2024 VCE Chemistry external assessment report

General comments

Overall, the examination included a good representative coverage of Units 3 and 4 content. This allowed students to demonstrate their understanding of key knowledge points and their application of key science skills. The new *VCE Chemistry Study Design* included new content, which, not surprisingly, was challenging for many students.

Key points for consideration relating to this new material are outlined below.

Melting points

Melting point and how it can be used to both identify a compound and its relative purity were addressed in Question 1a. The most common student misconception was that the difference in melting point of an unknown sample from that of a pure sample was solely due to the level of impurity. This cannot always be assumed to be true. For example, a product is isolated during the process of synthesising salicylic acid from benzoic acid. If this product has a melting point of 122 °C, and salicylic acid has a known melting point of 158.6 °C, then the compound isolated is not impure salicylic acid, but unreacted benzoic acid. The melting point range is always a better indicator of the purity of a compound. A pure compound will have a very narrow range, or spread, as it melts. If impure, then the melting point becomes broad as well as depressed from the literature value. The key point required from students was the understanding that the range of melting point indicated the degree of purity and the relative proximity to the literature value indicated the likelihood of it being a specific compound.

Resolution

This concept was assessed in Question 8b.iv. Resolution is a quantity directly linked to the ability of a piece of equipment to provide a numerical value for a measurement, and needs to contain units for this value. The display of the electronic balance used in the question was digital and therefore has a fixed resolution defined by the final digit it can display (in this case 0.1 g). Many students were able to successfully identify this. The determination of the resolution of the burette was more problematic. As explained in the *VCE Chemistry Study Design* on pages 18 and 19, a value can only be quoted with a volume of 0.5 mL if this measurement was taken from a burette that had graduations marked every 1 mL; therefore the resolution of this burette is 1 mL.

Integration curves

This concept was assessed in Q6d.i–v. In general, the concepts underpinning the use of integration curves were understood; however, often the language used in student responses did not align with the specific prompts.

Bond enthalpies

This concept was assessed in Q3c.iii. This question used the key word 'predict', which allowed students to give multiple valid responses, which greatly benefited the ability of students to respond. The key understanding students needed was to identify both the number and type of specific bonds that differed between these two compounds, and then use the data provided in the Data Book to predict an outcome. For future reference, students could be expected to provide a clear overall understanding of the nature of enthalpy changes based on more simplistic structures. When in this situation, students will need an understanding that bond enthalpies are based on the average energies required to break a bond type (endothermic process) and form new bonds (exothermic processes).

Balancing half equations using alkaline media

In general, this was not understood well. Students should ensure that they can demonstrate a greater degree of competence in writing these equations.

Important tips for students

- Students should thoroughly practise the use of stoichiometry to determine correct answers for both the multiple-choice and short answer section of this examination.
- It is very important that students follow instructions to supply information in specific locations on the examination paper (such as in Questions 2d.ii and 7c.ii). If their response is placed in another location, it may not be identified as a response by the assessor and cannot be assessed.
- If a unit is not supplied in the stem of a question, then it is essential for a correct unit to be quoted along with the calculated value. For example, in Question 7b.ii the stem of the question stated 'Calculate the mass of LiC_6 produced …'; the answer '3.68' needed units of grams in order to be awarded full marks.
- To aid the interpretation of information, diagrams can be extremely beneficial for some students. Question 7a is a typical example of where this greatly assists students' responses.
- When using enthalpy values in energy calculations, care must be taken when including the negative sign associated with exothermic processes. Students who left the negative sign in these calculations ended up with negative final answers, and this suggests that a negative energy is transferred, which is not a valid concept. This was frequently seen in answers to Question 5a.i, where responses for the energy *released* were quoted as −28.8 kJ. This also occurred in Question 5b.ii, where students used the −49 kJ mol^{-1} enthalpy value and calculated a negative temperature change for an exothermic process.

