2026
NHT

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Write your **student number** in the boxes above. **Letter**

Chemistry

Question and Answer Book

VCE (NHT) Examination – Wednesday 20 May 2026

- Reading time is **15 minutes**: 2.00 pm to 2.15 pm
- Writing time is **2 hours 30 minutes**: 2.15 pm to 4.45 pm

Approved materials

- One scientific calculator

Materials supplied

- Question and Answer Book of 44 pages
- Data Book
- Multiple-Choice Answer Sheet

Instructions

- Follow the instructions on your Multiple-Choice Answer Sheet.
- At the end of the examination, place your Multiple-Choice Answer Sheet inside the front cover of this book.

Students are **not** permitted to bring mobile phones and/or any unauthorised electronic devices into the examination room.

Contents

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY
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Section A – Multiple-choice questions

Instructions

- Answer **all** questions in pencil on your Multiple-Choice Answer Sheet.
- Choose the response that is **correct** or that **best answers** the question.
- A correct answer scores 1; an incorrect answer scores 0.
- Marks will **not** be deducted for incorrect answers.
- No marks will be given if more than one answer is completed for any question.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1

When comparing cellular respiration and the combustion of glucose, which statement is correct for both reactions?

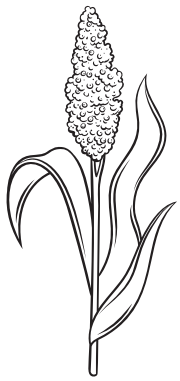
A. Oxygen is reduced.

B. The enthalpy is positive.

C. A catalyst is required.

D. They are equilibrium reactions.

Use the following information to answer Questions 2–4.



Sorghum is a plant that has three usable products: the grain, and the juice and fibre from the stalk.

Question 2

When photosynthesis occurs in sorghum

A. glucose in the juice is converted into energy.

B. ethanol is formed from glucose.

C. energy is stored in chemical bonds.

D. 1 g of glucose is formed for every 6 g of carbon dioxide consumed.

Question 3

Glucose can be stored in the form of amylose in the stalk of the sorghum.

For a section of amylose formed from 50 glucose units, the molecular formula would be

A. $C_{300}H_{500}O_{250}$

B. $C_{300}H_{551}O_{251}$

C. $C_{300}H_{550}O_{250}$

D. $C_{300}H_{502}O_{251}$

Question 4

When the juice from the stalk undergoes fermentation, which one of the following occurs?

A. Bioethanol and carbon dioxide are formed.

B. Carbon dioxide and water are formed.

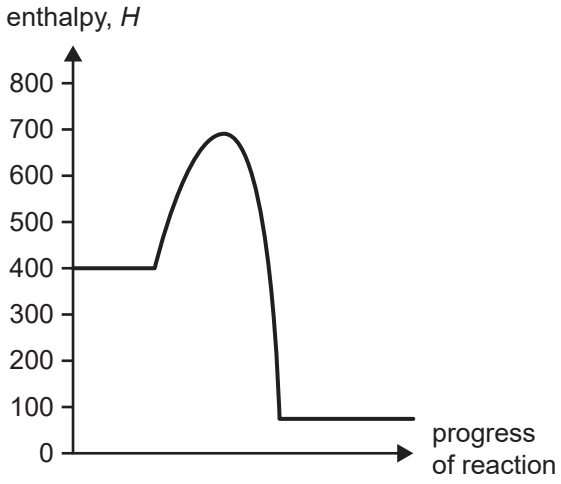
C. Only bioethanol is formed.

D. Only glucose is formed.

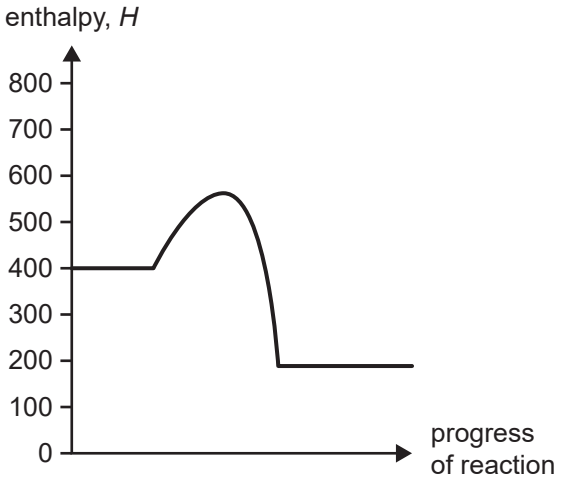
Question 5

Compare the energy profile diagrams below for two different reactions.

Reaction 1



Reaction 2



Which one of the following statements is correct?

A. Reaction 1 releases less energy because the activation energy required is larger.

B. Reaction 2 is faster under the same conditions because fewer bonds must be broken.

C. The total energy released in bond formation is higher in Reaction 1 than Reaction 2.

D. Reaction 2 is more likely to occur under the same conditions because it requires less energy to be released when forming stable products.

Question 6

Mercury ions, Hg^{2+}, react with liquid hydrazine, N_2H_4, according to the reaction below.

$$2Hg^{2+}(aq) + N_2H_4(l) \rightarrow 2Hg(l) + N_2(g) + 4H^+(aq)$$

If 0.375 mol of $N_2H_4(l)$ produces 0.625 mol of mercury, Hg(l), which one of the following is correct?

	Reactant in excess	Mass of N_2 produced (g)
A.	Hg^{2+}	8.75
B.	Hg^{2+}	10.5
C.	N_2H_4	8.75
D.	N_2H_4	10.5

Question 7

Shown below is the label for Honey Shapes cereal.

NUTRITIONAL INFORMATION

Honey Shapes cereal
Serving size: 50 g

	Per 100 g
carbohydrate	58 g
protein	10 g
fat	14 g

The calculated total energy for one serve of Honey Shapes cereal is

A. 2.5×10^3 kJ

B. 1.6×10^3 kJ

C. 1.3×10^3 kJ

D. 8.1×10^2 kJ

Question 8

A packet of crackers states that the energy content is 18.0 kJ g^{-1}. In an experiment, 1.00 g of the crackers is burnt to heat 100 g of water that was initially at standard laboratory conditions (SLC).

The maximum possible temperature, in degrees Celsius, of the 100 g of water is

A. 25.0

B. 29.3

C. 43.0

D. 68.0

Question 9

Primary cells always have

A. ions migrating to the electrodes.

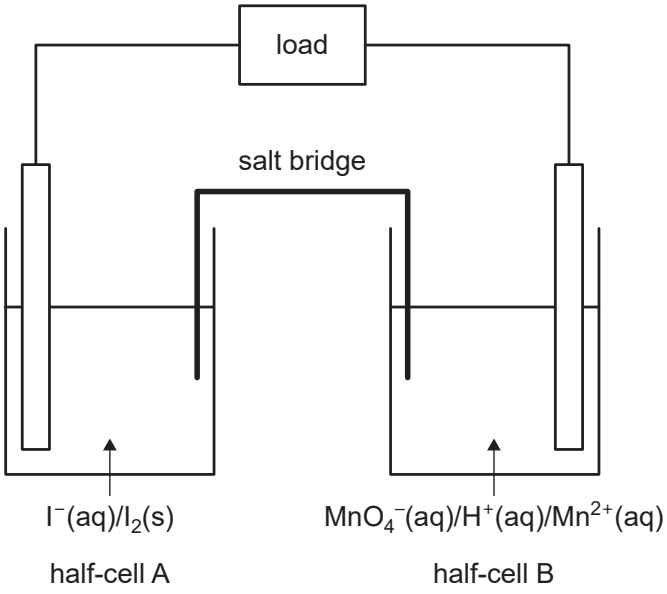
B. a positive anode while recharging.

C. two different metals as the electrodes.

D. products that stay in contact with the electrodes.

Use the following information to answer Questions 10 and 11.

The galvanic cell arrangement shown below is at SLC using 1.0 M electrolyte solutions.



Question 10

Consider the following statements relating to the half-cells above:

I MnO_4^- is the oxidising agent.

II A voltage of over 1.0 V is produced.

III Chemical energy is converted to electrical and heat energy.

Which of the statements above regarding the half-cells are correct?

A. I and II

B. I and III

C. II and III

D. I, II and III

Question 11

When the cell is under alkaline conditions, the half-equation for the reaction occurring at the cathode would be

A. $2I^- \rightarrow I_2 + 2e^-$

B. $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$

C. $MnO_4^- + 4H_2O + 5e^- \rightarrow Mn^{2+} + 8OH^-$

D. $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

Question 12

Sulfur dioxide, SO_2, and oxygen, O_2, form sulfur trioxide, SO_3, in a gaseous equilibrium reaction. The equilibrium constant for the reaction at 450 °C is 4.62 M^{-1}.

Initially, the system was not at equilibrium. The concentrations were measured to be:

- $[SO_2]$ = 1.00 M
- $[O_2]$ = 0.373 M
- $[SO_3]$ = 1.00 M

As the system reaches equilibrium, which one of the following occurs?

A. $[SO_3]$ will increase by the same amount at which the $[SO_2]$ decreases.

B. $[SO_2]$ will increase at twice the rate at which the $[O_2]$ increases.

C. The decrease in the mass of $O_2(g)$ will be half the decrease in the mass of $SO_2(g)$.

D. The mass of $SO_2(g)$ will be 80% of the mass of $SO_3(g)$.

Question 13

A current of 2.00 A is passed through a solution of copper(II) sulfate, $CuSO_4$, for 1800 seconds.

The amount of copper, Cu, in mol, formed was

A. 9.33×10^{-3}

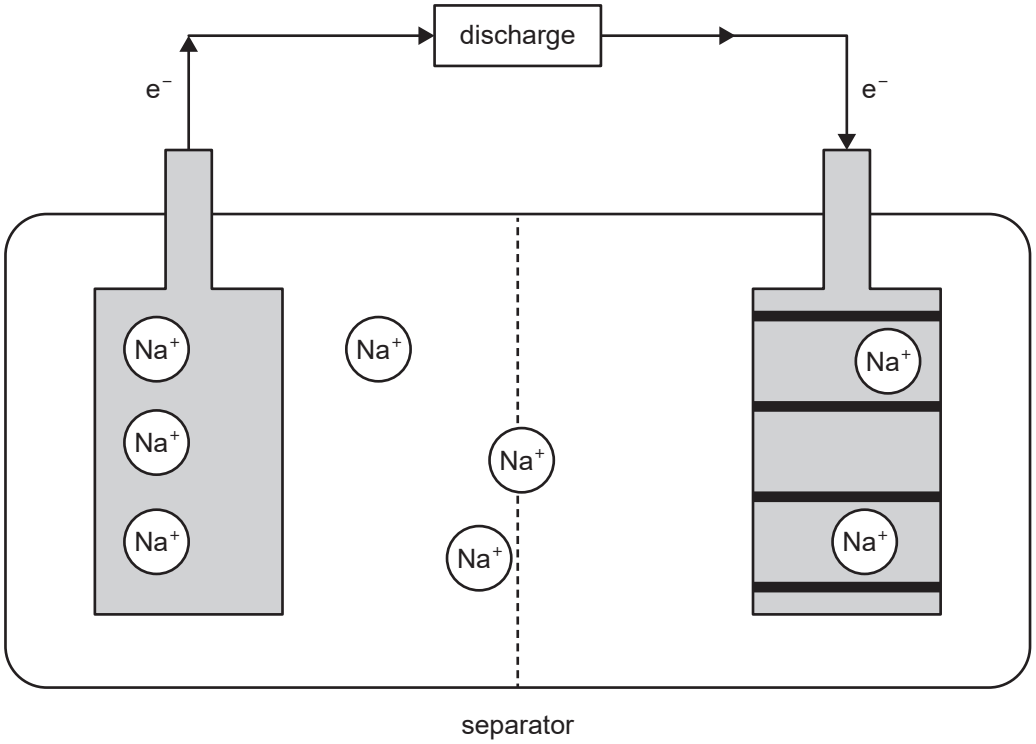
B. 1.87×10^{-2}

C. 3.73×10^{-2}

D. 7.47×10^{-2}

Use the following information to answer Questions 14–16.

Significant research is being done into replacing lithium-ion batteries with sodium-ion batteries in a range of applications. Both types of batteries operate in a similar manner. An example of a sodium-ion cell is provided below.



Source: Adapted from 'New electrolyte puts sodium batteries on the horizon', *Hive Blog* <hive.blog>

Question 14

Which one of the following is correct for the movement of sodium ions, Na^+, during discharge and recharge of the battery?

	During discharge, Na^+ move towards the	**During recharge, Na^+ move towards the**
A.	anode	left
B.	cathode	left
C.	anode	right
D.	cathode	right

Question 15

During recharge, the Na^+ concentration in the electrolyte

A. increases.

B. decreases.

C. remains the same.

D. cannot be determined.

Question 16

Consider the following true statements about the properties of lithium and sodium cells:

I Lithium is lighter.

II Sodium is more stable.

III Lithium is more likely to overheat.

IV Lithium has a higher energy output.

Which of the statements above would support a decision to replace lithium-ion batteries with sodium-ion batteries?

A. I and II

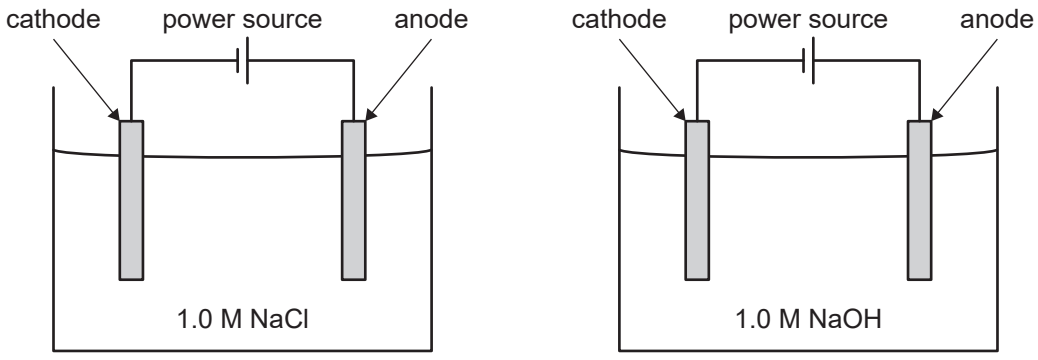
B. I and IV

C. II and III

D. II and IV

Question 17

Aziz and Irene were investigating the products formed when 1.0 M sodium chloride, NaCl, and 1.0 M sodium hydroxide, NaOH, aqueous solutions are electrolysed separately, as shown in the diagrams below.



