SUPERVISOR TO ATTACH
PROCESSING LABEL HERE

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

Chemistry

Question and Answer Book

VCE Examination – Day Date Month Year

- Reading time is **15 minutes**: — to —
- Writing time is **2 hours 30 minutes**: — to —

Materials supplied

- Question and Answer Book of 40 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

June 2024

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

VICTORIA State Government

Section A – Multiple-choice questions

Instructions

- Answer **all** questions in pencil on the 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

Compared with ethanol produced from coal, the ethanol produced from sugar cane

A. has a higher energy content.

B. can be classified as a biofuel.

C. cannot be used to generate electrical energy.

D. produces no greenhouse gases when it burns.

Question 2

In humans, the oxidation of which chemical is the primary carbohydrate energy source?

A. amylopectin

B. amylose

C. glucose

D. glycerol

Question 3

A box of rolled oats provides the following information.

Nutrition information Servings per package: 24 Serving size: 40.0 g	
	Average quantity per 100.0 g
Protein	13.3 g
Fat	8.50 g
Total carbohydrate	55.6 g

Which component of this breakfast cereal will contribute the least energy when one serve is completely digested?

A. protein, because it contributes a total of 90.4 kJ

B. protein, because it contributes a total of 226.1 kJ

C. fat, because there is the least quantity of this material

D. carbohydrate, because it has an energy content of only 16 kJ g^{-1}

Question 4

The equation for the complete combustion of ethane at standard laboratory conditions (SLC) is shown below.

$$C_2H_6(g) + 3\frac{1}{2}O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

Given that the molar mass of carbon dioxide is 44.0 g mol^{-1}, the combustion of 4.00 mol of ethane under these conditions will produce which of the following?

	Mass of CO_2 gas (g)	**Volume of greenhouse gas (L)**
A.	176	198
B.	352	198
C.	176	496
D.	352	496

Question 5

Which is a correct procedure to follow when using a solution calorimeter?

A. After calibration, the heating coil needs to be removed from the calorimeter before use.

B. Use the same lid, stirrer and thermometer throughout the experiment.

C. Double the calibration factor if the volume of the liquid is doubled.

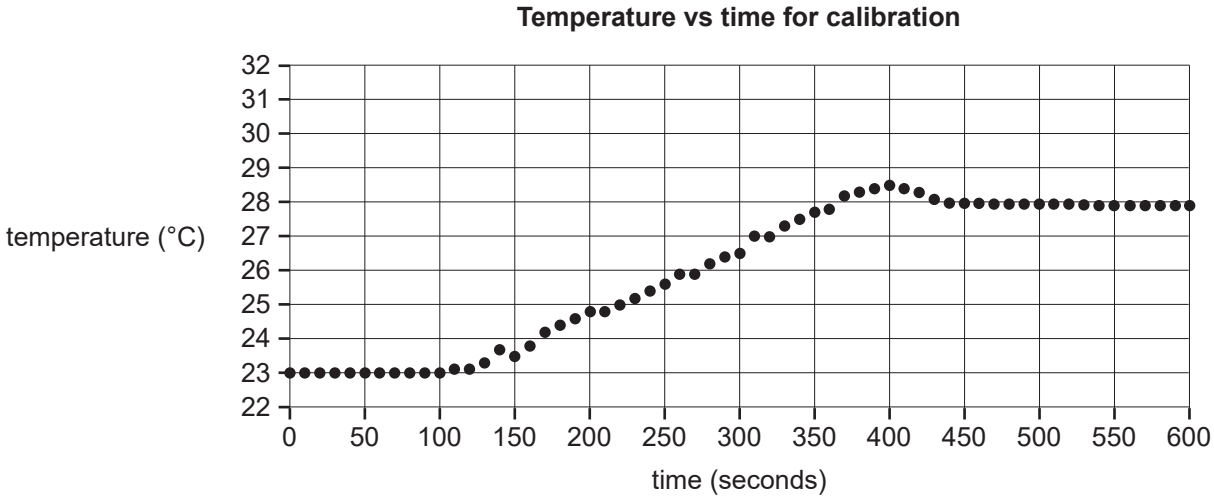
D. Halve the calibration factor if the volume of the liquid is doubled.

Question 6

Mila performed the following experiment:

- Add 120 mL of water to a clean, dry calorimeter, and monitor the temperature every 10 seconds over 100 seconds.
- After 100 seconds, apply a current of 1.80 A with a voltage of 6.00 V for 5.00 minutes, and then switch off the power. Stir the solution.

Mila's plot of the recorded temperatures over time is shown below.



Using the information from the plot, the temperature change that Mia should use for the calibration is closest to

A. 28.5 °C

B. 28.1 °C

C. 5.5 °C

D. 5.1 °C

Question 7

Oxygen gas is bubbled through a solution of sulfurous acid (H_2SO_3).

