with reductants that are lower on the electrochemical series. On the electrochemical series, $Ag^+(aq) + e^- \rightleftharpoons Ag(s) \quad E° = 0.80 \text{ V}$ $Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq) \quad E° = 0.77 \text{ V}$ $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s) \quad E° = 0.34 \text{ V}$ $Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s) \quad E° = -0.23 \text{ V}$ $Ru^{2+}(aq)$ does not react with either of the reductants $Fe^{2+}(aq)$ and $Ag(s)$, so must be below both of these reductants on the elelctrochemical series. $Ru^{2+}(aq)$ does react with both the reductants Cu and Ni, so must be above these on the electrochemical series. Hence: $Ag^+(aq) + e^- \rightleftharpoons Ag(s) \quad E° = 0.80 \text{ V}$ $Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq) \quad E° = 0.77 \text{ V}$ $\mathbf{Ru^{2+}(aq) + 2e^- \rightarrow Ru(s) \quad E° = ?}$ $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s) \quad E° = 0.34 \text{ V}$ $Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s) \quad E° = -0.23 \text{ V}$
26	20	8	57	16	0	Students were expected to base predictions on the information supplied in electrochemical series, where reaction may be predicted to be possible if the oxidant is higher in the series than the reductant. Beaker 1 – oxidant $Ag^+(aq)$, reductant $Ni(s)$, reaction may be predicted. Beaker 2 – oxidant $Cu^{2+}(aq)$, reductant $I^-(aq)$, reaction not predicted. Beaker 3 – oxidant $Cl_2(g)$, reductant $I^-(aq)$, reaction may be predicted. The selection of alternative A may have been due to students not identifying the KI(aq) contained $K^+(aq)$ and $I^-(aq)$ and since the reductant $I^-(aq)$ is lower on the electrochemical series than the oxidant $Cl_2(g)$, reaction may be predicted to occur.
27	11	42	36	11	0	Consider the relative positions of the half-cells in the electrochemical series. $Ag^+(aq) + e^- \rightleftharpoons Ag(s) \quad E° = 0.80 \text{ V}$ $Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s) \quad E° = -0.76 \text{ V}$ Oxidation $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$, at the anode. Reduction $Ag^+(aq) + e^- \rightarrow Ag(s)$, at the cathode. The anode is Zn and electrons flow from the Zn electrode to the Ag electrode. The concentration of Zn^{2+} ions does increase.

| Question	% A	% B	% C	% D	% No Answer	Comments
						The difference in $E°$ values based on the electrochemical series is $0.80 - (-0.76)$, i.e. 1.56 V … ; however, this could be the maximum voltage delivered **only** at standard conditions, i.e. 1 M Ag^+(aq), 1 M Zn^{2+}(aq) and 25 °C. Since these conditions are not specified for the cell, it is not possible to predict the maximum voltage. The maximum voltage **may** have been 1.56 V under specific conditions not associated with this question, the concentration of Zn^{2+}(aq) **will** increase as the cell discharges.
28	6	68	17	10	0	Since the reaction occurring at the Zn electrode is $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$, the electrode will decrease in size as the cell discharges. Students who chose alternative C may have been considering a situation where both half-equations occur in the same container; for example, Zn(s) in Ag^+(aq).
29	13	30	49	7	1	The half-equation for the oxidation of hydrogen in a hydrogen-oxygen fuel cell depends on whether the electrolyte is acidic or basic. Acid electrolyte: $H_2(g) \rightarrow 2H^+(aq) + 2e^-$ Alkaline electrolyte: $H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(g) + 2e^-$ $n(e^-) = 2 \times n(H_2)$ $\quad\quad = 2 \times 1.00 \times 10^{-5}$ $\quad\quad = 2.00 \times 10^{-5}$ $Q = n(e^-) \times F = 2.00 \times 10^{-5} \times 96500$ $\quad\quad\quad\quad = 1.93$ C $I = Q/t \quad = 1.93/1$ $\quad\quad\quad\quad = 1.93$ A Alternative C was consistent with not considering and/or accessing the half-equation for the oxidation of H_2.
30	29	23	31	17	0	CuO was decomposed by strong heating and the residual Cu remained in the tube after heating. The percentage by mass of Cu in the CuO was determined by dividing the mass of the residual Cu by the original mass of CuO. % Cu = [m(Cu) remaining/m(CuO) used] × 100 The m(Cu) remaining is determined by m(Cu) = m(tube and Cu) after heating – m(empty tube). The m(CuO) used is determined by m(CuO) = m(tube and CuO) before heating – m(empty tube). Consider the impact of each of the options in the alternatives on the % Cu. **A.:** If the CuO was contaminated with C then, at the high temperatures of the reaction that C would act as the reductant and be oxidised to CO (rather than CO_2 in the limited amount of oxygen available) according to the equation $C(s) + CuO(s) \rightarrow Cu(s) + CO(g)$. This would produce a greater decrease in mass of the sample and a lower m(Cu) remaining, leading to a lower than true calculated % Cu in CuO. **B.:** CuO has a higher molar mass than Cu, so unreacted CuO will cause a higher m(Cu) remaining, and lead to a higher than true calculated % Cu in CuO. **C.:** If contaimination originally on the outside is burnt off after heating, then the m(tube) after heating will be less than m(tube) before heating. However, the m(Cu) remaining = m(tube and Cu) after heating – m(empty tube). Because the m(empty tube) is larger than m(tube after heating), the m(Cu) remaining will be calculated as smaller than its true value and so this will lead to a lower than true %

Question	% A	% B	% C	% D	% No Answer	Comments
						Cu in CuO. **D.:** If some of the CuO is blown out of the tube during heating, less will be reduced to Cu and so the m(Cu) remaining will be calculated as smaller than the true value. This will lead to a lower calculated % Cu in CuO. The spread of responses to this question indicated that students had difficulty intepreting and effectively applying the supplied information. Students who selected alternative A did not perhaps realise than any C present would be oxidised at the high temperatures in the presence of the oxygen containing CuO. This meant that the m(Cu and tube after heating) would be lower than if the sample had been pure CuO. Students who selected alternative C did not realise that contamination on the ouside of the tube would not impact on the m(Cu) produced, but the mass of the tube would decrease during the reaction. The m(Cu and tube) after heating would be lower than if the contamination had not been present and since the intial recorded m(empty tube) is subtracted from this, the m(Cu) would be calculated as lower than its true value.

Section B – Short-answer questions

Question 1a.