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

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

Question	Correct answer	% A	% B	% C	% D	Comments
1	B	10	**54**	10	27	The reaction $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ is an endothermic process, as it is the reverse of a combustion reaction, which is exothermic. It should not be classed as a condensation reaction as this type of reaction is usually defined as occuring when two molecules are joined together in order to eliminate a single water molecule (small molecule).
2	B	20	**40**	15	25	From the Data Book, energy of combustion of glucose is 16 kJ / g or 2840 / 180 = 15.8 kJ / g and the energy of combustion of hydrogen is 286 / 2 = 143 kJ / g. The reduction of carbon dioxide to form glucose is photosynthesis, which cannot occur in the body. In option C, in the equation glucose is not the reactant, therefore it is not undergoing either oxidation or reduction. Cellular respiration involves the combustion of glucose.
3	B	16	**45**	32	6	$n(O_2)$ = 22 / 32 = 0.6875 mol To react with all the ethane, we need 1.75 mol of oxygen. Therefore, the reactant in excess is ethane. To react all the O_2, we only need 0.6875 / 3.5 = 0.20 mol, so 0.30 mol of ethane is in excess.
4	A	**49**	30	13	8	The $Cr_2O_7^{2-}$ is the oxidising agent and this is shown as it undergoes reduction to form Cr^{3+}. The correct conjugate redox pair for this reaction has to be I_2 / I^- as the pair I^- / I_2 shows the incorrect representation.
5	C	14	11	**54**	20	All galvanic cells transform chemical energy to electrical energy. Therefore, when operating, a galvanic cell's stored chemical energy will decrease as it produces electrical energy. The direction of electron flow occurs from half-cell B to half-cell A because Pb(s) is the strongest reductant and Sn^{4+}(aq) is the strongest oxidant.
6	C	11	29	**43**	16	The negative electrode is the anode where oxidation occurs and this takes place in half-cell 2. Therefore, the following reaction will occur in this half-cell: $4OH^-$ (aq) $\rightarrow$ O_2(g) + $2H_2O$(l) + $4e^-$ and the concentration of the hydroxide ion will decrease. I_2 is produced at the cathode. The reducing agent is the hydroxide ion. No electrode undergoes a mass change.
7	A	**63**	23	11	3	Cu^{2+}(aq) + $2e^-$ $\rightarrow$ Cu(s) For 0.50 mol of electrons being used, 0.25 mol of copper is deposited. Therefore, the m(Cu) = 0.25 × 63.5 = 15.9 g.

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Question	Correct answer	% A	% B	% C	% D	Comments
8	D	5	40	5	**51**	Porous electrodes improve the cell efficiency. As the efficiency increases there is no effect on the ratio of H_2 supplied and electrical energy, because as the hydrogen is increased, the limiting reagent (oxygen) gas dictates the electrical energy released. Some students did not establish the relevant half-equation using basic media.
9	D	20	27	23	**29**	The negative electrode is the anode, where oxidation occurs: $C_2H_6O + 3H_2O \rightarrow 2CO_2 + 12H^+ + 12e^-$ (in acidic conditions) $C_2H_6O + 12OH^- \rightarrow 2CO_2 + 9H_2O + 12e^-$ (in alkaline conditions) In general this question was not well answered; the use of alkaline conditions for balancing half-equations was not well understood.
10						As a result of psychometric analysis and review, all four options were accepted as correct.
11	A	**73**	18	1	7	When producing a product from the continual supply of raw material such as iron ore and fossil fuels, this is a typical example of a linear economy. The two quoted Sustainable Development Goals are not directly linked to the process in question.
12	C	16	20	**32**	32	Statistically, the probability of successful collisions occurring between the combined products of a combustion reaction colliding in the correct orientation with sufficient energy is so small that, in practice, it can never happen. Therefore, the reverse reaction of a combustion equation of C_4-based compounds or larger never occurs. The forward reaction is exothermic, but all equilibrium processes involve both an exothermic and endothermic reaction. The products are more stable than the reactants in an exothermic process. Combustion is not an equilibrium process, so LCP does not apply. A significant number of students selected 'D' as an option, which is not a valid response as to why the reaction is considered irreversible.
13	C	14	2	**82**	2	If a catalyst is removed from a reaction, the activation energy for this process will be increased. Catalysts do not alter the energy of the reactants or products. Removing a catalyst will reduce the rate of reaction.
14	C	15	11	**58**	15	To increase the yield of NO_2, the equilibrium will need to be shifted forward. This can be done for this endothermic equilibrium by having the maximum temperature and lowest pressure.