The relevant half-equations for this spontaneous reaction are

$$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$$

$$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons H_2SO_3(aq) + H_2O(l)$$

Oxygen gas is a more powerful oxidising agent than the sulfate ion SO_4^{2-}.

What is the balanced equation for this redox reaction?

A. $O_2(g) + 2H_2SO_3(aq) \rightarrow 2SO_4^{2-}(aq) + 4H^+(aq)$

B. $O_2(g) + SO_4^{2-}(aq) + 8H^+(aq) \rightarrow H_2SO_3(aq) + 3H_2O(l)$

C. $O_2(g) + H_2SO_3(aq) \rightarrow SO_4^{2-}(aq) + H_2O(l)$

D. $O_2(g) + 2SO_4^{2-}(aq) + 12H^+(aq) \rightarrow 2H_2SO_3(aq) + 3H_2O(l)$

Question 8

In the human body, the role of the enzyme in the esterification of fatty acids into triglycerides is best described as a process in which the protein

A. undergoes chemical changes and becomes inactive.

B. provides the necessary chemicals for the reaction to occur.

C. increases the rate of both the forward and backward reaction equally.

D. provides an alternative pathway that lowers the activation energy for the reaction.

Question 9

The reversible reaction

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

has an equilibrium constant K of 2.0 M^{-1} at a given temperature.

At that temperature, a particular closed vessel of fixed volume contains a mixture of SO_3, SO_2 and O_2 at equilibrium.

1 mol of O_2 is added to this equilibrium mixture and the temperature is kept constant.

At the instant the O_2 is added, the frequency and success of collisions between

A. SO_3 molecules instantly increases.

B. SO_3 molecules instantly decreases.

C. O_2 and SO_2 molecules instantly increases.

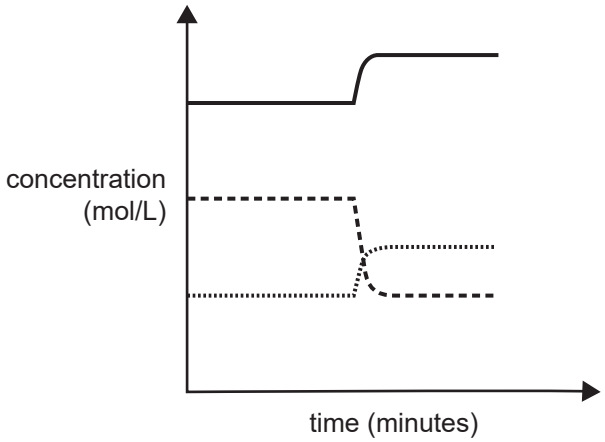
D. O_2 and SO_2 molecules instantly decreases.

Question 10

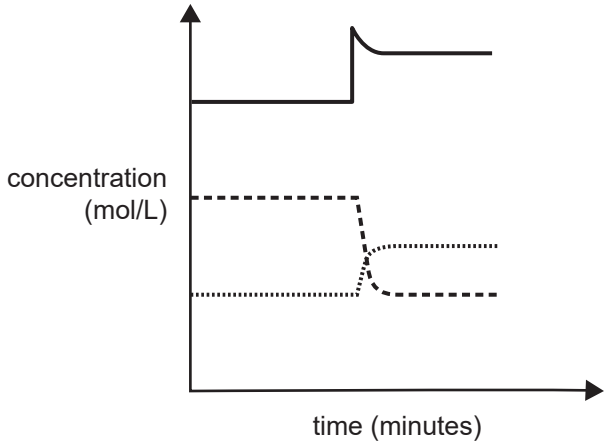
Which one of the following concentration–time graphs best represents the equilibrium system when the system shown below is heated?

$$A + 2B \rightleftharpoons C \qquad \Delta H = -450 \text{ kJ}$$

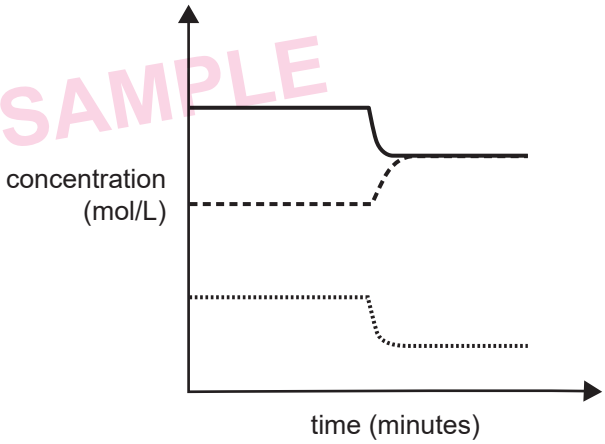
A.