Marks	0	1	2	3	Average
%	9	9	22	60	**2.4**
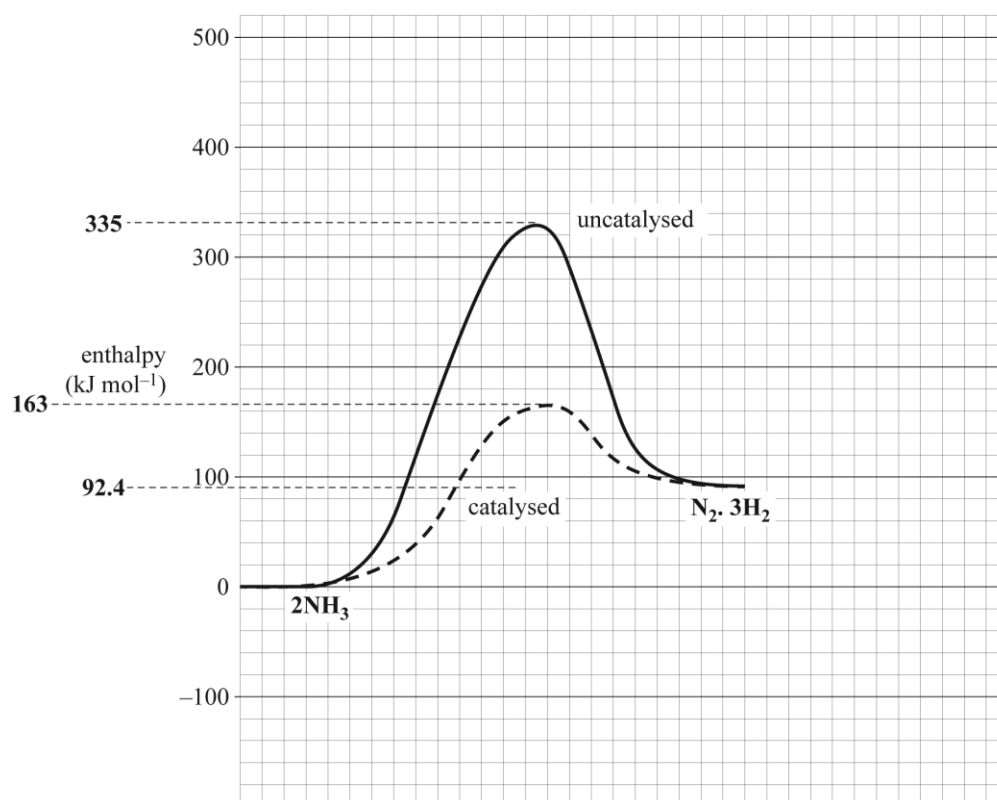
One mark each was awarded for:
- shape and location of uncatalysed profile
- shape and location of catalysed profile
- correct location of products.

This question was generally well handled, with marks awarded if the peak heights and the product enthalpy were within the appropriate vertical gradation. Most students provided the profiles for $2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$ (that is, the equation provided in the stem of the question) and, if accurate, these were awarded full marks.

Common errors included unusual shapes for profiles, adding activation energies to the ΔH, and thinking that ΔH referred to the distance between the top of each profile and the enthalpy of the products. There was some evidence of students not reading the vertical gradations on the supplied grid accurately.

When two profiles are drawn on the same grid students should be encouraged to label them. Students should be reminded that energy profiles do not have a horizontal axis.

Question 1b.

Marks	0	1	2	Average
%	16	42	42	**1.3**

Tungsten: with it the reaction has a lower activation energy, which means the proportion of collisions that are successful between NH_3 molecules will be higher.

One mark each was awarded for:
- tungsten and lower activation energy
- clear reference to a greater proportion or number of collisions that are successful.

Most students identified tungsten as the appropriate catalyst because of the greater impact on the activation energy; however, only half of those students were able to provide a clear justification of their choice. There was a reasonable range of points that were accepted, including more of the collisions occurring are successful and with tungsten the bonds in NH_3 molecules break more easily.

Students should be aware that the introduction of a catalyst does not increase the number of collisions but rather increases the proportion of collisions occurring that are successful. Students should be aware of the impact of the key factors that increase rate – higher temperature, higher concentration, larger surface area and the presence of a catalyst – in terms of collision theory.
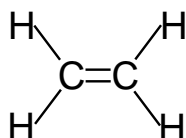
Question 2
Overall performance on Question 2 suggests that further revision on organic reaction pathways is needed.
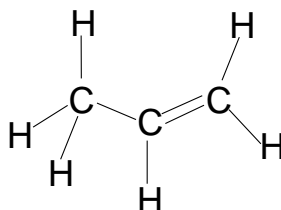
Question 2a.

Marks	0	1	2	3	4	Average
%	10	9	17	38	25	**2.6**

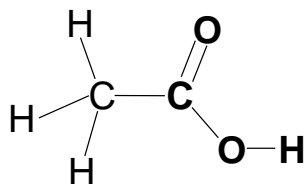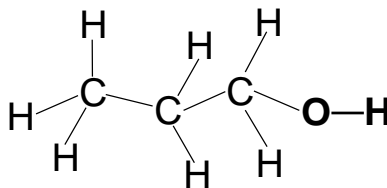Compound **A**   Compound **C**

Compound **D**

Compound **E**

Students needed to distinguish between structural formulas (part a.) and semi-structural formulas (part c.). In structural formulas all bonds should be shown.

There were a number of errors made with compound A and compound E. Students should know that alkanols are produced by addition reactions with alkenes and substitution reactions with chloroalkanes. Regular revision of organic reaction pathways should be encouraged.

Question 2b.

Marks	0	1	2	Average
%	21	40	40	**1.2**

Compound B: propan-1-amine or 1-propanamine or 1-propylamine
Compound D: ethanoic acid

Most errors in this part of the question were associated with the naming of compound B. Many students who had identified what the compound should be misspelt the name. Common names of compound B include propylamine and 1-aminopropane. Some students made significant errors in naming compound D. Students should be reminded that chemical names must be spelt correctly.

Question 2c.

Marks	0	1	2	Average
%	31	29	40	**1.1**

Semi-structural formula: $CH_3COOCH_2CH_2CH_3$, $CH_3COO(CH_2)_2CH_3$ or $CH_3CH_2CH_2O.COCH_3$
Name: propylethanoate or 1-propylethanoate

Many students showed a full structural formula rather than a semi-structural formula as required. Another issue was simple errors in the naming of the ester, a common one being 'proply' rather than 'propyl'.

Question 3a.