Which one of the following statements is correct?

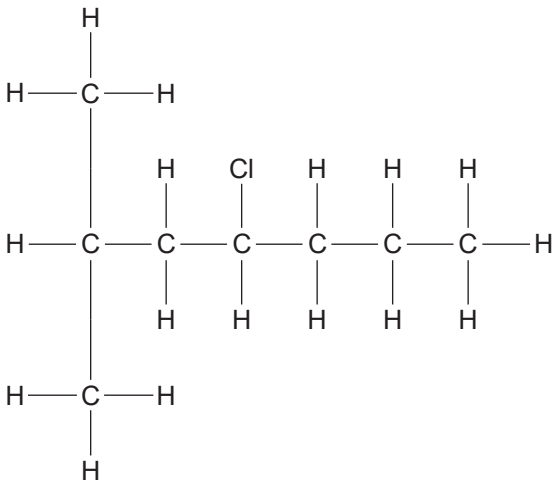
A. Only the NaCl solution could produce oxygen gas and hydrogen ions at the anode.

B. Only the NaOH solution could produce hydrogen gas and hydroxide ions at the cathode.

C. Both solutions could produce hydrogen gas and hydroxide ions at the anode.

D. Both solutions could produce oxygen gas and hydrogen ions at the cathode.

Question 18



The correct name for the compound shown above is

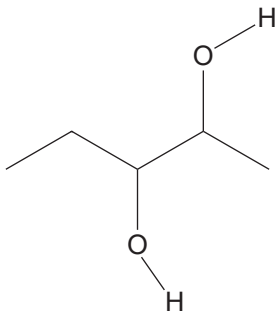
A. 1,1-dimethyl-3-chlorohexane

B. 3-chloro-1,1-dimethylhexane

C. 4-chloro-2-methylheptane

D. 2-methyl-4-chloroheptane

Question 19



Which one of the following could be formed when the compound above is oxidised?

A. 2-hydroxypentanal

B. 3-hydroxypentanal

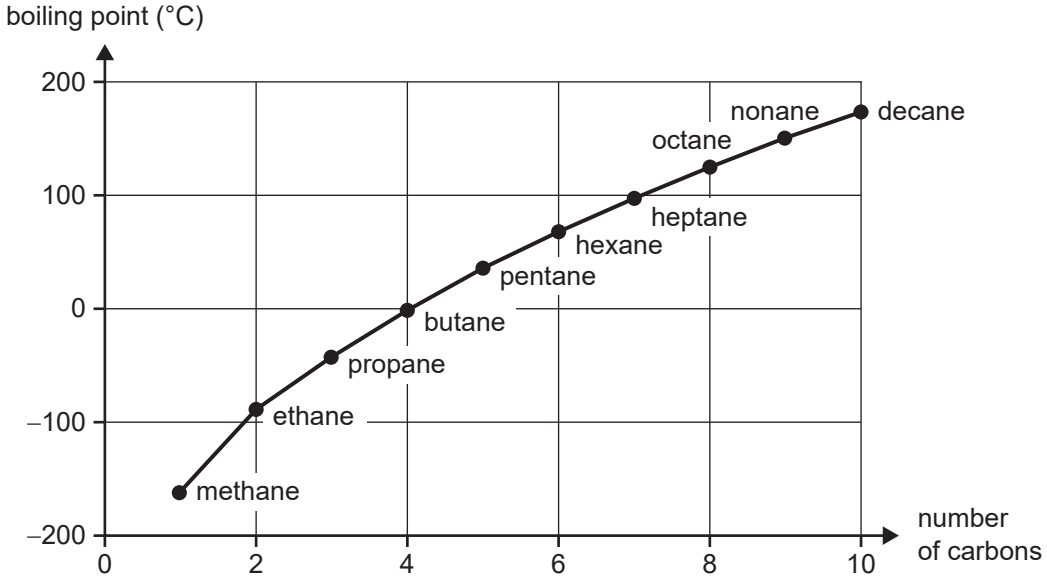
C. 3-hydroxypentan-2-one

D. 3-hydroxypentan-4-one

Question 20

Sarah researched the boiling points of the alkane homologous series. Her results are shown in the graph below.

Boiling point versus number of carbons in alkane



Source: 'Physical properties of alkanes', *OpenOChem* <learn.openochem.org>

Considering the relationship between boiling point and the alkane homologous series, which one of the following statements **best** explains Sarah's graph?

A. As the chain length increases, the strength of hydrogen bonding increases.

B. As the number of atoms increases, the intermolecular forces increase.

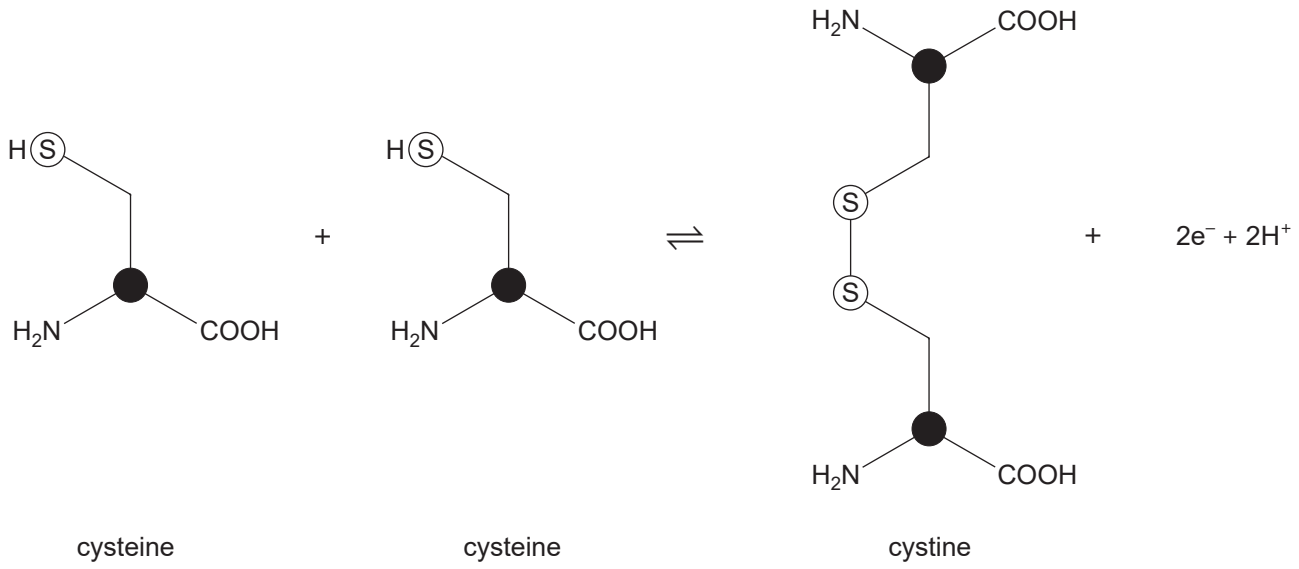
C. As the number of carbon–hydrogen bonds increases, the intermolecular forces decrease.

D. As the chain length increases, the energy required to separate the molecules decreases.

Use the following information to answer Questions 21 and 22.

Tom conducted a titration of iodine, I_2, solution with the amino acid cysteine. Both solutions should be freshly prepared to minimise reactions with dissolved oxygen. The equations for the half-reactions are shown below.

$$I_2 + 2e^- \rightleftharpoons 2I^-$$



cysteine cysteine cystine

Source: Adapted from OV Okoro et al., 'Enhanced keratin extraction from wool waste using a deep eutectic solvent', *bioRxiv*, 2021

A 20.00 mL aliquot of a cysteine solution required 15.00 mL of 0.0100 M I_2(aq) in a titration.

Question 21

Which one of the following is the correct concentration of the cysteine solution?

A. 0.00667 M

B. 0.00750 M

C. 0.0133 M

D. 0.0150 M

Question 22

A systematic error in the titration data could be due to

A. oxygen dissolved in the cysteine solution.

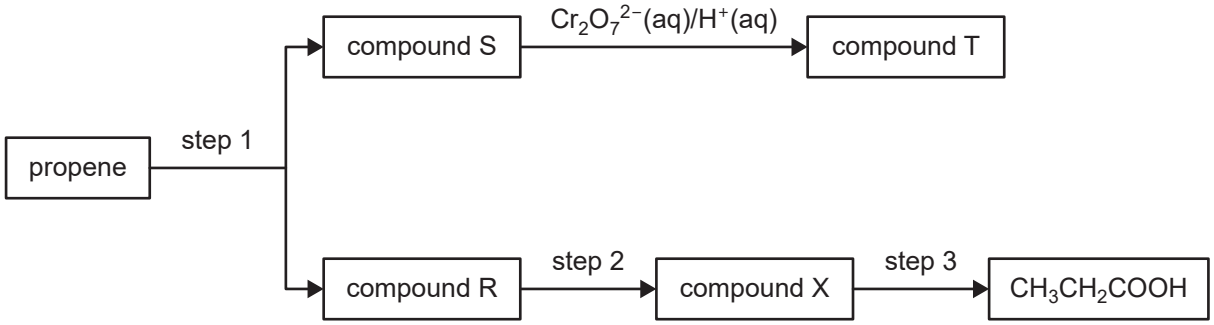
B. water present in the conical flask.

C. the appearance of a green colour at the end point.

D. using non-concordant titre values in the calculation.

Use the following information to answer Questions 23–25.

One pathway starting with propene is shown below. CH_3CH_2COOH is the desired product for this pathway and compound T is a usable by-product.



Question 23

Which one of the following statements is correct?

A. Compounds X and T have the same boiling point.

B. Compound S has a lower boiling point than compound R.

C. Step 1 is a substitution reaction.

D. Step 3 is an addition reaction.

Question 24

A semi-structural formula for compound T is

A. $CH_3C(OH)CH_2$

B. CH_3COCH_3

C. CH_3CH_2COH

D. CH_3CH_2COOH

Question 25

Compounds X and T have the same molecular formula.

Consider the following statements regarding compounds X and T:

I They are part of the same homologous series.

II Both can undergo oxidation.

Which of the statements above is/are correct?

A. I only

B. II only

C. both I and II

D. neither I nor II

Use the following information to answer Questions 26 and 27.

A pharmaceutical company replaces a commonly used organic solvent with a new solvent that is less toxic to workers and degrades safely when released into the environment. However, the new solvent requires slightly higher energy input during production.

Question 26

Which one of the following green chemistry principles is **most** represented in this example?

A. prevention of waste

B. designing safer chemicals

C. renewable feedstocks

D. atom economy

Question 27

Which one of the following statements would be considered scientific evidence to support the claim that the new solvent is 'more green' than the original?

A. Energy requirements in manufacturing the new solvent increased by 10% annually.

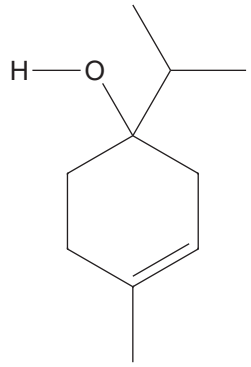
B. Workers commented that there were less fumes when they used the new solvent.

C. Degradation products were analysed by an external laboratory and found to be harmless.

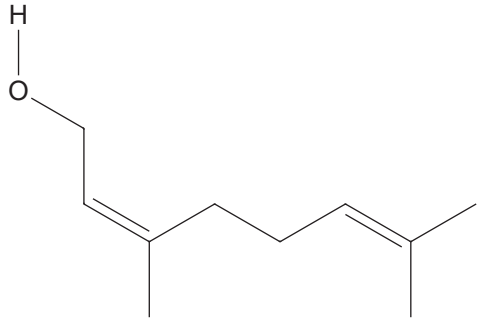
D. The company advertised that the new solvent is 20% greener than the original solvent.

Question 28

The skeletal structures of two active ingredients found in tea-tree oil are shown below.



terpinen-4-ol



nerol

A teacher sets up a challenge requiring her students to determine which of the two compounds is in an unlabelled bottle.

Which one of the following testing combinations would indicate that the sample is terpinen-4-ol?

	Test 1 and observations	Test 2 and observations
A.	addition of $Br_2(aq)$ no colour change	addition of $KMnO_4/H^+$ purple colour fades to pale pink
B.	addition of $Br_2(aq)$ reddish-brown colour disappears	addition of $KMnO_4/H^+$ purple colour stays
C.	addition of $Br_2(aq)$ no colour change	addition of $KMnO_4/H^+$ purple colour stays
D.	addition of $Br_2(aq)$ reddish-brown colour disappears	addition of $KMnO_4/H^+$ purple colour fades to pale pink

Question 29

A medicine has three amino acids in the following order.

–Lys–Gln–Ser–

Which one of the following correctly states the functional group present in the R group for each amino acid?

	Lys	Gln	Ser
A.	amino	amide	hydroxyl
B.	amine	carboxyl	alcohol
C.	amino	carboxyl	hydroxyl
D.	amine	amide	alcohol

Question 30

A student writes the following hypothesis for an investigation: 'The rate of the reaction will increase as the temperature increases.'

Which one of the following observations would best support this hypothesis?

A. A greater volume of gas was observed when a larger mass of reactant was used.

B. As the temperature increased from 25 °C to 50 °C, the colour in a gas equilibrium darkened.

C. The colour change of the indicator was observed at a lower titre when the conical flask was at 25 °C compared to 50 °C.

D. At 50 °C there was no further change to the volume of gas produced after 30 minutes, whereas at 25 °C the volume of gas was still increasing.