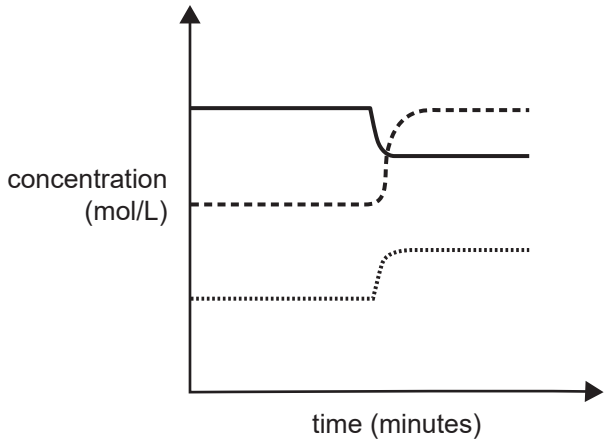
B.



C.



D.



Question 11

The equation for the decomposition of dinitrogen tetroxide, N_2O_4, is

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

The value of the equilibrium constant for this reaction is 36 M at 200 °C.

A sample of N_2O_4 is added into an empty container of fixed volume. The system is then sealed and heated to 200 °C. After a certain amount of time, both gases are analysed and the concentrations are found to be $[N_2O_4] = 0.4$ M and $[NO_2] = 2.4$ M.

It can be concluded that the

A. reaction is at equilibrium as $K = Q$.

B. backward reaction needs to be favoured to reach equilibrium as the value of $Q < K$.

C. forward reaction needs to be favoured to reach equilibrium as the value of $Q < K$.

D. concentrations of both gases will need to increase for the system to reach equilibrium.

Question 12

An alkaline solution is electrolysed to produce hydrogen and oxygen gas.

The half-equation for the reaction occurring at the anode in this cell will be

A. $2OH^-(aq) + 2e^- \rightarrow \frac{1}{2}O_2(g) + H_2O(l)$

B. $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$

C. $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$

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

Question 13

In a particular rechargeable battery, the overall equation for the discharge reaction is shown below.

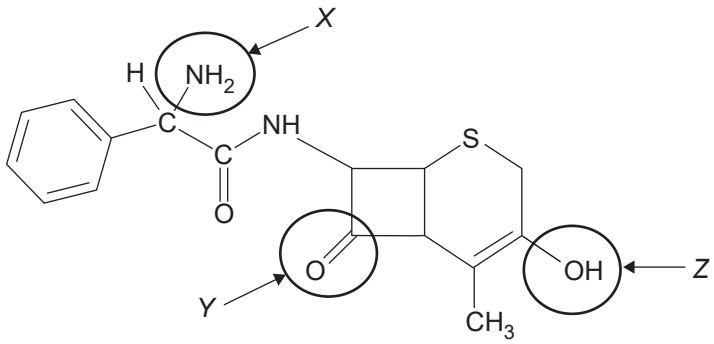
$$LiC_6 + CoO_2 \rightarrow LiCoO_2 + C_6$$

The polarities of the cathode during the discharge and recharge are

	Cathode during discharge	Cathode during recharge
A.	positive	positive
B.	positive	negative
C.	negative	positive
D.	negative	negative

Question 14

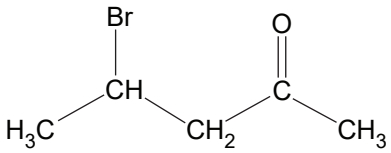
The structure of a new drug, which it is hoped will be effective against infections, is shown below.



Which of the following correctly names the circled functional groups labelled *X*, *Y* and *Z* on this molecule?

	X	***Y***	***Z***
A.	amino	carboxy	alcohol
B.	amide	ester	alcohol
C.	amide	ketone	hydroxyl
D.	amino	carbonyl	hydroxyl

Question 15



The correct IUPAC name for the compound shown above is

A. 4-bromopentanal.

B. 2-bromo-4-pentanal.

C. 2-bromobutan-4-one.

D. 4-bromopentan-2-one.

Question 16

Which of the following molecular formulas represents a straight-chain fatty acid containing the greatest degree of unsaturation?

A. $C_{10}H_{16}O_2$

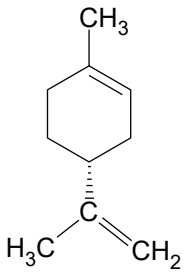
B. $C_{12}H_{22}O_2$

C. $C_{16}H_{32}O_2$

D. $C_{18}H_{34}O_2$

Question 17

The structure below is limonene, a compound commonly found in the leaves of some Australian native trees.



What is the most suitable solvent to extract limonene from leaves?

A. water

B. ethanol

C. hexane

D. propanone

Question 18

Enzymes commonly start to denature when temperatures reach 50 °C or more.

Which structural changes are most likely to occur in an enzyme if it is placed in a solution at 50 °C?

