

# 2020 VCE Chemistry examination report

## General comments

In 2020 the Victorian Curriculum and Assessment Authority produced an examination based on the adjusted 'Chemistry Study Design for 2020 only'. The examination provided students with the opportunity to demonstrate and apply a range of knowledge and skills.

The examination identified the following areas that require attention:

- Use of correct chemical language, including the use of hyphens to separate numbers from letters when naming organic compounds (for example '3-bromohexane' not '3-bromo-hexane') and the correct spelling of chemicals provided as one-word responses to questions (for example 'ketones' not 'keytones').
- Identification of the direction of half-cell redox reactions.
- The difference between chemical energy and heat energy.
- The effect of temperature on the shape of Maxwell-Boltzmann distributions.
- Use of concentrations rather than amounts (mols) when calculating the value of an equilibrium constant.

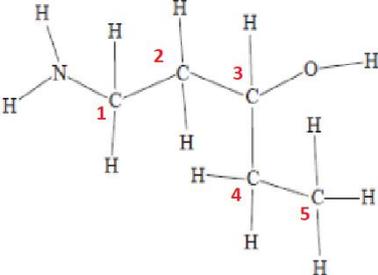
Students are advised to familiarise themselves with the content of the Data Book. Section B Questions 6c. and 8a. required students to access relevant data in order to respond to the question. Students should also read questions carefully in order that their answers are relevant to the specific information or response being requested. Care should be taken in the manipulation of mathematical relationships and the use of calculators.

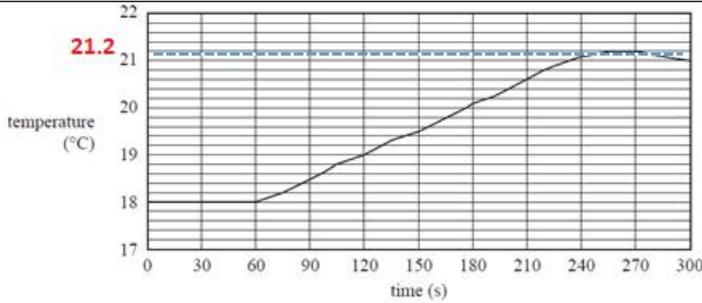
## Specific information

### Section A – Multiple-choice questions

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

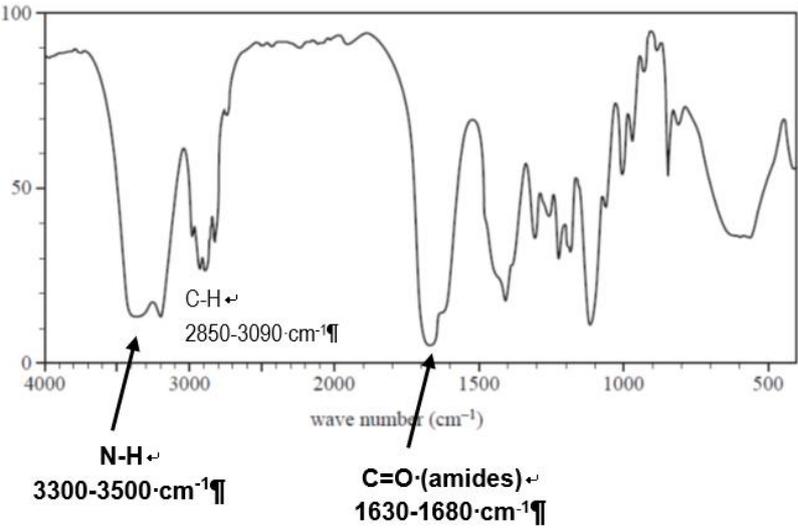
Question	% A	% B	% C	% D	% N/A	Comments
1	16	5	6	73	0	Glycogen is a condensation polymer of the monosaccharide glucose.
2	48	19	23	10	0	<p>Option A: Correct.</p> <p>Sufficiently large sample sizes are essential for a reliable measurement result (usually the mean of a set of values) since repetition and/or replication can demonstrate that individual measurements are consistent within an acceptable range. If the mean is taken for only a small number of measured values, it will be found to be less consistent than if a larger sample is taken.</p> <p>Option B: Incorrect. Precision refers to the closeness of agreement between measured values obtained by repeated measurements. It cannot be ascertained</p>

Question	% A	% B	% C	% D	% N/A	Comments															
						<p>without having several measurements, so precision is improved by a larger sample size. Repeated measurements, however, may not appear to improve precision in special cases:</p> <ul style="list-style-type: none"> <li>When the repeated measured values give the same value (due to the limitations of the instrument, in which case precision can only be known from calibration properties of the instrument).</li> <li>When a large number of measurement values have already been taken and increasing the number does not make a significant difference to the spread of values.</li> </ul> <p>Option C: Incorrect. A measurement is 'valid' if it measures what it is supposed to be measuring and depends on both procedure and instrument. Validity may therefore not be affected by increasing the sample size due to a consistent flaw in the method or equipment used.</p> <p>Option D: Incorrect. Uncertainty depends on both systematic and random errors. A larger sample size will reduce the contribution of random errors while systematic errors are not influenced by sample size; hence a larger sample size cannot increase the uncertainty.</p>															
3	8	2	86	3	0	Electrons leave the site of oxidation and move to the site of reduction, i.e. from Q to S, which is immersed in electrolyte R.															
4	5	6	26	63	0	 <p>-OH functional group is of higher priority than -NH<sub>2</sub> functional group, hence it is an alcohol with an amino functional group attached and not an amine with a hydroxy functional group attached.</p>															
5	10	67	12	11	0	In A, C and D water is a reactant.															
6	3	20	12	64	0	<table border="1"> <thead> <tr> <th></th> <th>Electrolysis cell</th> <th>Galvanic cell</th> </tr> </thead> <tbody> <tr> <td>A.</td> <td>Both electrodes are always inert. <input checked="" type="checkbox"/></td> <td>Both electrodes are always made of metal. <input checked="" type="checkbox"/></td> </tr> <tr> <td>B.</td> <td>Electrical energy is converted to chemical energy. <input checked="" type="checkbox"/></td> <td>The voltage of the cell is independent of the electrolyte concentration. <input checked="" type="checkbox"/></td> </tr> <tr> <td>C.</td> <td>Chemical energy is converted to electrical energy. <input checked="" type="checkbox"/></td> <td>The products are dependent on the half-cell components. <input checked="" type="checkbox"/></td> </tr> <tr> <td>D.</td> <td>The products are dependent on the half-cell components. <input checked="" type="checkbox"/></td> <td>Chemical energy is converted to electrical energy. <input checked="" type="checkbox"/></td> </tr> </tbody> </table>		Electrolysis cell	Galvanic cell	A.	Both electrodes are always inert. <input checked="" type="checkbox"/>	Both electrodes are always made of metal. <input checked="" type="checkbox"/>	B.	Electrical energy is converted to chemical energy. <input checked="" type="checkbox"/>	The voltage of the cell is independent of the electrolyte concentration. <input checked="" type="checkbox"/>	C.	Chemical energy is converted to electrical energy. <input checked="" type="checkbox"/>	The products are dependent on the half-cell components. <input checked="" type="checkbox"/>	D.	The products are dependent on the half-cell components. <input checked="" type="checkbox"/>	Chemical energy is converted to electrical energy. <input checked="" type="checkbox"/>
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7	29	46	18	6	0	<p>CH<sub>3</sub>CH<sub>2</sub>CHBrCl; 1-bromo-1-chloropropane</p> <p>CH<sub>3</sub>CHClCH<sub>2</sub>Br; 1-bromo-2-chloropropane</p> <p>CH<sub>2</sub>ClCH<sub>2</sub>CH<sub>2</sub>Br; 1-bromo-3-chloropropane</p>															