Marks	0	1	2	3	4	5	Average
%	23	15	12	7	12	31	**2.7**

$n(CH_3CH_2OH)$ = 1.80/46.0
= 0.0391 mol

$\Delta H_c(CH_3CH_2OH) = -1364$ kJ mol^{-1} ..... *Data Book Table 13*
Energy released by ethanol = 0.0391 mol × 1364 kJ mol^{-1}
= 53.4 kJ
Energy absorbed by water = 4.18 J g^{-1} °C^{-1} × 100.0 g × 15.0 °C
= 6.27 × 10^3 J
= 6.27 kJ
Energy not absorbed by water = 53.4 – 6.27
= 47.13 kJ
% heat lost = [47.13 kJ/53.4 kJ] × 100
= 88.3 %
One mark each was awarded for accurately calculating:

- n(ethanol)
- energy released by ethanol
- energy absorbed by water
- energy not absorbed by water
- percentage heat loss to the environment.

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Errors on this question included:
- using an incorrect molar mass for ethanol
- dividing, rather than multiplying, by the ΔH_c(ethanol)
- using incorrect units when calculating the energy absorbed by water
- not following through to working out the energy not absorbed by water.

Alternative valid methods used by students included:
- working out the temperature change that should have occurred if all the energy released by the combustion of ethanol was used to heat the water:
  $53.4 \times 10^3 = 4.18 \times 100.0 \times \Delta T \rightarrow \Delta T = 128$ °C.
  It then follows that
  % heat absorbed by water = $[(15)/128] \times 100 = 11.7$ %
  % heat lost = $100 - 11.7 = 88.3$ %
- working out an experimental molar enthalpy of combustion of ethanol from energy actually absorbed by water.
  Experimental ΔH_c(ethanol) = 6.27 kJ/0.0391 mol = 160 kJ mol^{-1}.
  % heat lost   = [(actual ΔH_c(ethanol) – experimental ΔH_c(ethanol)/actual ΔH_c(ethanol)] $\times$ 100
                  = [(1364 – 160)/1364] $\times$ 100 = 88.3 %

Students are reminded that there is often more than one way to derive a valid solution.

Question 3b.

Marks	0	1	Average
%	50	50	**0.5**

Acceptable responses included:
- insulate the side of the can
- put a lid/cover on the can
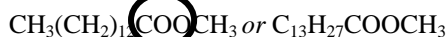- put a protective sleeve around the burner to reduce heat loss to the surroundings.

One mark was awarded for an acceptable adjustment consistent with the context of the question that would reduce the heat loss to the environment.

Students were expected to provide a response that was consistent with the apparatus used in the question. Responses such as 'put the apparatus in a sealed container' or 'insulate the can with polystyrene' (a flammable material) were incorrect. Responses such as 'move the flame closer to the bottom of the can' and those referring to a 'beaker' suggested cursory study of the diagram supplied.

Given that 'heat loss' is a common issue with energy transformations, discussion of appropriate methods of minimisation may be worth emphasising.

Question 3ci.

Marks	0	1	2	Average
%	43	49	8	**0.7**

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2COOCH_3$ or

$CH_3(CH_2)_{12}COOCH_3$ *or* $C_{13}H_{27}COOCH_3$
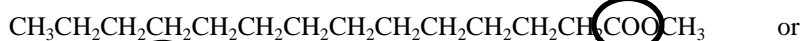
Ester

One mark each was awarded for:
- correct semi-structural formula
- accurately circling and naming 'ester' group.

This question was not answered well. Students should be aware that biodiesels are esters of fatty acids. Biodiesels formed from methanol and canola oil are methyl esters, i.e. $RCOOCH_3$. Given that the biodiesel formed has the molecular formula $C_{15}H_{30}O_2$, then its simplest semi-structural formula must be $C_{13}H_{27}COOCH_3$, i.e. $R = C_{13}H_{27}$.

Of those students who provided an appropriate semi-structural formula, many did not accurately circle the ester group. Students should be aware that this functional group contains only one C atom.

Question 3cii.

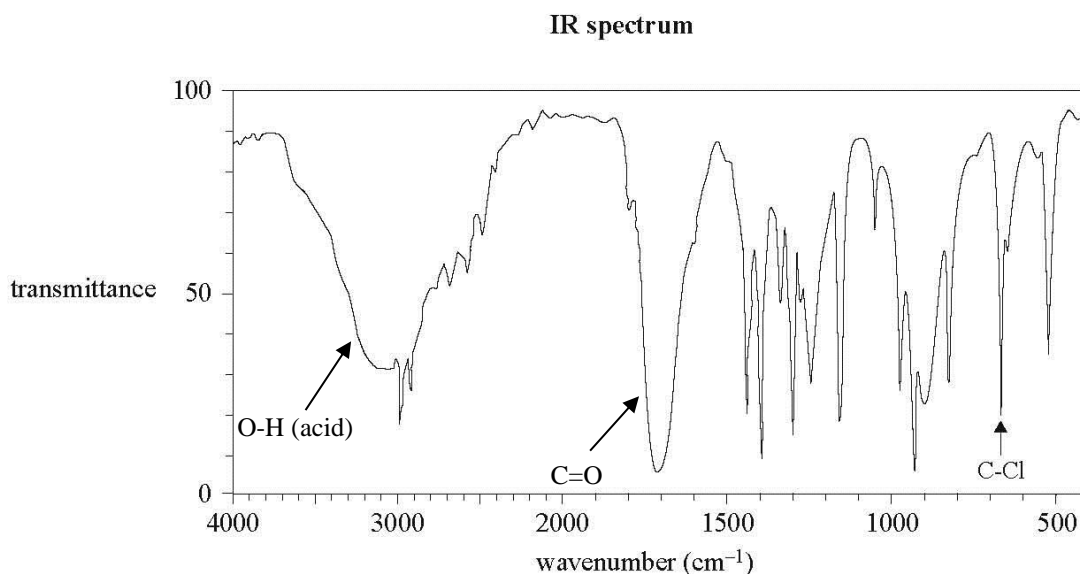| Marks	0	1	Average
%	74	26	**0.3**

Canola oil (biodiesel) is a mixture, and hence does not have a specific formula or molar mass, so the number of mole in a sample cannot be determined.

Most students were unable to provide a reasonable response as to why the number of mole of canola oil could not be determined. Incorrect responses included 'it is simple to use grams rather than moles', 'the average person does not know what moles are', 'oils are usually liquids hence grams is easier' and 'because canola oil has a high molar mass the number of mole will be too low'.

It would seem appropriate that when dealing with heats of combustion, chemical reasons for the variety of units – kJ mol^{-1}, kJ g^{-1}, kJ L^{-1} – for different fuels are discussed.

Question 4a.

Marks	0	1	2	Average
%	18	58	24	**1.1**

IR spectrum

Data: National Institute of Advanced Industrial Science and Technology

One mark each was awarded for:
- O-H (acid) absorption correctly identified
- for correctly identifying C=O absorption.