End of Section A

N
H
T

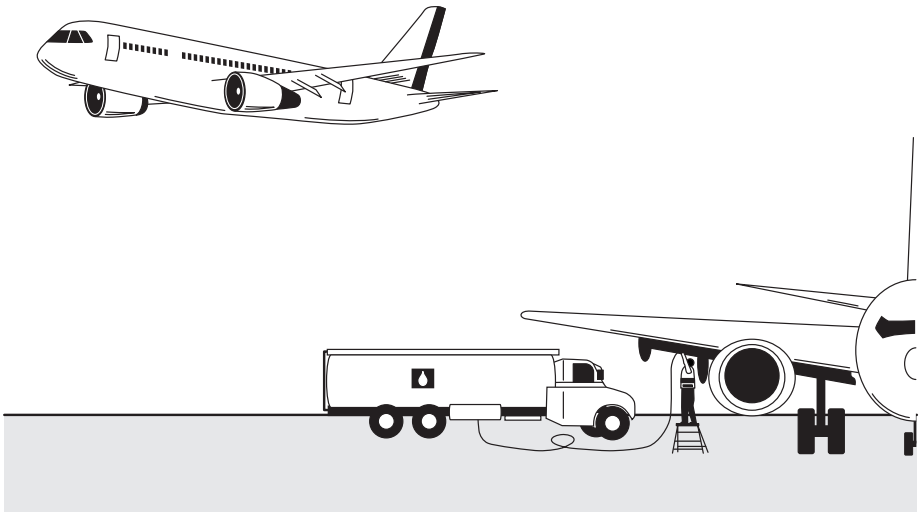
Section B

Instructions

- Answer **all** questions in the spaces provided.
- Write your responses in English.
- Give simplified answers to all numerical questions, with an appropriate number of significant figures; unsimplified answers will not be given full marks.
- Show all working in your answers to numerical questions; no marks will be given for an incorrect answer unless it is accompanied by details of the working.
- Ensure that chemical equations are balanced and that the formulas for individual substances include an indication of state, for example, $H_2(g)$, NaCl(s).
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1 (14 marks)

Traditional aviation jet fuel is a mixture of hydrocarbons distilled from crude oil with a range of 9 to 16 carbons in the chain.



One of the minor components found in aviation jet fuel is a straight-chain hydrocarbon called tridec-1-ene, $C_{13}H_{26}$ (M = 182 g mol^{-1}).

$C_{13}H_{26}$(l) undergoes complete combustion to release 8217 kJ mol^{-1} of energy.

a. Write the thermochemical equation for the complete combustion reaction at standard laboratory conditions (SLC). 2 marks

b. A jet engine operating at 650 °C completely combusts 6.04 mol of $C_{13}H_{26}$ every hour.

Calculate the total mass, in kilograms, of **all** greenhouse gases produced by this engine in one hour. 3 marks

c. Iodine, I_2, reacts with $C_{13}H_{26}$.

i. State the degree of unsaturation of the hydrocarbon $C_{13}H_{26}$. 1 mark

Do not write in this area.

ii. Determine the mass of I_2, in kilograms, that will react completely with 1.0 kg of $C_{13}H_{26}$. 2 marks

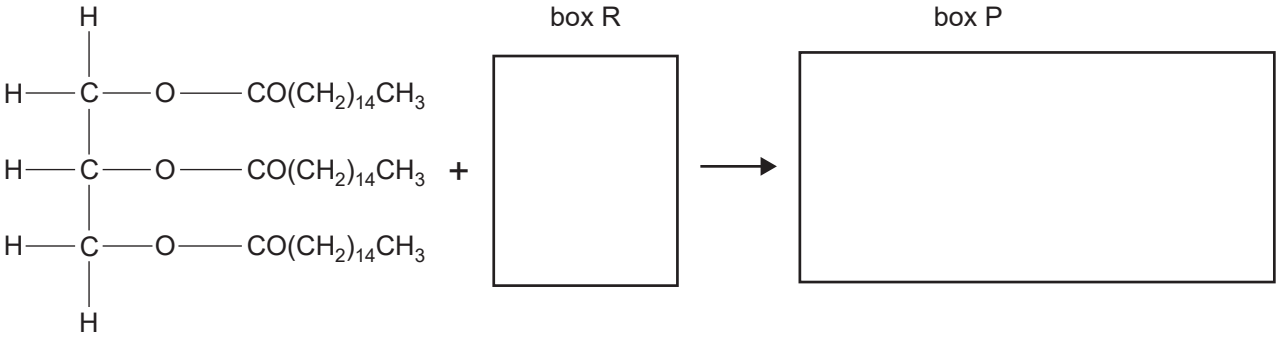
The aviation industry contributes 2.5% of global CO_2 emissions. Sustainable aviation fuel (SAF) has the potential to help the industry reach net zero by 2050.

SAF can be made via different processes depending upon the feed material used. Food crops, waste oils and agricultural waste are all potential feed materials.

References: H Ritchie, 'What share of global CO_2 emissions come from aviation?', *Our World in Data* <ourworldindata.org/global-aviation-emissions> and Oskar Meijerink, 'Technology basics', *SkyNRG* <skynrg.com/sustainable-aviation-fuel/technology-basics>

d. Explain why SAFs are considered renewable, while traditional aviation fuels are not. 2 marks

e. One SAF manufacturing process can use plant triglycerides to make fatty acid methyl esters, which are then used as biodiesel. The reaction pathway is outlined below.



i. In box R, draw the structural formula of the other reactant. Include the correct stoichiometric ratio. 1 mark

ii. In box P, identify all products. 2 marks

iii. State why this reaction can be described as a transesterification reaction. 1 mark

Question 2 (13 marks)

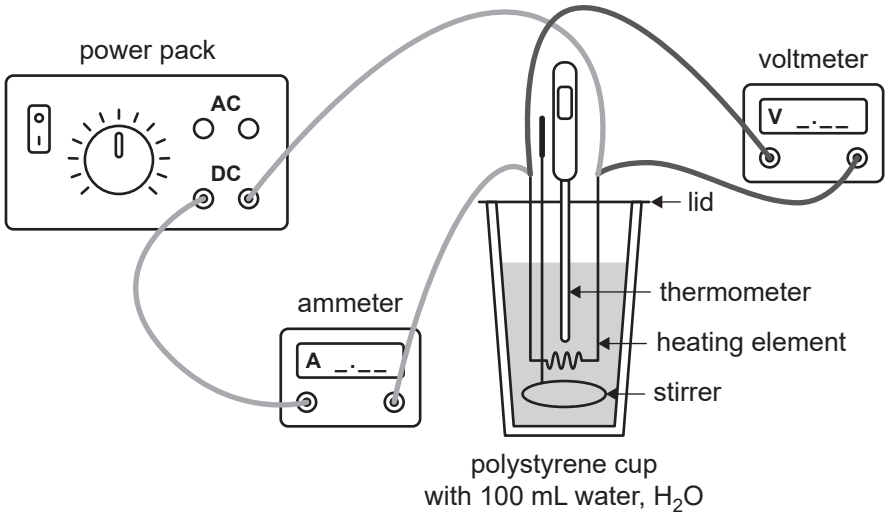
A company produces pellets of sodium hydroxide, NaOH, using waste from a nearby desalination plant. The waste would otherwise be released into the ocean.

The company claims that the pellets are at least 90.0% pure NaOH. The impurities are water and salts from the desalination process. NaOH readily absorbs water from the atmosphere.

a. Identify **one** way in which the production of the pellets aligns with the principles of a circular economy. 1 mark

A student, Saleem, tested the claim of 90.0% purity of the pellets using solution calorimetry. The reaction he used was the neutralisation of NaOH with hydrochloric acid, HCl.

He first calibrated a polystyrene cup, as shown below.



Saleem recorded the following results for the calibration.

Voltage	6.0 V
Current	2.0 A
Time	3.0 min
Mass of water	100 g
Temperature change	5.7 °C

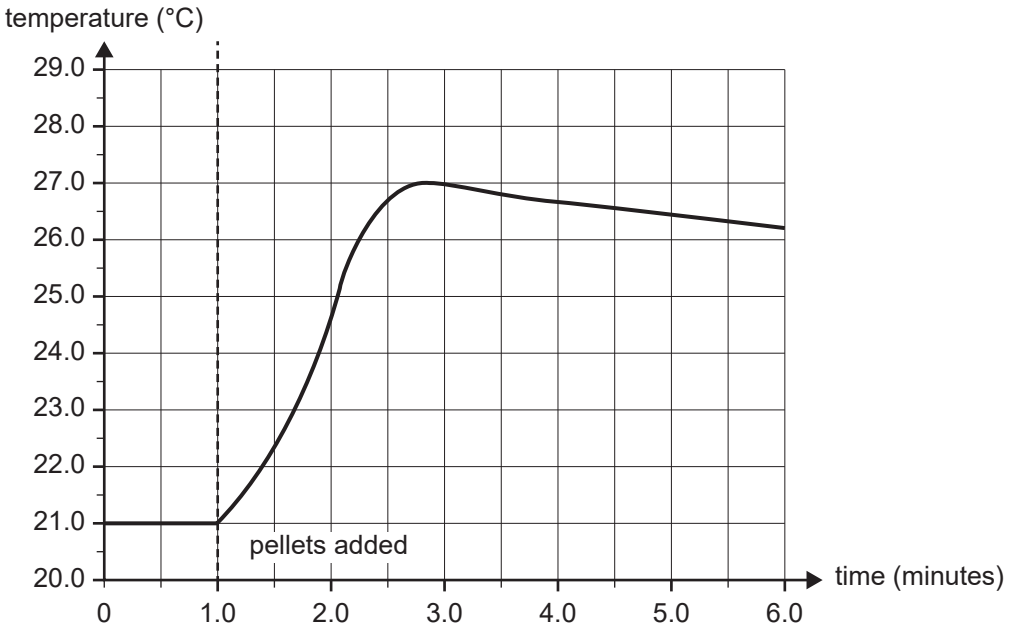
Do not write in this area.

b. Using the results on page 20, calculate the electrical calibration factor (CF). 2 marks

To conduct his experiment, Saleem used the following procedure:

- Weigh out 2.40 g of the pellets on a watch glass.
- Add 100 mL of 1.00 M HCl(aq) to the empty polystyrene cup.
- Start recording the temperature of the solution.
- Add the pellets to the polystyrene cup.
- Place the lid on the polystyrene cup.
- Stir continuously and record the temperature for 5.0 minutes.

The temperature profile graph for the experiment is shown below.



c. Calculate the amount of energy released by the pellets in this experiment, in kJ g^{-1}. 3 marks

Question 2 continues on the next page.

d. The reaction occurring in the calorimeter is provided below.

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) \qquad \Delta H = -57.3 \text{ kJ mol}^{-1}$$

i. Convert the theoretical amount of energy released in the reaction above from kJ mol^{-1} to kJ g^{-1} for NaOH. 1 mark

ii. The percentage (%) purity of the NaOH pellets can be estimated from the amount of energy released.

Evaluate the company's % purity claim for the pellets using the formula below. 2 marks

$$\% \text{ purity} = \frac{\text{actual energy released}}{\text{theoretical energy released}} \times 100$$

e. Saleem repeated the experiment a second time and calculated the % purity of the pellets to be 80.1%. He reflected on his method.

State two reasons related to his experimental procedure that resulted in the calculated purity being lower than the stated value of 90.0%. Justify each response. 4 marks

Reason 1

Justification 1

Reason 2

Justification 2

Question 3 (6 marks)

The Haber process for the synthesis of ammonia gas, NH_3, is considered one of the most important chemical processes of the last 120 years. The process currently releases about 1.8% of global carbon dioxide, CO_2, emissions. It typically uses an iron-based catalyst and runs under high pressures and high temperatures. The relevant reaction is provided below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

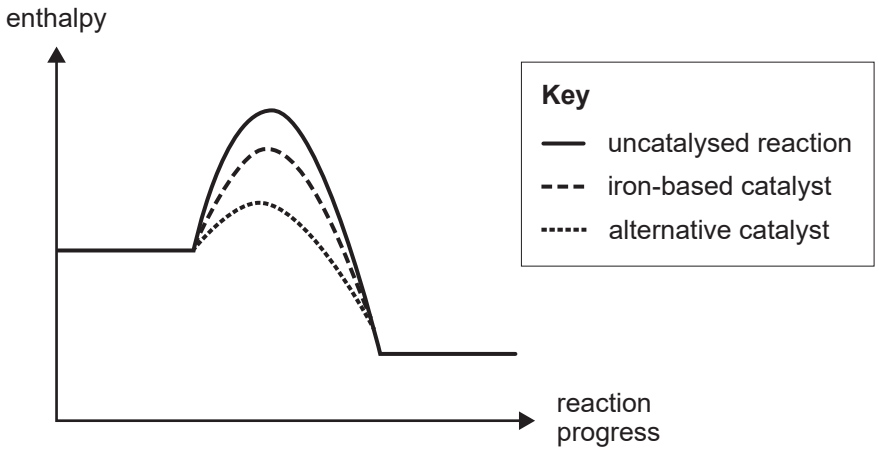
a. During the synthesis reaction, the operating temperature is maintained at about 450 °C.

Explain how this temperature addresses the conflict between rate and yield. 2 marks

b. What effect will a catalyst have on the rate and the yield of the reaction above at a constant temperature? Circle **one** response for the rate and **one** response for the yield. 2 marks

- Rate of reaction increase / decrease / no change
- Yield of reaction increase / decrease / no change

c. Alternative catalysts have been trialled to replace iron-based ones in the Haber process to uphold the green chemistry principle of catalysis. A comparison of the energy profiles for the different catalysts is shown below.



One advantage of using alternative catalysts is that the operating temperature can be lowered to 300 °C.

Explain why this is desirable. 2 marks

Question 4 (12 marks)

Hydrogen is needed as a reactant for the production of many important chemicals. One method for producing hydrogen, $H_2(g)$, is to react methane, $CH_4(g)$, with high-temperature steam, $H_2O(g)$, at high pressures.

a. The reaction for step 1 of this method is shown below.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +251 \text{ kJ mol}^{-1}$$

i. Write the equilibrium expression for this reaction. 1 mark

ii. A 5.0 L vessel containing 0.15 mol of CH_4, 0.33 mol of H_2O, 0.30 mol of carbon monoxide, CO, and 0.10 mol of H_2 was found to be at equilibrium.