Question	Correct answer	% A	% B	% C	% D	Comments
15	AD	**17**	21	19	**43**	$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$ When this system reaches equilibrium at any temperature, the only facts we can establish are: • $[SO_2]$ will be twice as high as $[O_2]$ • therefore, the $n(SO_2)$ will be twice as high as $n(O_2)$ • therefore, the $m(SO_2)$ will be four times as high as $m(O_2)$ due to the $M_r(SO_2) = 64$ and $M_r(O_2) = 32$ Given that the wording for option D could have been interpreted as stating that, no matter how the temperature of an equilibrium is altered, the sum of $n(SO_2)$ and $n(SO_3)$ will always equal the same value, this response was subsequently awarded as being correct in addition to option A.
16	C	17	9	**49**	25	At t_3, the system is not at equilibrium and Q < K (added reactant). When Q < K, the rate of the forward reaction needs to be faster than the rate of the reverse reaction in order for Q to increase and reach K. K will not change as temperature has not changed. The chemical energy of the system decreases for an exothermic process. The concentration of iron(III) ions will have decreased as the system returns to equilibrium.
17	D	20	27	15	**38**	When either iron or nickel metals present in the blister of copper preferentially undergo oxidation, then Cu^{2+} ions in solution will have to undergo reduction at the cathode. Therefore, with the loss of Cu^{2+} ions from the solution, the concentration of the Cu^{2+} ions in the electrolyte will decrease. The blister of copper will need to be the anode. The pure copper is held in place until the blister of copper is totally reacted. Students were unable to consistently answer this question correctly about the practical aspects of the process of purifying a metal through electrowinning.
18	B	13	**48**	17	22	Carboxylic acids easily form dimers with strong intermolecular forces holding them together. These forces will be much more significant than the $-CH_2-OH$, ester or N-methyl bonding.
19	A	**34**	14	22	30	Linear compounds with the same molecular formula of both C_6C_{12} (any pentene) and C_6H_6 (1,5-hexadiyne) can and do exist. Average bond strengths in benzene are much greater than cyclohexane. These molecules do not have the same functional groups, and therefore cannot be members of the same homologous series. Each carbon in both structures have the same number of valence electrons. Many students confused the structural differences between cyclohexane and benzene.
20	C	24	19	**51**	7	There are four structural isomers that are aldehydes (not including enantiomers). Two of these isomers have a single methyl side chain: $CH_3CH_2CH(CH_3)CHO$ and $(CH_3)_2CHCH_2CHO$

Question	Correct answer	% A	% B	% C	% D	Comments
21	D	33	5	20	**42**	Structure shown in A is propyl-3-chloropentanoate. Structure shown in B is 3-chloropropyl pentanoate. Structure shown in C is butyl-3-chlorobutanoate.
22	D	9	21	21	**49**	The fatty acid for this methyl ester must be $C_{18}H_{28}O_2$. To form the triglyceride, $3C_{18}H_{28}O_2 + C_3H_8O_3 - 3H_2O$ gives $C_{57}H_{86}O_6$
23	B	8	**59**	30	3	Esterification reactions are equilibrium systems with water as a product. Therefore, in the presence of water, any ester formed is going to potentially undergo hydrolysis and form the fatty acid rather than the desired biodiesel.
24	D	14	35	24	**26**	From the Data Book: MnO_4^- (aq) $+ 8H^+$(aq) $+ 5e^- \rightarrow Mn^{2+}$(aq) $+ 4H_2O$(l) Therefore, the reaction between MnO_4^- and $C_2H_2O_4$ will have a 2:5 stoichiometric ratio. $n(MnO_4^-) = 0.001$ mol, therefore $n(C_2H_2O_4) = 0.0025$ mol $V(C_2H_2O_4) = 0.0025/0.1 = 0.025$ L $= 25$ mL Many students did not identify and apply the second half-equation and hence establish the stoichiometry needed for this question.
25	D	19	14	17	**50**	Using a non-polar stationary phase, the most non-polar compound will have the highest retention time, and the most polar compound will have the lowest retention time. Hexane is the most non-polar compound present, and hexan-1-ol is the most polar.
26	A	**63**	11	21	4	Using a series of known concentration solutions and establishing a calibration curve is the most common method used to accurately determine the concentration of an unknown material in an HPLC trace. Using published data is not a valid technique as each HPLC set-up will have unique responses, which is why individually prepared calibration curves must be used.
27						As a result of psychometric analysis and review, all four options were accepted as correct.
28	A	**63**	16	15	7	The compound shows a C=C (alkenyl), an -NH-CO- (amide) and an -OH (hydroxyl) group. There are no carboxyl, carbonyl or amine groups present in the compound.
29	C	14	11	**57**	19	The presence of sulfur atoms in amino acids like cysteine allows for the possible formation of disulfide links, and these do contribute to the tertiary structure of a protein.
30	C	1	15	**81**	3	The correct response is C. Some students appeared to be challenged in classifying Statements II and III in particular.

Section B

Question 1a.

Marks	0	1	2	Average
%	43	46	11	0.7

The first mark was awarded for clear identification of one of the following:

- when the melting point range is narrow this implies a pure compound
- a broad range indicates an impure compound.

The second mark was awarded for either of the following concepts being communicated:

- When the melting point is narrow and it matches the melting point of the pure compound, the identity of the component can be confirmed as being the same as the pure compound.
- A small sample of the unknown compound can be mixed with a sample of a pure compound. If the melting point of the mixture was the same as that of the pure compound, the unknown can be confirmed as being the same as the pure compound.