The main issues with this question were associated with the O-H (acid) component of the carboxyl group. Students were expected to clearly label it as O-H (acid), not just O-H. Students should be aware from the infrared absorption band information in Table 7 of the Data Book that the O-H (acid) absorption occurs across a broad band (2500 – 3300 cm–1) and not just at a specific wavenumber.

Many students drew an arrow pointing directly at the peak above 3000 cm–1 associated with C-H vibration rather than to the broad absorption of the O-H(acid) vibration.

Question 4b.

Marks	0	1	2	Average
%	20	17	63	**1.5**

$x = 3$, $y = 5$

The ^{13}C NMR spectrum showed three different carbon environments, the ^1H NMR spectrum showed three different hydrogen environments, and the molecule has a carboxyl –COOH functional group, and a chloro –Cl functional group. There is no evidence of a C=C on the IR spectrum. Also the mass spectrum suggests parent molecular ions at m/z = 108 and 110. All of this leads to the molecular formula $C_3H_5O_2Cl$.

Alternatively, subtracting the relative masses of COOH (45) and ^{35}Cl (35) from m/z = 108 leaves a relative mass of 28, suggesting 2 'C' and 4 'H' atoms consistent with the molecular formula $C_3H_5O_2Cl$.

Question 4ci. and 4cii.

Marks	0	1	2	Average
%	44	33	23	**0.8**

Part ci. was not handled well, with many students simply mentioning 'three hydrogen environments' without referring to information that may be deduced from the splitting pattern. A number of these students had a correct structure for 4cii. and so were able to access the second mark. Overall, this emphasised the difficulties many students have in providing appropriate written descriptions of deductions made from supplied data and/or information.

4ci.
Acceptable responses included (one of):
- there are three hydrogen environments on the molecule – one with three neighbouring H, one with one neighbouring H and one with no neighbouring H atoms
- two of the three hydrogen environments are CH_3 and CH (the third is COOH)
- the number of lines in the split signals is one more than the number of H atoms on the adjacent or neighbouring C atoms.

4cii.
The correct structure was:
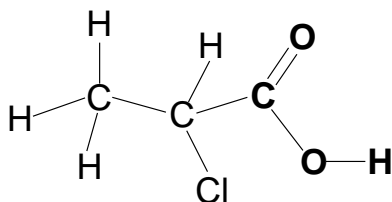
Question 4d.

Marks	0	1	Average
%	64	36	**0.4**

Acceptable responses included (one of):
- the presence of the two chlorine isotopes, ^{35}Cl and ^{37}Cl
- the two peaks are due to $[CH_3CH^{35}ClCOOH]^+$ and $[CH_3CH^{37}ClCOOH]^+$
- the two chlorine isotopes have a mass difference of 2.

Most students struggled to frame an acceptable response to this question. Some simply referred to the presence of different isotopes but made no specific reference to the different chlorine isotopes. Some tried, unsuccessfully, to answer in terms of fragmentation patterns. Students were expected to recognise, given appropriate isotopic information, that some substances, particularly haloalkanes, can have more than one significant parent molecular ion.

Question 5a.

Marks	0	1	Average
%	27	73	**0.8**
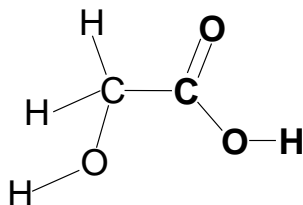
The O-H bond was overlooked in a number of responses.

Question 5b.

Marks	0	1	2	Average
%	64	11	25	**0.6**

The pH increases because the equilibrium moves to the left to partially compensate for the addition of glycolate ions, $CH_2(OH)COO^-(aq)$. This causes the $[H_3O^+]$ to decrease and so the pH increases.

Students may not have recognised that $CH_2(OH)COONa$ would release $CH_3(OH)COO^-(aq)$ into the solution and that subsequent changes should be explained via Le Chatelier's principle. Statements such as 'because glycolic acid is acidic and sodium glycolate is basic they will neutralise each other' and 'a base was added therefore pH increases' overlooked the equilibrium provided. Students were expected to relate changes in pH to changes in the $[H_3O^+]$ and explain why, in the context provided the $[H_3O^+]$ changes.

Question 5c.

Marks	0	1	Average
%	41	59	**0.6**

n(glycolic acid) in 1 L $= [1.0 \times 10^6/1000]$ g$/76$ g mol^{-1}

$= 1000/76$

$= 13$ mol

c(glycolic acid) $= 13$ mol L^{-1} $(13 - 13.2)$

Question 5d.

Marks	0	1	2	Average
%	29	16	55	**1.3**

n(glycolic acid) $= 13$ mol L$^{-1} \times 0.100$ L

$= 1.3$ mol

$n(Na_2CO_3)$ $= \frac{1}{2} \times 1.3$

$= 0.65$ mol

$m(Na_2CO_3)$ $= 0.65 \times 106$

$= 70$ g

One mark each was awarded for:
- correct calculation of $n(Na_2CO_3)$
- $m(Na_2CO_3)$ consistent with calculations.

Students could obtain full marks for Question 5d. if their answer from 5c. was used correctly. The most common error was overlooking the mole ratio between Na_2CO_3 and glycolic acid.

Question 5e.

Marks	0	1	Average
%	9	92	**0.9**

Acceptable responses included:
- use in a well-ventilated area; for example, under a fume hood

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- use a face mask or breathing apparatus
- use appropriate eye protection; for example, safety goggles
- wear gloves and appropriate protective clothing to prevent skin exposure.

This question was answered well. Students are reminded to give explanations of acronyms used in their responses.

Question 6ai.

Marks	0	1	Average
%	11	89	0.9

Either of:
- $K = [HI]^2/[H_2][I_2]$
- $[HI]^2/[H_2][I_2]$

Question 6aii.

Marks	0	1	2	3	Average
%	23	23	15	39	1.7

$n(I_2)$ reacting $= 3.00 - 1.07$
$\qquad\qquad = 1.93$ mol

$n(H_2)$ reacting $= 1.93$ mol

$n(H_2)$ at equilibrium $= 2.00 - 1.93$
$\qquad\qquad\qquad = 0.07$ mol

$n(HI)$ produced $\quad = 2 \times 1.93$
$\qquad\qquad\qquad = 3.86$ mol

Equilibrium concentrations:

$[H_2] = 0.07$ M, $[HI] = 3.86$ M, $[I_2] = 1.07$ M

$K \quad = 3.86^2/(0.07 \times 1.07)$
$\quad = 2 \times 10^2/199$

One mark each was awarded for:
- correct $[H_2]$
- correct $[HI]$
- K value consistent with calculated concentrations and equilibrium law in Question 6ai.

Errors in this part of the question were generally associated with misinterpretation of the supplied data, particularly 'The amount of iodine present at equilibrium was 1.07 mol', which a significant number of students seemed to read as '1.07 mol of HI'.

