SUGGESTED SOLUTION VCAA 2024 SAMPLE EXAM

Answers to multiple-choice questions

Section A

Question	Answer	Question	Answer
1	B	16	A
2	C	17	C
3	A	18	C
4	B	19	B
5	B	20	D
6	D	21	A
7	A	22	A
8	D	23	C
9	C	24	A
10	D	25	C
11	C	26	C
12	B	27	B
13	B	28	D
14	D	29	A
15	D	30	C

Question 1 (7 marks)

In a school laboratory, Amelia and Dylan fermented plant biomass and then distilled it to produce bioethanol.

a. State which **one** of the seven ‘Principles of Green Chemistry’ is the most relevant to the production of bioethanol from fermentation. Use **item 26.ii** of the Data Book. 1 mark

"Use of renewable feedstocks." Bioethanol is produced from plant biomass, which is a renewable resource.

1 mark for correctly identifying the principle.

b. i. Calculate the % atom economy for the production of bioethanol from glucose. 1 mark

$$\text{Atom economy} = \frac{\text{Mass of desired product}}{\text{Total mass of reactants}} \times 100$$

- Desired product: 2 mol of C_2H_5OH = $2 \times 46.0 = 92.0\,\text{g}$
- Total mass of reactants: 1 mol of $C_6H_{12}O_6$ = $180.0\,\text{g}$

$$\text{Atom economy} = \frac{92.0}{180.0} \times 100 = 51.1\%$$

- **1 mark for correct calculation and answer.**

ii. Calculate the % yield of ethanol if 100.0 g of glucose reacts to form 7.15 g of ethanol. 3 marks

- Molar mass of glucose, $M(C_6H_{12}O_6) = 180.0\,\text{g/mol}$
- Molar mass of ethanol, $M(C_2H_5OH) = 46.0\,\text{g/mol}$
- Stoichiometry: 1 mol glucose produces 2 mol ethanol.

1 mol of glucose $\mathrm{C_6H_{12}O_6}$ produces $2 \times 46.0 = 92.0\,\text{g}$ ethanol.

$$\text{Moles of glucose in 100.0 g} = \frac{100.0\,\text{g}}{180.0\,\text{g/mol}} = 0.5556\,\text{mol}$$

From 0.5556 mol of glucose:

$$\text{Theoretical yield of ethanol} = 0.5556\,\text{mol} \times 92.0\,\text{g/mol} = 51.11\,\text{g}$$

$$\%\ \text{yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100 = \frac{7.15\,\text{g}}{51.11\,\text{g}} \times 100 = 14.0\%$$

- 3 marks total:
  - 1 mark for calculating moles of glucose,
  - 1 mark for theoretical yield of ethanol,
  - 1 mark for % yield calculation.

c. Explain why fermented biomass required distillation by Amelia and Dylan to produce usable bioethanol.
2 marks

Fermented biomass produces a mixture of ethanol and water along with other byproducts. Distillation is required to:

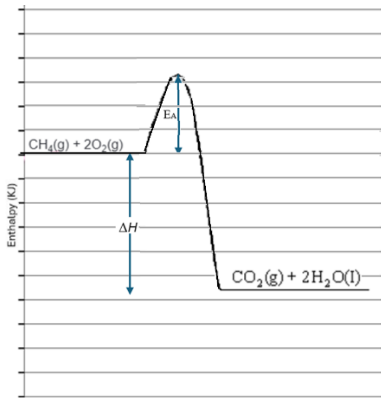
1. **Separate ethanol from water**: The ethanol concentration in the fermentation broth is low, and distillation increases its purity.
2. **Increase ethanol concentration**: To produce usable bioethanol as a fuel, the ethanol needs to be concentrated to a higher percentage.

- 1 mark for explaining the need to separate ethanol from water.
- 1 mark for the explanation of increasing ethanol concentration.

Question 2 (8 marks)

a. Complete the following energy profile diagram for the complete combustion of methane gas. Indicate on the diagram the Δ*H* and the activation energy.

2 marks



• 1 mark for correctly positioning reactants, products, and ΔH (exothermic).
• 1 mark for correctly indicating activation energy (EA).

b.
i. Write the balanced overall equation using semi-structural formulas. States are not required.