Question 1b.i.

Marks	0	1	Average
%	31	69	0.7

There is a single chiral centre.
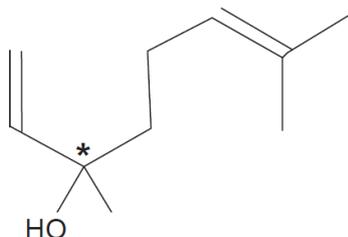
Question 1b.ii.

Marks	0	1	2	3	Average
%	42	13	18	26	1.3

The first mark was awarded for the correct calculation of n(linalool) = 0.042 / 2 = 0.021 mol

The second mark was awarded for the correct m(linalool) = 0.021 × 154 = 3.234 mol

The third mark was awarded for the correct percentage m(linalool) = 3.234 / 15.0 = 22%

Question 1b.iii.

Marks	0	1	2	Average
%	18	54	29	1.1

The first mark was awarded for any valid extraction technique:

- solvent extraction / steam distillation / filtration.

The second mark was awarded for any valid purification technique:

- distillation (fractional distillation) / HPLC.

Some students attempted to respond to the purification process with 'recrystallisation', but as linalool is identified in the stem of the question as an oil, this could not be accepted.

Question 2a.i.

Marks	0	1	Average
%	27	73	0.8

C_5H_{12}

Students should be aware that they should not provide 'working out' material in the response boxes provided as this can invalidate a correct response.
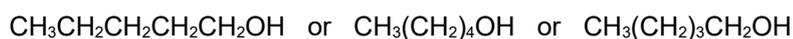
Question 2a.ii.

Marks	0	1	Average
%	25	75	0.8

The type of reaction is a substitution reaction.

Question 2b.

Marks	0	1	Average
%	30	70	0.7

Any valid semi-structural representation of pentan-1-ol. Typical examples of acceptable forms are:

$CH_3CH_2CH_2CH_2CH_2OH$ or $CH_3(CH_2)_4OH$ or $CH_3(CH_2)_3CH_2OH$

Students should be aware that a representation such as '$OHCH_2CH_2CH_2CH_2CH_3$' is an incorrect representation of a terminal hydroxyl group.

Question 2c.

Marks	0	1	Average
%	31	69	0.7

Either propan-1-ol or 1-propanol were acceptable responses. Both of these follow IUPAC nomenclature conventions.

Question 2d.i.

Marks	0	1	2	Average
%	34	16	50	1.2

Any of the following qualitative tests were accepted for the first mark.

The second mark was associated with the correct observation applicable to the test chosen.

Test	Observation
pH test using a pH meter	pH would be shown as less than 7
pH testing using an indicator / pH paper*	Correct colour observation stated
Adding any metal carbonate (carbonate test)	Bubbles forming
Adding an alcohol and sulfuric acid (esterification)	Distinct smell being formed**
Adding a group 2 metal***	Bubbles forming
IR spectroscopy	Both the O-H bond at 2500–3500 cm^{-1} and the C=O at around 1800 cm^{-1}

The indicator must be able to undergo a distinct colour change at a pH less than 7.
*** Normally the smell is described as 'sweet' or 'fruity', but any 'smell' was accepted as a significant number of students would have manufactured biodiesel as part of their laboratory work and biodiesels do not have this type of 'fruity' smell.*
*** *Group 1 metals were not accepted as these produce gas if any labile hydrogen is present, and therefore cannot be used to identify the compound specifically as a carboxylic acid.*

Incorrect responses such as 'limewater test' could not be awarded marks as this tests the product of the reaction between a carboxylic acid and a metal carbonate, not the carboxylic acid itself. The addition of an acid to limewater produces a salt and water, which cannot be observed.

In order to gain these marks for the limewater test, the student needed to indicate that the unknown organic compound had to be reacted with a metal carbonate first, and the gas produced then tested using the limewater test to confirm the presence of carbon dioxide being evolved.

Question 2d.ii.

Marks	0	1	2	Average
%	23	17	60	1.4

A clear skeletal diagram was required as represented below.
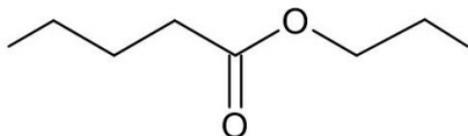
The only significant issue that arose from this question related to the fact that some students did not use the box provided on page 14 (as specified in the question) and instead provided their response in the blank space at the bottom of page 15. Students are reminded to provide responses in the correct location on the examination.

Question 3a.

Marks	0	1	Average
%	36	64	0.7

Students needed to calculate the correct value for the energy released, with units.