A. Peptide links in the primary structure will be broken.

B. Covalent bonds in the secondary structure will be broken.

C. Intermolecular forces in the tertiary structure will be disrupted.

D. Disulfide links present in the structure will be broken.

Question 19

When a single cysteine residue is present in the primary structure of a protein, which one of the following shows the strongest type of bond that can form between the R-group on this cysteine residue and any other amino acid R-group along this chain?

A. dispersion forces

B. dipole–dipole attraction

C. ionic bonding

D. covalent bonding

Question 20

There are many chemical pathways in which 2-chlorohexane can be made.

Which of the following is a reaction step that could be used to make 2-chlorohexane?

A. reacting chlorine gas with 1-hexene

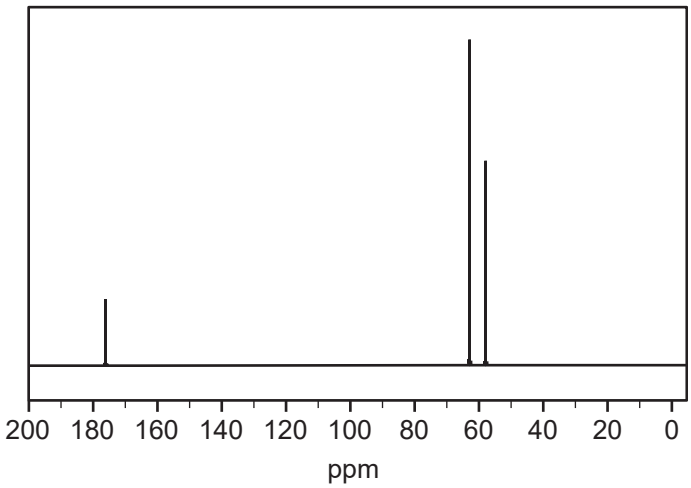
B. reacting chlorine gas with 2-hexene

C. reacting hydrogen chloride in the presence of UV light with hexane

D. reacting hydrogen chloride in the presence of a catalyst with 1-hexene

Question 21

A ^{13}C NMR spectrum of a naturally occurring 2-amino acid is shown below.



Data: SDBS WEB <sdbs.db.aist.go.jp.>
National Institute of Advanced Industrial Science and Technology

Which of the following could be the 2-amino acid represented in the spectrum?

A. serine

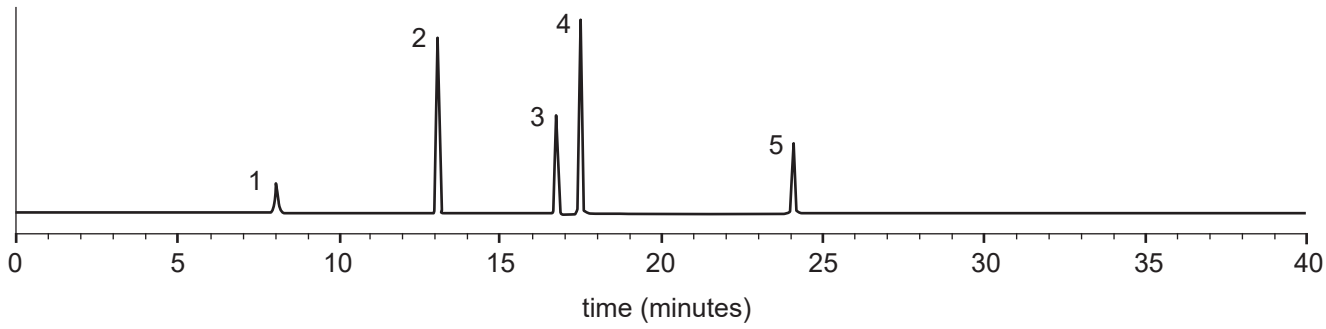
B. valine

C. alanine

D. glycine

Question 22

A mixture of propan-1-ol, octane, hexan-1-ol, octan-1-ol and 1-chloropentane was passed through an HPLC column that had a non-polar stationary phase and a polar mobile phase. The chromatogram obtained is shown below.



Peak 5 in this chromatogram is most likely to be that of

A. octane.

B. octan-1-ol.

C. propan-1-ol.

D. 1-chloropentane.

Question 23

In which section of a VCE Chemistry poster should a student identify the limitations in their data and method?

A. introduction

B. method

C. discussion

D. conclusion

Question 24

Ideally, before a scientist can publish experimental results, the research that has been undertaken should undergo a process in which the experiment is repeated by an independent group of scientists.

This process will verify the

A. reproducibility of the experiment.

B. repeatability of the experiment.

C. accuracy of the experiment.

D. validity of the experiment.

Question 25

The following is an extract from a safety data sheet for a chemical that Suresh considered using as an organic reagent in his student-designed scientific investigation.