1 mark

The balanced equation for the substitution reaction of 2-chloro-2-methylpropane with sodium hydroxide:

$$(CH_3)_3CCl + NaOH \rightarrow (CH_3)_3COH + NaCl$$

- 1 mark for the correct balanced equation using semi-structural formulas.

ii. Identify whether this process is going to be exothermic or endothermic. Use **item 10** of the Data Book to determine the theoretical Δ*H* associated with this reaction. 2 marks

From data book

C-Cl bond energy = 324 kJ/mol and
C-O bond energy = 358kJ/mol

ΔH = Energy of bonds broken – energy of bonds formed
= 324 – 358 = -34 KJ/mol

As the value of ΔH is negative, the reaction is exothermic

- 1 mark for correct calculation of ΔH
- 1 mark for identifying that the react is exothermic

iii. The rate of this reaction is controlled by the first step in the mechanism, the breaking of the carbon-halogen bond.

Explain whether the reaction between 2-iodo-2-methylpropane with sodium hydroxide would be predicted to react at a faster or slower rate than 2-chloro-2-methylpropane under the exact same reaction conditions.

3 mark
According to VCAA data book, the bond energies for C-Cland C-Iare as follow:

- C-I bond energy = 228 KJ/mol
- C-Cl bond energy = 324 KJ/mol

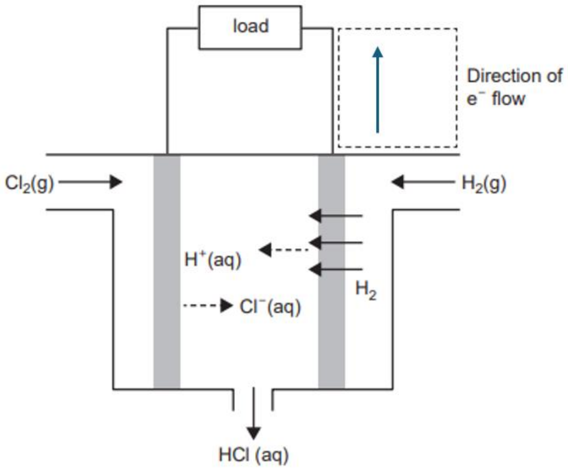
Since less energy is required to break the C-I bond, meaning it is weaker, and will break faster, hence will lead to faster ate of reaction. Therefore 2-iodo-2-methylpropane will react faster than 2-chloropropane under the same condition

3 marks:

- 1 mark for identifying the bond strength difference.
- 1 mark for linking the bond strength to the reaction rate.
- 1 mark for concluding that 2-iodo-2-methylpropane reacts faster.

Question 3 (8 marks)

Hydrogen-chlorine fuel cells (HCFC) are being investigated for potential use for grid-scale energy production. The HCFC fuel cell uses an aqueous acidic system. A diagram of an HCFC is shown below



a. Identify the energy transformation that takes place in this fuel cell. 1 mark

The energy transformation in the hydrogen-chlorine fuel cell is from chemical energy to electrical energy. The chemical reactions between hydrogen and chlorine generate electricity.

- 1 mark for identifying the correct energy transformation.

b. Write the balanced half-equation for the reaction occurring at the cathode. 1 mark

In an acidic hydrogen-chlorine fuel cell, chlorine undergoes reduction at the cathode:

$$\mathrm{Cl_2}(g) + 2e^- \rightarrow 2\mathrm{Cl}^-(aq)$$

- **1 mark for the correct half-equation.**

c. Place an arrow in the box shown on the diagram above to indicate the direction of the flow of electrons in the wire. 1 mark

From Anode (H_2 half cell) to cathode (Cl_2 half cell)

d. Calculate the voltage that this cell would be expected to produce when operating under standard conditions. 1 mark

To calculate the voltage, use the standard reduction potentials:

- **H_2 (oxidation)** at the anode: $E^\circ = 0.00\,\mathrm{V}$
- **Cl_2 (reduction)** at the cathode: $E^\circ = +1.36\,\mathrm{V}$

The overall cell voltage E° is calculated as:

$$E^\circ = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} = 1.36\,\mathrm{V} - 0.00\,\mathrm{V} = 1.36\,\mathrm{V}$$

- **1 mark for correctly calculating the voltage (1.36 V).**

e. State one design feature of the electrodes used within a fuel cell that would increase the efficiency of the cell.

One key design feature that increases the efficiency of the fuel cell is using **porous electrodes**. Porous electrodes increase the surface area available for the reactions, allowing for more efficient gas diffusion and reaction rates.