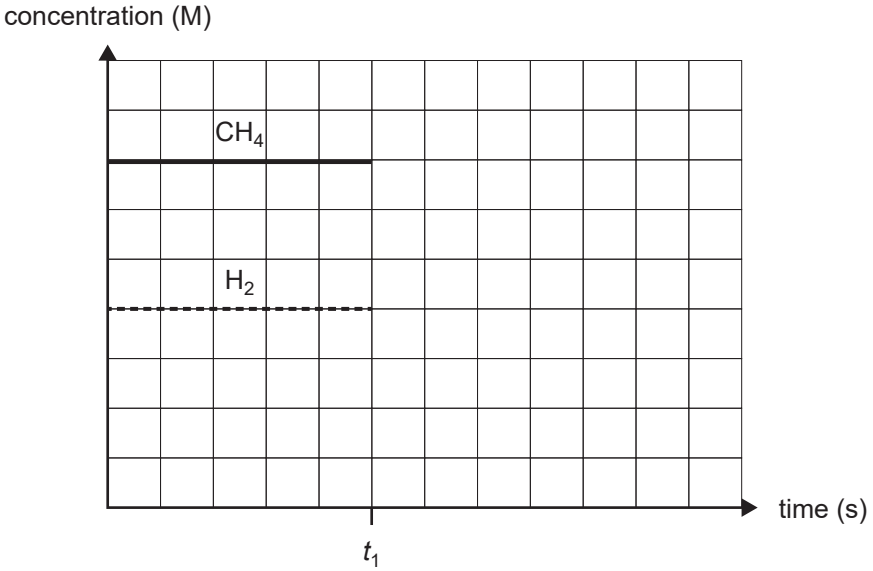
Calculate K. 2 marks

iii. During step 1, the concentrations of CH_4 and H_2 are monitored.

The initial temperature of the mixture was 700 °C.

The concentration–time graph is shown below. At t_1 the temperature increased to 900 °C.

Complete the graph below to show how the concentrations of CH_4 and H_2 change as the system reaches equilibrium. 2 marks



Do not write in this area.

b. Step 2 of the process occurs when the CO produced in step 1 reacts with H_2O, as shown in the reaction below.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H = -41.2 \text{ kJ mol}^{-1}$$

Explain why a high pressure is used in step 2 of the process. 2 marks

c. The combined equation for both step 1 and step 2 in **parts a** and **b** that produces H_2 is shown below.

$$CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g) \qquad \Delta H = +209.8 \text{ kJ mol}^{-1}$$

The process runs at a constant temperature of 900 °C.

i. Use Le Châtelier's principle to explain how the yield of H_2 would be affected by adding excess $H_2O(g)$. 2 marks

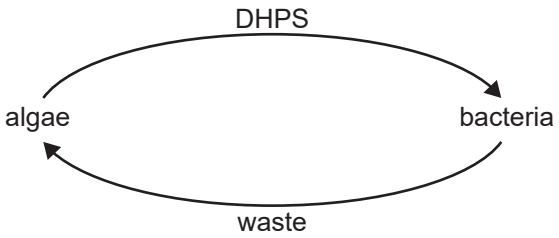
ii. The atom economy for the process is 15% and the percentage yield is 70%.

Suggest **two** reasons why this reaction could be considered an unsustainable method of producing H_2. Outline **one** change that could improve sustainability. 3 marks

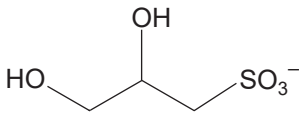
Question 5 (8 marks)

In 2025, South Australia experienced a harmful algal bloom along its coast. Algae produce toxins hazardous to marine life and can cause health issues.

Algae produce dihydroxypropane sulfonate (DHPS). Marine bacteria use DHPS as an energy source and the by-products of the metabolism are used by the algae.



a. Identify the chiral centre(s) on the DHPS molecule below using an asterisk(s). 1 mark

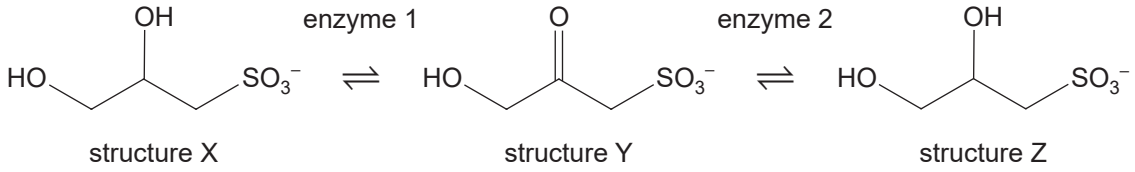


To develop strategies to reduce the algal blooms, Fred, a researcher, investigated the pathway used by the bacteria to break down DHPS. The pathway is as follows:

- Structure X is converted to structure Y in the presence of enzyme 1.
- Structure Y is converted to structure Z in the presence of enzyme 2.

Structure Z is not able to be used by the algae.

DHPS reaction pathway



structure X structure Y structure Z

b. State the new functional group in structure Y formed from structure X. 1 mark

c. When trying to isolate structures X and Z, Fred needs to ensure that the isolated compound is pure and not a mixture.

Explain why a melting point determination would **not** distinguish between pure samples of structures X and Z. 2 marks

d. The DHPS reaction pathway shown on page 26 requires a protein-based enzyme. Fred found that the amino acid alanine, Ala, is part of the enzyme.

i. Draw the expected structure of Ala in a neutral aqueous solution. 1 mark

ii. The enzyme also contains the amino acid arginine, Arg. Both the Ala and Arg residues interact with DHPS in an aqueous solution.

Discuss why the Arg residue has a stronger interaction with DHPS than the Ala residue. 2 marks

e. Fred is examining ways to reduce the size of the algal bloom by stopping the enzyme from functioning in the pathway.

What could disrupt the functioning of an enzyme? 1 mark

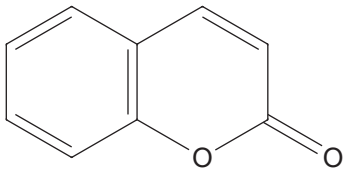
Question 6 (12 marks)

Cinnamon is a spice commonly used around the world in cooking as well as in traditional and herbal medicine. It is made from the dried inner bark of the cinnamon tree. There are two common species of cinnamon tree.

The inner bark of the tree contains many natural plant compounds such as coumarin and another compound, compound Q.

Source: Britannica Editors, 'Cassia', *Encyclopaedia Britannica* <britannica.com/plant/cinnamon>

The structure of coumarin is shown below.



coumarin, $C_9H_6O_2$

Compound Q is being investigated as the starting material for the synthesis of potential medicines.

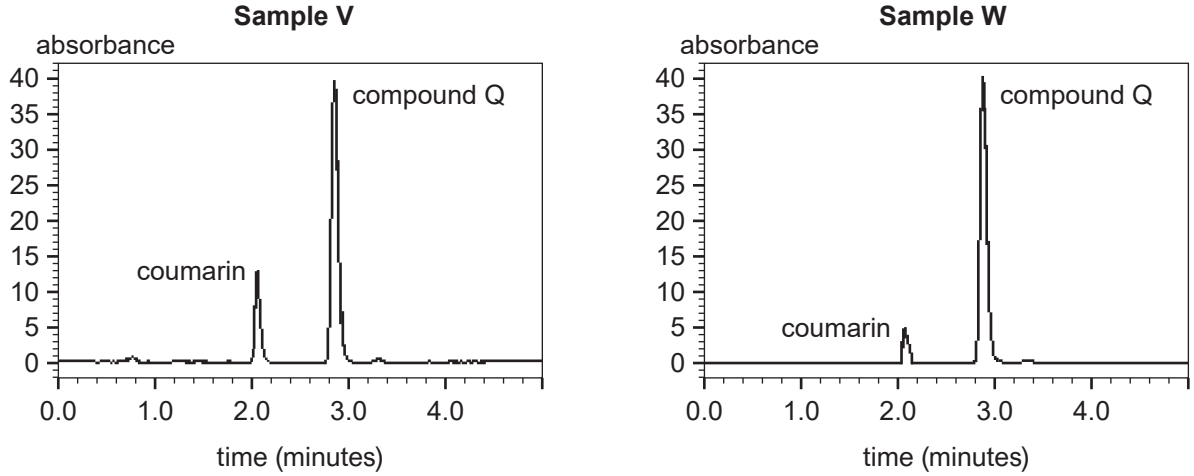
a. Name **one** method that can be used to extract these natural plant compounds from the bark. 1 mark

_____

As coumarin may have adverse health effects if consumed at high levels, it is important to know the concentrations of coumarin and compound Q present in bark samples.

Samples of bark from the two species of cinnamon tree (V and W) were tested, and the concentrations of both coumarin and compound Q were measured under the same conditions using high performance liquid chromatography (HPLC).

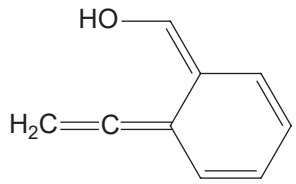
The chromatograms of the two samples are shown below.



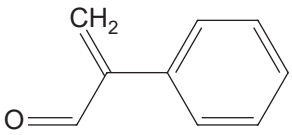
Source: Adapted from GJ Schad and N Iwata, 'High performance liquid chromatography analysis of cinnamon from different origin', *LCGC International*, vol. 18, no. 12, 6 December 2022, pp. 18–21

b. Using the HPLC chromatograms above, compare the relative amount of coumarin in samples V and W. Justify your response. 2 marks

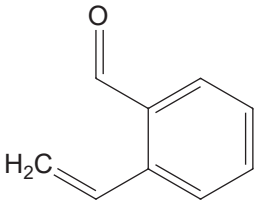
Compound Q has a molecular formula of C_9H_8O. Six possible representations are shown below.



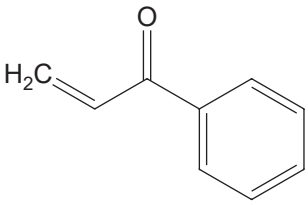
structure 1



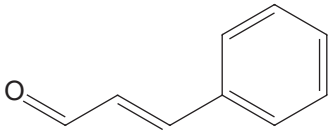
structure 2



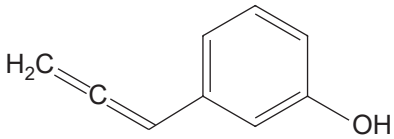
structure 3



structure 4

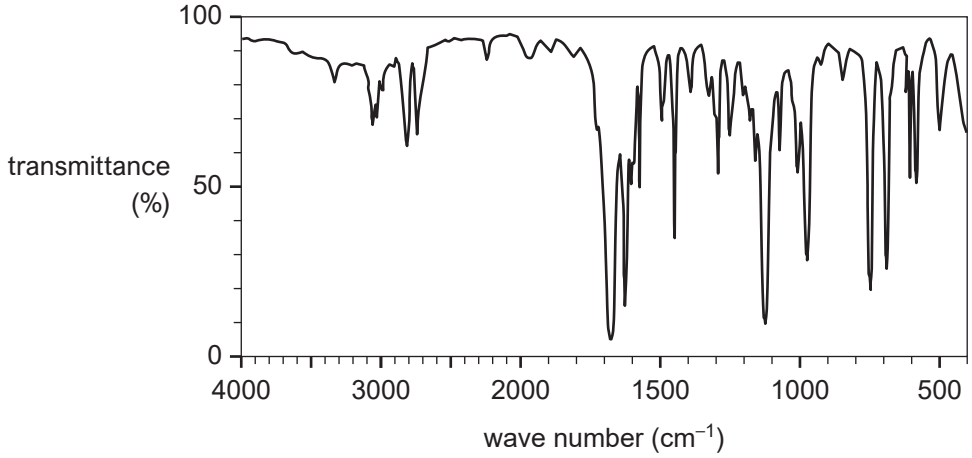


structure 5



structure 6

The infrared (IR) spectrum of compound Q, C_9H_8O, is shown below.

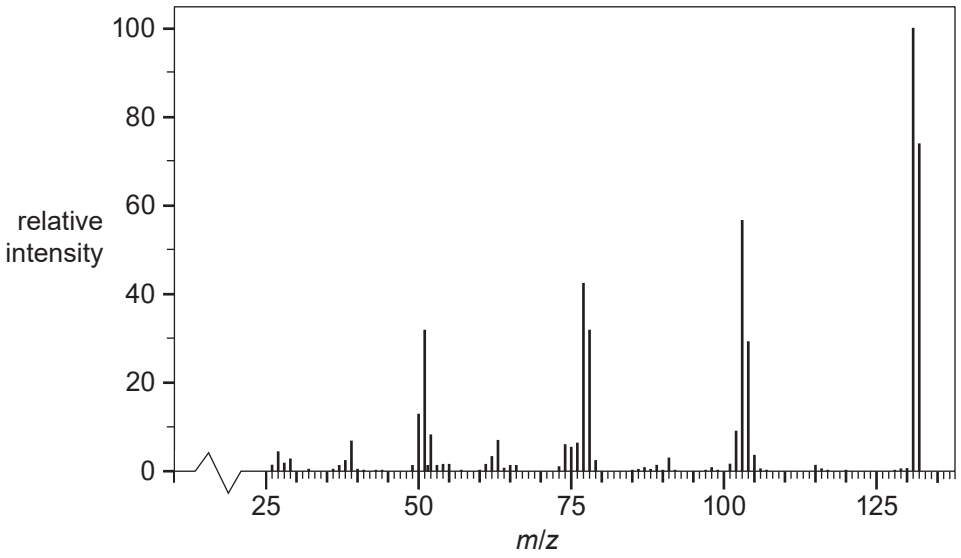


Source: *Chemical Book* <chemicalbook.com>

c. Select the **two** structures from structures 1–6 that can be excluded using the information from the IR spectrum. Justify your selections. 2 marks

Do not write in this area.

d. The mass spectrum of compound Q, C_9H_8O, is shown below.