Energy released: $9.5 \times 17 + 3.4 \times 3.7 + 47.3 \times 16 = 1044$ kJ or 1.0×10^3 kJ

Question 3b.i.

Marks	0	1	Average
%	35	65	0.7

Peptide bond/link or amide bond/link

Question 3b.ii.

Marks	0	1	Average
%	24	76	0.8

The reaction type is a condensation reaction.

Question 3b.iii.

Marks	0	1	Average
%	48	52	0.5

Either of leucine or serine was accepted.

Many students were unable to successfully identify either of these compounds.

Question 3c.i.

Marks	0	1	Average
%	29	71	0.7

Students needed to identify that oleic acid has just one C=C present in its structure, and that stearic acid does not have a C=C. This response could also have been represented by stating that oleic acid had two fewer hydrogens present in its structure compared with stearic acid.

Students needed to be careful and not state that stearic had 'no double bonds', as this could not be accepted.

When asked to identify a difference, a direct comparison of the two compounds is usually required. It was insufficient to provide a response such as 'Oleic acid has one C=C double bond' as this did not indicate whether the stearic has no C=C bonds or has multiple C=C bonds.

Question 3c.ii.

Marks	0	1	2	Average
%	10	26	64	1.6

Either of the following equations was accepted:

$C_{18}H_{34}O_2 + 25\frac{1}{2}O_2 \rightarrow 18CO_2 + 17H_2O$

$2C_{18}H_{34}O_2 + 51O_2 \rightarrow 36CO_2 + 34H_2O$
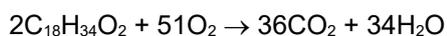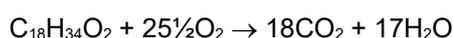
The first mark was awarded for the correct identification of reactants and products.

The second mark was awarded for correct balancing of the equation.

Question 3c.iii.

Marks	0	1	2	Average
%	25	66	9	0.9

The first mark was awarded for correctly identifying two bond types that differed in the structures of oleic acid and stearic acids and then using the data provided in the Data Book to predict the greatest enthalpy change.

The second mark was awarded to students who correctly identified an extra bond type that enhanced their prediction.

It was common to see responses gain the first mark for the comparison of data for the C=C (614 kJ) associated with oleic acid and either the C-C (346 kJ) or the C-H (414 kJ) of stearic acid. The second mark was harder to obtain as fewer responses demonstrated that ½(O=O) or 2(O-H) were also involved in the enthalpy change.

Question 4a.

Marks	0	1	Average
%	14	86	0.9

The correct response required by students was:

$$K_p = \frac{P_{NH_3}{}^2}{P_{N_2} \times P_{H_2}{}^3}$$

However, given the nature of this question being novel, and the lack of familiarity of students with this expression, a correct representation of the relevant product and reactant concentrations was also accepted for this examination.

Question 4b.

Marks	0	1	Average
%	66	34	0.4

Students needed to calculate the correct value for the partial pressure.

$$1.60 \times 10^{-6} = \frac{P_{NH_3}{}^2}{43.4 \times 88.7^3}$$

therefore P_{NH_3} = 0.696 kPa

This question was not well answered, even when the correct representation was used.

Question 4c.

Marks	0	1	2	3	Average
%	33	38	16	13	1.1

The first mark was awarded for any one of the following three valid stresses that caused $Q \neq K$:

- removal of product / addition of reactant / reduction in volume (increase in all partial pressures).

The second mark was awarded for the correct identification of the forward shift in the equilibrium.

The third mark was awarded for a description of how this shift applied to either:

- the partial changes in quantities associated with the stress
- restoring the equilibrium so that $Q = K$.

Some responses did not gain full marks as they failed to provide sufficiently specific responses that linked directly to the stress they had selected.

Attempts to provide a response based on temperature change could not be accepted as the stem of the question emphasised that the process occurred at a constant temperature. Students are reminded to fully read the stem of each question.

Question 4d.

Marks	0	1	2	3	Average
%	23	41	18	18	1.3

The first mark was awarded for a clear identification of what the term 'conflict' related to in terms of the optimal rate and temperature when ammonia is being produced. A good example showing detailed understanding of this conflict could have been:

> *Due to the exothermic nature of the equilibrium, at high temperature the rate of formation of ammonia is high but the yield will be low, whereas at low temperature the rate of formation of ammonia is too slow but the yield is very high.*

The second mark was awarded for a clear statement that linked the presence of the catalyst to allowing a sufficiently fast rate to be occurring at a lower temperature, and hence reducing energy requirements.

The third mark was awarded for a clear statement that linked the lower temperature requirements with the green chemistry principle of 'catalysis', which states that 'Catalysts … using less energy and reagents in reaction processes/pathways'. Therefore, a student needed to show reasoning for this choice based on linking the lower temperature to this concept.