Section 2 - Hazards Identification

2.1 Classification of the substance or mixture

Classification according to Regulation (EC) No 1272/2008

Acute toxicity, Oral (Category 3), H301
Acute toxicity, Inhalation (Category 3), H331
Acute toxicity, Dermal (Category 3), H311
Skin sensitisation (Sub-category 1B), H317 Carcinogenicity (Category 2), H351
Specific target organ toxicity - repeated exposure (Category 1), H372
Long-term (chronic) aquatic hazard (Category 3), H412
Hazardous to the ozone layer (Category 1), H420

For the full text of the H-Statements mentioned in this Section, see Section 16

'Material Safety Data Sheet – Carbon Tetra Chloride', Smart-Lab Indonesia, 23/05/2019, <https://smartlab.co.id/assets/pdf/MSDS_CARBON_TETRA_CHLORIDE.pdf>

According to the information in the safety data sheet above, which of the following statements is the best recommendation for the use of this chemical in a secondary school laboratory?

A. It should be safe if only small quantities are used.

B. It should be safe if it is only used in a fume cupboard.

C. It is not safe to use at all due to its long-term risks.

D. It should be safe if the wastes are washed down the sink with a lot of water.

Question 26

A student, Ruby, investigated how the total surface area of a piece of marble, $CaCO_3$, affects its rate of reaction with hydrochloric acid, HCl.

$$M(CaCO_3) = 100.1 \text{ g mol}^{-1}$$

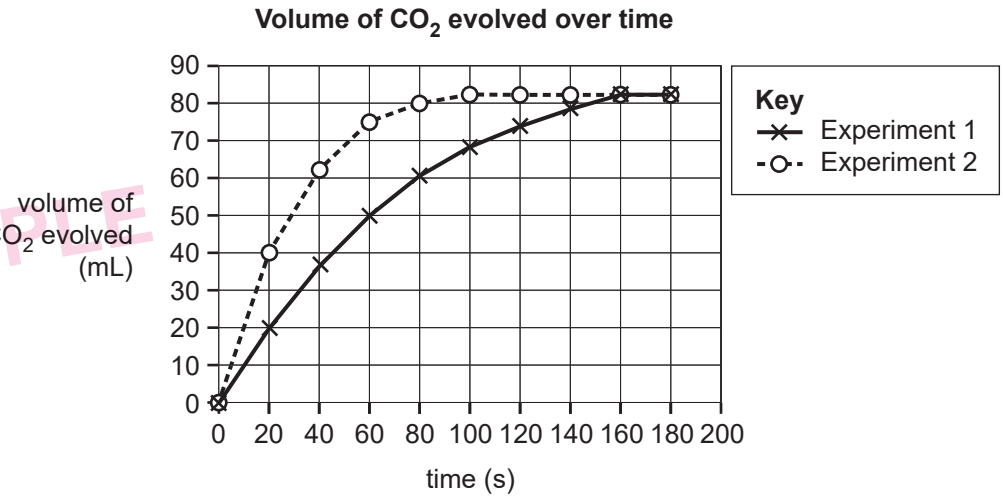
The equation for the reaction is:

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

Ruby conducted two experiments, Experiment 1 and Experiment 2. In each experiment, she used a different-shaped piece of marble, with each piece having a mass of 0.34 g. The marble used in Experiment 2 had a greater total surface area than the marble used in Experiment 1.

In each experiment, Ruby added 100 mL of 1.0 M HCl to the marble, and collected the gas that evolved in a gas syringe at SLC. She measured the volume of the gas at 20-second intervals.

Ruby used the data she generated to plot the following graph.



Which of the following is a valid conclusion that Ruby could draw from the graph?

A. Both reactions have reached equilibrium at 160 s.

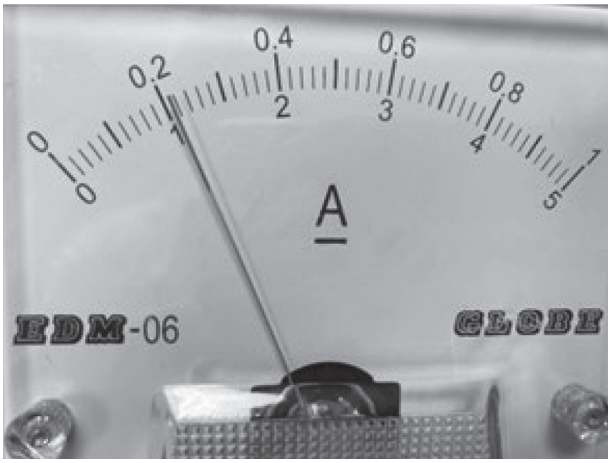
B. In each experiment, both reactants had been totally consumed at $t = 160$ s.