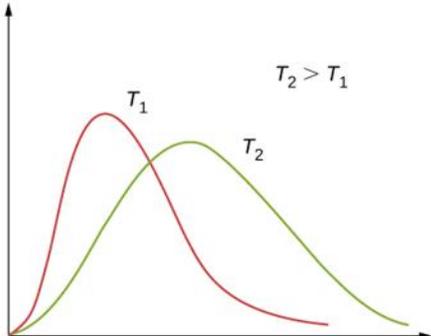
Question	% A	% B	% C	% D	% N/A	Comments
						$\text{CH}_3\text{CHBrCH}_2\text{Cl}$ ; 2-bromo-1-chloropropane $\text{CH}_3\text{CBrClCH}_3$ ; 2-bromo-2-chloropropane
8	11	14	9	66	0	<p>Option A: Fuel cells are not rechargeable, they have a continuous supply of reactants.</p> <p>Option B: Thermal energy is produced in both types of cell.</p> <p>Option C: Anode is negative in a fuel cell; it is either negative (discharging) or positive (recharging) in a secondary cell.</p> <p>Option D: Correct.</p>
9	7	28	29	35	0	 <p>According to the temperature v. time graph, the temperature is approximately 21.1 °C when the current was stopped at 240 seconds (after being applied for 180 seconds).</p> <p>However, the temperature continues to rise to 21.2 °C – a more accurate indicator of the thermal energy generated from the current flow.</p> <p>Calibration Factor = Electrical Energy / Change in temperature  <math>= VIt / \Delta T</math>  <math>= 5.4 \times 2.7 \times 180 / (21.2 - 18.0)</math>  <math>= 2624 \text{ J} / 3.2^\circ\text{C}</math>  <math>= 820 \text{ J } ^\circ\text{C}^{-1}</math></p> <p>This calibration factor is higher than the true value because it does not allow for energy loss due to the quality of the insulation.</p> <p>This is a better value for the calibration factor than that which would be determined using <math>\Delta T = 3.1^\circ\text{C}</math> (consistent with T when current is stopped), i.e. <math>847 \text{ J } ^\circ\text{C}^{-1}</math> (option C).</p> <p>Option D is consistent with <math>\Delta T = 3.0^\circ\text{C}</math>, which is an inaccurate reading of the temperature.</p>
10	3	16	54	26	0	<p>Option A: Incorrect. Heat loss is evident on the graph, as the temperature drops from 21.2 °C.</p> <p>Option B: Incorrect. Solution calorimeters are not suitable for the combustion reactions associated with bomb calorimetry.</p> <p>Option C: Incorrect. Both types of calorimeters can be calibrated using chemical reactions with known heats of reaction.</p> <p>Option D: Correct. Answers the question best in the sense that, in both types of calorimeter, it measures temperature changes that reflect the energy changes occurring during calibration or during the reaction under investigation.</p>

Question	% A	% B	% C	% D	% N/A	Comments
11	6	22	56	16	0	<p>Option A: Incorrect. A biofuel is a fuel produced from biomass that was alive in the recent past. Fossil fuels such as crude oil are produced by very slow geological processes.</p> <p>Option B: Incorrect. Biofuels can also have significant environmental impact, e.g. use of land needed for food production to produce biofuel.</p> <p>Methane processed from biomass has the same environmental impact in that it is a greenhouse gas and produces CO<sub>2</sub> on combustion.</p> <p>Option C: Correct. Ethene (CH<sub>2</sub>=CH<sub>2</sub>), used to produce ethanol (by reaction with steam in the presence of an acid catalyst), is obtained from crude oil.</p> <p>Option D: Incorrect. Hydrogen can also be obtained from coal – a fossil fuel. This hydrogen also does not produce CO<sub>2</sub> on combustion.</p>
12	11	8	14	67	0	
13	16	14	41	29	0	<p>Statement I: Incorrect. H<sub>2</sub>O(g) is a greenhouse gas.</p> <p>Statement II: Incorrect. Fuel cells are more efficient than combustion engines hence less H<sub>2</sub> is used per kilometre for the H<sub>2</sub> fuel cell powered car.</p> <p>Statement III: Correct. In combustion engines chemical energy is converted to thermal then to mechanical energy. In fuel cell powered vehicles chemical energy is converted to electrical energy then to mechanical energy. Hence correct alternative was option C.</p>
14	45	26	25	4	0	<p><math>\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}); \Delta H = -92.3 \text{ kJ mol}^{-1}; K_c = 640</math></p> <p>Divide coefficients by 3</p> <p><math>\frac{1}{3} \text{N}_2(\text{g}) + \text{H}_2(\text{g}) \rightleftharpoons \frac{2}{3} \text{NH}_3(\text{g});</math></p> <p><math>\Delta H = -92.3/3 = -30.8 \text{ kJ mol}^{-1}</math></p> <p><math>K_c = (640)^{1/3} = 8.6 \text{ (M}^{-2}\text{)}</math></p> <p>Note: The 'magnitude' refers to numerical value and does not require units.</p> <p>Options B and C did not accurately apply the impact of a change in equation coefficients on the <i>K</i> value.</p>
15	14	25	53	8	0	<p>Option A: Incorrect. A catalyst increases the proportion of collisions which are successful (by lowering activation energy) but does not affect the frequency of collisions.</p>

Question	% A	% B	% C	% D	% N/A	Comments
						<p>Option B: Correct. Increase in temperature increases the rate of nearly all reactions.</p> <p>Option C: Incorrect. A catalyst reduces the activation energies of forward and backward (reverse) reaction by the same amount – not the same proportion.</p> <p>Option D: Incorrect. Since the forward reaction is exothermic, it has a lower activation energy than the reverse reaction.</p> <p>Students should note that while an increase in temperature will favour the endothermic reaction in an equilibrium system it increases the rate of both endothermic and exothermic reactions.</p> <p>In the equilibrium with exothermic forward reaction, the activation energy of the forward reaction is lower than the activation energy of the reverse reaction. While the introduction of a catalyst will decrease the activation energies for both forward and reverse reactions equally, this decrease will be a greater proportion (fraction) of the smaller activation energy of the forward reaction.</p>
16	20	25	35	20	0	<p>Boiling points of molecular compounds such as X, Y and Z are related to the strength of the intermolecular bonding.</p> <p>Since all three are polar molecules, the intermolecular bonding will have contributions from both dispersion forces and dipole-dipole bonding.</p> <p>All three molecules have the same molar mass, so the contribution from dispersion forces will be similar for all.</p> <p>Compounds X and Y will both have hydrogen bonding, due to the O-H groups.</p> <p>Since compound Z does not have intermolecular hydrogen bonding, it would have the lowest boiling point.</p>
17	60	8	13	20	0	<p>The gradual adjustment to the change at 1 minute is consistent with a change in temperature. Since the reverse endothermic reaction is favoured the temperature was increased.</p> <p>The sudden, and proportional, decrease in all concentrations at 7 minutes is consistent with a volume increase to which the system responds by favouring the reverse reaction to partially compensate for the imposed decrease in concentration/pressure.</p>
18	7	16	67	9	1	<p>Energy added to water = <math>4.18 \text{ J } ^\circ\text{C}^{-1} \text{ K}^{-1} \times m(\text{H}_2\text{O}) \times \Delta T</math>  = <math>4.18 \times 150 \times (40.6 - 22.1)</math>  = <math>1.16 \times 10^4 \text{ J}</math>  = <math>11.6 \text{ kJ}</math></p> <p><math>n(\text{C}_3\text{H}_8\text{O}) = 0.557 \text{ g} / 60.0 \text{ g mol}^{-1} = 9.28 \times 10^{-3} \text{ mol}</math></p> <p>Enthalpy of combustion = <math>-(11.6 \text{ kJ} / 9.28 \times 10^{-3} \text{ mol})</math>  = <math>-1250 \text{ kJ mol}^{-1}</math></p>
19	19	22	53	5	0	<p>Subjecting an equilibrium system to a temperature change impacts on both reaction rates and position of equilibrium.</p> <p>The rate-time graph provided indicates that the rate of the forward reaction increased because of the change imposed at <math>t_1</math>. The implication in the alternative responses is that this was due to a temperature change and so must have been a temperature increase.</p>