- **1 mark for identifying "porous electrodes" as a feature to improve efficiency.**

f.

i. Determine which chemical is the limiting reagent. 1 mark

At SLC, 1 mole of any gas occupies 24.8 L (24,800 mL). The moles of gases are calculated as:

$$\text{Moles of } O_2 = \frac{350}{24,800} = 0.01411 \text{ mol}$$

$$\text{Moles of } H_2 = \frac{450}{24,800} = 0.01815 \text{ mol}$$

From the balanced equation, the reaction requires **2 moles of H_2 per 1 mole of O_2**.

- Required moles of H_2 for 0.01411 mol of O_2: $2 \times 0.01411 = 0.02822 \text{ mol}$.
- But only 0.01815 mol of H_2 is available, meaning **H_2 is the limiting reagent**.
- **1 mark for identifying hydrogen as the limiting reagent.**

ii. ii. Calculate the volume, in litres, of the unreacted gas. 2 mark

Since hydrogen is the limiting reagent, some oxygen will remain unreacted. The balanced equation shows that 1 mole of O_2 reacts with 2 moles of H_2. Therefore, 0.01815 mol of H_2 will react with:

$$\text{Moles of } O_2 \text{ reacted} = \frac{0.01815}{2} = 0.009075 \text{ mol}$$

Initial moles of O_2 were 0.01411 mol, so the unreacted moles of O_2 are:

$$\text{Moles of unreacted } O_2 = 0.01411 - 0.009075 = 0.005035 \text{ mol}$$

The volume of unreacted oxygen is:

$$\text{Volume of unreacted } O_2 = 0.005035 \text{ mol} \times 24.8 \text{ L/mol} = 0.125 \text{ L}$$

- **2 marks total:**
  - 1 mark for calculating the moles of unreacted O_2.
  - 1 mark for correctly calculating the volume of unreacted gas (0.125 L).

Question 4 (13 marks)

A biodiesel consists as a pure sample of a fatty acid methyl ester. The molecular formula of this compound is $C_{19}H_{36}O_2$ and its molar mass is 296 g mol^{-1} .

a. Calculate the mass, in grams, of iodine, I2, that would react with 100 g of this biodiesel. 3 marks

$$\text{Moles of biodiesel} = \frac{100\,\text{g}}{296\,\text{g/mol}} = 0.338\,\text{mol}$$

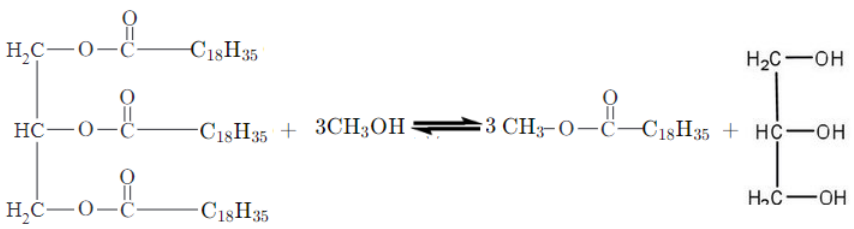
Since the biodiesel molecule is monounsaturated, it needs one mole of I_2 to add on C=C

Moles of biodiesel = Moles of I_2 = 0.338 mol

Mass of I_2 = 0.338 x 253.8 = 85.8 g

- 3 marks total:
  - 1 mark for calculating the moles of biodiesel.
  - 1 mark for determining the moles of I_2 needed.
  - 1 mark for calculating the mass of iodine.

b. Using molecular formulas, write the chemical equation for the reversible transesterification reaction that produces this biodiesel. Assume that three identical fatty acids form this triglyceride. 3 marks



- 1 mark for including methanol.
- 1 mark for correctly showing the products.
- 1 mark for balancing the equation.

c. Transesterification is a reversible reaction. Explain one way that the yield of biodiesel could be maximised. 2 marks

One way to maximise the yield of biodiesel in the transesterification process is to remove one of the products (glycerol) from the reaction mixture. By applying Le Chatelier's principle, the reaction equilibrium will shift to the right, favoring the formation of more biodiesel.