C. The greater the total surface area of the marble, the greater the rate of reaction.

D. The greater the total surface area of the marble, the greater the amount of CO_2 gas produced.

Question 27

Below is an image of the reading on an ammeter used by a student, Lien, during the electrolysis of a solution. Lien connected the ammeter so that the lower scale, the 0–5 ampere scale, was used to measure the current.



Which one of the following is correct regarding the resolution value for the data being generated by this instrument and the correct value of the current that Lien should record?

	Resolution value	Correct value
A.	0.1 A	0.25 A
B.	0.1 A	1.05 A
C.	0.01 A	0.25 A
D.	0.01 A	1.05 A

Use the following information to answer Questions 28 and 29.

Vitamin C can be analysed using a redox titration where a 2,6-dichloroindophenol (DCP) solution is used as a suitable titrant. A volumetric analysis of a vitamin C drink was performed by a VCE Chemistry class. In this titration, 20.00 mL aliquots of the vitamin C drink were titrated against a standard DCP solution.

Question 28

Another student, Diego, consistently found that he was getting higher results for his titres of DCP compared with all the other students in the class.

This systematic error could have resulted from Diego continually rinsing his

A. pipette with water before each use.

B. pipette with DCP solution before each use.

C. pipette with vitamin C solution before each use.

D. conical flask with vitamin C solution before each use.

Question 29

Four students recorded data from the experiment, as shown in the table below.

	Ben	Chang	Olivia	Ravinder
	15.90 mL	15.05 mL	16.90 mL	16.75 mL
	16.10 mL	15.25 mL	17.50 mL	16.30 mL
	16.00 mL	15.50 mL	16.95 mL	17.60 mL
	16.20 mL	15.00 mL	17.45 mL	17.35 mL
Average	16.05 mL	15.20 mL	17.20 mL	17.00 mL

The true value expected for this titration was a titre of 17.05 mL.

Which student was able to obtain the most precise data?

A. Ben

B. Chang

C. Olivia

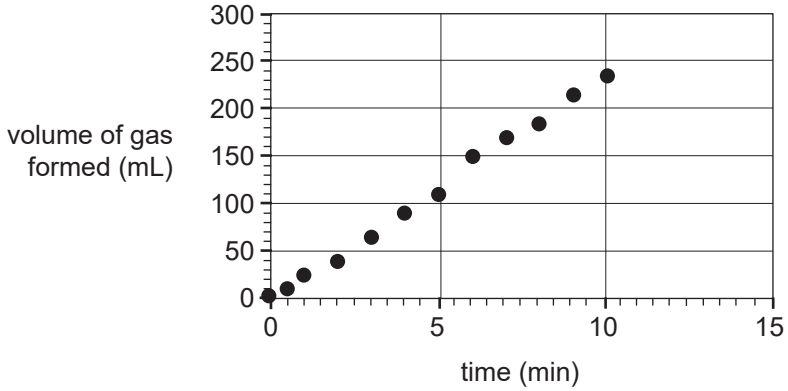
D. Ravinder

Question 30

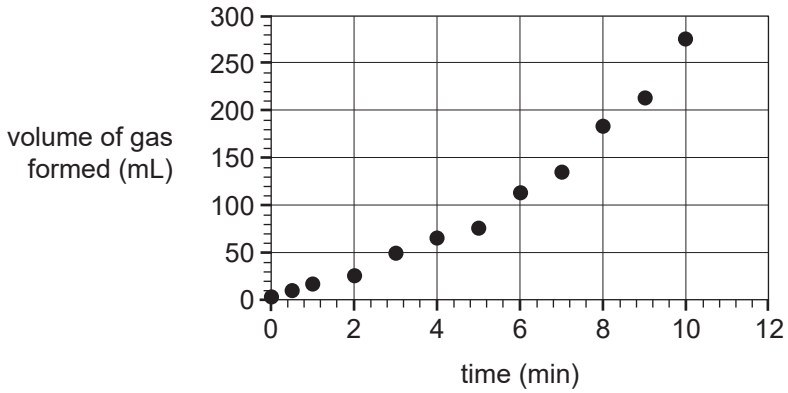
Daiyu plots data generated during an experiment in which she measured the volume of gas being formed over a period of time.

Which one of the following plots shows a non-linear relationship, as well as clear evidence of a systematic error being present?

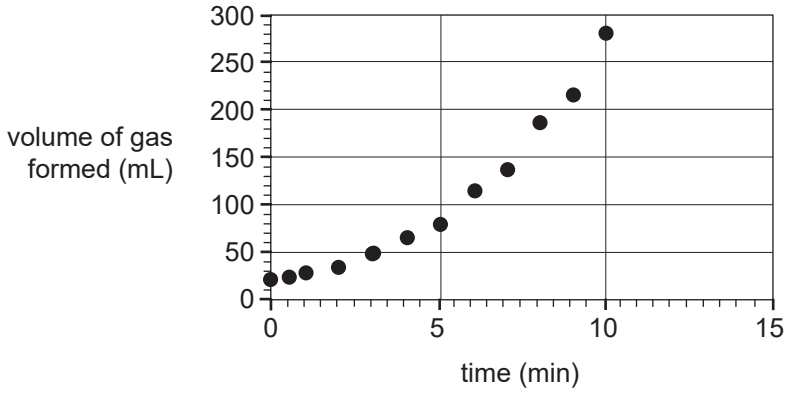
A.