Source: Adapted from *NIST Chemistry WebBook* <webbook.nist.gov>

i. State the *m*/*z* value of the molecular ion peak. 1 mark

ii. Suggest what fragment has been lost from compound Q to form the peak at *m*/*z* = 77. 1 mark

Question 6 continues on the next page.

e. The information from the low-resolution ^{1}H NMR spectrum for compound Q, C_9H_8O, is shown below.

Chemical shift (ppm)	Integration curve
6.6	1
7.5–7.6	5
7.7	1
9.7	1

Source: *Chemical Book* <chemicalbook.com>

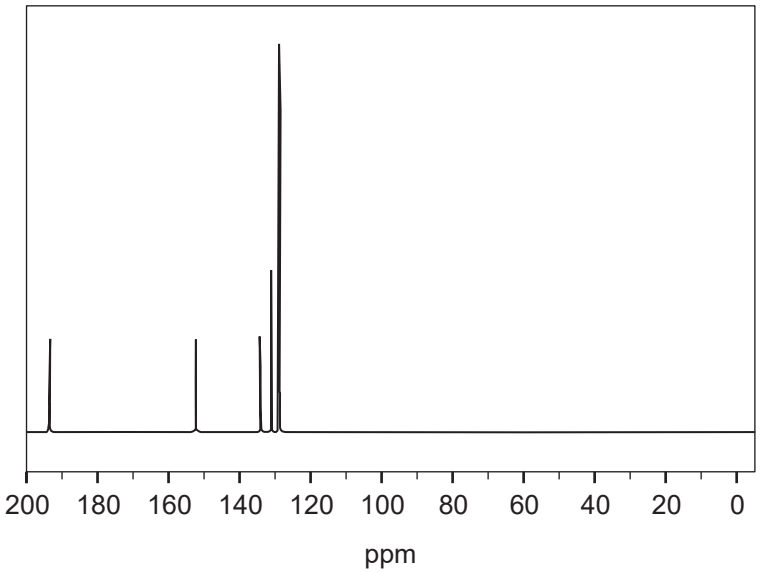
i. What do the integration curve values of 1, 5, 1 and 1 indicate about the number of H atoms in each environment? 1 mark

ii. Identify the type of proton that could be responsible for the peaks at 7.5–7.6 ppm in the low-resolution ^{1}H NMR spectrum. 1 mark

iii. The high-resolution ^{1}H NMR spectrum shows that the peak at 9.7 ppm is a doublet.

What information does this provide about the structure of the molecule? 1 mark

The ^{13}C NMR spectrum of compound Q, C_9H_8O, is shown below. Some signals are so close in their chemical shifts that they overlap.



Source: *Chemical Book* <chemicalbook.com>

f. The ^{13}C NMR spectrum above shows a single peak around 190 ppm.

Name the class of compound responsible for the peak. Reference **item 19** in the Data Book. 1 mark

g. Use the information in **parts c–f** to identify which one of the structures from structures 1–6 on page 30 is compound Q, C_9H_8O. 1 mark

Question 7 (16 marks)

Compounds containing hydrogen, such as solid metal hydrides, are safe sources for generating hydrogen gas, $H_2(g)$, for use in fuel cells. There are various methods of extracting $H_2(g)$ from metal hydrides. One easy and safe method is to react the metal hydride with ethanoic acid, $CH_3COOH(aq)$, to determine if the yield is suitable.

Amy, a VCE Chemistry student, was interested in the production of $H_2(g)$ when solid magnesium hydride, $MgH_2(s)$, reacted with $CH_3COOH(aq)$ according to the equation below.

$$2MgH_2(s) + 2H_2O(l) + 2CH_3COOH(aq) \rightarrow Mg(OH)_2(s) + Mg(CH_3COO)_2(aq) + 4H_2(g)$$

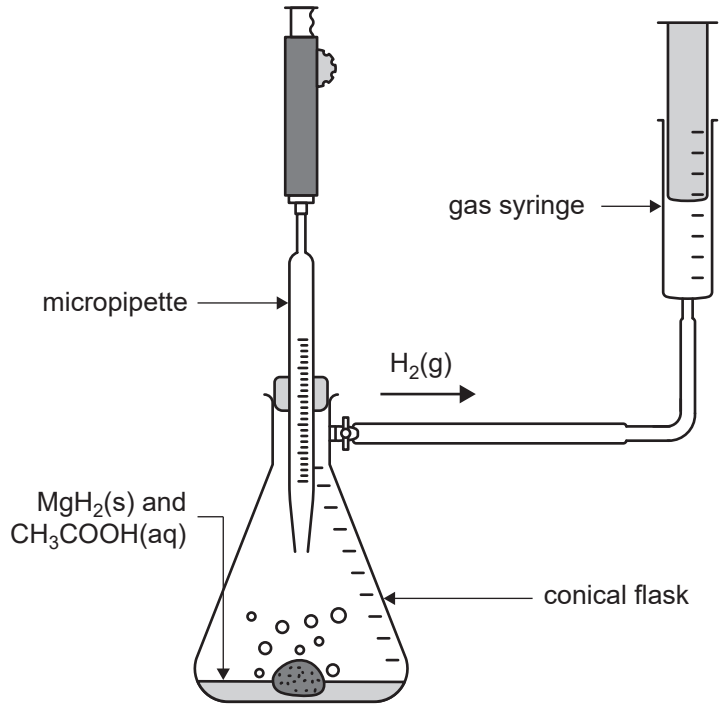
a. Using the equation above, calculate the maximum theoretical amount of $H_2(g)$, in mol, produced from 150 mg of $MgH_2(s)$ (M = 26.3 g mol^{-1}). 1 mark

Amy conducted an experimental investigation to compare the accuracy of two different methods of measuring the $H_2(g)$ produced in this reaction. These methods are outlined below:

- Method A – Use a gas syringe to directly measure the volume of $H_2(g)$ produced.
- Method B – Use operating data from a fuel cell to determine the amount of $H_2(g)$ produced.

Method A

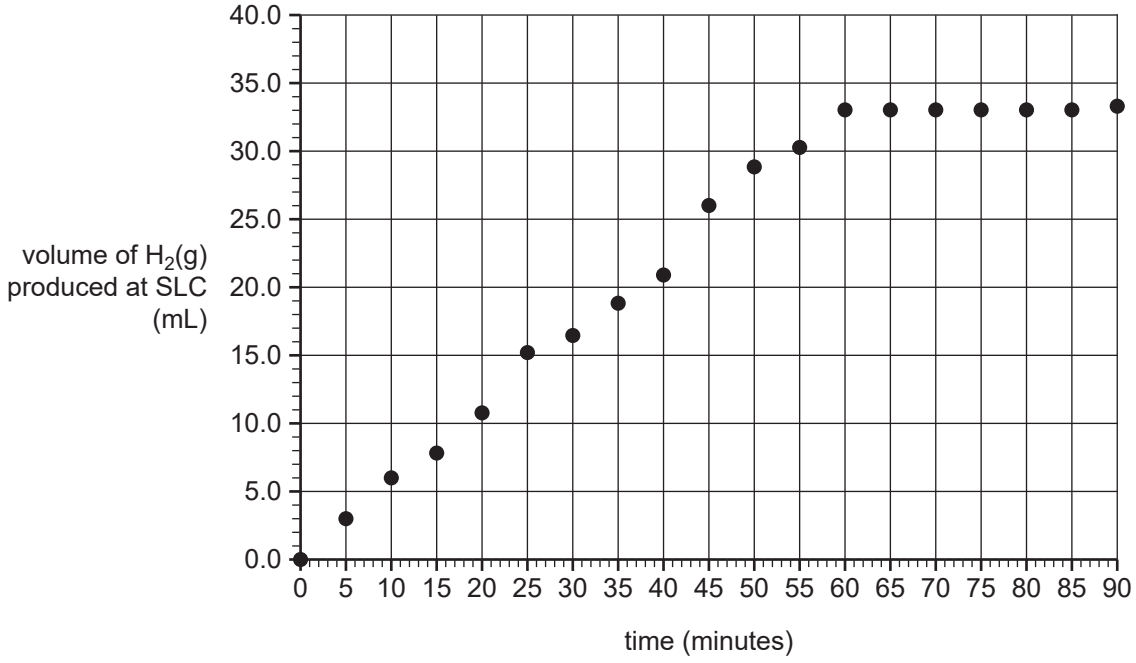
1. Add 150 mg of $MgH_2(s)$ powder to a conical flask connected to a 300 mL gas syringe.
2. Pipette 10.0 mL of 2.00 M $CH_3COOH(aq)$ solution into the flask.
3. Record the volume of gas in the syringe every 5 minutes for 90 minutes.



Source: Adapted from A Bailey et al., 'Hydrogen storage experiments for an undergraduate laboratory course – clean energy: hydrogen/fuel cells', *Journal of Chemical Education*, vol. 92, no. 4, 2015, pp. 688–692

b. Provide **one** safety reason for using a very small amount of $MgH_2(s)$ in Method A. 1 mark

The graph below shows the data produced using Method A.



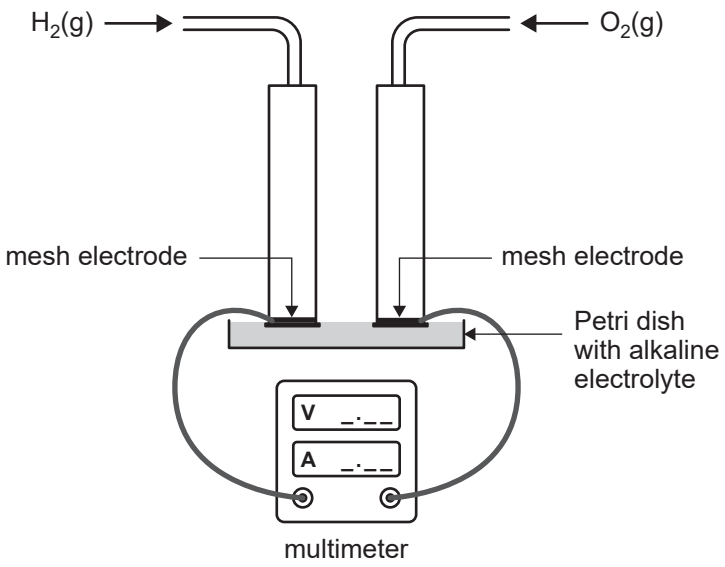
c. Use the data in the graph above to calculate the amount, in mol, of $H_2(g)$ produced over 90 minutes using Method A. 2 marks

d. Using your responses to **parts a** and **c**, and **item 2** of the Data Book, calculate the percentage yield of $H_2(g)$ produced using Method A. 1 mark

Question 7 continues on the next page.

Construction of fuel cell for Method B

An alternative method to estimate the amount of $H_2(g)$ produced is to use a fuel cell. Amy constructed and tested a simple alkaline hydrogen–oxygen fuel cell. A simplified diagram of Amy's fuel cell is shown below.



Source: Adapted from G Lisensky et al., 'Inexpensive alkaline fuel cell for introductory chemistry classes', *Journal of Chemical Education*, vol. 98, no. 7, 2021, pp. 2387–2391

e. To establish the operating conditions for the fuel cell, Amy ran some trials. She measured the voltage and current output of the fuel cell under various electrolyte concentrations.

The following results were obtained.

Electrolyte concentration (M)	0.10	1.0	5.0
Average voltage output (V)	0.79	0.81	0.80
Average current generated (A)	0.014	0.014	0.014

i. Identify **two** factors that could affect the current generated. Do **not** refer to concentration and voltage. Suggest how Amy could control **one** of the identified factors.

3 marks

ii. Amy decided to use the 0.10 M electrolyte solution rather than 1.0 M or 5.0 M.

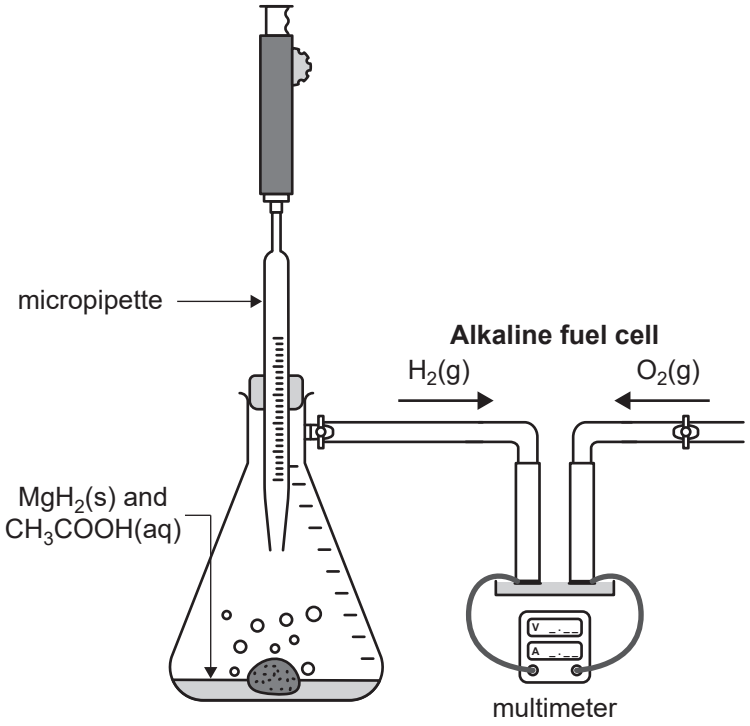
Justify her decision. 2 marks

Question 7 continues on the next page.

After Amy constructed the fuel cell, she used it in Method B, shown below, to determine the amount of $H_2(g)$ produced from $MgH_2(s)$.

Method B

1. Connect the multimeter to the fuel cell constructed earlier and turn on the $O_2(g)$ supply.
2. Add 150 mg of $MgH_2(s)$ powder to a conical flask connected to the fuel cell.
3. Pipette 10.0 mL of 2.00 M $CH_3COOH(aq)$ solution into the flask.
4. Record the voltage and current generated by the fuel cell every 10 minutes for 90 minutes.