- 1 mark for identifying glycerol removal.
- 1 mark for explaining how it shifts equilibrium to increase biodiesel production.

d. A sample of 0.510 g of biodiesel was burned. Birrani recorded that the initial temperature of the water was 22.2 °C and the final temperature was 35.7 °C. Assume that the biodiesel is fully combusted and that the system was known to operate with a 55% energy transfer efficiency. Calculate the energy released by the biodiesel, in kilojoules per gram, based on the experimental results. 3 marks

$$q = mc\Delta T$$

$$= (200\,\text{g}) \times (4.18\,\text{J/g}^\circ\text{C}) \times (35.7 - 22.2\,^\circ\text{C})$$

$$= 200 \times 4.18 \times 13.5 = 11,286\,\text{J} = 11.286\,\text{kJ}$$

Since only 55% of the energy was transferred to the water:

$$\text{Energy released by biodiesel} = \frac{11.286\,\text{kJ}}{0.55} = 20.52\,\text{kJ}$$

$$\text{Energy per gram} = \frac{20.52\,\text{kJ}}{0.510\,\text{g}} = 40.2\ \text{kJ/g}$$

3 marks total:

- 1 mark for calculating the energy absorbed by water.
- 1 mark for adjusting for efficiency.
- 1 mark for determining the energy released per gram of biodiesel.

e. The following three molecular formulas represent members of the same homologous series of a fatty acid methyl ester. $C_{19}H_{36}O_2$ $C_{17}H_{32}O_2$ $C_{15}H_{28}O_2$. Explain how the viscosity of these compounds will vary. 2 mark

Viscosity decreases. Longer chain molecules ($C_{19}H_{36}O_2$) have stronger van der Waals forces due to greater molecular size and surface area, leading to higher viscosity. Shorter chains ($C_{15}H_{28}O_2$) have weaker intermolecular forces, resulting in lower viscosity.

- 1 mark for identifying that viscosity decreases with shorter chain length.
- 1 mark for explaining the relationship with intermolecular forces.

Question 5 (7 marks)

a. Discuss whether the melting points of these two forms of ibuprofen will be the same or different. 2 marks

The two forms of ibuprofen, S-ibuprofen and R-ibuprofen, are stereoisomers (enantiomers), meaning they are mirror images of each other. These enantiomers have identical physical properties in an achiral environment, including melting points, as they have the same molecular structure and intermolecular forces. Therefore, the melting points will be the same for S- and R-ibuprofen.

- 1 mark for identifying them as stereoisomers/enantiomers.
- 1 mark for stating that their melting points will be the same due to identical molecular properties.

b. Explain, by referring to substrate–enzyme interactions, what is meant by the description of S-ibuprofen as a 'competitive inhibitor of an enzyme'. You may use diagrams in your answer. 2 marks

A **competitive inhibitor** is a molecule that binds to the **active site** of an enzyme, competing with the natural substrate for the same binding site. In this case, **S-ibuprofen** competes with the natural substrate (the precursor to prostaglandins) for the enzyme's active site. By binding to the active site, S-ibuprofen prevents the enzyme from forming prostaglandins, reducing inflammation.

The enzyme has a specific active site where the natural substrate fits, but S-ibuprofen binds to this site, blocking the substrate.

- **2 marks total**:
  - 1 mark for explaining that S-ibuprofen binds to the active site.
  - 1 mark for describing how this blocks prostaglandin production.

c. State one reason why R-ibuprofen is not effective as an anti-inflammatory medicine. 1 mark

R-ibuprofen is not effective because it **cannot bind** properly to the enzyme's active site due to its different three-dimensional structure. Only the **S-enantiomer** fits correctly and can act as a competitive inhibitor.

- 1 mark for explaining that R-ibuprofen does not fit the enzyme's active site or interact properly.

d. State which molecule, naproxen or morphine, would be most likely to work via a very similar pathway to S-ibuprofen. Give a reason for your choice. 2 marks

Naproxen is more likely to work via similar pathway, as the S-ibuprofen. This is due to similarity of structures of naproxen and S-ibuprofen, and hence will inhibit the enzyme that produces prostaglandins, thereby reducing inflammation.

- 1 mark for identifying naproxen as the drug most similar to S-ibuprofen.
- 1 mark for explaining that naproxen, like S-ibuprofen, inhibits prostaglandin synthesis.

