

VCE Chemistry sample examination answers and marking guide (2024)

Specific information

This report provides sample answers and a marking scheme for Section B, and answers with comments for Section A. Unless otherwise stated, these are not intended to be exemplary or complete responses. Questions marked with an asterisk (*) are ones where reference to the Data Book is required or may be of assistance.

Please note that they are not official VCAA answers. They have been produced by the Chemistry Education Association, primarily on the work of Alan Nash and Cinnamon Lane and are intended to assist teachers and students of VCE Chemistry in their study.

Section A

The following table indicates the correct answer, and the percentage of students who chose each option during the 2024 practice exams.

Question	A	B	C	D	N/A	Comment
1.						Straightforward. Note that the energy content of bioethanol and ethanol produced from coal is exactly the same – they are both ethanol. They both produce greenhouse gases when they burn.
2.						Cellular respiration and combustion are both examples of the oxidation of a fuel. Starch (amylopectin and amylose) and glycerol need to be hydrolysed to glucose first.
3.*						The question considers the energy content of one serve , which is 40.0g. So the contributions of each macronutrient is: Protein: $40.0/100.0 \times 13.3\text{g} \times 17 \text{ kJ g}^{-1} = 90.4 \text{ kJ}$ Fat: $40.0/100.0 \times 8.50\text{g} \times 37 \text{ kJ g}^{-1} = 126 \text{ kJ}$ Carb: $40.0/100.0 \times 55.6\text{g} \times 16 \text{ kJ g}^{-1} = 356 \text{ kJ}$ Option B is designed for students who did not pay attention to the words “one serve” in the question. Also note that fats have a much higher energy content than proteins or carbohydrates, so a small quantity of fats can still make a large contribution to energy content.
4.*						4 mol of ethane produces $2 \times 4 = 8$ mol of CO_2 , so $m(\text{CO}_2) = 8 \times 44.0 = 352 \text{ g}$ and $V(\text{CO}_2) = 8 \times 24.8 = 198 \text{ L}$ (using $V_m = 24.8 \text{ mol L}^{-1}$)
5.						Straightforward. The relationship between volume of liquid and calibration factor is not necessarily linear so C and D incorrect. D is also incorrect in that a higher volume of liquid results in a higher calibration factor. The experiment is done with the same calorimeter as used for calibration: heating coil still there; same lid, stirrer and thermometer.

Question	A	B	C	D	N/A	Comment
6.						A bit tricky. The straight line from 450s indicates a well insulated calorimeter. The “bump” in temperature before it is likely due to uneven final heat distribution. The temperature drops very slightly from 430 to 600 s. Extrapolating this back to 100 s when power switched on gives a final temperature of 28.1°C. C is incorrect. A and B are incorrect as these are the final temperatures. Temperature change = final – initial temperature (23°C). The temperature change was about 5.1°C.
7.						Straightforward. Given that O ₂ is the more powerful oxidant, the two half equations represent a mini-E ⁰ table. The second equation needs to be doubled, however, to balance the electrons: R: O ₂ + 4H ⁺ + 4e ⁻ → 2H ₂ O 2xO: 2H ₂ SO ₃ + 2H ₂ O → 2SO ₄ ²⁻ + 8H ⁺ + 4e ⁻ Add together to get the overall equation (2H ₂ O, 4e ⁻ and 4H ⁺ cancel)
8.						Straightforward. A and B are incorrect as enzymes are not altered in a reaction, nor do they supply reactants. Inorganic catalysts increase the rate of the forward and backward reactions equally, but enzymes are specific for one reaction only so only catalyse the forward or backward reaction, so “C” is incorrect.
9.						Straightforward. Adding more of a reactant to an equilibrium system causes an immediate increase in frequency of collisions between reactants and hence an increase in the forward reaction.
10.						Heating an exothermic reaction favours the endothermic reverse reaction. In this case [C] should decrease and [A] and [B] should increase (with [B] increasing at twice the rate of [A]). Concentrations do not spike when a reaction is heated, so [B] is incorrect. Only graph D shows two species’ concentrations increasing with one increasing at twice the rate of the other. In graph A the two species increase concentration at the same rate, and the decrease of [C] is doubled.
11.*						At the time specified, the value of the reaction quotient (Q) will be $[\text{NO}_2]^2/[\text{N}_2\text{O}_4] = (2.4\text{M})^2/0.4\text{M} = 14.4\text{M}$. Since $Q < K$, the reaction is not at equilibrium. For the value of Q to increase, [NO ₂] needs to increase, which can only happen if the forward reaction is favoured.
12.*						Oxidation occurs at the anode. Options A and D are reduction half reactions. An alkaline solution involves OH ⁻ not H ⁺ so C is incorrect.
13.						During discharge a rechargeable battery (secondary cell) acts as a galvanic cell, and the cathode is positive. During recharge it acts as an electrolytic cell and the cathode is negative.
14.*						“alcohol” and “ketone” are not the names of functional groups. –NH ₂ is amino ; –C=O is carbonyl; –O–H is hydroxyl
15.*						The carbonyl carbon takes priority when determining from which end of the parent chain to start counting. The C atoms must begin from the right-hand side of the molecule. The –Br is ∴ on C number 4 so B and C are incorrect. The molecule is of a halogenated ketone, not aldehyde, so A is incorrect.