Question	% A	% B	% C	% D	% N/A	Comments
						<p>Since the forward reaction is exothermic, the temperature increase will favour the reverse (endothermic) reaction. Hence the position of equilibrium shifts to the left and as concentration of <math>\text{NO}_2</math> increases, the colour of the mixture will darken.</p> <p>Hence option B was the correct answer.</p> <p>The majority of students selected option C. Perhaps these students assumed that since the rate of the forward reaction was increased, the forward reaction must be favoured, which would be a natural consequence of a decrease in temperature at <math>t_1</math>. However, if the temperature decreases, the immediate impact should mean that the rates of both the forward and reverse reactions decrease. This is not indicated in the graph.</p>
20	20	47	15	18	0	<p>I – decreasing the viscosity of the mobile phase will enable it to move through the column more quickly; this will reduce retention time.</p> <p>II – a more tightly packed mobile phase will make it more difficult for the mobile phase to move through the column; this will increase retention time.</p> <p>III – since sugar molecules are polar (due to the presence of O-H groups), they will be strongly attracted to a more polar mobile phase and elute more quickly; this reduces retention time.</p>
21	18	10	48	24	0	 <p>The first (leftmost) peak on the spectrum is in the absorption region of N-H and O-H (alcohols).</p> <p>The second peak is in the absorption region of C-H.</p> <p>The third peaks is in the absorption region of C=O (amides).</p> <p>Only alternative C is consistent with the data.</p>
22	20	12	22	46	1	<p>Option A: Energy = <math>100 \text{ g} \times 49097 \times 10^{-6} \text{ MJ g}^{-1} = 4.91 \text{ MJ} = 4.91 \times 10^3 \text{ kJ}</math></p> <p>Option B: Energy = <math>100 \text{ g} \times 11.63 \text{ kJ g}^{-1} = 1.16 \times 10^3 \text{ kJ}</math></p> <p>Option C: Energy = <math>(100/74) \text{ mol} \times 2670 \text{ kJ mol}^{-1} = 3.73 \times 10^3 \text{ kJ}</math></p> <p>Option D: Energy = <math>(100/26) \text{ mol} \times 1300 \text{ kJ mol}^{-1} = 5.0 \times 10^3 \text{ kJ}</math></p> <p>The selection of option A suggests issues with the energy units. However, the popularity of option C was surprising given the similar calculation technique to that of the correct response.</p>

Question	% A	% B	% C	% D	% N/A	Comments
23	30	20	32	17	1	<p>Since there are three carboxyl groups on each citric acid molecule, there will be 3 mol NaOH required for each 1 mol citric acid.</p> <p>Equation for titration.  <math>\text{C}_3\text{H}_5\text{O}(\text{COOH})_3(\text{aq}) + 3\text{NaOH}(\text{aq}) \rightarrow \text{C}_3\text{H}_5\text{O}(\text{COO})_3\text{Na}_3(\text{aq}) + 3\text{H}_2\text{O}(\text{l})</math></p> $n(\text{NaOH}) = 0.0250 \text{ mol} \times 24.0 \times 10^{-3}$ $= 6.00 \times 10^{-4} \text{ mol}$ $n(\text{citric acid}) = n(\text{NaOH}) / 3$ $= 6.00 \times 10^{-4} / 3$ $= 2.00 \times 10^{-4} \text{ mol}$ $c(\text{citric acid}) = 2.00 \times 10^{-4} \text{ mol} / 25.0 \times 10^{-3} \text{ L}$ $= 8.0 \times 10^{-3} \text{ M (mol L}^{-1}\text{)}$ <p>Alternative B is consistent with confusing aliquot and titre sizes.  Alternative C is consistent with not dividing by 3 and confusing aliquot and titre sizes.</p>
24	14	20	21	45	0	<p>Since a 25.0 mL aliquot of citric acid solution was titrated with a 0.0250 M solution of NaOH, the citric acid was added via a pipette and the NaOH(aq) added via a burette. So the appropriate rinsing procedures are:</p> <ul style="list-style-type: none"> <li>• pipette – <math>\text{C}_3\text{H}_5\text{O}(\text{COOH})_3(\text{aq})</math></li> <li>• burette – NaOH(aq)</li> <li>• conical flask – water.</li> </ul> <p>Rinsing the pipette or the conical flask with NaOH(aq) means less <math>\text{C}_3\text{H}_5\text{O}(\text{COOH})_3</math> will be available for titration and the <math>V(\text{NaOH}(\text{aq}))</math> needed to reach the endpoint will be lower, leading to a lower calculated concentration of citric acid.</p> <p>Rinsing the conical flask with <math>\text{C}_3\text{H}_5\text{O}(\text{COOH})_3(\text{aq})</math> will increase the amount of NaOH(aq) required to reach the endpoint during the titration leading to a higher calculated <math>c(\text{C}_3\text{H}_5\text{O}(\text{COOH})_3)</math>.</p>
25	13	68	12	7	0	<p>Option A: Incorrect. <math>\text{C}_{12}\text{H}_{26}</math> – non-polar, intermolecular attraction via dispersion forces.</p> <p>Option B: Correct. <math>\text{C}_{11}\text{H}_{22}\text{O}_{11}</math> – polar C=O present, stronger via intermolecular attraction via dipole-dipole and dispersion force.</p> <p>Option C: Incorrect. <math>\text{C}_{11}\text{H}_{22}\text{O}_{11}</math> – higher viscosity; more hydroscopic due to polarity allowing for better attraction to <math>\text{H}_2\text{O}</math> molecules.</p> <p>Option D: Incorrect. <math>\text{C}_{11}\text{H}_{22}\text{O}_{11}</math> – lower energy content (is already partially oxidised) and produces less <math>\text{CO}_2</math> (11 mol) per mol compared to <math>\text{C}_{12}\text{H}_{26}</math> (12 mol).</p>
26	22	38	15	25	0	<p>Primary cell batteries are not 100 per cent efficient and so will produce heat energy as well as the necessary electrical energy.</p> <p>Since the cell requires a flow of electrons from the site of oxidation to the site of reduction, through the device being powered, Zn (reductant) cannot be in contact with <math>\text{MnO}_2</math> (oxidant).</p> <p>Students should be aware that in all cells the oxidant and reductant are not in contact, and that as well as electrical energy heat energy is generated during discharge, as evident in the fact that mobile phones get hotter during extended</p>