The data should be considered in light of the three stages in the process – initial amounts, amounts reacting and produced, and amounts at equilibrium. This initial data would appear as:

	$I_2(g)$	+	$H_2(g)$		$2HI(g)$	
Initially	3.00		2.00		-	mol
Reacting	___		____	→	____	mol
Eq'm	1.07		____		____	mol

From that point, to establish the rest of the equilibrium data:

	$I_2(g)$	+	$H_2(g)$		$2HI(g)$	
Initially	3.00		2.00		-	mol
Reacting	1.93		1.93	→	3.86	mol
Eq'm	1.07		0.07		3.86	mol

and proceed to calculate the value of K.

Question 6bi.

Marks	0	1	2	Average
%	37	28	35	1
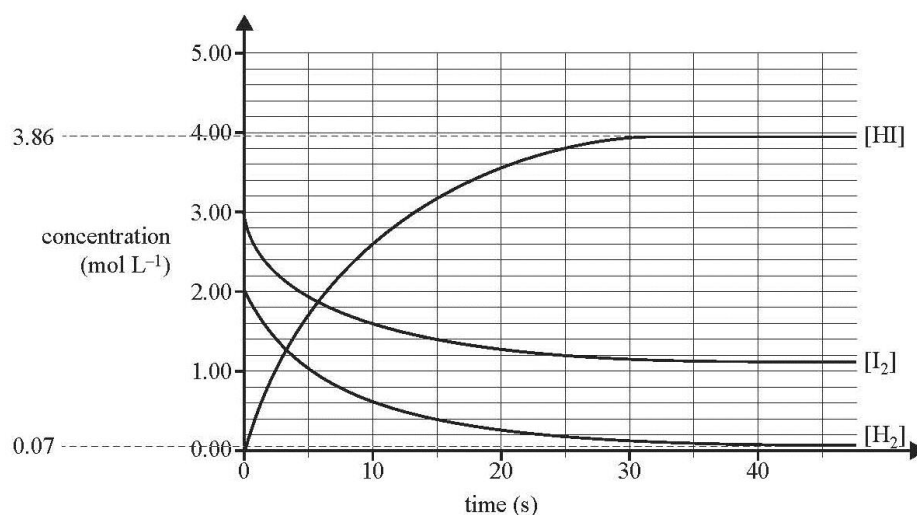
One mark for:
- the graph of HI starting at 0 mol L^{-1} and leveling around 30–35 s
- the graph of H$_2$ starting at 2 mol L^{-1} and leveling around 30–35 s.

These graphs proved challenging for many students. Some student struggled with the starting points of both graphs (based on initial concentrations), the final concentration for each graph (based on equilibrium concentrations), and the point at which the graphs levelled out (i.e. when equilibrium was reached). This latter point was often missed, with students overlooking the fact that all three species would reach their equilibrium concentrations at the same time. The difficulty was further compounded by vertical scale location, where it was required that the graphs levelled off within the correct vertical gradation.

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Question 6bii.

Marks	0	1	Average
%	41	59	**0.6**
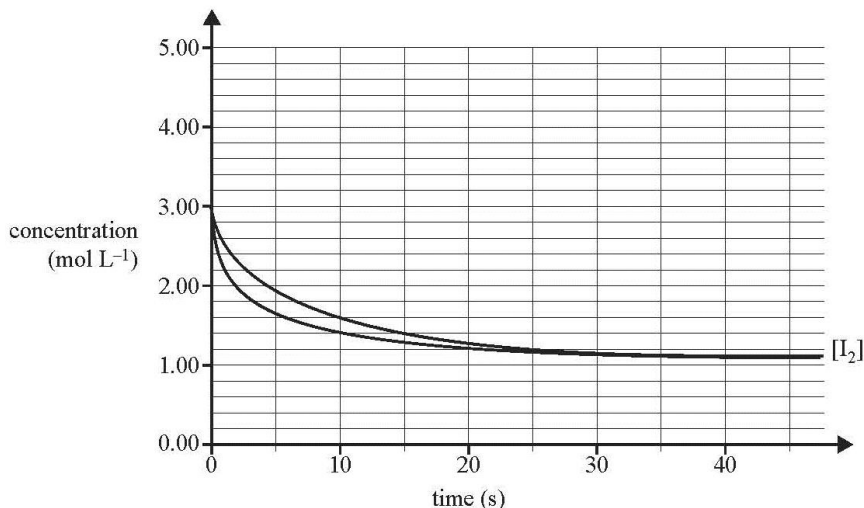
Students were expected to show that for the catalysed reaction the initial gradient of the graph would be larger (more steep) and it would reach equilibrium (level off) earlier. The gradient and levelling off time proved most problematic.

Question 7a.

Marks	0	1	2	Average
%	13	29	58	**1.5**

- non-polar side chain (one of):
  alanine/glycine/isoleucine/leucine/methionine/phenylalanine/proline/valine/Ala/Gly/Ile/Leu/Met/Phe/Pro/Val
- acidic side chain (one of):
  aspartic acid/glutamic acid/Asp/Glu

Most students were able to identify an amino acid with a non-polar side chain. The acidic side chain proved to be more challenging.

Question 7b.
Overall, students did not perform well on parts bii.–biv. of this question. The answers to parts bi.– biii. were obtained from the table supplied in the question. Most students struggled to identify the groups on the given side chain structures that could form hydrogen bonds ($-OH$ and $-NH_2$) in part bii., or that could form ionic bonds ($-COO^-$ and $-NH_3^+$) in part biii.

Students should be aware that hydrogen bonds can occur between species within which hydrogen is covalently bonded to O or N atoms.

Question 7bi.

Marks	0	1	Average
%	11	89	**0.9**

cysteine or Cys

Question 7bii.

Marks	0	1	Average
%	61	39	**0.4**

Acceptable responses were:
- asparagine and serine *or* Asn and Ser
- $-CH_2CONH_2$ and $-CH_2OH$.

Question 7biii.

Marks	0	1	Average
%	55	45	**0.5**

Acceptable responses were:
- aspartic acid and lysine *or* Asp and Lys
- $-CH_2COO^-$ and $-CH_2CH_2CH_2CH_2NH_3^+$

Question 7biv.

Marks	0	1	Average
%	65	35	**0.4**

Dispersion force attraction

Some students responded with covalent bonding; however, the side chains are **non-polar** methyl groups.

Question 7c.

Marks	0	1	Average
%	57	43	**0.5**

The tertiary structure/active site/side chain charges will be different at a lower pH.

One mark was awarded for recognition that at pH 4 there will be significant structural changes to tertiary structure or active site compared to the pH range 7.5 to 8.5.