Question	A	B	C	D	N/A	Comment
16.*						$C_{10}H_{16}O_2$ has two C=C double bonds (i.e. it is caprylic acid less 4 H atoms). $C_{12}H_{22}O_2$ has one C=C double bond (i.e. it is lauric acid less 2 H atoms). The remaining formulas are palmitic acid (saturated) and oleic acid (one C=C double bond).
17.						Limonene is a hydrocarbon, so a non-polar solvent is required.
18.						Straightforward. Denaturation does not disrupt primary structures, and secondary structures are not due to covalent bonds (they are formed due to hydrogen bonding between peptide links). A temperature of 50°C is not high enough to break the covalent bonds in the primary structure or in the disulfide links.
19.						The thiol group (SH) on the cysteine residue can only form a disulfide bridge (covalent bond) with another cysteine residue, the question specifies, however, that only one cysteine residue is present in the protein. It cannot participate in hydrogen bonding but does contain a (weakly) polar site so dipole-dipole attractions are possible. This question must be read very closely to get the correct answer as it states "one" cystine.
20.						Straightforward. Using Cl_2 in an addition reaction with hexene will result in 2 rather than 1 chloro groups being added, so A and B are incorrect. Reacting hexane with chlorine gas in presence of UV light produces 1-chlorohexane first, then more Cl atoms substitute onto the molecule so 2-chlorohexane not possible, so C is incorrect. Reacting hydrogen chloride with 1-hexene would produce a mixture of 1-chlorohexane and 2-chlorohexane, with the latter being more predominant.
21.*						The spectrum shows three peaks, indicating three C environments, so it cannot be glycine (2 environments) or valine (4 environments). There is no peak in the range 8-25 for a R-CH_3 environment, so this rules out alanine.
22.						Peak 5 has the highest retention time. Since the mobile phase is polar, the molecule that is least polar in character will have the highest retention time. Octane is a hydrocarbon, so is entirely non-polar. The other molecules at least have polar sites.
23.						Straightforward.
24.						Reproducibility refers to whether the same results are obtained under different conditions, including when the experiment is conducted by different experimenters. Repeatability refers to whether the same results are obtained under the same conditions.
25.						This chemical, carbon tetrachloride, is stated as have acute toxicity through exposure to the skin and through breathing. It is also stated as possible causing cancer (carcinogenicity) with specific organ toxicity due to repeated exposure. It is therefore not safe to use in a secondary school laboratory..

Question	A	B	C	D	N/A	Comment
26.						Straightforward. Note that this is not a reversible reaction, so Option A will not apply. Only 3.40×10^{-3} mol of CaCO_3 compared to 0.1 mol of HCl, so HCl is in excess; by 160s all of the marble has been dissolved, but some of the other reactant remains so Option B is wrong (not "both reactants"). Option D is demonstrably wrong, as the two conditions produced the same volume of CO_2 .
27.						Straightforward. The information question specifies that it is the lower scale that is being used, which increases in 0.1A increments. The needle lies between 1.0A and 1.1A, so the best that can said of the reading is 1.05A.
28.						The student's results use more of the standard solution than other students. This could happen if his standard solution had become diluted (e.g. by rinsing the burette with water) or if his aliquots were more concentrated than they should have been (e.g. by rinsing the conical flask with the analyte instead of water – option D). Options A and B would result in <u>less</u> standard solution being required; Option C is correct rinsing practice.
29.						Precision is a measure of the extent to which repeated measured agree with each other, regardless of how accurate they are. Ben's results have a maximum difference of 0.30 mL compared to Chang (0.50 mL), Olivia (0.60 mL) and Ravinder (0.90 mL).
30.						Options A and D show a linear relationship. If a systematic error is present, all data measures should be too high or too low. The graph in Option C does not start at (0,0) as would be expected, suggesting a systematic error occurred.

Section B

Question 1

Question 1a.*

Use of renewable feedstocks.

1 mark

Question 1bi.*

Assuming that ethanol is the desired product, atom economy is $(2 \times 46.0)/180 \times 100\% = 51.1\%$ (3 SF)

1 mark

Question 1bii.*

$n(\text{glucose}) = 100.0/180.0 = 0.55556 \text{ mol glucose}$

1st mark

Hypothetical $n(\text{ethanol}) = 2 \times n(\text{glucose}) = 1.1112 \text{ mol}$

Hypothetical $m(\text{ethanol}) = 1.1112 \text{ mol} \times 46.0 \text{ g mol}^{-1} = 51.111 \text{ g}$

(2nd mark); or

Actual $n(\text{ethanol}) = 7.15/46.0 = 0.1554 \text{ mol}$

(2nd mark)

$\% \text{ yield} = \text{actual moles ethanol/hypothetical moles ethanol} \times 100\% = 0.1554/1.1112 \times 100\% = 14\%$

(3rd mark); or

$\% \text{ yield} = \text{actual mass ethanol/hypothetical mass ethanol} \times 100\% = 7.15/51.111 \times 100\% = 14\%$

(3rd mark)

Question 1c.