Question	% A	% B	% C	% D	% N/A	Comments
						use.
27	53	16	15	14	0	<p>Heats of combustion indicate the relative amounts of chemical energy converted to heat energy during combustion. Ethanoic acid (<math>-876 \text{ kJ mol}^{-1}</math>) releases less energy per mole so has the lower chemical energy per mol.</p> <p>Autoignition temperatures indicate the relative amounts of energy per mole (activation energy) needed to initiate combustion. Methyl methanoate (<math>449 \text{ }^\circ\text{C}</math>) has the lower autoignition temperature so has the lower activation energy.</p>
28	13	22	39	25	1	<p>The combustion reaction for both ethanoic acid and ethanoic acid is <math>\text{C}_2\text{H}_4\text{O}_2 + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 2\text{H}_2\text{O}</math>.</p> <p>Since the products and their relative amounts are identical for both compounds, the chemical energies of the products will be identical for both.</p>  <p>Maxwell-Boltzmann distributions show a plot of the number (proportion) of molecules against kinetic energy or particle velocity. At higher temperatures the kinetic energies and velocities of the particles increases and the distribution flattens and broadens.</p> <p>The temperature of the product mixture after combustion depends on the amount of heat energy released. Since methyl methanoate (<math>-973 \text{ kJ mol}^{-1}</math>) releases more energy per mole its product mixture will be at the higher temperature and it will have a broader Maxwell-Boltzmann distribution. Ethanoic acid releases less energy per mol so its product mixture is at a lower temperature, and it will have a narrower Maxwell-Boltzmann distribution.</p> <p>The popularity of alternatives C and D seems to suggest that the difference between chemical energy and heat energy and the effect of temperature on the shape of Maxwell-Boltzmann distributions are aspects that are not well understood.</p>
29	12	61	22	5	0	<ul style="list-style-type: none"> <li>• Primary structure – covalent bonding only.</li> <li>• Secondary structure – hydrogen bonding only.</li> <li>• Tertiary structure – multiple bond types including covalent bonding in disulfide links.</li> <li>• Quaternary structure – mainly dispersion forces but ionic; hydrogen bonding and dipole attraction also possible but not covalent bonding.</li> </ul>
30	13	18	55	13	1	<p>According to information from the electrochemical series</p> $\text{Cl}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-(\text{aq}) \quad +1.36 \text{ V}$

Question	% A	% B	% C	% D	% N/A	Comments
						$\text{Fe}^{3+}(\text{aq}) + \text{e}^{-} \rightleftharpoons \text{Fe}^{2+}(\text{aq}) \quad +0.77 \text{ V}$ $\text{I}_2(\text{s}) + 2\text{e}^{-} \rightleftharpoons 2\text{I}^{-}(\text{aq}) \quad +0.54 \text{ V}$ Based on the information supplied in the question, $\text{ClO}_2 / \text{ClO}_2^{-}$ is located above $\text{Fe}^{3+}/\text{Fe}^{2+}$ but below $\text{Cl}_2/\text{Cl}^{-}$ , i.e. the order of the redox pairs in terms of decreasing oxidising agent strength / increasing reducing agent strength) is: <ul style="list-style-type: none"> <li>• <math>\text{Cl}_2(\text{g})/\text{Cl}^{-}(\text{aq})</math></li> <li>• <math>\text{ClO}_2(\text{g})/\text{ClO}_2^{-}(\text{aq})</math></li> <li>• <math>\text{Fe}^{3+}(\text{aq})/\text{Fe}^{2+}(\text{aq})</math></li> <li>• <math>\text{I}_2(\text{s})/\text{I}^{-}(\text{aq})</math>.</li> </ul> Hence $\text{Fe}^{2+}(\text{aq})$ will be oxidised by $\text{Cl}_2(\text{g})$ and $\text{ClO}_2(\text{g})$ but not by $\text{I}_2(\text{s})$ .

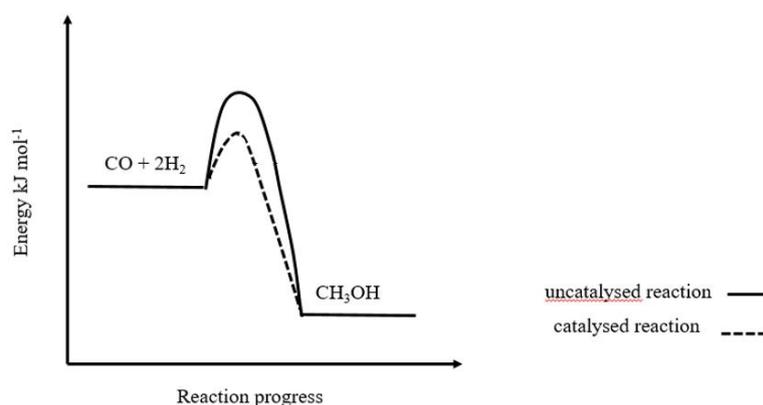
## Section B

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

Asterisks (\*) are used for some questions to show where marks were awarded.

### Question 1a.

Marks	0	1	Average
%	11	89	0.9



Students needed to ensure that the line drawn started and finished at the correct location.

### Question 1bi.

Marks	0	1	2	Average
%	28	15	57	1.3

Either of: \*

- The yield is higher at low temperatures.
- The yield is lower at high temperatures.

Either of the following was required for the second mark.

- Forward reaction is exothermic so, according to Le Chatelier's principle, if the temperature is lowered the system will move to raise the temperature (partially compensate) by favouring the exothermic forward reaction.
- Forward reaction is exothermic so, according to Le Chatelier's principle, if the temperature is increased the system will move to lower the temperature (partially compensate) by favouring the endothermic backward (reverse) reaction.

## Question 1bii.

Marks	0	1	2	Average
%	22	22	55	1.3

Either of: \*

- The yield is greater at high pressure.
- The yield is lower at low pressure.

Either of the following responses was required for the second mark.

- According to Le Chatelier's principle, at high pressure, the system moves to decrease pressure by favouring the reaction that produces fewer particles in a given volume (forward reaction, 3 mol → 1 mol), thus increasing the yield of methanol.
- According to Le Chatelier's principle, at low pressure, the system moves to increase pressure by favouring the reaction that produces more particles in a given volume (back reaction, 1 mol → 3 mol), thus decreasing the yield of methanol.

In both responses to Question bi. and Question bii., many students wrongly attempted to explain the process by using the change in rates or yield instead of using Le Chatelier's principle. Many students also lost time by explaining both a higher and a lower change (temperature/pressure), which they then found difficult to fit into the space provided.

## Question 1c.

Marks	0	1	Average
%	17	83	0.8

$$K_c = \frac{[CH_3OH]}{[CO][H_2]^2}$$

The most common mistake was the accidental use of CO<sub>2</sub> rather than CO.

## Question 1d.

Marks	0	1	2	3	Average
%	27	16	23	34	1.6

	CO	H <sub>2</sub>	CH <sub>3</sub> OH
n <sub>initial</sub>	0.760 mol	0.525 mol	0
n <sub>change</sub>	-0.122 mol	-2x0.122 mol	+0.122 mol
n <sub>equilibrium</sub> *	0.638 mol	0.281 mol	0.122 mol
Final concentrations *	0.638/0.500 = 1.276 M	0.281/0.500 = 0.562 M	0.122/0.500 = 0.244 M

$$K_c = \frac{[0.244]}{[1.276][0.562]^2} = 0.605 \text{ M}^{-2} * \text{ (correct units and significant figures)}$$

Students needed to be careful with correct units and significant figures. Those who set up a table usually made fewer mistakes than those who didn't. The failure to notice the stoichiometry of the equation was a common error, as was the use of the mol values rather than the concentrations when calculating the value of the equilibrium constant.

## Question 2a.

Marks	0	1	Average
%	22	78	0.8

Cathode.