Source: Adapted from A Bailey et al., 'Hydrogen storage experiments for an undergraduate laboratory course – clean energy: hydrogen/fuel cells', *Journal of Chemical Education*, vol. 92, no. 4, 2015, pp. 688–692

Using Method B, Amy recorded the following data.

Time (minutes)	0	10	20	30	40	50	60	70	80	90
Voltage (V)	0	0.69	0.70	0.71	0.70	0.70	0.71	0.71	0.70	0.70
Current (A)	0	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014

f. Use the data provided above, and **item 1** and **item 2** in the Data Book, to calculate the quantity, in mol, of $H_2(g)$ consumed by the alkaline fuel cell over 90 minutes using Method B. 3 marks

g. Amy repeated the experiment and calculated the amount of $H_2(g)$ produced by both methods. She discovered that the amount produced by one method was significantly higher than the amount produced by the other method.

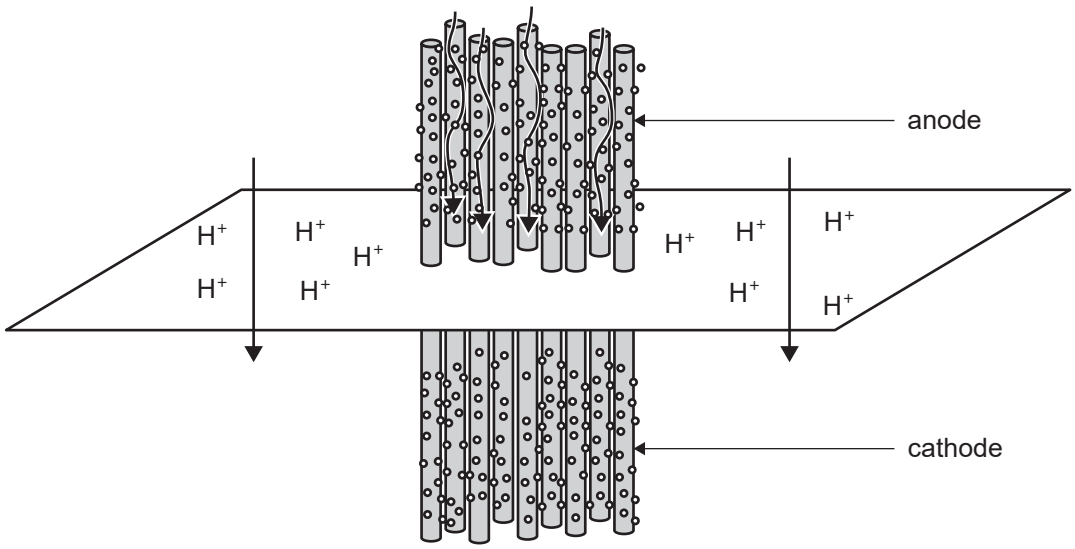
i. State **one** key assumption that enables a direct comparison of the amount of $H_2(g)$ produced by each method. 1 mark

ii. The aim of this investigation was to determine which method was more accurate at measuring the amount of $H_2(g)$ produced from $MgH_2(s)$.

Suggest which method – Method A or Method B – would provide more accurate results. Justify your response with reference to the experimental design of Method A and Method B. 2 marks

Question 8 (9 marks)

a. Artificial photosynthesis is a new approach being considered for the production of hydrogen, $H_2(g)$. A diagram of the process is shown below.



Source: Adapted from RS Poudyal et al., 'Hydrogen production using photobiological methods', *Compendium of Hydrogen Energy*, eds V Subramani et al., Woodhead Publishing, Cambridge, 2015, pp. 289–317; with permission from Elsevier

Demonstrate your knowledge of this process by explaining how $H_2(g)$ is produced.

In your response, include the reactions occurring at each electrode and the operating principles needed to produce H_2. 4 marks

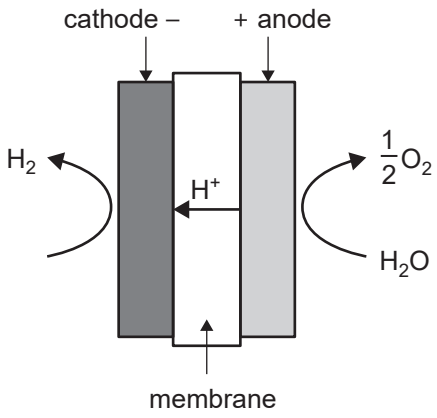
b. The established technology of proton exchange membrane (PEM) electrolysis and the newer microbial electrolysis cell (MEC) technology both produce H_2.

The features of PEM electrolysis and MEC technology are provided in the table below.

Feature	PEM electrolysis	MEC technology
applied voltage (V)	1.4–2.0	0.2 (approximately)
feedstock	high-purity water	biomass and waste biomass
anode material	platinum, Pt, or iridium, Ir	graphite coated with electron-transferring bacteria
products	H_2 and O_2	H_2 and other by-products depending on the feedstock

Diagrams and reaction equations for the two processes are shown below.

PEM electrolysis

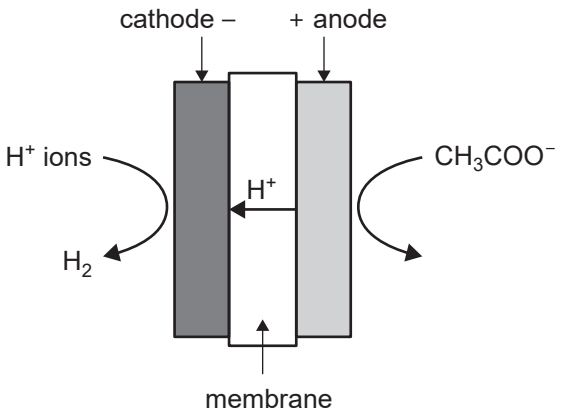


anode $H_2O \rightarrow 2H^+ + \frac{1}{2}O_2 + 2e^-$

cathode $2H^+ + 2e^- \rightarrow H_2$

overall cell $H_2O \rightarrow H_2 + \frac{1}{2}O_2$

MEC technology



anode $CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + 9H^+ + 8e^-$

cathode $8H^+ + 8e^- \rightarrow 4H_2$

overall cell $CH_3OO^- + 4H_2O \rightarrow 2HCO_3^- + H^+ + 4H_2$

Source: SS Kumar and V Himabindu, 'Hydrogen production by PEM water electrolysis: a review', *Materials Science for Energy Technologies*, vol. 2, no. 3, 2019, pp. 442–454

Using the information provided above, evaluate PEM electrolysis and MEC technology in terms of:

- feedstocks used
- relevant advantages of each technology.

Use your evaluation to recommend one of these methods for the sustainable production of green hydrogen. 5 marks

Question 8 continues on the next page.

End of examination questions

End of examination. There are no more questions.

2026

NHT

Chemistry

2026 Data Book

Contents pages

You may keep this Data Book.

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

VICTORIA State Government

1. Electrochemical series

Reaction	Standard electrode potential (E^0) in volts at 25 °C
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$PbO_2(s) + 4H^+(aq) + 2e^- \rightleftharpoons Pb^{2+}(aq) + 2H_2O(l)$	+1.47
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.36
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	−0.28
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	−1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	−1.66
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	−2.37
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	−2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	−2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	−2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	−3.04

2. Chemical relationships

Name	Formula
amount of substance (number of moles)	$n = \frac{m}{M}; \quad n = cV; \quad n = \frac{V}{V_m}$
universal gas equation	$pV = nRT$
chemical calibration factor (CF) for calorimetry	$\text{CF} = \frac{E}{\Delta T}$
electrical calibration factor (CF)	$\text{CF} = \frac{VIt}{\Delta T}$
thermal energy transferred	$q = mc\Delta T$
molar enthalpy change	$\Delta H = \frac{q}{n}$
electric charge	$Q = It$
amount of electrons (number of moles)	$n(e^-) = \frac{Q}{F}$
% atom economy	$\frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times \frac{100}{1}$
% yield	$\frac{\text{actual yield}}{\text{theoretical yield}} \times \frac{100}{1}$
equilibrium constant	$K = \frac{[\text{C}]^c \times [\text{D}]^d \times \ldots}{[\text{A}]^a \times [\text{B}]^b \times \ldots}$ for the equation $a\text{A} + b\text{B} + \ldots \rightleftharpoons c\text{C} + d\text{D} + \ldots$

3. Physical constants and standard values

Name	Symbol	Value
Avogadro constant	N_A or L	6.02×10^{23} mol^{-1}
Faraday constant	F	96 500 C mol^{-1}
molar gas constant	R	8.31 J mol^{-1} K^{-1}
molar volume of an ideal gas at SLC (25 °C and 100 kPa)	V_m	24.8 L mol^{-1}
specific heat capacity of water	c	4.18 kJ kg^{-1} K^{-1} or 4.18 J g^{-1} K^{-1}
density of water at 25 °C	d	1.0 g mL^{-1}
molar latent heat of vaporisation of water at 25 °C	$\Delta H_{vap}(H_2O)$	+44.0 kJ mol^{-1}
molar latent heat of vaporisation of water at 100 °C	$\Delta H_{vap}(H_2O)$	+40.7 kJ mol^{-1}

4. Unit conversions

Measured value	Conversion
0 °C	273 K
100 kPa	0.987 atm
1 litre (L)	1 dm^3 or 1×10^{-3} m^3 or 1×10^3 cm^3 or 1×10^3 mL

5. Metric prefixes

The following prefixes are commonly used within the International System of Units (SI) to modify the base units and express quantities in multiples or fractions of those units.

Prefixes	Scientific notation	Multiplying factor
giga (G)	10^9	1 000 000 000
mega (M)	10^6	1 000 000
kilo (k)	10^3	1000
deci (d)	10^{-1}	0.1
centi (c)	10^{-2}	0.01
milli (m)	10^{-3}	0.001
micro (μ)	10^{-6}	0.000001
nano (n)	10^{-9}	0.000000001
pico (p)	10^{-12}	0.000000000001

6. Acid-base indicators

Name	pH range	Colour change from lower pH to higher pH in range
thymol blue (1st change)	1.2 – 2.8	red → yellow
methyl orange	3.1 – 4.4	red → yellow
bromophenol blue	3.0 – 4.6	yellow → blue
methyl red	4.4 – 6.2	red → yellow
bromothymol blue	6.0 – 7.6	yellow → blue
phenol red	6.8 – 8.4	yellow → red
thymol blue (2nd change)	8.0 – 9.6	yellow → blue
phenolphthalein	8.3 – 10.0	colourless → pink

7. Colours of selected conjugate redox reagents

Redox reagent in oxidised state		Redox reagent in reduced state	
Name/formula	**Colour**	**Name/formula**	**Colour**
bromine, Br_2	brown	bromide ion, Br^-	colourless
chlorine, Cl_2	yellow/green	chloride ion, Cl^-	colourless
copper(II) ion, Cu^{2+}	blue	copper(I) ion, Cu^+	red
dichromate ion, $Cr_2O_7^{2-}$	orange	chromium(III) ion, Cr^{3+}	green
iodine, I_2	brown in aqueous solutions	iodide ion, I^-	colourless
iron(III) ion, Fe^{3+}	yellow/brown	iron(II) ion, Fe^{2+}	pale green
manganese(IV) dioxide, MnO_2	black/brown	manganese(II) ion, Mn^{2+}	very pale pink
permanganate ion, MnO_4^-	intense purple	manganese(II) ion, Mn^{2+}	very pale pink

8. Formulas and charges for selected ions

Cations

1+		2+		3+	
Name	**Formula**	**Name**	**Formula**	**Name**	**Formula**
ammonium	NH_4^+	barium	Ba^{2+}	aluminium	Al^{3+}
copper(I)	Cu^+	calcium	Ca^{2+}	chromium(III)	Cr^{3+}
hydronium	H_3O^+	copper(II)	Cu^{2+}	iron(III)	Fe^{3+}
lithium	Li^+	iron(II)	Fe^{2+}	**4+**	
potassium	K^+	lead(II)	Pb^{2+}	titanium(IV)	Ti^{4+}
silver	Ag^+	magnesium	Mg^{2+}		
sodium	Na^+	mercury(II)	Hg^{2+}		
		nickel(II)	Ni^{2+}		
		tin(II)	Sn^{2+}		
		zinc	Zn^{2+}		

Anions

1−		2−		3−	
Name	**Formula**	**Name**	**Formula**	**Name**	**Formula**
bromide	Br^-	carbonate	CO_3^{2-}	citrate	$C_6H_5O_7^{3-}$
chlorate	ClO_3^-	chromate	CrO_4^{2-}	nitride	N^{3-}
chloride	Cl^-	dichromate	$Cr_2O_7^{2-}$	phosphate	PO_4^{3-}
chlorite	ClO_2^-	monohydrogen phosphate	HPO_4^{2-}		
cyanide	CN^-	oxide	O^{2-}		
dihydrogen phosphate	$H_2PO_4^-$	peroxide	O_2^{2-}		
ethanoate	CH_3COO^-	sulfate	SO_4^{2-}		
fluoride	F^-	sulfide	S^{2-}		
hydrogen carbonate	HCO_3^-	sulfite	SO_3^{2-}		
hydrogen sulfate	HSO_4^-	thiosulfate	$S_2O_3^{2-}$		
hydrogen sulfide	HS^-				
hydrogen sulfite	HSO_3^-				
hydroxide	OH^-				
hypochlorite	ClO^-				
iodide	I^-				
nitrate	NO_3^-				
nitrite	NO_2^-				
perchlorate	ClO_4^-				
permanganate	MnO_4^-				

9. Solubility table

Salts	Soluble	Insoluble
sodium	All	None
potassium		
ammonium		
nitrate		
ethanoate		
bromide, chloride, iodide	Most are soluble.	lead(II), silver, $CuBr_2$, CuI_2
sulfate	Most are soluble.	barium, calcium, lead(II), silver
carbonate	Group 1 ions, ammonium	Most are insoluble.
phosphate	Group 1 ions, ammonium	Most are insoluble.
hydroxide	Group 1 ions, ammonium	Most are insoluble.