The expected emphasis in explaining enzyme activity in chemistry is very much about reference to structure. 'Denaturation' is not sufficient. Students should be aware of the significance of the tertiary structure and active site in enzyme activity. Key factors that affect these and reduce enzyme activity are high temperature and change in pH.

Question 8a.

Marks	0	1	Average
%	20	80	**0.8**

Oxidation or redox

Question 8bi.

Marks	0	1	2	3	4	Average
%	10	7	11	37	35	**2.8**

$m(BaSO_4)$ collected $= 1.338 - 0.864$
$= 0.474$ g
$n(SO_2)$ in sample $= n(BaSO_4)$ $= 0.474/233.4$
$= 2.03 \times 10^{-3}$ mol
$m(SO_2)$ $= 2.03 \times 10^{-3} \times 64.1$
$= 0.130$ g
$\%(SO_2)$ $= (0.130/50.0) \times 100$
$= 0.260$ %

One mark each was awarded for:
- accurately calculating $m(BaSO_4)$
- accurately calculating $m(SO_2)$
- accurately calculating $\%(SO_2)$
- expressing answer to three significant figures.

The most common errors included not giving an answer to three significant figures, dividing by the $m(BaSO_4)$ rather than the m(sample) when calculating the $\%SO_2$ and not subtracting the mass of filter paper when determining the $m(BaSO_4)$.

Question 8bii.

Marks	0	1	Average
%	83	17	0.2

0.260 % SO_2 by mass → 0.260 g SO_2 in 100 g apricots

To get ppm (m/m) it is necessary to find $m(SO_2)$ in 10^6 g apricots

$m(SO_2)$ in 10^6 g apricots = (0.260/100) × 10^6

= 2.60 × 10^3 g

2.60 × 10^3 g SO_2 in 10^6 g apricots → 2.60 × 10^3 ppm (m/m) SO_2

Many students were unable to accurately determine the concentration in ppm (m/m).

A relatively common answer was 1300 ppm, suggesting that many students assumed that the 0.130 g SO_2 in the 50.00 g sample of apricots ended up in 100 mL of solution and that the required concentration in ppm was simply mg L^{-1}, i.e mg SO_2 in one litre solution. However, the question did not require the concentration of the solution formed when the SO_2 was released from the apricots dissolved but rather the concentration of SO_2 in the unprocessed apricots.

The $m(SO_2)$ in the 50.00 g sample of apricots also leads to 2.60 × 10^3 ppm (m/m) if the correct conversion factor is used: 0.130 g SO_2 in 50.00 g → (0.130/50) × 10^6 → 2.60 × 10^3 g in 10^6 apricots.

Question 8biii.

Marks	0	1	Average
%	88	12	0.1

Acceptable repsonses included (one of):

- to speed up the release of SO_2 from the apricots
- to ensure all SO_2 is available to react.

Most responses referred to 'speed up the rate of reaction', which was not sufficient in the context of this question. It was not the apricots that were reacting but the SO_2 present in the apricots, and grinding the apricots to a fine powder makes it more likely that all the SO_2 will be released and will react. Students are reminded to consider context in framing written responses.

Question 8ci.

Marks	0	1	Average
%	12	88	0.9

1:1 or they are equal

The most common incorrect response was 2:1, which is the ratio of iodine atoms, I, to water molecules.

Question 8cii.

Marks	0	1	2	Average
%	39	35	26	0.9

$n(I_2)$ used to prepare 500 mL solution = 15.0/253.8

= 0.0591 mol

$n(I_2)$ in 4.95 mL titre = (0.0591/500) × 4.95

= 5.85 × 10^{-4} mol

$n(H_2O)$ present = 5.85 × 10^{-4} mol

$m(H_2O)$ present = 5.85 × 10^{-4} × 18.0

= 0.0105 g (10.5 mg)

One mark each was awarded for accurate calculation of:

- $n(I_2)$ in titre
- $m(H_2O)$ from calculated $n(I_2)$ in titre.

Many students struggled to effectively interpret and use the data provided. While most worked out the $n(I_2)$ in 500 mL solution, many did not then proceed to work out $n(I_2)$ in 4.95 mL of the same solution. The fact that water was the analyte may have confused some students.

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Question 8ciii.

Marks	0	1	2	Average
%	55	10	34	**0.8**

m(oil sample) = $d \times V$ = 0.918 g mL$^{-1} \times$ 10.0
                                  = 9.18 g
% H_2O in oil   = (0.0105/9.18) $\times$ 100
                        = 0.115 %

One mark each was awarded for accurate calculation of:
- m(oil) in sample
- % (m/m) of water from the answer to 8cii. and m(oil sample).

Many students were unable to link together the required data – V(oil), d(oil) and m(H_2O) in oil sample – to arrive at the % (m/m) of water in the oil.

Students should be aware that detemining the percentage by mass requires the mass of the specific ingredient (H_2O), and the mass of the sample (10 mL of oil). The inclusion of the density of the oil should have been an indication that the relationship $d = m/V$ could be used to detemine the mass of the 10 mL of oil.

Question 9a.

Marks	0	1	2	Average
%	59	26	15	**0.6**

Cathode: $Mg^{2+}(l) + 2e^- \rightarrow Mg(l)$
Anode: $2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$
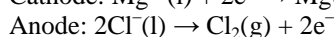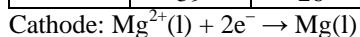
Most students missed out on marks for the use of incorrect states and/or use of equilibrium arrows.

The information in the stem of the question indicated that both $MgCl_2$ and Mg were molten (i.e. liquid), so the use of (aq) in the half-equations was inappropriate.

The reduction half-equations provided in the electrochemical series (Table 2 in the Data Book) include equilibrium arrows because the direction of each half-equation is determined by the combination of oxidant and reductant used in the reaction. In the actual half-equations occurring in the electrolysis of molten $MgCl_2$, equilibrium arrows are not shown because at the cathode $Mg^{2+}(l)$ will react, and at the anode $Cl^-(l)$ will react. Equilibria between an oxidant, its conjugate reductant and electrons are not established at the electrodes.

Students should be aware that oxidation (the loss of electrons) occurs at the anode and reduction (the gain of electrons) occurs at the cathode.

Question 9b.

Marks	0	1	Average
%	78	22	**0.2**

To prevent:
- molten Mg reacting with oxygen in the air
- contact between Mg and air/oxygen.

The stem of Question 9 stated that 'molten magnesium reacts vigorously with oxygen'. While the marks for part a. do not reflect it, the majority of students showed that Mg was produced at the cathode. It seemed that most tried to answer part b. as a question without taking into account the information provided earlier and framed inaccurate responses such as 'to increase pressure', 'to remove all the Cl_2' and 'to increase reaction rate'.