An answer demonstrating an understanding that fermentation of biomass produces an aqueous solution of ethanol/"ethanol broth"/solution that includes water, yeast and other products.

1st mark

Further recognising that the presence of water in bioethanol will reduce its energy content/make it unable to combust at all.

2nd mark

Question 2

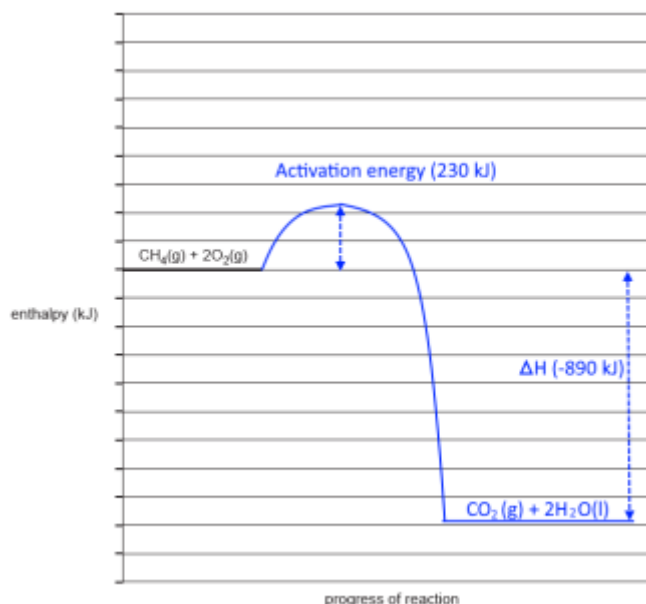
Question 2a.

An energy profile is required that uses the scale provided and includes reference to the products after the reaction, with a labelled ΔH of - 890 kJ

1 mark

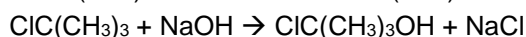
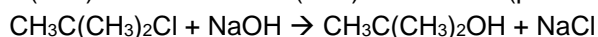
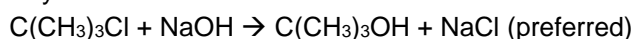
A labelled activation energy of 230 kJ. A possible way to show this using each gradation of the y-axis = 100 kJ is shown below.

1 mark



Question 2bi.

Any of:



1 mark

Question 2bii.*

From table 10 of the Data Book:

Energy needed to break C-Cl bond: 324 kJ mol^{-1}

Energy released from the formation of C-O bond: 358 kJ mol^{-1}

More energy is released than is required for the reaction to occur, so it will be **exothermic**

1 mark

The hypothetical ΔH is $324 - 358 = -34 \text{ kJ mol}^{-1}$

1 mark

Question 2biii.*

From table 10 of the Data Book:

Energy needed to break C-Cl bond: 324 kJ mol^{-1}

Energy needed to break a C-I bond: 228 kJ mol^{-1}

Recognising that the energy required to break the carbon-halogen bond effectively is the **activation energy** of the reaction

1 mark

identifying that the energy needed to break a C-I bond is less than that required to break a C-Cl bond (228 kJ mol^{-1} compared with 324 kJ mol^{-1})

1 mark

stating that the reaction with 2-iodo-2-methylpropane therefore will occur at a **faster rate** because under the same conditions more reactant particles will have the required activation energy for the reaction to occur.

1 mark

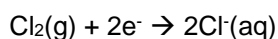
Question 3

Question 3a.

Chemical potential energy is transformed into **electrical energy** (and some thermal energy)