## Question 2b.

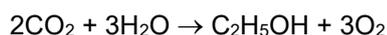
Marks	0	1	Average
%	91	9	0.1

>0.73 V

The vast majority of students did not recognise that for electrolysis to occur, the calculated value has to be greater than that shown by the difference in voltages on the SEP table. Use of exactly 0.73 V will not generate any reaction due to the overpotential needed.

## Question 2c.

Marks	0	1	Average
%	52	48	0.5



Many students wrote the reverse equation, suggesting confusion in establishing the correct direction for half-equations required for this electrolysis reaction.

## Question 2d.

Marks	0	1	2	Average
%	50	32	18	0.7

CO<sub>2</sub> \*

Either of the following responses was required for the second mark. \*

- CO<sub>2</sub> is the oxidising agent since CO<sub>2</sub> is reduced; the oxidation number of C decreases from +4 in CO<sub>2</sub> to an average of -2 in C<sub>2</sub>H<sub>5</sub>OH.
- CO<sub>2</sub> is the oxidising agent since it oxidises H<sub>2</sub>O and the oxidation number of O in H<sub>2</sub>O increases from -2 in H<sub>2</sub>O to 0 in O<sub>2</sub>.

A common mistake was referring to the element carbon as the oxidising agent rather than the required carbon dioxide. Carbon was not a reactant in this equation and could not therefore be accepted as a viable answer. Performance on this question was also impacted by errors in Question 2a. and lack of, or superficial, reference to the role of oxidation numbers. Students need to be aware that the correct convention for oxidation numbers is to always show the sign prior to the digit, i.e. +2 not 2+.

## Question 2e.

Marks	0	1	2	3	Average
%	35	17	25	22	1.4

$$n(\text{CO}_2) \text{ consumed} = 6.05 \times 10^{-3}$$

$$n(e^-) = 6 \times n(\text{CO}_2) = 6 \times 6.05 \times 10^{-3} \text{ mol} = 0.0363 \text{ mol}^*$$

$$Q = 0.0363 \times 96500 = 3.5 \times 10^3 \text{ C}$$

$$t = Q / I = 3.5 \times 10^3 / 2.70 = 1.3 \times 10^3 \text{ s}^*$$

Since cell efficiency = 58 %

$$1297.4 \text{ s} = 0.58 \times \text{time of cell operation}$$

$$\text{Time} = 1297.4 / 0.58 = 2.24 \times 10^3 \text{ s} = 37 \text{ or } 37.3 \text{ (minutes)}^*$$

Common mistakes were failure to convert  $n(\text{CO}_2)$  to  $n(e^-)$  and, more significantly, failure to understand how to apply the percentage efficiency. Many students also lacked the ability to reliably manipulate mathematical relationships.

## Question 3a.

Marks	0	1	Average
%	37	63	0.6

3-bromohexane.

Students need to be careful when using hyphens. Hyphens are only used to separate numbers from letters and cannot be used to separate letters as commonly seen in responses such as '3-bromo-hexane'.

## Question 3b.

Marks	0	1	Average
%	62	38	0.4

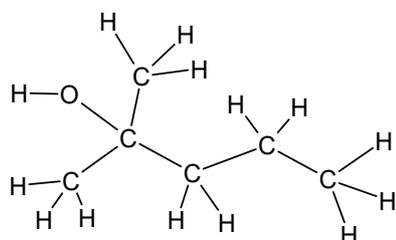
$\text{H}_2\text{O} / \text{H}^+$

'Steam' and any specific inorganic strong acid (apart from HCl) was also accepted.

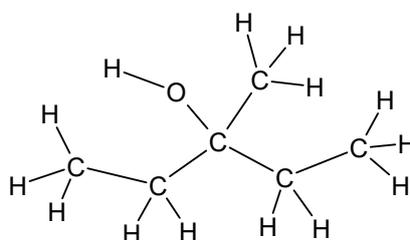
### Question 3c.

Marks	0	1	Average
%	51	49	0.5

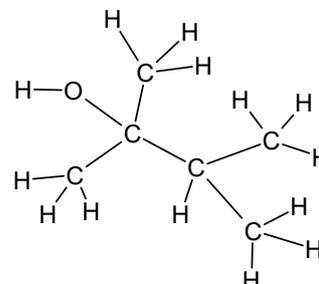
Any of the following drawn structures was accepted.



2-methylpentan-2-ol



3-methylpentan-3-ol



2,3-dimethylbutan-2-ol

Students need to be reminded to avoid grouping the -OH and ensure that they show clearly the -O-H bond.

### Question 3d.

Marks	0	1	Average
%	48	52	0.5

Either of:

- $\text{CH}_3\text{COOH}$
- $\text{HOOCCH}_3$ .

There was confusion over the interpretation of what reagents were used to form compound L. Some students assumed that since compound L was drawn in skeletal form that they also had to draw the ethanoic acid this way. Careful reading of the question stem is vital.

### Question 3ei.

Marks	0	1	Average
%	61	39	0.4

Any of:

- $\text{CH}_3\text{CH}_2\text{COCH}_2\text{CH}_2\text{CH}_3$
- $\text{CH}_3\text{CH}_2\text{CH}_2\text{COCH}_2\text{CH}_3$
- $\text{CH}_3\text{CH}_2\text{CO}(\text{CH}_2)_2\text{CH}_3$ .

A significant number of sketches of aldehydes were attempted along with carboxylic acids. Oxidation of a secondary alcohol only produces a ketone and students who sketched out all the structures in the blank spaces on the examination paper made far fewer errors on this question.

### Question 3eii.

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

Ketone.

Students are expected to be able to spell the names of functional groups correctly.

### Question 3f.

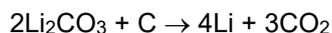
Marks	0	1	Average
%	43	57	0.6

Oxidation.

Students may not have recognised that acidified permanganate produces the same products as acidified dichromate.

### Question 4a.

Marks	0	1	Average
%	59	41	0.4



Here too there was an incorrect understanding of which direction each half-cell reaction needed to be written in during the recharge process. The most common mistake was that the overall reaction was written in reverse.

### Question 4b.

Marks	0	1	2	Average
%	29	39	32	1.0

Reduces battery life / Performance reduced / Limits the extent of recharging / number of recharges / reduced ability to hold full charge.

As lithium carbonate breaks away from the cathode, this reduces the amount of  $\text{Li}_2\text{CO}_3$  available for recharging.

OR

Products of electrolysis need to stay in contact with electrodes for effective recharge.

One mark was awarded for describing the effect on the performance of the battery. This was frequently not done.

One mark was awarded for describing how this affected the performance of the battery.

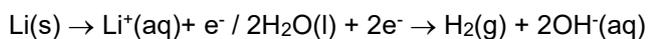
### Question 4c.

Marks	0	1	2	3	Average
%	58	17	18	8	0.7

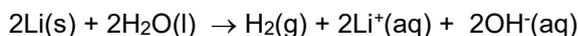
Students used two approaches to respond to this question.

### Galvanic cell approach

Li(s) is a very strong reducing agent (reductant) and will reduce water to produce H<sub>2</sub>(g).



OR



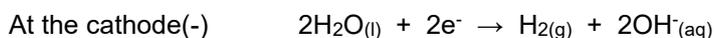
H<sub>2</sub>(g) is explosive / flammable / builds up pressure in battery

OR

The reaction is highly exothermic and may cause battery to catch fire.

### Electrolytic cell approach

Water will be reduced in preference to Li<sup>+</sup> ions producing H<sub>2</sub>(g).



Build-up of H<sub>2</sub>/O<sub>2</sub> leading to a potential explosion due to pressure or a potential explosion due to spontaneous combustion.

One mark was awarded for identifying the products that could cause a safety concern.