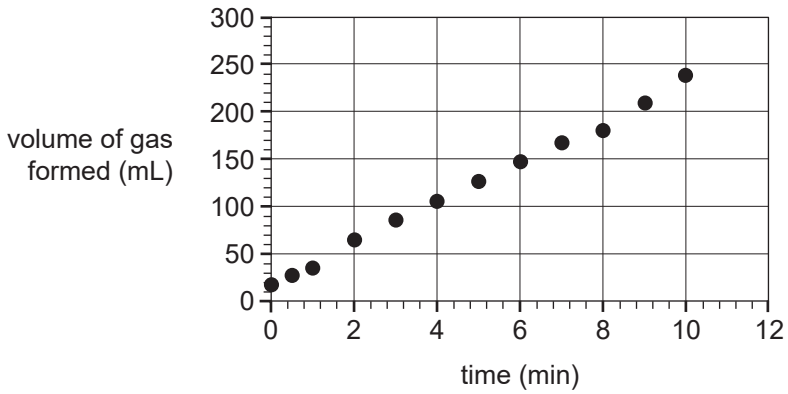
B.



C.



D.



End of Section A

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 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 (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

b. The following equation represents the production of bioethanol from glucose.

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

$M(C_6H_{12}O_6) = 180.0$ g mol^{-1}, $M(C_2H_5OH) = 46.0$ g mol^{-1}, and $M(CO_2) = 44.0$ g mol^{-1}

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

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

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

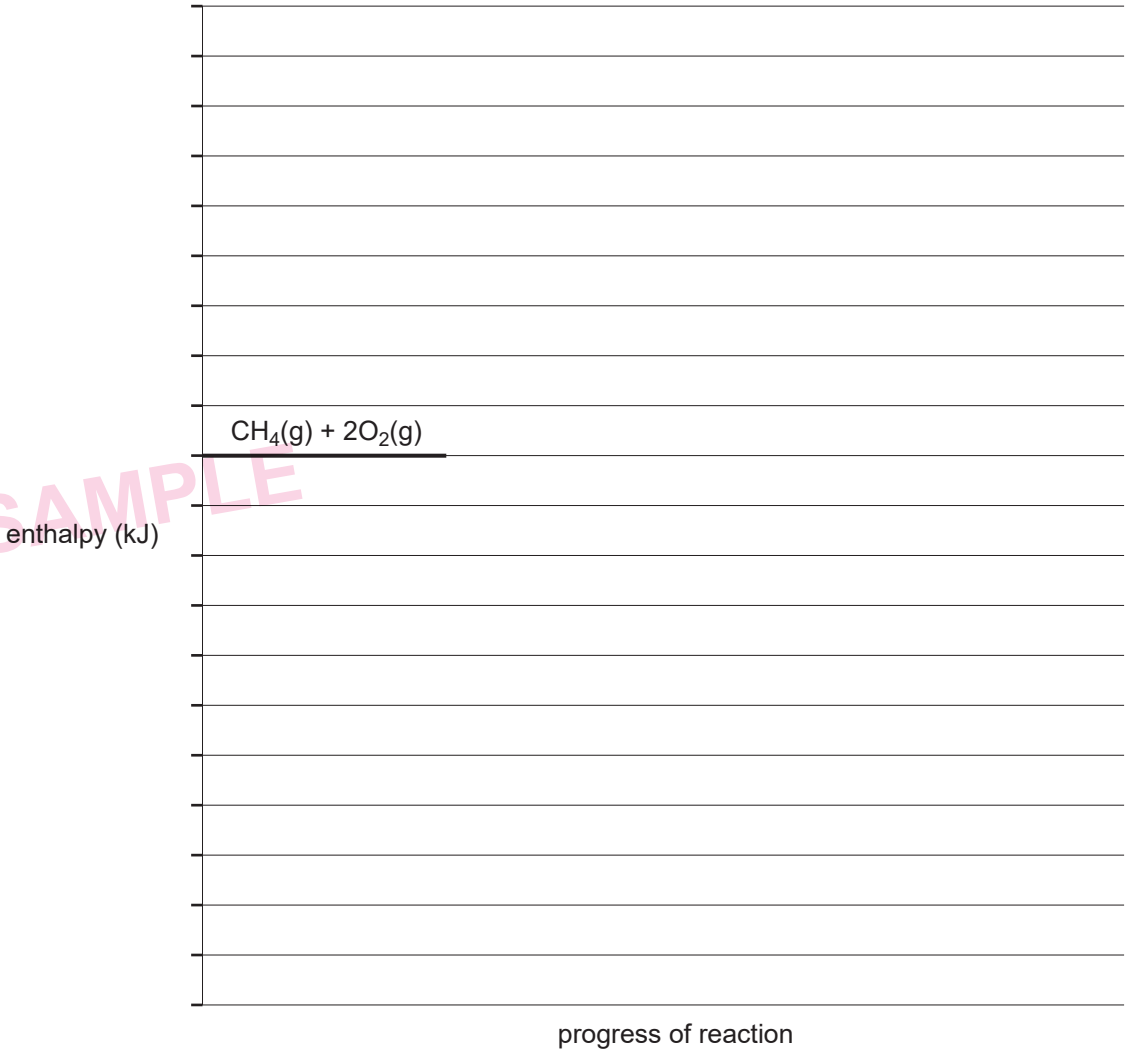
Question 2 (8 marks)