1 mark

Question 3b.*

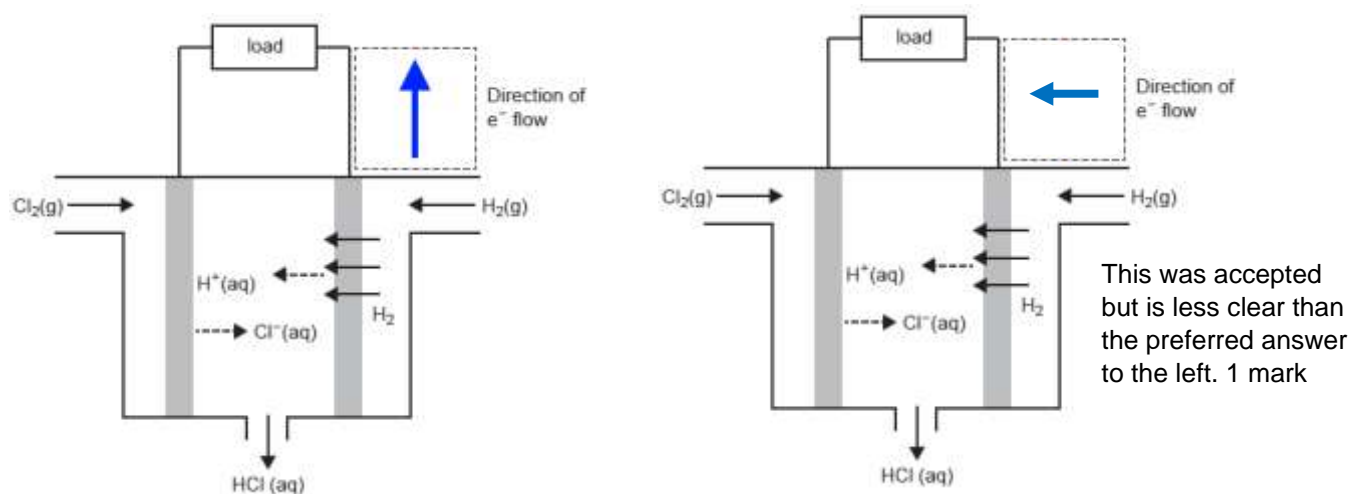


1 mark

Note that this question helps answer the next question, as it shows that electrons are consumed at the cathode.

Question 3c.

Electrons flow from the anode (where the fuel is oxidised) to the cathode, so:



Question 3d.*

From the Electrochemical series: $+1.36\text{V} - (0.00\text{V}) = \mathbf{1.36\text{V}}$

1 mark

Question 3e.

Either **porous electrodes** or embedded **catalyst** nanoparticles

1 mark

Question 3fi.

At constant pressure and temperature, gaseous reactants combine in volume ratios that are the same as their molar ratios. So $\text{O}_2(\text{g}) + 2\text{H}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})$ means the volume ratio of O₂ to H₂ is 1:2.

→ 350mL of O₂ would require 700 mL of H₂ compared to the 450 mL of H₂ supplied

→ Hydrogen gas is the limiting reagent

1 mark

Question 3fii.

450mL of H₂ gas is enough to react with $450/2 = \mathbf{225\text{ mL}}$ of O₂ gas consumed

1 mark

$350\text{ mL} - 225\text{ mL} = \mathbf{125\text{ mL O}_2\text{ unreacted}}$

1 mark

Question 4

Question 4a.*

A fatty acid methyl ester has the same formula as the fatty acid on which it is based +CH₂ (that is, the H on the COOH group is replaced with a CH₃ group). In this case, the fatty acid methyl ester is based on oleic acid (C₁₈H₃₄O₂ + CH₂ = C₁₉H₃₆O₂), so it has one C=C double bond per molecule.

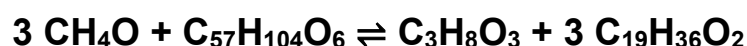
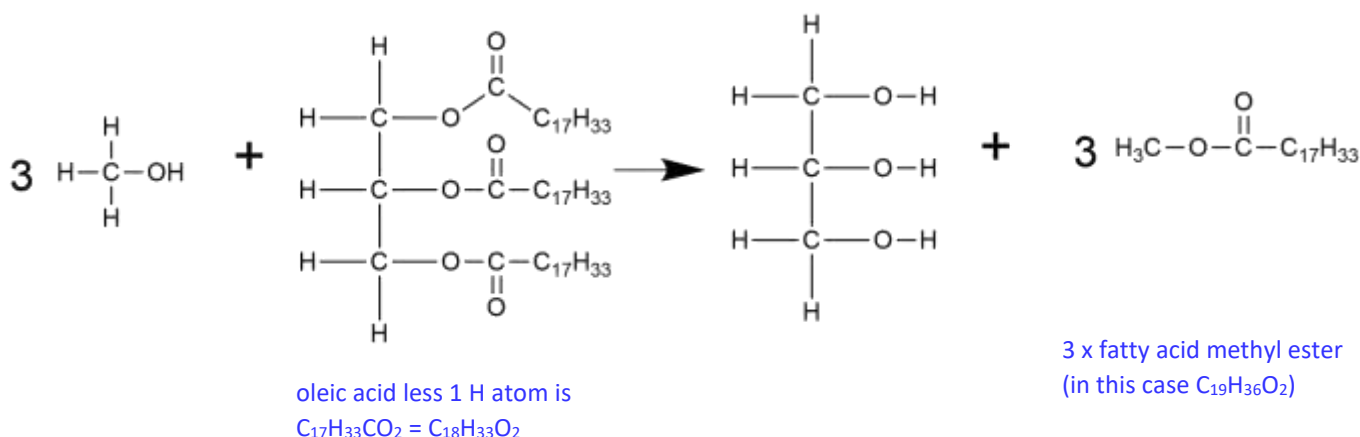
$n(\text{C}=\text{C bonds}) = n(\text{fatty acid methyl ester}) = 100\text{g}/296\text{g mol}^{-1} = \mathbf{0.3378 \text{ mol}}$ (or otherwise recognising that there is one C=C bond per fatty acid molecule) 1 mark

$n(\text{I}_2) \text{ reacting} = n(\text{C}=\text{C bonds}) \rightarrow n(\text{I}_2) = \mathbf{0.3378 \text{ mol}}$ 1 mark