One mark was awarded for the equations (either both half-equations or the full equation) to back up the formation of this product.

One mark was awarded for the reason this chemical poses a safety risk.

Students needed to show these three key sections in their response. Not many included the last point.

## Question 4d.

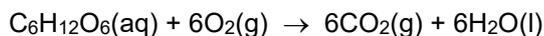
Marks	0	1	Average
%	51	49	0.5

No. The CO<sub>2</sub>(g) absorbed during discharge will be released during recharge.

A reason had to be given by the student in order to obtain the mark.

## Question 5a.

Marks	0	1	Average
%	41	59	0.6

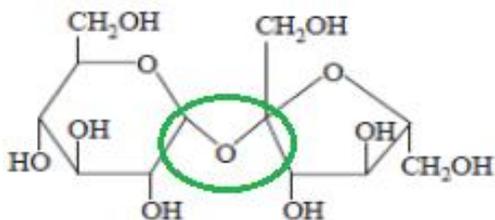


A number of students struggled to produce this equation. There were also issues with students including ATP as a product but this produced an unbalanced equation and so could not be accepted.

## Question 5bi.

Marks	0	1	Average
%	41	59	0.6

A significant number of students either did not answer this question or forgot to include the correct name of



the link on the diagram.

## Question 5bii.

Marks	0	1	Average
%	14	86	0.9

Glucose and fructose.

This question was well handled by students, and most provided both names required for the mark.

## Question 5biii.

Marks	0	1	Average
%	30	70	0.7

Humans lack the enzyme (cellulase) necessary for the digestion of cellulose.

The specific name of the enzyme was not required for the mark, just the recognition that the enzyme was missing from the human body. Reference to the substrate, cellulose, having incorrect shape for the human digestion enzymes was also accepted.

## Question 5c.

Marks	0	1	2	3	Average
%	20	12	20	48	1.9

$$\begin{aligned}\text{Energy in 100 g banana} &= 1.1 \times 17 + 22.8 \times 16 + 0.3 \times 37 \\ &= 18.7 + 364.8 + 11.1 \\ &= 395 \text{ kJ (394.6) }^*\end{aligned}$$

$$\begin{aligned}\text{Energy from one banana} &= (395 / 100) \times 116 \\ &= 458 \text{ kJ (457.7) }^*\end{aligned}$$

$$\begin{aligned}\text{Number of bananas} &= \text{Energy} / \text{Energy from one banana} \\ &= 300 / 457.7 \\ &= 0.66 \text{ }^* (0.65-0.67)\end{aligned}$$

In general, this question was handled well, though some students failed to quote their final answer to two decimal places as instructed in the question.

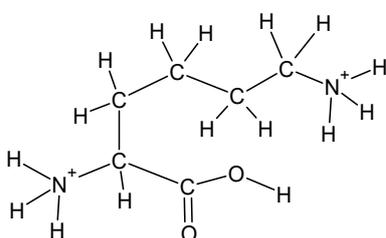
### Question 5di.

Marks	0	1	Average
%	27	73	0.7

Hydrolysis.

### Question 5dii.

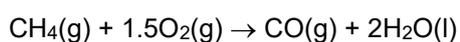
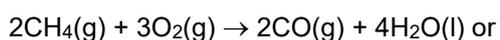
Marks	0	1	Average
%	65	35	0.3



Both amino groups needed to be clearly shown as being protonated, with the charge on the nitrogen.

### Question 6a.

Marks	0	1	Average
%	25	75	0.8



### Question 6b.

Marks	0	1	2	Average
%	16	19	64	1.5

$$n(\text{CH}_4) = 20.0 / 16.0 = 1.25 \text{ mol}^*$$

$$\text{Pressure}(\text{CH}_4) = nRT / V = 1.25 \times 8.31 \times 298 / 5.0 = 6.2 \times 10^2 \text{ kPa}^*$$

Units for pressure needed to be included to obtain full marks. In general students performed well on this question. One common mistake was not converting the temperature to Kelvin.

### Question 6c.

Marks	0	1	2	3	Average
%	20	19	17	45	1.9

Energy from CH<sub>4</sub> = 0.485 g x 55.6 kJ g<sup>-1</sup> = 27.0 kJ

Energy absorbed by water = 4.18 J g<sup>-1</sup> K<sup>-1</sup> x 350.0 x (32.3 – 20.0)  
= 1.80x10<sup>4</sup> J  
= 18.0 kJ

Energy lost to environment = 27.0 – 18.0 = 9.0 kJ

% energy lost = (9.0 / 27.0) x 100 = 33.3 %

One mark was awarded for calculating the energy from CH<sub>4</sub>.

One mark was awarded for calculating the energy absorbed by water.

One mark was awarded for working out the percentage of energy loss.

This question was generally handled well, although some students incorrectly converted the mass of water using the density value of 0.997 g ml<sup>-1</sup>.

Students also used a wide variety of approaches such as calculating the expected temperature of the water rise of 18.3°C and then producing the energy lost via (18.5 – 12.3) / 18.5 yielding the 34% energy loss. A number of students did not access the Data Booklet and so were unable to establish the energy generated from the methane.

## Question 6d.

Marks	0	1	2	Average
%	37	44	19	0.8

### Similarity – methane from both sources

- Both produce atmospheric carbon dioxide through combustion.
- Methane from both sources contains small amounts of nitrogen and sulfur; combustion of natural gas leads to the formation of acidic oxides such as SO<sub>x</sub> and NO<sub>x</sub>.

### Difference – landfill versus natural gas

- Methane from landfill can be produced renewably, whereas methane from natural gas releases stored carbon.
- Methane from landfill is more carbon neutral, methane from natural gas increases atmospheric CO<sub>2</sub> levels.
- Obtaining methane from natural gas via fracking causes additional significant environmental damage, whereas when obtaining methane from a landfill the damage has already been done in the formation of the landfill.
- Landfill gases contain less methane and release more CO<sub>2</sub> (for the same amount of energy generated), natural gas contains more methane and releases comparatively less CO<sub>2</sub>.
- Methane captured from landfill and used as a source on energy may have a positive impact as it is a more potent greenhouse gas than CO<sub>2</sub>.
- CH<sub>4</sub> from landfill is more easily collected compared to fracking/sourcing methane from fossil fuels.

Two marks were awarded for any two valid comparison points.

Students often made two very good statements, but more frequently than not these did not compare the environmental impact between the two sources. The key word 'compare' in the question means that a direct comparison is required to obtain full marks.

## Question 7a.

Marks	0	1	2	3	Average
%	61	25	12	3	0.6

- Cooking denatures protein in egg white and yolk. Denaturation changes secondary / tertiary structures of protein and allows proteins to coagulate and egg to harden.
- Vinegar contains an acid and the change in pH also causes denaturation.

One mark was awarded for each of the dot points above and one mark for linking them to how the egg yolk can more easily remain running in any of the following points.

- The vinegar can only access the surface of the egg and so only causes the egg white to solidify whilst the yolk remains runny.
- Yolk is not as affected since it is covered by a thin film of egg white protecting it to some degree from the vinegar.
- Yolk is not as affected since it is a larger proportion of the egg.
- Once the egg white has solidified the heat source can be removed before the yolk heats up enough to solidify.
- Quickly denaturing the egg white protects the yolk from denaturation so it stays runny.
- Yolk protein is intermixed with fats which protect or prevent it from precipitating, so it is denatured more slowly and stays runny.