10. Average bond enthalpies at 25 °C – single bonds

ΔH (kJ mol^{-1})								
	C	H	O	N	Br	Cl	F	I
C	346	414	358	286	285	324	492	228
H	414	436	463	391	366	431	567	298
O	358	463	144	214	201	206	191	234
N	286	391	214	158		192	278	

11. Average bond enthalpies at 25 °C – multiple bonds

Bond	ΔH (kJ mol^{-1})
C=C	614
C≡C	839
C=N	615
C≡N	890
C=O	804
O=O	498
N=N	470
N≡N	945

12. Energy content of food groups

The energy that is typically available for the body to use as a result of the digestion and absorption of fats and oils, proteins and carbohydrates is shown in the table below. These values may vary based on the specific composition of foods and individual metabolic factors.

Food	Energy content (kJ g^{-1})
fats and oils	37
protein	17
carbohydrate	16

13. Molar enthalpies of combustion

The molar enthalpies of combustion in the following table are calculated at SLC (25 °C and 100 kPa) with combustion products being $CO_2(g)$ and $H_2O(l)$. Enthalpies of combustion, ΔH, for the substances in this table are reported for one mole of fuel and are shown as negative values, indicating the exothermic nature of the combustion reaction.

$$C_2H_6(g) + 3\frac{1}{2}O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l) \qquad \Delta H = -1560 \text{ kJ mol}^{-1}$$

Fuel	Formula	Molar enthalpy of combustion (kJ mol^{-1})
hydrogen	$H_2(g)$	−286
methane	$CH_4(g)$	−890
ethane	$C_2H_6(g)$	−1560
propane	$C_3H_8(g)$	−2220
butane	$C_4H_{10}(g)$	−2880
octane	$C_8H_{18}(l)$	−5470
methanol	$CH_3OH(l)$	−726
ethanol	$C_2H_5OH(l)$	−1370
carbon (graphite)	C(s)	−394
glucose	$C_6H_{12}O_6(s)$	−2840

14. Heats of combustion of selected blended fuels

Blended fuels are mixtures of compounds with different mixture ratios and, hence, determination of a generic molar enthalpy of combustion is not realistic. The values provided in the following table are typical values for heats of combustion at SLC (25 °C and 100 kPa) with combustion products being $CO_2(g)$ and $H_2O(l)$. Values for heats of combustion will vary due to the composition of the different fuels. Additionally, for natural gas, the values may vary based on the source and processing.

Fuel	State	Heat of combustion ($kJ\ g^{-1}$)	Heat of combustion ($kJ\ mL^{-1}$)
diesel	liquid	45	37
kerosene	liquid	46	37
natural gas	gas	54	0.035
petrol	liquid	45	34

15. Heats of combustion of selected biofuels

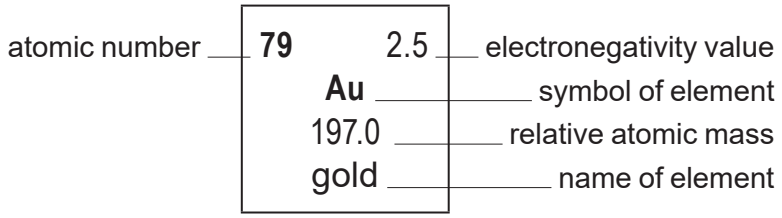
The following table provides typical values for the heat of combustion of selected biofuels. The values may vary significantly, particularly for biogas, depending on the source of the biofuel and, hence, its composition. The amount of energy consumed during any purification process must also be considered when determining the net energy obtained from a biofuel.

Fuel	State	Heat of combustion ($kJ\ g^{-1}$)
biodiesel	liquid	Approx 37
bioethanol	liquid	29.7
biogas	gas	14–24 This depends on its methane content, which can vary from 45% to 75% methane by volume, depending on its source. The other main constituent is CO_2, which does not burn.

16. Periodic table of the elements

1 2.2 **H** 1.0 hydrogen									
3 1.0 **Li** 6.9 lithium	**4** 1.6 **Be** 9.0 beryllium								
11 0.9 **Na** 23.0 sodium	**12** 1.3 **Mg** 24.3 magnesium								
19 0.8 **K** 39.1 potassium	**20** 1.0 **Ca** 40.1 calcium	**21** 1.4 **Sc** 45.0 scandium	**22** 1.5 **Ti** 47.9 titanium	**23** 1.6 **V** 50.9 vanadium	**24** 1.7 **Cr** 52.0 chromium	**25** 1.6 **Mn** 54.9 manganese	**26** 1.8 **Fe** 55.8 iron	**27** 1.9 **Co** 58.9 cobalt
37 0.8 **Rb** 85.5 rubidium	**38** 1.0 **Sr** 87.6 strontium	**39** 1.2 **Y** 88.9 yttrium	**40** 1.3 **Zr** 91.2 zirconium	**41** 1.6 **Nb** 92.9 niobium	**42** 2.2 **Mo** 96.0 molybdenum	**43** 1.9 **Tc** (98) technetium	**44** 2.2 **Ru** 101.1 ruthenium	**45** 2.3 **Rh** 102.9 rhodium
55 0.8 **Cs** 132.9 caesium	**56** 0.9 **Ba** 137.3 barium	**57–71** lanthanoids	**72** 1.3 **Hf** 178.5 hafnium	**73** 1.5 **Ta** 180.9 tantalum	**74** 2.4 **W** 183.8 tungsten	**75** 1.9 **Re** 186.2 rhenium	**76** 2.2 **Os** 190.2 osmium	**77** 2.2 **Ir** 192.2 iridium
87 0.7 **Fr** (223) francium	**88** 0.9 **Ra** (226) radium	**89–103** actinoids	**104** **Rf** (261) rutherfordium	**105** **Db** (262) dubnium	**106** **Sg** (266) seaborgium	**107** **Bh** (264) bohrium	**108** **Hs** (267) hassium	**109** **Mt** (268) meitnerium

57 1.1 **La** 138.9 lanthanum	**58** 1.1 **Ce** 140.1 cerium	**59** 1.1 **Pr** 140.9 praseodymium	**60** 1.1 **Nd** 144.2 neodymium	**61** **Pm** (145) promethium	**62** 1.2 **Sm** 150.4 samarium	**63** **Eu** 152.0 europium
89 1.1 **Ac** (227) actinium	**90** 1.3 **Th** 232.0 thorium	**91** 1.5 **Pa** 231.0 protactinium	**92** 1.4 **U** 238.0 uranium	**93** 1.4 **Np** (237) neptunium	**94** 1.3 **Pu** (244) plutonium	**95** 1.3 **Am** (243) americium



								2 4.0 **He** 4.0 helium
			5 2.0 **B** 10.8 boron	**6** 2.6 **C** 12.0 carbon	**7** 3.0 **N** 14.0 nitrogen	**8** 3.4 **O** 16.0 oxygen	**9** 4.0 **F** 19.0 fluorine	**10** **Ne** 20.2 neon
			13 1.6 **Al** 27.0 aluminium	**14** 1.9 **Si** 28.1 silicon	**15** 2.2 **P** 31.0 phosphorus	**16** 2.6 **S** 32.1 sulfur	**17** 3.2 **Cl** 35.5 chlorine	**18** **Ar** 39.9 argon
28 1.9 **Ni** 58.7 nickel	**29** 1.9 **Cu** 63.5 copper	**30** 1.7 **Zn** 65.4 zinc	**31** 1.8 **Ga** 69.7 gallium	**32** 2.0 **Ge** 72.6 germanium	**33** 2.2 **As** 74.9 arsenic	**34** 2.6 **Se** 79.0 selenium	**35** 3.0 **Br** 79.9 bromine	**36** 3.0 **Kr** 83.8 krypton
46 2.2 **Pd** 106.4 palladium	**47** 1.9 **Ag** 107.9 silver	**48** 1.7 **Cd** 112.4 cadmium	**49** 1.8 **In** 114.8 indium	**50** 2.0 **Sn** 118.7 tin	**51** 2.1 **Sb** 121.8 antimony	**52** 2.1 **Te** 127.6 tellurium	**53** 2.7 **I** 126.9 iodine	**54** 2.6 **Xe** 131.3 xenon
78 2.3 **Pt** 195.1 platinum	**79** 2.5 **Au** 197.0 gold	**80** 2.0 **Hg** 200.6 mercury	**81** 1.6 **Tl** 204.4 thallium	**82** 2.3 **Pb** 207.2 lead	**83** 2.0 **Bi** 209.0 bismuth	**84** 2.0 **Po** (210) polonium	**85** 2.2 **At** (210) astatine	**86** **Rn** (222) radon
110 **Ds** (271) darmstadtium	**111** **Rg** (272) roentgenium	**112** **Cn** (285) copernicium	**113** **Nh** (280) nihonium	**114** **Fl** (289) flerovium	**115** **Mc** (289) moscovium	**116** **Lv** (292) livermorium	**117** **Ts** (294) tennessine	**118** **Og** (294) oganesson

64 1.2 **Gd** 157.3 gadolinium	**65** **Tb** 158.9 terbium	**66** 1.2 **Dy** 162.5 dysprosium	**67** 1.2 **Ho** 164.9 holmium	**68** 1.2 **Er** 167.3 erbium	**69** 1.3 **Tm** 168.9 thulium	**70** **Yb** 173.1 ytterbium	**71** 1.3 **Lu** 175.0 lutetium

96 1.3 **Cm** (247) curium	**97** 1.3 **Bk** (247) berkelium	**98** 1.3 **Cf** (251) californium	**99** 1.3 **Es** (252) einsteinium	**100** 1.3 **Fm** (257) fermium	**101** 1.3 **Md** (258) mendelevium	**102** 1.3 **No** (259) nobelium	**103** 1.3 **Lr** (262) lawrencium

Values in brackets indicate the mass number of the longest-lived isotope.

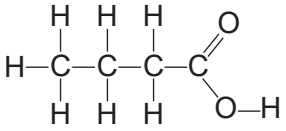
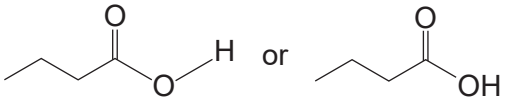
17. Names of selected elements

Element	Symbol	Atomic number	Relative atomic mass (amu)
aluminium	Al	13	27.0
argon	Ar	18	39.9
arsenic	As	33	74.9
barium	Ba	56	137.3
beryllium	Be	4	9.0
boron	B	5	10.8
bromine	Br	35	79.9
cadmium	Cd	48	112.4
caesium	Cs	55	132.9
calcium	Ca	20	40.1
carbon	C	6	12.0
chlorine	Cl	17	35.5
chromium	Cr	24	52.0
cobalt	Co	27	58.9
copper	Cu	29	63.5
fluorine	F	9	19.0
gallium	Ga	31	69.7
germanium	Ge	32	72.6
gold	Au	79	197.0
helium	He	2	4.0
hydrogen	H	1	1.0
iodine	I	53	126.9
iron	Fe	26	55.8
krypton	Kr	36	83.8
lead	Pb	82	207.2
lithium	Li	3	6.9

Element	Symbol	Atomic number	Relative atomic mass (amu)
magnesium	Mg	12	24.3
manganese	Mn	25	54.9
mercury	Hg	80	200.6
neon	Ne	10	20.2
nickel	Ni	28	58.7
nitrogen	N	7	14.0
oxygen	O	8	16.0
phosphorus	P	15	31.0
platinum	Pt	78	195.1
potassium	K	19	39.1
rubidium	Rb	37	85.5
scandium	Sc	21	45.0
selenium	Se	34	79.0
silicon	Si	14	28.1
silver	Ag	47	107.9
sodium	Na	11	23.0
strontium	Sr	38	87.6
sulfur	S	16	32.1
tin	Sn	50	118.7
titanium	Ti	22	47.9
tungsten	W	74	183.8
vanadium	V	23	50.9
xenon	Xe	54	131.3
yttrium	Y	39	88.9
zinc	Zn	30	65.4
zirconium	Zr	40	91.2

18. Representations of organic molecules

The following table shows different representations of organic molecules, using butanoic acid as an example.