Question 9c.

Marks	0	1	2	Average
%	65	18	17	**0.5**

According to the electrochemical series:
- both Na^+ and Ca^{2+} are weaker oxidants than Mg^{2+} and so are unlikely to interfere with the production of Mg at the cathode.

- Zn^{2+} is a stronger oxidant than Mg^{2+}(aq) and could be reduced to Zn, thus either preventing the production of Mg or contaminating the Mg produced.

One mark was awarded for recognition that:
- Na^+ and Ca^{2+} are weaker oxidants that Mg^{2+}
- Zn^{2+} is a stronger oxidant than Mg^{2+} and an implication of this for the production of Mg.

This question proved challenging for the majority of students. Some restated information supplied in the question and focused on melting temperature, which was inappropriate.

Some students accessed the electrochemical series and identified that Na^+ and Ca^{2+} are weaker oxidants than Mg^{2+}, and Zn^{2+} is a stronger oxidant, but in their responses stated that 'sodium and calcium' are weaker oxidants and 'zinc' is a stronger oxidant rather than the correct species 'sodium, calcium or zinc cations', or Na^+, Ca^{2+} and Zn^{2+}. Other students used statements such as 'NaCl is a stronger oxidant', which is inappropriate because NaCl contains both an oxidant, Na^+, and a reductant, Cl^-.

Question 9d.

Marks	0	1	2	3	Average
%	56	20	21	3	0.7

According to the electrochemical series Fe is a stronger reductant than Cl^-.
At the anode, Fe would be oxidised instead of Cl^-/Fe^{2+} would be produced rather than Cl_2.
Half-equation: $Fe(s) \rightarrow Fe^{2+}(l) + 2e^-$
The cations $Fe^{2+}(l)$ would migrate to the cathode/Fe^{2+} is a stronger oxidant than Mg^{2+} hence Fe could be produced/cathode half-equation would be $Fe^{2+}(l) + 2e^- \rightarrow Fe(s)$.

One mark each was awarded for:
- explaining why Fe^{2+} is produced at the anode
- the correct anode half-equation
- explanation of, or half-equation for, production of Fe at the cathode or other valid consequence of the production of Fe at the anode.

The focus of this question – 'what would happen at the anode if Fe was used instead of the unreactive graphite' – was missed by most students, and hence they struggled to make significant progress.

Question 10a.

Marks	0	1	Average
%	33	67	0.7

$Zn(s) + 2OH^-(aq) \rightarrow Zn(OH)_2(s) + 2e^-$
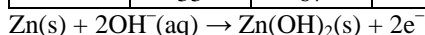
Some students ignored the alkaline electrolyte and deduced a balanced half-equation, which, while balanced, included both $Zn(OH)_2$ and H^+(aq) as products. Students should realise that this is not a logical chemical situation.

Question 10b.

Marks	0	1	Average
%	69	31	0.3

Acceptable responses included:
- KOH is the electrolyte
- allow for electrolytic conduction between the electrodes
- provide K^+ ions (cations) to move towards the cathode and OH^- (anions) to move towards the anode and balance the charges around the electrodes
- provide the internal circuit in the cell.

Most students did not identify KOH as the electrolyte or medium through which ions move in the cell. There were many responses that were not accepted because there was no indication that students appreciated the significance of the movement of ions in the internal circuit.

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A number of students simply stated that KOH was a reactant; this was not accepted. Answers such as 'provides OH⁻ ions for the oxidation half-equation' were acceptable.

Students are not expected to remember the details of specific electrochemical cells but should have an understanding of the role of electrolytes in electrochemical cells.

Question 10c.

Marks	0	1	2	3	Average
%	30	13	26	31	**1.6**

$Q = 2.36 \times 10^{-3} \times 10 \times 60 \times 60$
$\quad = 85$ C
$n(e^-) = 85/96500$
$\quad = 8.8 \times 10^{-4}$ mol
$n(Zn)$ reacting $= ½ \times 8.8 \times 10^{-4}$
$\quad = 4.4 \times 10^{-4}$ mol
$m(Zn)$ reacting $= 4.4 \times 10^{-4} \times 65.4$
$\quad = 0.029$ g

One mark each was awarded for:
- correctly calculating charge.
- correctly calculating $n(e^-)$
- calculating $m(Zn)$ consistent with equation given in part a.

Common errors on this question included:
- not converting or incorrectly converting current from mA to A
- incorrectly converting time from hours to seconds
- not dividing the $n(e^-)$ by 2 to calculate the $n(Zn)$
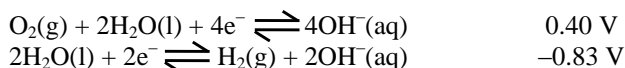- multiplying by $M(Zn(OH)_2)$ rather than $M(Zn)$.

Question 10d.

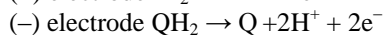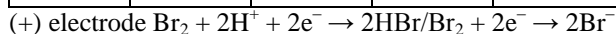| Marks	0	1	Average
%	68	32	**0.3**

$H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(l) + 2e^-$
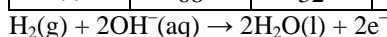
Students should be aware that in a fuel cell the fuel (in this case H_2) is oxidised at the anode, that since the electrolyte is alkaline OH⁻(aq) must be present in the half-equations and that the half-equations for an alkaline hydrogen-oxygen fuel cell are accessible from the electrochemical series.

On the electrochemical series the half-equations relevant to this fuel-cell are:

$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$ ⠀⠀⠀⠀⠀ 0.40 V
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$ ⠀⠀⠀⠀⠀ –0.83 V

Question 11a.

Marks	0	1	2	Average
%	50	25	25	**0.8**

(+) electrode $Br_2 + 2H^+ + 2e^- \rightarrow 2HBr / Br_2 + 2e^- \rightarrow 2Br^-$
(–) electrode $QH_2 \rightarrow Q + 2H^+ + 2e^-$

Students needed to recognise that oxidation occurred at the (–) electrode and reduction occurred at the (+) electrode.
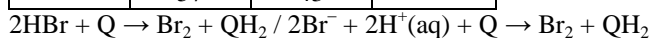
The question stated that QH_2 was converted to Q and Br_2 was converted to HBr, from which it could be deduced that Br_2 was reduced (the oxidation number of Br decreases from 0 to –1) and so QH_2 was oxidised. Given that the diagram suggested the movement of H⁺ ions, the half-equations should have included H⁺.

As the question referred to the Br_2/Br^- redox pair, $Br_2 + 2e^- \rightarrow 2Br^-$ was also accepted for the half-equation at the (+) electrode.