$M(\text{I}_2) = 2 \times 126.9 = 253.8 \text{ g mol}^{-1}$ so $m(\text{I}_2) = 0.3378 \times 253.8 = \mathbf{85.7\text{g}}$ 1 mark

Question 4b.*

Transesterification involves 1 triglyceride + 3 methanol → 3 fatty acid methyl esters + 1 glycerol molecule. In this case the triglyceride is based on oleic acid (as discussed in the previous question), which is C₁₈H₃₄O₂, which can also be written as C₁₇H₃₃CO₂H. Working out the molecular formula of the triglyceride is easier with a diagram, showing it to be C₍₃₊₁₈₊₁₈₊₁₈₎H₍₅₊₃₃₊₃₃₊₃₃₎O₍₂₊₂₊₂₎:



1 mark for correct coefficients

1 mark for correct reactants (methanol and triglyceride) and products (glycerol and fatty acid methyl ester)

1 mark for the correct molecular formula for the triglyceride

Question 4c.

Various options based on Le Chatelier's Principle:

- Continuously add reactants: favours the forward reaction to remove added reactants and increase yield
- Continuously remove products: favours the forward reaction to replace products and increase yield
- If it is assumed the forward reaction is endothermic, use of high temperatures favour the forward reaction and therefore improves yield
- If it is assumed the forward reaction is exothermic, use of low temperatures favour the forward reaction and therefore improves yield

1 mark for correct method, 1 mark for matching explanation

Question 4d.*

Energy absorbed by the water:

$m(\text{H}_2\text{O}) = 200 \text{ g}$

$c = 4.18$

$$\Delta T = 35.7 - 22.2 = 13.5^{\circ}\text{C}$$

$$q \text{ (in joules)} = mc\Delta T = 200 \times 4.18 \times 13.5 = 11286 \text{ J}$$

$$q \text{ (in kJ)} = \mathbf{11.286 \text{ kJ}}$$
 (1 mark)

Total energy released by the fuel:

$$11.286 \text{ kJ} = 0.55 \times \text{total} \rightarrow \text{total} = 11.286 \text{ kJ}/0.55 = 20.52 \text{ kJ}$$

1 mark

Energy content of the fuel

$$m(\text{fuel}) = 0.510 \text{ g}$$

$$\Delta H = q/m = 20.52/0.510 = \mathbf{40 \text{ kJ g}^{-1}}$$
 (2 SF)

1 mark

Question 4e.

Recognising that viscosity increases from $\text{C}_{15}\text{H}_{28}\text{O}_2$ to $\text{C}_{19}\text{H}_{36}\text{O}_2$.

1 mark

An answer linking the increasing viscosity to the increasing strength of intermolecular forces, For example:

- The viscosity will **increase** as the length/size of the molecule **increases**, so $\text{C}_{19}\text{H}_{36}\text{O}_2$ will have the highest viscosity and $\text{C}_{15}\text{H}_{28}\text{O}_2$ will have the lowest viscosity
- This is because as the molecular length increases, the strength of the intermolecular forces/dispersion forces between molecules will increase, making them move less freely.

1 mark, OR

1 mark

Question 5

Question 5a.

An answer recognising that the melting points of S- and R-ibuprofen will be the **same**.

1 mark

An explanation recognising that **optical isomers/enantiomers** have **identical physical properties** with the exception of the rotation of polarised light.

1 mark

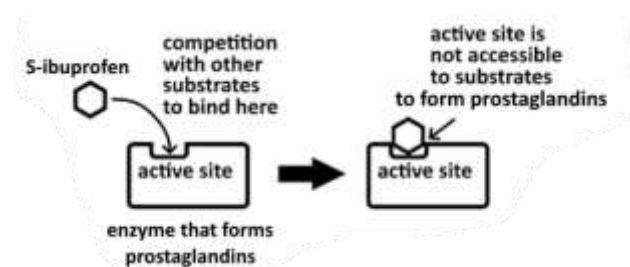
Question 5b.

An answer referring to S-ibuprofen's ability to **compete** with other substrates for the **active site** on enzymes that produce prostaglandins.

1 mark

Explaining that by S-ibuprofen forming an **enzyme-substrate complex** as a result, the active site is not available for other substrates to be metabolised into prostaglandins and so the enzyme's activity is **inhibited**.

1 mark



An example of an appropriate diagram to communicate or enhance those two points is shown above

Question 5c.

Recognising that R-ibuprofen (being the enantiomer/mirror image of S-ibuprofen) does not have an arrangement of groups around its chiral centre that is **complementary** to those present on the active site of enzymes that produce prostaglandins.

1 mark

Question 5d.

Specifying that **naproxen** has a similar mechanism of action to S-ibuprofen when relieving pain.

1 mark

An answer pointing to the similarity of the **groups bonded to the chiral centre** in naproxen compared to S-ibuprofen (a H atom, methyl group, carboxyl group and section starting with a phenyl structure).