Most responses effectively linked the green chemistry principle to this issue, but often did not fully identify the 'conflict' that was asked for in the stem of the question.

Question 5a.i.

Marks	0	1	2	Average
%	19	20	62	1.5

The first mark was awarded for the correct calculation of the mole of butane:

$n(C_4H_{10}) = 0.580 / 58 = 0.010$ mol

The second mark was awarded for calculating the correct quantity of energy released, with units:

$E = 0.010 × 2880 = 28.8$ kJ

Question 5a.ii.

Marks	0	1	Average
%	34	66	0.7

The mark was awarded for the correct calculation of the energy change of the water, with units:

$E = 100 × 4.18 × 35.6 = 14.9$ kJ

It was concerning to see some responses using the density of water, 0.997, in these calculations as, even if it was relevant, this was only applicable in the previous study design and Data Book.

Question 5a.iii.

Marks	0	1	2	Average
%	29	20	51	1.2

The first mark was awarded for the correct calculation of the % energy efficiency.

The second mark was awarded for the value being quoted to three significant figures.

% Efficiency = $100 × 14.9 / 28.8 = 51.7\%$

Question 5b.i.

Marks	0	1	2	Average
%	56	35	9	0.6

The first mark was awarded for the response demonstrating that a solution calorimeter needs to be calculated because energy is needed to heat the water **and** it is needed to heat the internal components of the calorimeter; that is, energy from the reaction is not solely transferred to the water (hence why $q = mC\Delta T$ cannot be used).

The second mark was awarded for understanding that, without this calibration factor, we cannot use the change in temperature of an unknown reaction to determine an accurate value for the enthalpy change. Without calibration, the enthalpy value obtained will always be less than the true value for a given calorimeter using a fixed quantity of solution.

Question 5b.ii.

Marks	0	1	2	3	Average
%	43	9	24	23	1.3

The first mark was awarded for the correct calculation of energy released, with units:

- energy released$_{(based\ in\ limiting\ reagent)}$ = 0.048 × 24.5 = 1.176 kJ or 1176 J

The second mark was awarded for the correct change in temperature:

- change in temperature = 1176 / 470 = 2.5 °C

The third mark was awarded for the correct final temperature:

- maximum temperature reached = 25.0 + 2.5 = 27.5 °C

Errors occurred when:

- the stoichiometry was not taken into account when determining the energy released
- there was no consideration of the units of the energy and the calibration factor
- responses determined a negative energy released and subtracted the temperature change.

Question 5b.iii.

Marks	0	1	Average
%	87	13	0.2

Any of the following were valid responses:

- The concentration of KI in the stock solution was higher than 0.960 M.
- The amount of KI added to the calorimeter was too high.
- The total volume of solution in the calorimeter was lower than that used to calibrate it.
- The calorimeter's calibration factor was smaller than the true value.

This question was not well answered.

Question 6a.

Marks	0	1	Average
%	32	68	0.7

To gain the mark, the response needed to clearly identify the bond type as O-H **and** state that it was due to an 'alcohol' as shown in the Data Book (i.e. O-H (alcohol)).

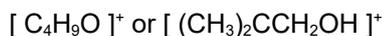## Question 6b.i.

Marks	0	1	Average
%	25	75	0.8

m/z = 56

Students should avoid attempting to use 'm/z' as a unit (for example, '56 m/z').

Question 6b.ii.

Marks	0	1	Average
%	50	50	0.5

Either of the following representations were accepted:

[C_4H_9O]$^+$ or [$(CH_3)_2CCH_2OH$]$^+$

Question 6c.

Marks	0	1	2	3	Average
%	14	26	41	19	1.7

One mark was awarded for recognising that the compound had only four carbon environments.

One mark was awarded for recognising that the compound must have two carbons in the same environment.

The third mark could be obtained from any one of the following:

- a statement that Compound X has a side chain/branch or is a non-linear molecule
- a statement that Compound X has a point of symmetry
- any reference to one of the specific peaks located on the spectra being matched to a particular carbon type and chemical shift from item 23 of the Data Book.

Question 6d.i.

Marks	0	1	Average
%	80	20	0.2

The integration curve is a representation of the area of a signal for a hydrogen environment or a 'peak area'.

This question was not well answered, and often responses to Question 6d.ii were repeat answers. Careful reading of the question was needed to understand the correct terminology that applied to each of these two questions.

Question 6d.ii.

Marks	0	1	Average
%	68	32	0.3

The relative size of an integration curve is proportional to the **ratio** or the **relative number** of hydrogens present in that hydrogen environment.