Students often did not mention of the denaturation occurring due to the egg being placed into hot water. Some reference to the disruption of the type of bonds was required and it was not enough to just say 'denatured'. A significant number of responses tried, incorrectly, to use the increased protein content of the egg yolk to justify that it became more denatured and hence the egg yolk remained runny.

## Question 7bi.

Marks	0	1	2	3	Average
%	52	24	21	3	0.8

Chromatography can be used to separate a mixture of methyl esters because they have different strengths of attraction to the stationary and mobile phases.

OR

The methyl esters all contain the ester functional group so retention times will depend on molecular mass/size and extent of unsaturation. \*

Calibrate by running pure samples of each of the methyl esters through the HPLC under the same conditions to determine individual retention times. \*

The relative amounts and hence percentage composition of the egg yolk can be determined from the relative areas under the peaks/peak heights at the retention times of the associate methyl esters. \*

Students who broke this question up into clear dot points generally performed well. Underlining or highlighting the key points also greatly assisted them. Reasons students did not gain full marks included:

- They related their responses to the fatty acids themselves and not the methyl esters.
- They thought the chromatography was referring to TLC/paper chromatography and quantitative analysis is not possible via this technique.
- They did not address key aspects outlined in the question in their responses, i.e.
  - What are the basic principles of chromatography?

- How can the methyl esters be identified?
- How can the percentage be determined?

## Question 7bii.

Marks	0	1	2	3	4	Average
%	32	18	23	21	6	1.5

Arachidonic acid. \*

The weaker the attraction (intermolecular forces) between molecules, the lower the flashpoint.\*

(Data indicates) that melting points increase as the number of C atom increases and (data indicates) that melting points decrease when C=C is present \*

This effect of C=C on the melting point/flashpoint is greater than the effect caused by increasing chain length and so the greater the number of C=C causes a greater effect than the effect caused by increasing chain length and hence arachidonic acid should have the lowest melting point/flashpoint. \*

In general, this question was not handled well by students. The use of trends in data and the relative effect of the two major influencing factors was not well understood. Some students limited their responses to the fatty acids that had actual melting point data. Frequently chain length was ignored.

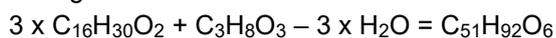
## Question 7ci.

Marks	0	1	2	Average
%	38	38	23	0.9

$C_{51}H_{92}O_6$ \*

Molar mass =  $51 \times 12.0 + 92 \times 1.0 + 6 \times 16.0 = 800 - 801 \text{ (g mol}^{-1}\text{)}$  \*

Many mathematical errors showed up here, but these became significantly reduced if students worked through the correct formula:



## Question 7cii.

Marks	0	1	2	3	Average
%	43	11	20	27	1.3

$$n(C_{51}H_{92}O_6) = 100 \text{ g} / 800 \text{ g mol}^{-1} = 0.125 \text{ mol} *$$

$$n(C=C) = 3 \times 0.125 = 0.375 \text{ mol}$$

$$n(I_2) = 0.375 \text{ mol} *$$

$$m(I_2) = 0.375 \times 253.8 = 95.2 \text{ g} *$$

Most students were able to obtain some marks on this question. Some had difficulty determining the amount of C=C double bonds and hence how this related to the amount of iodine required. This was further compounded by the number of students who did not recognise that iodine is a diatomic molecule.

## Question 8a.

Marks	0	1	2	Average
%	45	9	46	1.0

Compound is not an alcohol, since there is no O-H bond in the molecule.

This is shown by a lack of a peak in the O-H(alcohols) range ( $3200-3600\text{ cm}^{-1}$ ).

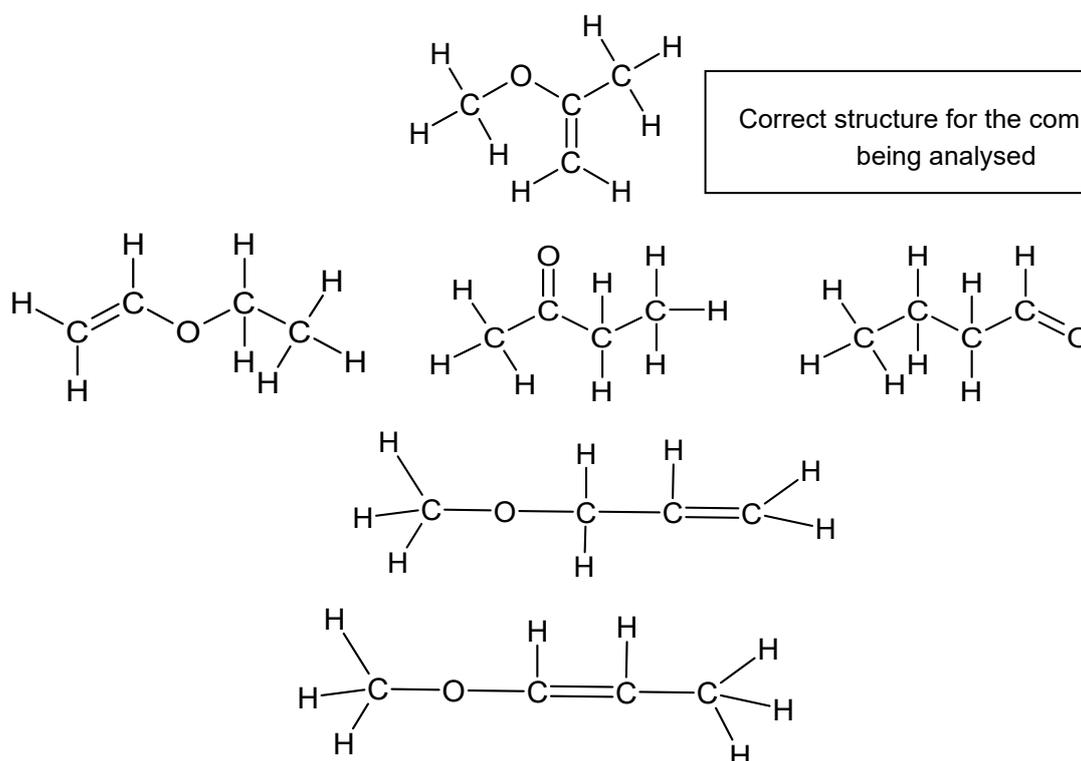
One mark was awarded for recognising the lack of any O-H peak and one mark for the use of evidence to support this.

Students needed to pay attention to the quoted range of  $3100-3400\text{ cm}^{-1}$ . A significant number of responses was centred on incorrectly discussing the C-H bonding peak being an O-H peak and therefore the compound must be an alcohol. Careful use of the Data Book could have avoided this error.

## Question 8b.

Marks	0	1	2	Average
%	27	18	56	1.3

Any two of the following were accepted.



The compounds accepted had to show four distinct carbon environments and also not show an O-H bond.

## Question 8c.

Marks	0	1	2	3	Average
%	25	35	27	12	1.3

Any three of the following were accepted.

- Three sets of peaks on the  $^1\text{H}$  NMR spectrum indicates three (hydrogen) environments.
- No signal splitting (single peaks) on  $^1\text{H}$  NMR spectrum indicates there are no regions in the molecule where H atoms are attached to adjacent C atoms / there are no neighbouring H atoms.
- The peak area ratio 3:3:2 indicates the three different hydrogen environments contain 3, 3 and 2 hydrogen atoms respectively.
- The type of environment is indicated by the chemical shift, for example  $\delta = 1.82$  indicates  $-\text{CH}=\text{CH}-\text{CH}_3$ ,  $\delta = 3.53$  indicates  $-\text{OCH}_3$ .