1 mark

Question 6

Question 6a.*

Coulombs of charge:

$$Q = It = 10.0\text{A} \times (5.00 \times 60)\text{s} = 3000\text{ C}$$

1 mark

Moles of electrons:

$$n(e^-) = Q/F = 3000/96500 = 0.0311\text{ mol} \text{ (} 3.11 \times 10^{-2} \text{ mol) (3 SF)}$$

1 mark,

Question 6b.*

No aluminium would be produced/zero.

1 mark

Water is a stronger oxidant than Al^{3+} ions (especially at the low concentration of Al^{3+}) so will be reduced in preference to Al^{3+} .

Question 6c.*

Oxygen gas/ O_2 .

1 mark

The anode is the site of oxidation. The strongest reductant present is water, which oxidises to form O_2 gas.

Question 6d.

The same amount of gas.

1 mark

Recognising that the current/passage of electrons is consistent throughout the circuit. For example, the 0.0311 mol of electrons in Question 6a. is sufficient to produce the same moles of O_2 at either anode.

1 mark

Question 7

Students should recognise the reagents of the first reaction as being those required to add an OH group to an alkene, especially given the formation of isomers and the information provided in Question 7b. The remainder of Question 7 is easily answered based on that recognition.

Question 7a.

Alkenes.

1 mark

Question 7bi.*

Proposing an oxidation test using either acidified dichromate ($\text{Cr}_2\text{O}_7^{2-}$) or permanganate (MnO_4^-).

1 mark

Identifying the relevant colour change (orange to green for dichromate, purple to pale pink/colourless for permanganate).

1 mark

Question 7bii.

Option 1:

1 mark for recognising that tertiary alcohols do not undergo oxidation.

1 mark for identifying that both Compound Q and Compound S are depicted as undergoing oxidation to form new compounds.

Option 2:

1 mark for recognising that tertiary alcohols require branching at the carbon atom to which the hydroxyl group is bonded.

1 mark for referring to the fact that Compound P is identified as being unbranched.

Option 3:

1 mark for identifying that Compound P must be *but-1-ene*, since that is the only unbranched alkene 4 carbons long that produces two isomers in an addition reaction with water.

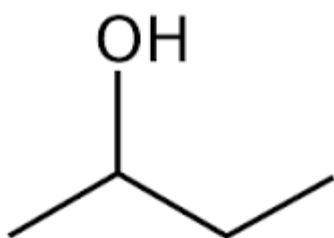
1 mark for identifying that Compound S and Compound Q therefore are *butan-2-ol* (a secondary alcohol) and *butan-1-ol* (a primary alcohol) respectively, neither of which are tertiary alcohols.

Question 7c.

an answer recognising that the total of all the integration curves/area under the peaks will be $1 + 1 + 2 + 3 + 3 = 10$ units, so the number of hydrogen atoms is a multiple of 10. 1 mark

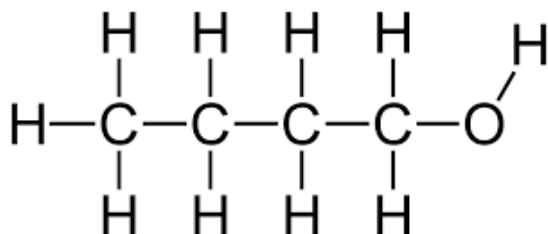
Recognising that due to the relatively short length of the alcohol, the total number of hydrogen atoms can only be 10 and hence the middle peak (whose integration curve is two units) represents an environment with 2 hydrogen atoms. 1 mark

Question 7d.



1 mark

Question 7e.



The O-H bond must be included to get the mark.

1 mark

Question 7f.*

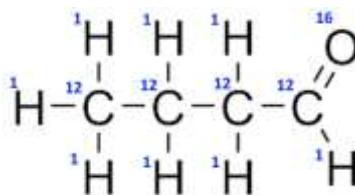
1 mark for each of:

- Carboxyl group
- The wide strong band in the region wavenumber $2500 - 3500 \text{ cm}^{-1}$ shows the O-H bond in the group.
- The narrow strong band in the region wavenumber $1680 - 1740 \text{ cm}^{-1}$ shows the C=O bond in the group.

The second two items should be done by labelling the appropriate bands "O-H (acids)" and "C=O (acids)" and/or the region ranges on the spectrum provided.

Question 7gi.

Molecule T is *butanal*, which has this structure shown below (atomic masses marked), the formula C_4H_8O and the molar mass 72.0.



The fragment ion has a m/z of 57, and given $72 - 57 = 15$ it is likely to be the molecular ion less the CH_3 at the end, so the answer is:



Variations/diagrams are also acceptable but must show the + charge.

1 mark

Question 7gii.

The m/z value of a molecular ion or fragment ion, which represents its **mass-to-charge ratio/mass divided by its charge**.

1 mark

Question 8

Question 8a.

There are arguments either way given the looseness of the question asked (i.e. “a clear focus”).

Sam’s hypothesis arguably provides a “clear focus” in that it identifies the predicted relationship between the independent variable and the dependent variable (albeit not in completely general terms) and provides a link to theory underpinning the prediction.