Question 6d.iii.

Marks	0	1	Average
%	80	20	0.2

The relative size of an integration curve shown in the table indicates that the ratio of hydrogens present in each of the compound's four hydrogen environments are 1:2:2:6.

This question was not well answered, and often responses did not relate understanding of these integration curves back to the structure of Compound X.

Question 6d.iv.

Marks	0	1	2	Average
%	13	68	19	1.1

The first mark was awarded for understanding that the peak at 0.96 suggests that an R-CH_3 group is present.

The second mark was awarded for linking the information from Question 6d.iii and stating that therefore there must be two R-CH_3 groups present in Compound X.

Question 6e.

Marks	0	1	2	Average
%	31	49	20	0.9

The first mark was awarded for any structure showing the correct atoms connected to form an alcohol with a chemical formula of $C_5H_{11}ClO$.

The second mark was awarded for the correct structure of 3-chloro-2,2-dimethylpropan-1-ol.
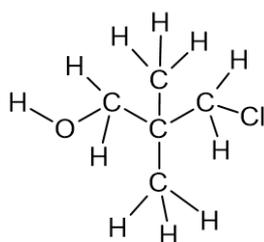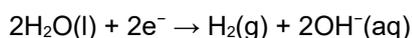
Question 7a.i.

Marks	0	1	Average
%	24	76	0.8

The anode is the iron (Fe) electrode.

Question 7a.ii.

Marks	0	1	Average
%	75	25	0.3

$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

This question was assessed for the use of states.

Students need to be aware that for reactions that occur during a specific redox process, the single-headed arrow '$\rightarrow$' is required.

A significant number of students responded to this question by writing an equation based on either iron or platinum reacting. It is recommended that students sketch out a diagram of the cell to assist them to understand the processes occurring at each electrode.

Question 7a.iii.

Marks	0	1	Average
%	94	6	0.1

Any of the following were valid responses:

- One of the products of the reaction is hydrogen gas, which does not stay in contact with the electrode and therefore is not available to react spontaneously.
- Iron(II) hydroxide would form and may not remain in contact with the electrode, and therefore is not available to react spontaneously.
- There are no oxidants/reductants present that are strong enough to react spontaneously with a reductant/oxidant.

Students needed to provide a specific response – statements such as 'this is a non-spontaneous process' do not demonstrate the required understanding of chemical processes.

Question 7b.i.

Marks	0	1	Average
%	31	69	0.7

Electrode X is positive during recharging.

Question 7b.ii.

Marks	0	1	2	3	4	Average
%	15	3	4	18	60	3.1

The first mark was awarded for the correct calculation of charge.

- $Q = 1.25 \times 1 \times 60 \times 60 = 4500$ C

The second mark was awarded for the correct n(e).

- $n(e) = 4500 / 96\,500 = 0.04663$ mol

The third mark was awarded for the correct $n(LiC_6)$.

- From equation stoichiometry, $n(LiC_6) = n(e) = 0.04663$ mol

The fourth mark was awarded for the correct $m(LiC_6)$, with units.

- $m(LiC_6) = 78.9 \times 0.04663 = 3.68$ g

In general, this question was answered extremely well.

Question 7c.i.

Marks	0	1	Average
%	67	33	0.4

Electromagnetic / light energy / sunlight to chemical energy

Question 7c.ii.

Marks	0	1	Average
%	41	59	0.6

$\longrightarrow$

The arrow needed to be drawn in the box provided, and be pointing to the right.

Question 7c.iii.

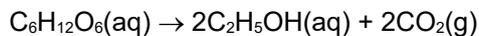| Marks	0	1	2	Average
%	68	25	7	0.4

Any two of the following were valid responses:

- Electrons are continually generated at the anode and used up at the cathode, hence maintaining the charge balance.
- H^+ ions are continually generated at the anode and flow to the cathode where they are removed, hence maintaining the charge balance.
- The flow of electrons to the cathode is balanced by the flow of protons to the cathode.
- Ions flow through the system to balance the charge.

Some students attempted to show a balance by using hydroxide ions, but this was not accepted due to the clear information in the question that the reaction was occurring under acidic conditions.

Question 8a.i.

Marks	0	1	Average
%	50	50	0.5

$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$

Question 8a.ii.

Marks	0	1	Average
%	63	37	0.4

The high temperature will denature the enzyme.

Many responses stated that the 'yeast would be killed/destroyed/denatured'. These responses could not be accepted as they showed no understanding that the enzyme is the key component needed for this reaction to occur and not the organism itself.

Question 8b.i.

Marks	0	1	Average
%	39	61	0.6

The mark was awarded for the correct calculation of the amount of carbon dioxide.