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Question 11b.

Marks	0	1	Average
%	57	43	0.5

$2HBr + Q \rightarrow Br_2 + QH_2$ / $2Br^- + 2H^+(aq) + Q \rightarrow Br_2 + QH_2$

One mark was awarded for a 'recharging' equation consistent with the 'discharging' half-equations in part a. – that is, if the equation was balanced and consistent with the reverse of the overall equation implied in part a.

While students realised that they needed to add together the reverse of their half-equations from part a., a significant proportion provided an unbalanced overall half-equation.

Question 11ci. and 11cii.

Marks	0	1	2	Average
%	40	40	20	0.8

11ci.

direction of
H^+ movement
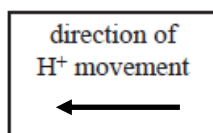
During recharging the reaction at the (–) electrode is $Q + 2H^+ + 2e^- \rightarrow QH_2$, hence electrons are moving towards the Q/QH_2 half of the redox flow battery.

11cii.
Acceptable responses included:
- if the oxidant and reductant are allowed to come into contact they can react together in the solution rather than individually at the electrodes
- chemical energy would be converted to thermal energy rather than electrical energy
- to prevent the oxidant and reductant coming into contact with each other
- to prevent spontaneous direct reaction between the oxidant and reductant
- to ensure that the cell can be recharged.

Students needed to identify a significant disadvantage of the oxidant and reductant being in the same half of the flow battery – that is, coming into contact.

Most students struggled to frame an appropriate response. A key factor in the effective operation of a battery is that oxidant and reductant react at different electrodes to ensure conversion of chemical energy to electrical energy and a flow of electrons through the external circuit. Should the oxidant and reductant come into contact spontaneous reaction may occur with chemical energy being converted to thermal energy and the cell not operating as intended.

Question 11d.

Marks	0	1	Average
%	86	14	0.2

$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$
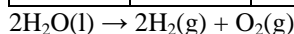
Few students recalled the overall equation for the decomposition of water.

It is possible to deduce the overall equation from the half-equations for the oxidation and reduction of water – that is, $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$ and $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ from which the overall equation $6H_2O(l) \rightarrow O_2(g) + 2H_2(g) + 4H^+(aq) + 4OH^-(aq)$ can be deduced and simplified down to $2H_2O(l) \rightarrow O_2(g) + 2H_2(g)$

Many students simply provided a half-equation or included Q and/or Br in their equation.

Question 11e.

Marks	0	1	2	Average
%	65	24	11	**0.5**

$QH_2(l) + H_2O(l) \rightleftharpoons QH^-(aq) + H_3O^+(aq)$ or $QH_2(l) \rightleftharpoons QH^-(aq) + H^+(aq)$ and one of:

- $K_a = [QH^-][H_3O^+]/[QH_2]$
- $[QH^-][H_3O^+]/[QH_2]$
- $10^{-7} = [QH^-][H_3O^+]/[QH_2]$
- $K_a = [QH^-][H^+]/[QH_2]$
- $[QH^-][H^+]/[QH_2]$
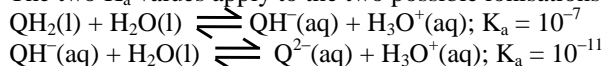- $10^{-7} = [QH^-][H^+]/[QH_2]$

One mark each was awarded for:
- a correctly balanced equation including equilibrium arrows
- acidity constant expression consistent with equation.

The main errors included:
- inaccurate or inappropriate equations
- equilibrium arrows not included in the equation
- poorly constructed acidity constant expressions
- acidity constant expressions not consistent with the equation.

The two K_a values apply to the two possible ionisations of the diprotic quinone – that is:
$QH_2(l) + H_2O(l) \rightleftharpoons QH^-(aq) + H_3O^+(aq)$; $K_a = 10^{-7}$
$QH^-(aq) + H_2O(l) \rightleftharpoons Q^{2-}(aq) + H_3O^+(aq)$; $K_a = 10^{-11}$

Students should be aware that they must use equilibrium arrow notation when writing equations for known equilibrium reactions.

Question 11f.

Marks	0	1	Average
%	43	57	**0.6**

Rhubarb (the raw material for the quinones) can readily be replenished. Rhubarb is a plant-based source of quinones and can be easily grown.

Many students answered this question well. Statements such as 'can be produced as fast as it is needed' were also acceptable.

Some students made incorrect statements such as 'recycled', 'used again', 'environmentally friendly' and 'carbon neutral', suggesting that further improvement is needed in achieving real understanding of the concept of renewability.

Question 12

Marks	0	1	2	3	4	5	Average
%	17	6	14	33	19	11	**2.7**

Three marks were available for the identification of three improvements or modifications in the student's experimental design. Acceptable improvements/modifications included:
- use the same volume of H_2O_2 in both trials
- use the same concentration of H_2O_2 in both trials
- use the same mole amounts of both catalysts
- use a device with better insulation such as a calorimeter to minimise heat losses
- investigate more than two different catalysts
- repeat the trials a number of times
- use a mechanical stirrer to ensure thorough mixing of reactants
- use catalysts of the same state.

One mark was available for identification of the expected outcome of the trials. Acceptable responses included the following.

- Different catalysts will have no effect on the molar heat of reaction since the molar enthalpy of the decomposition reaction of hydrogen peroxide is independent of the catalyst used.
- The same molar heat of reaction should be determined irrespective of the catalyst used, assuming all other variables are controlled.
- A catalyst has no effect on the relative enthalpies of the reactants and products, hence does not affect the molar heat of reaction.
- The same molar enthalpy should be determined for the decomposition of H_2O_2, irrespective of the catalyst used.

One mark was available for the application of chemistry ideas in the context of the question. Acceptable responses included the following.

- If investigating the effect of different catalysts on the molar enthalpy of decomposition, the only variable should be the catalyst. The results presented were inconclusive because independent variables, such as the concentration of H_2O_2, were not kept constant.
- The conclusion that the different temperatures for the two trials verify that the molar enthalpy of decomposition depends on the catalyst used is invalid because $n(H_2O_2)$ reacting in Trial 2 is four times the $n(H_2O_2)$ reacting in Trial 1 and this will cause a greater temperature change.
- Different catalysts will decrease the activation energy for the decomposition by different amounts but will have no effect on the molar enthalpy of decomposition. (Some students used energy profiles to emphasise this point.) However, since one catalyst may increase the rate of reaction more than the other, and because the faster reaction will reach completion in a shorter time, this will produce a larger temperature change in that time. If the catalyst is the only variable, the overall temperature change, in well-insulated reaction vessels, will be the same for both catalysts, consistent with the fact that a catalyst does not affect the molar enthalpy of decomposition.