Sam’s hypothesis arguably does not provide a clear focus, because (for example):

- it is unclear whether the purpose of the experiment is to test the validity of the predicted relationship between concentration and rate of reaction, or to test the usefulness of using that relationship as a means of measuring concentration;
- it is not concise/a concise statement of the link between the independent and dependent variables;
- it includes additional information about how the predicted relationship is operationalised and how the results should be interpreted, which are matters better suited for the method and discussion sections.

Either way, two marks are awarded for offering a conclusion supported by a reasonable analysis of the hypothesis.

Question 8bi.

Temperature.

1 mark

Question 8bii.

Temperature also can affect the rate of a chemical reaction because:

- the **additional kinetic energy** of the reactant particles means they **move faster** and hence **collisions between reactant particles** occur more **frequently** and 1 mark;
- the **additional kinetic energy** of the reactant particles means that when a collision occurs, more of the reactant particles will have at least the **activation energy** required for a **successful collision/collision** that results in a **reaction** 1 mark

Question 8ci.

A variety of points can be made, but 1 mark is allocated to a comment on the consistency of the trend in the data, for example:

- There is a clear trend in the data showing a **positive** relationship/**linear** trend between $[C_2H_2O_4]$ and rate of reaction.
- There is a relationship but given the variation in data at higher concentrations it is not entirely clear whether the trend is **linear or non-linear**.

and 1 mark for a comment on the assertion that there is “little variation of data within each trial”; for example:

- There is little variation in Sam’s data at low concentrations of oxalic acid/Sam’s data are reasonably **precise**, but the variation becomes more pronounced at higher concentrations.

Question 8cii.

The data support Sam’s hypothesis

1 mark

As the concentration of oxalic acid increased, the rate of removal of MnO_4^- ions also increased/the plot shows the predicted **positive relationship** between oxalic acid concentration and rate of reaction.

1 mark

Question 8ciii.

“Reproducibility” requires the same results to be obtained when the experiment is carried out under **changed conditions**, for example by other experimenters. In this case the question is phrased ambiguously, so:

If it is assumed that Sam asserts that the results *are already* reproducible, the answer is “**no**” since they have not yet been tested under changed conditions.

If it is assumed that Sam asserts that the results *could be* reproducible, the answer is “**yes**” since the experiment in theory could be carried out under changed conditions, e.g. by other observers, in the future.

Answers that emphasise a possible failure to control variables (like temperature) as undermining reproducibility also would be acceptable.

Either way, 1 mark for a “yes” or “no” answer with an appropriate justification.

Question 8civ.

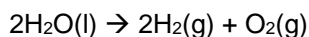
If the purpose was to use Sam’s method to determine $[C_2H_2O_4]$ in an analyte, a number of other pieces of evidence would be required, such as:

- whether the same results are obtained by others following his method/oxalic acid from other sources/different temperatures/different equipment/under any other relevant different condition (reproducibility)
- the range of concentrations within which Sam’s method is accurate, given the variation in his data at higher concentrations/whether the method accurately allows interpolation for concentrations between the specific concentrations tested;
- whether the method accurately measures concentrations of oxalic acid above the highest concentration tested by Sam or very low concentrations of oxalic acid/concentrations below the lowest concentration tested by Sam.

2 marks for an appropriate piece of evidence with a brief explanation of the connection of this evidence to the claim of validity

Question 9

Question 9ai.



1 mark

Question 9aii.

'Green hydrogen' is so called because:

- it is produced from a renewable feedstock, namely water; and
- the energy required from its production is also sourced renewably, for example solar or hydro power

1 mark

1 mark

Question 9b.*

Various options, 1 mark for the goal and 1 mark for a reasonable explanation. Some of the benefits of green hydrogen and hydrogen hubs are relevant to more than one goal. Possible responses include:

- Goal 7: Affordable and clean energy; hydrogen hubs produce 'green' hydrogen and therefore a source of 'clean' energy/an energy source that does not rely on fossil fuels/an energy source created from a plentiful resource.
- Goal 7: Affordable and clean energy; hydrogen hubs produce 'green' hydrogen, which has a much higher energy content per gram than carbon-based fuels, making it likely to be more affordable/efficient than other biofuels.
- Goal 7: Affordable and clean energy; hydrogen hubs produce 'green' hydrogen, which does not produce carbon dioxide when it is used as an energy source, making it a very clean energy source.
- Goal 9: Industry, innovation and infrastructure; hydrogen hubs support the production of green steel, green cement and other materials, enabling industries that rely on those materials to be more sustainable.
- Goal 9: Industry, innovation and infrastructure; hydrogen hubs support the production of green hydrogen, which is a more sustainable alternative to existing transport fuels and energy in industries like long haul transport, iron and steel.
- Goal 11: Sustainable cities and communities; hydrogen hubs are designed to be placed in locations where the hydrogen produced can be used and thereby minimise the cost, energy consumption and pollution associated with transportation, improving the sustainability of the local industry.
- Goal 12: Responsible consumption and production; hydrogen hubs allow the production of a green energy source, namely green hydrogen.
- Goal 13: Climate action; hydrogen hubs allow the production of hydrogen gas using renewable energy sources that do not of themselves produce greenhouse gases as a product, and the production of hydrogen gas itself produces only hydrogen and oxygen gases, neither of which is a greenhouse gas.
- Goal 13: Climate action; hydrogen hubs allow the production of green hydrogen as a replacement for fossil fuels to power long-haul transport and other industries, eliminating the production of carbon dioxide.