This question was designed so that the students only needed to provide information from the  $^1\text{H}$  NMR spectrum or the table of data to answer it. Some students, however, tried to match their chosen structure to the data. Some students also assumed the peak area was linked to peak splitting.

### Question 9a.

Marks	0	1	2	Average
%	46	49	5	0.6

Refer to the Safety Data Sheets (SDS or MSDS) for each of the chemicals or a prepared approved risk assessment document. \*

Follow all suggested storage, handling and personal protective equipment guidelines given in the material safety data sheets.

OR

Identify hazard and precaution relevant to the experiment (acid/glass). \*

The study design has a specific reference on following recommended protocols from safety data sheets. To obtain the first mark students needed to indicate that they understood this. Only a handful of students were awarded the second mark, as most suggested precautions for the acid without first identifying the hazard associated with it.

### Question 9b.

Marks	0	1	Average
%	9	91	0.9

Temperature of the HCl solution.

### Question 9c.

Marks	0	1	2	Average
%	11	30	58	1.5

Either of: \*

- The dependent variable is the rate of production of  $\text{CO}_2$  gas / rate of the reaction.
- The dependent variable may be time.

It is measured by timing how long the balloon takes to rise 10 cm over the test tube. \*

Generally this question was well handled. However, students need to make sure that they have addressed all aspects of the question, i.e. both 'what' and 'how' in this case.

## Question 9di.

Marks	0	1	2	3	Average
%	11	41	31	16	1.5

- As temperature increases, the rate of reaction increases / the time taken for the balloon to reach 10 cm decreases. \*
- This is because increased temperature increases the speed of particles which increases the frequency of collisions (number of collisions per unit time) between reactants thereby increasing the rate of the reaction. \*
- Increased temperature also increases the energy of the particles which means that a greater proportion of particles have enough energy to overcome the activation energy barrier resulting in a greater proportion of collisions that are successful which also increases the reaction rate. \*

Most students found it easy to obtain the first mark, but a significant number did not use the appropriate terminology for the rest of the question. It was important to realise that 'time' or 'frequency' was a key aspect of the response and thus it was not enough to say 'an increase in the number of collisions occurs'. Likewise, in the third key point, students needed to refer to 'a greater proportion' rather than 'a greater number' of collisions to obtain the mark.

## Question 9dii.

Marks	0	1	Average
%	75	25	0.2

One of:

- No. There is not a consistent trend, time for reaction is lower / rate is higher at 15°C than at 25°C.
- Yes. If the data was presented using a line of best fit the overall trend is consistent with the prediction.
- Yes. If the outlier (data point showing 25°C) is ignored.

It is important that students recognise the presence of anomalous data and avoid generalisations when specific information is shown/given.

## Question 9e.

Marks	0	1	2	Average
%	33	46	21	0.9

Any two of the following:

- The temperature is the independent variable so it should be on the horizontal axis.
- The rate of the reaction – the dependent variable – should be on the vertical axis.
- The line of best fit / trendline rather than 'join the dots' / ignore outlier.

Most responses did not focus on what the experiment was actually attempting to do, which is to determine how temperature affected the rate of the reaction. Instead, a large number of students proposed 'converting the graph into a bar graph' or gave superficial responses such as using 'better titles' or 'adjusted axis'.

## Question 9f.

Marks	0	1	2	Average
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Marks	0	1	2	Average
%	56	33	11	0.6

Acceptable responses included:

- Use a more accurate way of measuring the volume, e.g. gas syringe. The balloons may have different shapes which means that the volume of each balloon when it rises 10 cm over the top of the conical flask may vary.
- Ensure that the initial quantities are measured to a greater number of significant figures, i.e. acid concentration to 2.0 M (rather than 2 M) and/or change mass of CaCO<sub>3</sub> to 0.60 g (rather than 0.6 g).
- Find a faster way of sealing the test tube once the reactants are mixed. This will ensure that none of the gas escapes.
- Use uniformly powdered CaCO<sub>3</sub> to minimise surface variations.

## Question 10a.

Marks	0	1	2	3	Average
%	70	17	10	2	0.5

Qualitative analysis

- Alcohols react with carboxylic acids to produce esters which can be identified by smell.
- No colour change with Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> / H<sup>+</sup>, not a primary or secondary alcohol, could be tertiary
- Colour change with Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> / H<sup>+</sup>, either primary or secondary alcohol
- If product of reaction with Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> / H<sup>+</sup>, reacts with NaHCO<sub>3</sub> – primary alcohol.
- If product of reaction with Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> / H<sup>+</sup>, does not react with NaHCO<sub>3</sub> – secondary alcohol.
- Addition of Br<sub>2</sub> – decolourisation implies a possible alkenol.
- If a pH test shows neutral it could be an alcohol.

Quantitative analysis

- Can be titrated using a redox titration to determine concentration.
- Oxidise alcohol to acid and titrate with base.

Two marks were awarded for the qualitative analysis as long as a clear link to an observation could be made, i.e. a colour change, a smell, production of bubbles etc.

The last mark was associated with the quantitative change and a clear link to a titration or similar wet chemical analysis needed to be shown.

A large number of students struggled with this question, and responded solely by talking about instrumental analysis, which was not the requirement of the question. Many also did not seem to be aware that a qualitative analysis must involve an observation.

## Question 10b.

Marks	0	1	2	3	4	Average
%	40	27	28	4	2	1.0

IR spectroscopy – Principle

- IR measures the vibrations of atoms in a molecule and can give information about the type of bonds (functional groups) present in a molecule.
- IR involves the absorption of infrared radiation the wavenumber of which alters with different bond types.

### Interpretation of spectra

- In primary alcohols the O-H bond will show a distinct peak between 3200–3600  $\text{cm}^{-1}$ .
- In ketones the C=O bond will show a distinct peak between 1680–1850  $\text{cm}^{-1}$ .
- The lack of a peak in a region of the spectra can indicate the absence of a type of bond in a molecule. For example, the lack of a peak between 1680–1850  $\text{cm}^{-1}$  due to C=O indicates that the compound is unlikely to be a ketone.
- Since an alcohol  $\text{C}_3\text{H}_6\text{O}$ , is unsaturated it must have a C=C bond and it would have a peak at 1620–1680  $\text{cm}^{-1}$ .

### $^1\text{H}$ NMR spectroscopy – Principle

- $^1\text{H}$  NMR measures the change in the spin state of nuclei and can give information about the H environment present in the molecule.
- $^1\text{H}$  NMR involves the absorption of radio waves, the chemical shift alters with the neighbouring environment.
- Neighbouring hydrogens will induce a splitting in the peak of a hydrogen atom leading to the 'n+1' rule. The peak area can indicate the number of hydrogens in the environment.

### Interpretation of spectra

- Primary alcohols show chemical shift of 3.3–4.5 ppm for H atoms adjacent to the -OH functional group and a singlet between 1–6 ppm for functional group H.
- Ketones show a chemical shift is 2.1–2.7 ppm for H atoms adjacent to the C=O functional group.
- The symmetry of the  $\text{C}_3\text{H}_6\text{O}$  ketone means that there is only one HNMR peak in the spectrum whereas there are four peaks in the spectrum of the  $\text{C}_3\text{H}_6\text{O}$  primary alcohol.
- The ratio of peak areas on the alcohol ( $\text{CH}_2=\text{CHCH}_2\text{OH}$ ) spectrum will be 2:1:2:1;  
HO-CH=CH- $\text{CH}_3$  – 1:1:1:3

One mark each was awarded for stating the principle by which  $^1\text{H}$  NMR and IR spectroscopy operated.

One mark each was awarded for stating how the interpretation of the spectra could be used to uniquely identify the two isomers.