Question 6 (6 marks)

a. Calculate the amount, in moles, of electrons passing through this circuit. 2 marks

$$Q = I \times t$$

$$Q = 10.0\,\mathrm{A} \times 300\,\mathrm{s} = 3000\,\mathrm{C}$$

$$\mathbf{ne} = \frac{Q}{F} = \frac{3000\,\mathrm{C}}{96,500\,\mathrm{C/mol}} = 0.0311\,\mathrm{mol}$$

$$\text{Moles of electrons} = 0.0311\,\mathrm{mol}$$

- 1 mark for calculating the charge.
- 1 mark for converting charge to moles of electrons.

b. Determine the mass of aluminium produced. 1 mark

$$\mathrm{Al}^{3+} + 3e^- \rightarrow \mathrm{Al\,(s)}$$

$$\text{Moles of Al} = \frac{\text{Moles of electrons}}{3} = \frac{0.0311\,\mathrm{mol}}{3} = 0.01037\,\mathrm{mol}$$

$$\text{Mass of Al} = 0.01037\,\mathrm{mol} \times 27.0\,\mathrm{g/mol} = 0.280\,\mathrm{g}$$

- 1 mark for calculating the mass of aluminium.

c. Identify the gas being produced at both anodes. 1 mark

The gas produced at both anodes is **oxygen (O_2)**

d. Determine whether the same quantity of gas would be produced at each of the anodes. Justify your answer. 2 marks

The **same quantity** of oxygen gas is produced at each anode.
At both anodes, the oxidation of water to form oxygen gas involves 4 moles of electrons for each mole of O_2 gas produced.

- 1 mark for concluding the same amount of oxygen is produced.
- 1 mark for recognizing the same number of electrons pass through both cells.

Question 7 (14 marks)

a. State the homologous series to which Compound P belongs. 1 mark

Alkene

b.

i. Identify a chemical test that can be used to confirm the presence of the hydroxyl functional group through an observable colour change. Describe the expected colour changes that would be observed. 2 marks

The test for the hydroxyl group (-OH) can be done using acidified potassium dichromate ($K_2Cr_2O_7$) or acidified potassium permanganate ($KMnO_4$).

- Expected result with $K_2Cr_2O_7$: The solution would change from orange to green as oxidation occurs

OR

- Expected result with $KMnO_4$: The purple solution would become colorless as oxidation occurs

  - 1 mark for identifying the test with acidified potassium dichromate **or** potassium permanganate.
  - 1 mark for describing the expected color changes.

ii. Based on the information provided, explain why both Q and S cannot be classified as tertiary alcohols. 2 marks

Tertiary alcohols contain a hydroxyl group attached to the carbon atom, which is connected to 3- alkyl groups (i.e is must be branched). As the question stem mentions that the compound P is unbranched, which means corresponding alcohol would also be unbranched and cannot be tertiary

- 1 mark for defining/describing tertiary alcohol
- 1 mark for stating that linear hydrocarbon cannot be tertiary

  (Also accept the following reason for second mark)

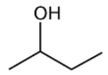
Since both Q and S were formed after reacting Compound P with an oxidizing agent, neither can be classified as a tertiary alcohol, as they are susceptible to oxidation.

c.Use the integration curves, shown directly above each set of peaks in the ^1H NMR spectrum, to verify that the peak present at 1.46 ppm results from the presence of two equivalent hydrogens. 2 marks

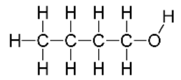
The peak at 1.46 ppm corresponds to two equivalent hydrogens. Using the integration curve (a ruler may be used), it can be seen that this peak represents two protons (H), which are in equivalent environments (likely two hydrogens on a single $-CH_2$ group).

- 1 mark for referring to the integration curve showing two equivalent hydrogens.
- 1 mark for identifying these as two hydrogens on a $-CH_2$ group.

d.Draw a skeletal structure for Compound Q. 1 mark



e. Draw a structural diagram for Compound S, an isomer of Compound Q. 1 mark



(must show all single bonds, including O-H)

f. Name the functional group present in Product U and use item 22 of the Data Book to identify on the spectrum the two absorption regions associated with this functional group. 3 marks

Based on the IR spectrum of **Product U**, the functional group present is likely a **carboxyl group (-COOH)**.

- A strong, broad peak at around **2500-3300 cm^{-1}** corresponds to the **O-H stretch** of the carboxylic acid.
- A sharp peak at around **1700 cm^{-1}** corresponds to the **C=O stretch** of the carboxylic acid.

3 marks:

- 1 mark for identifying the functional group as a carboxyl group.
- 1 mark for identifying the **O-H** absorption region.
- 1 mark for identifying the **C=O** absorption region.

g.

i. Identify a possible fragment that has produced the peak at m/z = 57. 1 mark

The fragment with m/z = 57 is likely **$C_3H_5O^+$**

(must have positive charge)

ii. ii. State what the 'm/z' symbol means on this mass spectrum. 1 mark

The symbol **m/z** stands for the **mass-to-charge ratio** of the ions

Question 8 (12 marks)

a. Explain whether Sam's hypothesis provides a clear focus for this investigation. 2 marks

Sam's hypothesis provides a clear focus because it:

Identifies the dependent variable (rate of reaction), which will be measured using the rate of color change (decrease in purple color).