Question 9c.*

Bearing in mind that Goal 6 relates to ensuring the availability of clean water and sanitation, 1 mark each for various options, including:

- Using water as a feedstock for the production of hydrogen makes that water unavailable for use as a source of drinking water.

- Using water as a feedstock for the production of hydrogen makes that water unavailable for use in washing, bathing and other sanitation purposes.
- The use of water as a feedstock represents a particular challenge in maintaining a sufficient water supply for other uses in countries/locations that are dry/arid/have large desert regions.
- The use of water as a feedstock represents a particular challenge in maintaining a sufficient water supply for other uses during times of drought.
- Extracting water as a feedstock for an industrial process risks disrupting environmental water flows (in a similar way to using river water for irrigation)
- Extracting water as a feedstock risks contaminating or polluting the water source from which it is taken.

Question 9d.

Various options, 1 mark for a relevant limitation and an explanation outlining why it is a barrier:

- Lack of infrastructure to handle hydrogen storage and transport: significant investment in infrastructure would be needed to enable distribution of hydrogen gas as an energy source (e.g. “hydrogen stations” to take the place of petrol stations, construction of the hydrogen hubs themselves).
- Lack of current domestic technologies using hydrogen gas: most cars and domestic applications requiring energy are not compatible with hydrogen gas, so technological advancements and/or significant consumer investment would be required for its widescale use in society.
- Storage/safety issues: hydrogen is an explosive gas that must be transported and stored under high pressure, which poses risks that are multiplied with scale of use.
- Consumer resistance: most consumers are unfamiliar with hydrogen technology, and the dangers associated with its storage and/or the cost of acquiring new equipment that runs on hydrogen are likely to inhibit its widespread adoption.
- Competition: the development of electric cars and domestic solar energy to replace fossil fuels and mains electricity has a significant headstart over hydrogen fuel cells technology.

Question 10

A variety of points can be made in response to this question in support of an overall **positive evaluation** for the potential for electrochemical synthesis of ammonia to be a more sustainable method of ammonia production. For full marks, there needs to be an actual evaluation (1 mark) that is supported by at least one observation around the three factors referred to in the question. Potential points that can be made in favour of the fuel cell process include:

Reaction conditions: (up to 2 marks)

- The fuel cell operates at room temperature; the equilibrium-based process requires elevated temperatures.
- The fuel cell operates just above atmospheric pressure; the equilibrium-based process requires high pressure.
- Separating the NH_3 from the reaction mixture is necessary in the equilibrium-based process.

Optimisation of equilibrium reactions: (up to 2 marks)

- The equilibrium-based process is forced to compromise between rate and yield because high temperature favours high rate of reaction but lowers yield because the reaction is exothermic; the fuel-cell process does not have this drawback.
- The equilibrium-based process is forced to use high pressure since this favours the forward reaction as there are fewer product particles than reactant particles; the fuel-cell process does not have this drawback.

Green-chemistry principles: (up to 2 marks)

- Atom economy/Prevention of waste: Both processes have 100% atom economy based on the overall reaction, but the reversible nature of the equilibrium-based process means that the fuel cell process will have a better yield overall/will not have as big an issue with unreacted reactants.
- Design for energy efficiency: The fuel cell operates at room temperature, so avoids the need to expend energy resources/expend economic resources/potentially greenhouse gas-producing processes needed to achieve the elevated temperatures used in the equilibrium-based process.
- Design for energy efficiency: The fuel cell process also produces electrical energy, in a form that makes it able to be used. The equilibrium-based process produces heat energy which might be able to be recycled to (for example) heat the system, but also is likely to be wasted energy.
- Design for energy efficiency: The transformation of chemical potential energy into electrical energy is generally more efficient than transformation into heat energy (although energy production is not the main focus of the overall reaction).

There are points on which the two processes might be said to be “tied”, but which can be a valid part of the evaluation since they mean the fuel cell process does not make things worse. These include:

- Reaction conditions/Catalysis: If it is assumed that the fuel cell has porous electrodes that contain catalyst nano-particles, both processes employ catalysts to increase rate of reaction (although insufficient information is provided as to their relative scarcity).
- Reaction conditions/Use of renewable feedstocks: Both processes use the same reactants, which can include green hydrogen.

There may be scope to arrive at a **negative** evaluation for the fuel-cell process. For example:

- Fuel cells are generally expensive in terms of their materials
- The lithium required for the fuel cell may be a scarcer resource than the iron/iron oxide used in the equilibrium-based process
- The fuel cell process may not be as readily scalable as the equilibrium-based process.