$n(CO_2) = 0.1 / 44 = 0.0023$ mol

Question 8b.ii.

Marks	0	1	Average
%	57	43	0.5

The mark was awarded for the correct calculation of the amount of carbon dioxide.

$V(CO_2) = 32.5 - 0.5 = 32.0$ mL

$n(CO_2) = 0.032 / 24.8 = 0.00129$ mol

The most common errors were caused by failure to:

- subtract the initial volume from the final volume
- divide the volume of gas by 1000 to convert to litres.

Question 8b.iii.

Marks	0	1	Average
%	73	27	0.3

Any of the following valid responses were accepted:

- The gas collected behaves as an ideal gas.
- Carbon dioxide does not react with / dissolve in water, so all CO_2 produced ends up as gas in the burette.
- Gas collected in the burette is 25 °C.
- Gas collected in the burette is 100 kPa.
- The only gas present in the burette is carbon dioxide.

Responses simply stating that 'the experiment was being conducted at SLC' contained insufficient information as the question clearly states that the glucose reacting with yeast enzymes occurs at 35 °C.

Question 8b.iv.

Marks	0	1	2	Average
%	86	13	1	0.2

One mark was awarded for each correct resolution value.

- In method A, the resolution of the balance was 0.1 g.
- In method B, the resolution of the burette must have been 1 mL.

Units were required for resolution quantities.

While some students could identify the correct resolution of the balance, a significant number of students was unable to determine the resolution of the burette. For further details about this question, please refer to the introductory section of this report.

Question 8c.i.

Marks	0	1	Average
%	31	69	0.7

The independent variable is the concentration of the glucose solution.

Question 8c.ii.

Marks	0	1	2	Average
%	52	30	17	0.7

The first mark was awarded for identifying that the hypothesis is not supported.

The second mark was awarded for a clear reference to the graph that indicated that the 'slope of the line' or the 'quantity of gas formed' over the first 15 minutes was the same.

Students often responded to this question without making a direct reference to the graph. A response that simply stated that the 'rate' was the same for the first 15 minutes was not awarded the mark.

Question 8d.i.

Marks	0	1	Average
%	67	33	0.4

Any of the following valid responses were accepted:

- The gas may dissolve in the water as it bubbles through.
- The collected gas pressure may not be the same as atmospheric pressure.
- Some gas may escape before the stopper is applied / Not all gas was collected in the burette.
- There may be difficulty in setting up the complex arrangement.
- The gas temperature is not at 25 °C (originally at 35 °C).
- The burette cannot collect the 500 mL of gas shown forming in the graph.

The only condition that could have voided one of these responses was if the student had used the same response in Question 8b.iii.

Question 8d.ii.

Marks	0	1	Average
%	13	87	0.9

The discussion is where the limitation should be identified.

This was well answered by students.

Question 9a.i.

Marks	0	1	2	3	4	Average
%	15	9	18	19	39	2.6

n(paracetamol) = 1.4 / 109 = 0.01284 mol and therefore m(paracetamol) = 0.01284 × 151 = 1.94 g

The first mark was awarded for the correct calculation of the % yield of reaction P2.

- % yield = 100 × 0.80 / 1.94 = 41%

The second mark was awarded for the correct % atom economy.

- % atom economy = 100 × 151 / (109 + 60) = 89%

The third mark was awarded for the comparison of % yield.

- The percentage yield is higher for reaction P1 with 87% compared to reaction P2, which is 41%.

The fourth mark was awarded for the correct $m(LiC_6)$.

- The percentage atom economy is higher for reaction P2 with 89% compared to reaction P1, which is 72%.

In general, this question was well answered, although some students either calculated the % atom economy or the % yield, rather than both of these as required.

Question 9a.ii.

Marks	0	1	2	Average
%	31	18	51	1.2

The first mark was awarded for identifying % atom economy as the relevant green chemistry principle, as % yield is not specifically addressed as a green chemistry principle.

The second mark was awarded for responding that the % atom economy for reaction P2 was better aligned with this green chemistry principle because it had the higher % atom economy.

Question 9b.

Marks	0	1	2	3	Average
%	26	23	28	23	1.5

The first two marks were awarded for identifying the following two points.

- Reaction P1 produces waste ethanoic acid (with other contaminates).
- Reaction P2 produces wastewater (with other contaminates).

The third mark was awarded for any one of the following valid comments.

- Reaction P1 has a much higher yield, and therefore potentially produces much less waste.
- Reaction P2 has a much lower yield, and therefore potentially produces much greater waste.
- Recycling of ethanoic acid or unused reactants can reduce the waste from reaction P1.
- Any suitable comment that related waste back to the % atom economy values.