OR

Predicts the relationship between the independent variable (concentration of oxalic acid) and the dependent variable, suggesting a positive correlation. More oxalic acid should increase the rate of reaction due to more frequent particle collisions.

- **1 mark** for stating that the hypothesis provides a clear focus by identifying key variables.
- **1 mark** for explaining the relationship between the concentration of oxalic acid and the rate of reaction.

b.

i. Identify a variable that has the greatest potential to affect the rate of any reaction, but which has not been controlled or referred to in this experimental design. 1 mark

Temperature is a variable that significantly affects the rate of reaction but has not been controlled in the experimental design.

- **1 mark** for identifying temperature as the uncontrolled variable.

ii. Explain, in terms of reactant particle collisions, why the variable identified above needs to be controlled in this experiment. 2 marks

If temperature increases, particles move faster due to increased kinetic energy, leading to more frequent and energetic collisions. This would increase the rate of reaction, making it difficult to isolate the effect of oxalic acid concentration on the rate of reaction. Controlling temperature ensures that any observed changes in the rate are only due to changes in the concentration of oxalic acid.

- **1 mark** for explaining that temperature affects particle movement and collision frequency.
- **1 mark** for stating that controlling temperature isolates the impact of oxalic acid concentration on the reaction rate.

c.

i. Comment on Sam's claim. 2 marks

Sam's claim is partially valid. The consistent trend in the data suggests a clear relationship between the concentration of oxalic acid and the rate of reaction, indicating reliable data collection. However, without seeing specific error bars or individual trial results, it is difficult to definitively confirm the claim of little variation within each trial.

- **1 mark** for acknowledging the consistent trend as supporting a good design.
- **1 mark** for critiquing the lack of detailed information about variation within trials.

ii. Justify whether the data shown in the plot 'Rate of reaction vs [C2H2O4]' supports Sam's hypothesis. 2 marks

The data supports Sam's hypothesis, as the plot shows a positive relationship between the concentration of oxalic acid and the rate of reaction. This aligns with the hypothesis that increasing the concentration of oxalic acid would increase the rate due to more frequent collisions between reactant particles.

- **1 mark** for stating that the data supports the hypothesis.
- **1 mark** for explaining that the positive correlation is consistent with the predicted effect of more frequent particle collisions.

iii. State whether Sam can claim that the results are reproducible. 1 mark

Yes, Sam can claim that the results are reproducible, as the experiments were repeated three times for each concentration, and the data showed consistency across these trials.

- **1 mark** for stating that reproducibility is confirmed by consistent results across multiple trials.

iv. Outline any further evidence that would be required before Sam could claim that this new experimental design was a valid way of determining the concentration of an oxalic solution. 2 marks

Further evidence required includes:

1. Independent replication of the experiment by others to confirm the reproducibility of the results.
2. Comparison of the results with another validated method of determining oxalic acid concentration, such as traditional titration, to ensure the new method's accuracy.

- **1 mark** for mentioning independent replication.
- **1 mark** for suggesting validation through comparison with an established method.

Question 9 (9 marks)

a.

i. Write the equation for the overall reaction that occurs in this PEM electrolyser. 1 mark

The overall reaction for water electrolysis in a PEM electrolyser is:

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

Marking Scheme:

- **1 mark** for correctly writing the balanced equation.

ii. Explain why the hydrogen produced will be considered 'green'. 2 marks

The hydrogen produced is considered "green" because it is generated using renewable energy sources such as solar or wind power, which do not produce carbon dioxide (CO_2) or other greenhouse gases during the energy generation process. Since no fossil fuels are involved in the production, the process contributes to reducing carbon emissions and supports the goal of decarbonization.