Formula	Representation
molecular formula	$C_4H_8O_2$
structural formula	
semi-structural (condensed) formula	$CH_3CH_2CH_2COOH$ or $CH_3(CH_2)_2COOH$
skeletal structure	

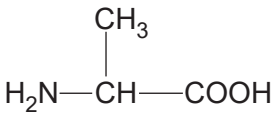
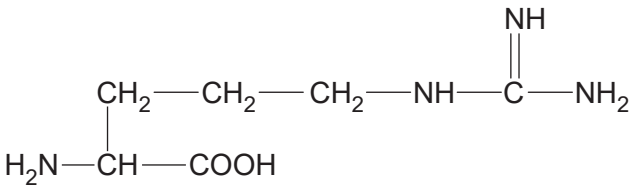
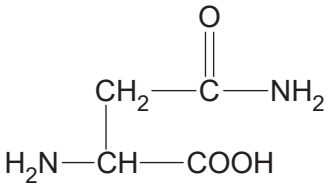
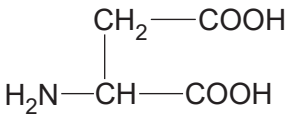
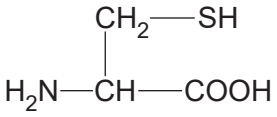
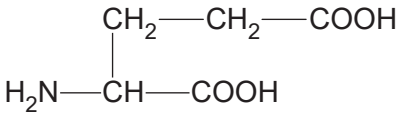
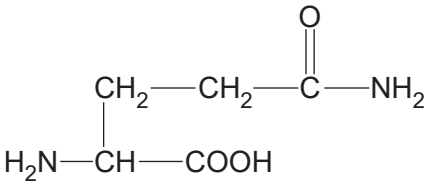
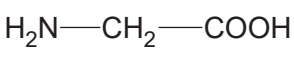
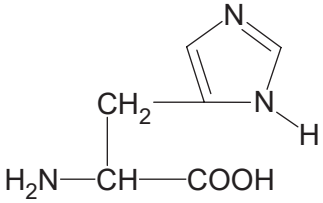
19. Functional group nomenclature in organic chemistry

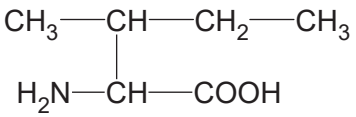
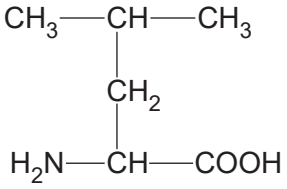
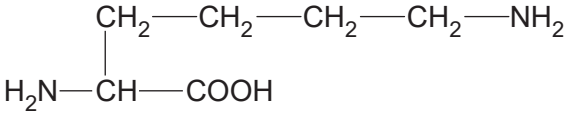
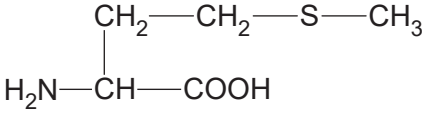
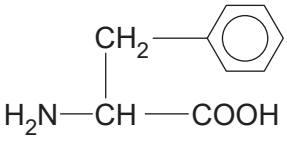
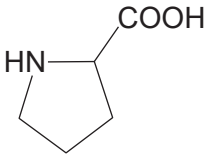
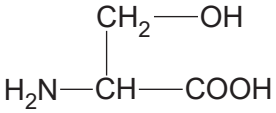
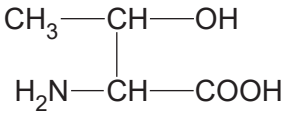
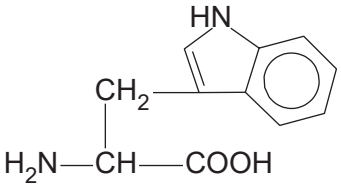
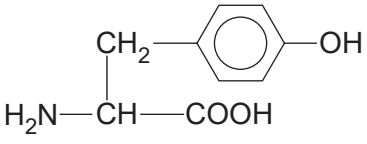
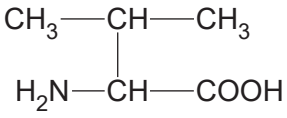
The following table shows the priority of functional groups when naming organic compounds that contain more than one functional group. The functional group with the highest priority determines the suffix of the compound.

Class of compound	Functional group name	Prefix	Suffix
carboxylic acid	carboxyl	–	-oic acid
ester	ester	–	-oate
amide	amide	–	-amide
aldehyde	carbonyl	–	-al
ketone	carbonyl	–	-one
alcohol	hydroxy/ hydroxyl	hydroxy-	-ol
amine	amino	amino-	-amine
alkene	alkenyl	–	-ene
halogen	'halo' (i.e. bromo, chloro, fluoro, iodo)	bromo- chloro- fluoro- iodo-	–

20. 2-amino acids (α-amino acids)

The table below provides simplified structures for amino acids. These amino acids may all be classified as '2-amino acids' since the amino group (-NH_2) is attached to the second carbon atom in the carbon chain, numbered from the carboxyl (-COOH) end. They may also be classified as 'α-amino acids', since both the amino group and the carboxyl group are attached to the same carbon atom, known as the alpha carbon. These structures may be used as the basis for drawing zwitterions, identifying the products of protein hydrolysis and drawing the structures formed in the condensation polymerisation of amino acid monomers.

Name	Symbol	Structure
alanine	Ala	
arginine	Arg	
asparagine	Asn	
aspartic acid	Asp	
cysteine	Cys	
glutamic acid	Glu	
glutamine	Gln	
glycine	Gly	
histidine	His	

Name	Symbol	Structure
isoleucine	Ile	
leucine	Leu	
lysine	Lys	
methionine	Met	
phenylalanine	Phe	
proline	Pro	
serine	Ser	
threonine	Thr	
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	

21. Formulas of selected fatty acids

Name	Molecular formula	Semi-structural formula
caproic	$C_6H_{12}O_2$	$CH_3(CH_2)_4COOH$
capric	$C_{10}H_{20}O_2$	$CH_3(CH_2)_8COOH$
lauric	$C_{12}H_{24}O_2$	$CH_3(CH_2)_{10}COOH$
myristic	$C_{14}H_{28}O_2$	$CH_3(CH_2)_{12}COOH$
palmitic	$C_{16}H_{32}O_2$	$CH_3(CH_2)_{14}COOH$
palmitoleic	$C_{16}H_{30}O_2$	$CH_3(CH_2)_5CH=CH(CH_2)_7COOH$
stearic	$C_{18}H_{36}O_2$	$CH_3(CH_2)_{16}COOH$
oleic	$C_{18}H_{34}O_2$	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$
linoleic	$C_{18}H_{32}O_2$	$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOH$
linolenic	$C_{18}H_{30}O_2$	$CH_3(CH_2CH=CH)_3(CH_2)_7COOH$
arachidic	$C_{20}H_{40}O_2$	$CH_3(CH_2)_{18}COOH$
arachidonic	$C_{20}H_{32}O_2$	$CH_3(CH_2)_4(CH=CHCH_2)_3CH=CH(CH_2)_3COOH$

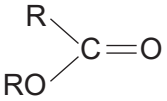
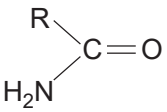
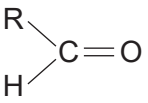
22. Characteristic ranges for infrared absorption

Bond	Wave number (cm^{-1})	Bond	Wave number (cm^{-1})
C=O (amides)	1630–1680	C–H (alkanes, alkenes, arenes)	2850–3090
C=O (aldehydes)	1660–1745	O–H (acids)	2500–3500
C=O (acids)	1680–1740	O–H (alcohols)	3200–3600
C=O (ketones)	1680–1850	N–H (amines and amides)	3300–3500
C=O (esters)	1720–1840		

23. ^{13}C NMR data

Typical ^{13}C shift values relative to TMS = 0

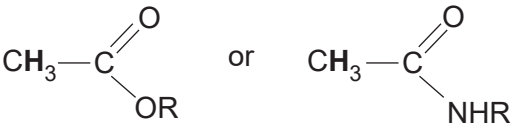
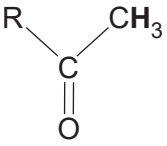
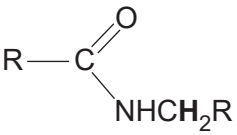
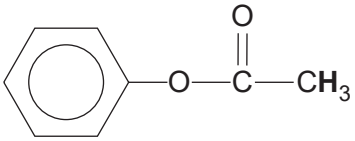
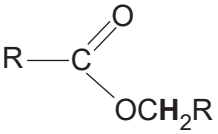
These can differ slightly in different solvents.

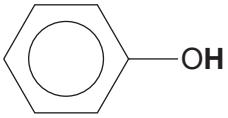
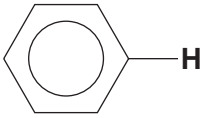
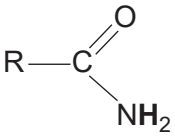
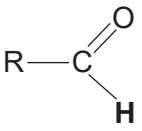
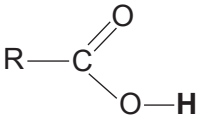
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$, $R_3C–NR$	35–70
$R–CH_2–OH$	50–90
$R_2C=CR_2$	110–150
arenes $C_6H_5–R$	110–150
RCOOH	160–185
	165–175
	165–185
	190–200
$R_2C=O$	205–220

24. ^{1}H NMR data

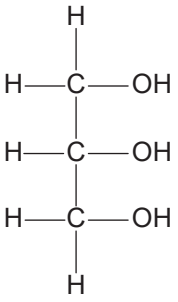
Typical proton shift values relative to TMS = 0

These can differ slightly in different solvents. The shift refers to the proton environment that is indicated in bold letters in the formula.

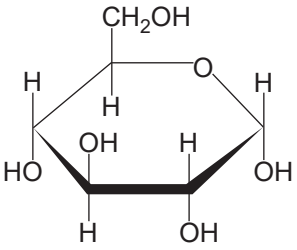
Type of proton	Chemical shift (ppm)
R–C**H**$_3$	0.9–1.0
R–C**H**$_2$–R	1.3–1.4
RCH=CH–C**H**$_3$	1.6–1.9
R$_3$–C**H**	1.5
	2.0
	2.1–2.7
R–C**H**$_2$–X (X = F, Cl, Br or I)	3.0–4.5
R–C**H**$_2$–OH, R$_2$–C**H**–OH	3.3–4.5
	3.2
R—O—C**H**$_3$ or R—O—C**H**$_2$R	3.3–3.7
	2.3
	3.7–4.8
R–O–**H**	1–6 (varies considerably under different conditions)
R–N**H**$_2$	1–5
RHC=C**H**R	4.5–7.0

Type of proton	Chemical shift (ppm)
	4.0–12.0
	6.9–9.0
	6.0–8.0
	9.4 – 10.0
	9.0–13.0

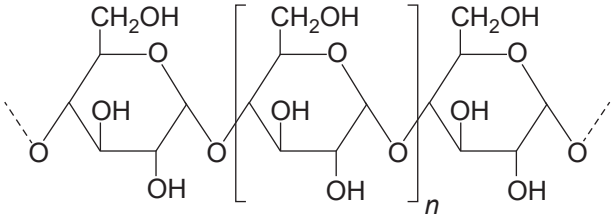
25. Representations of selected biomolecules



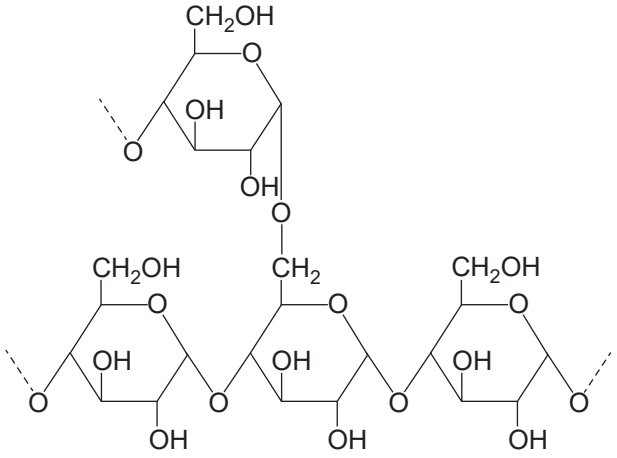
glycerol



α-D-glucose



amylose (starch)



amylopectin (starch)

26. Sustainability

i. United Nations Sustainable Development Goals

The following nine goals are relevant to VCE Chemistry:

- Goal 2: Zero hunger
- Goal 6: Clean water and sanitation
- Goal 7: Affordable and clean energy
- Goal 9: Industry, innovation and infrastructure
- Goal 11: Sustainable cities and communities
- Goal 12: Responsible consumption and production
- Goal 13: Climate action
- Goal 14: Life below water
- Goal 15: Life on land

Source: Adapted from 'The 17 Goals',
Department of Economic and Social Affairs,
Sustainable Development, United Nations
<https://sdgs.un.org./goals>

ii. Green chemistry principles

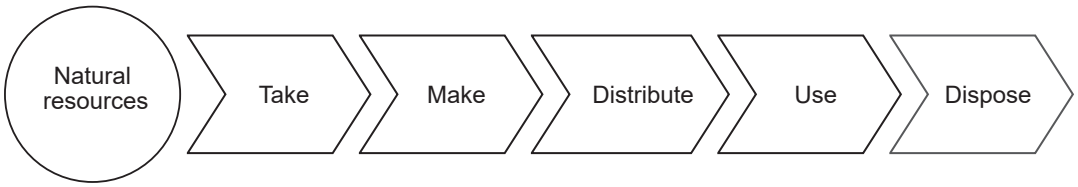
The following seven green chemistry principles are relevant to VCE Chemistry:

- Atom economy: Processes/pathways should be designed to maximise incorporation of all reactant materials used in the process into the final product.
- Catalysis: Catalysts should be selected to generate the same desired product(s) with less waste and using less energy and reagents in reaction processes/pathways.
- Design for degradation: Chemical products should be designed so that at the end of their use they break down into harmless degradation products and do not persist in the environment.
- Design for energy efficiency: Processes/pathways should be designed for maximum energy efficiency and with minimal negative environmental and economic impacts.
- Designing safer chemicals: Chemical products should be designed to achieve their intended function while minimising toxicity.
- Prevention of wastes: It is better to prevent waste than to treat or clean up waste after it has been produced.
- Use of renewable feedstocks: Raw materials or feedstocks should be made from renewable (mainly plant-based) materials, rather than from fossil fuels, whenever practicable.

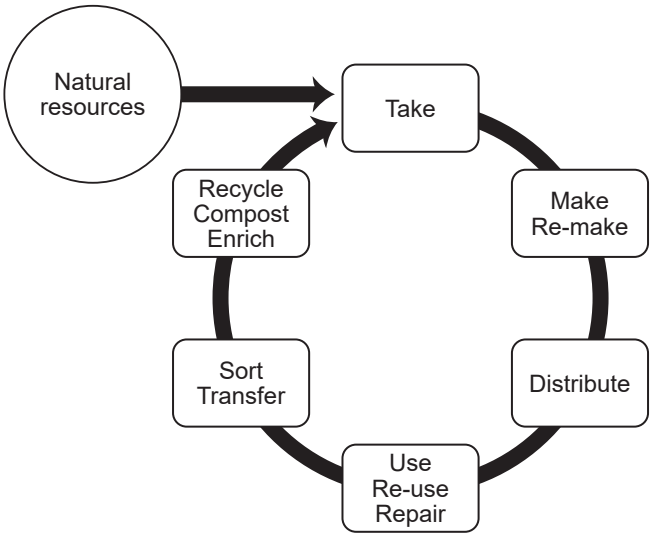
Source: Adapted from PT Anastas and JC Warner,
Green Chemistry: Theory and Practice, Oxford University Press, New York, 1998, p.30

iii. Types of economies

Linear



Circular



End of Chemistry Data Book