- 1 mark for stating that renewable energy is used in the production of hydrogen.
- 1 mark for linking this to the absence of carbon emissions during the process.

b. Using a relevant Sustainable Development Goal (SDG) that applies to the use of 'green' hydrogen in this system, explain how hydrogen hubs could support this sustainable development goal. Refer to item 26.i of the Data Book. (2 marks)

Hydrogen hubs support Sustainable Development Goal 13 (Climate Action), which aims to combat climate change by reducing greenhouse gas emissions. By producing "green" hydrogen using renewable energy, hydrogen hubs contribute to decarbonizing industries like steel production and transportation, thereby helping to reduce global CO_2 emissions and align with the targets of a 45% reduction by 2030 and achieving net-zero emissions by 2050.

- 1 mark for correctly identifying SDG 13 (Climate Action).
- 1 mark for explaining how hydrogen hubs contribute to reducing emissions and supporting climate action.

c. Suggest two sustainability challenges presented by the use of water as a feedstock in terms of United Nations Sustainable Development Goal 6. (2 marks)

Two sustainability challenges in terms of SDG 6 (Clean Water and Sanitation) are:
Water scarcity: Large-scale electrolysis requires significant amounts of water, which could strain local water supplies, particularly in regions already facing water scarcity.
Water quality: Electrolysis may require high-purity water, and treating or purifying water for use in the electrolyser can consume additional resources and energy, potentially impacting the sustainability of water management practices.

- 1 mark for mentioning water scarcity as a sustainability challenge.
- 1 mark for identifying the challenge of maintaining water quality or resource intensity in water purification

(d) Outline one possible limitation of the widespread introduction of 'green' hydrogen into society. (2 marks)

One possible limitation of widespread green hydrogen use is the lack of infrastructure. The current infrastructure for producing, storing, and distributing hydrogen on a large scale is limited. Establishing hydrogen storage facilities, transport networks, and refueling stations will require significant investment and time, potentially delaying the adoption of green hydrogen in various sectors.

(accept other a reasonable answers)

Question 10 (6 marks)

The electrochemical synthesis of ammonia has several advantages over the traditional Haber process in terms of sustainability, primarily due to its operating conditions and adherence to green chemistry principles.

In terms of reaction conditions, the Haber process operates under extreme conditions: high pressures (10,000–25,000 kPa) and high temperatures (400–450°C). These conditions require significant energy input, much of which is sourced from fossil fuels, contributing to global greenhouse gas emissions (about 1.5% of total emissions) (1 mark) . In contrast, the new electrochemical method operates at room temperature and near atmospheric pressure, significantly reducing the energy requirements for ammonia production. Lower energy consumption directly reduces carbon emissions, aligning with sustainability goals (1 mark)

In addition, the Haber process is exothermic ($\Delta H=-92$ kJ), so lower temperatures would increase the yield of ammonia. However, low temperatures slow down the reaction rate, so high temperatures are used to balance rate and yield. High pressures also favor the formation of ammonia (fewer gas molecules on the product side), but maintaining these pressures is energy-intensive (1 mark)
The electrochemical synthesis bypasses the need for equilibrium optimization entirely by using a stepwise reaction mechanism that does not rely on the delicate balance between temperature, pressure, yield, and rate. The reactions proceed directly through intermediate compounds (e.g., lithium nitride, Li3NLi_3NLi3N), producing ammonia efficiently at mild conditions (1 mark)

Finally, the electrochemical method aligns with green chemistry principles in several ways. For example, by operating at room temperature and near atmospheric pressure, the process consumes far less energy than the Haber process, reducing the overall carbon footprint. The electrochemical process could potentially be powered by renewable energy sources (e.g., solar or wind), further enhancing its sustainability by minimizing reliance on fossil fuels. Moreover, the new method does not generate large amounts of by-products, whereas the traditional Haber process is often associated with significant waste heat and CO_2 emissions from energy use (1 mark)

In conclusion while the new method offers potential sustainability improvements, its scalability and commercial viability are still under investigation. The electrochemical synthesis of ammonia provides a potentially more sustainable alternative to the traditional Haber process due to its significantly lower energy requirements, adherence to green chemistry principles, and reduced greenhouse gas emissions. However, further research is needed to assess its scalability and long-term viability in industrial applications. (1 mark)

- **2 marks**: Comparison of the reaction conditions of both methods (high temperature and pressure vs room temperature and atmospheric pressure) for both processes
- **2 marks**: Discussion on the optimisation of equilibrium reactions (balancing yield and rate in the Haber process **vs** bypassing equilibrium constraints in the electrochemical process).
- **1 marks**: Evaluation of the green chemistry principles, such as energy efficiency, waste prevention, and potential for integration with renewable energy.
- **1 marks**: Concluding remarks with final thoughts about both processes