The following thermochemical equation shows the complete combustion of methane under standard laboratory conditions (SLC).

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l) \qquad \Delta H = -890 \text{ kJ}$$

The activation energy for this reaction is 230 kJ.

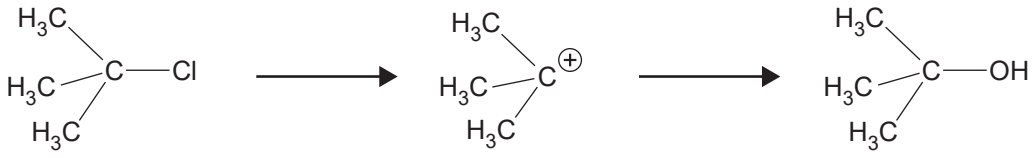
a. Complete the following energy profile diagram for the complete combustion of methane gas. Indicate on the diagram the ΔH and the activation energy. 2 marks



b. A two-step reaction mechanism takes place when the tertiary haloalkane, 2-chloro-2-methylpropane, reacts with sodium hydroxide in a substitution reaction to form 2-methyl-2-propanol. The two steps in this reaction are:

Step 1: The bond between the C and Cl is broken, and

Step 2: A new bond between the C and OH is formed.



i. Write the balanced overall equation using semi-structural formulas. States are not required. 1 mark

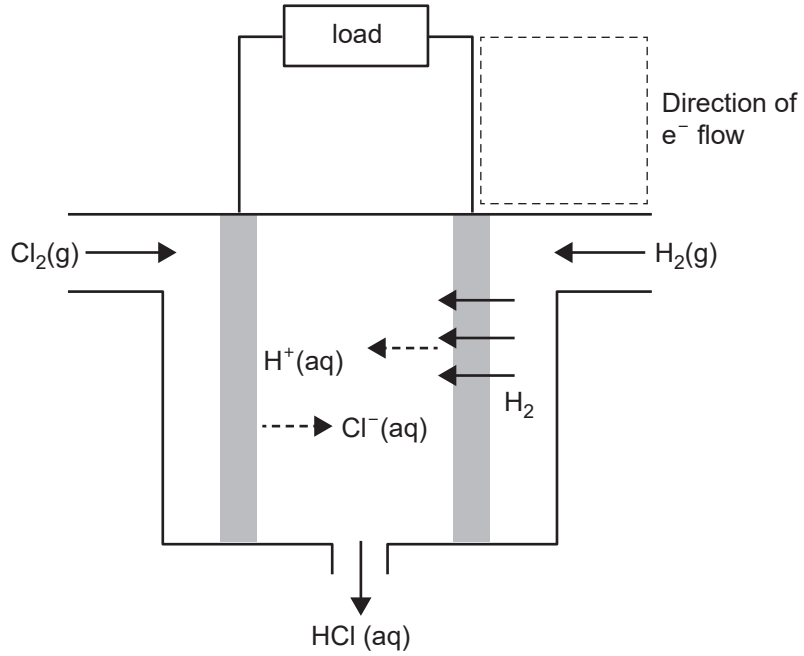
ii. Identify whether this process is going to be exothermic or endothermic. Use **item 10** of the Data Book to determine the theoretical ΔH associated with this reaction. 2 marks

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 marks

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

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

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

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

e. State **one** design feature of the electrodes used within a fuel cell that would increase the efficiency of the cell. 1 mark

f. A similar fuel cell is used in a school laboratory and operates for 3.00 hours at a constant current. The equation for the overall reaction in this fuel cell is

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

Under SLC, a total of 350 mL of oxygen and 450 mL of hydrogen was pumped through the fuel cell.

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

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

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}.

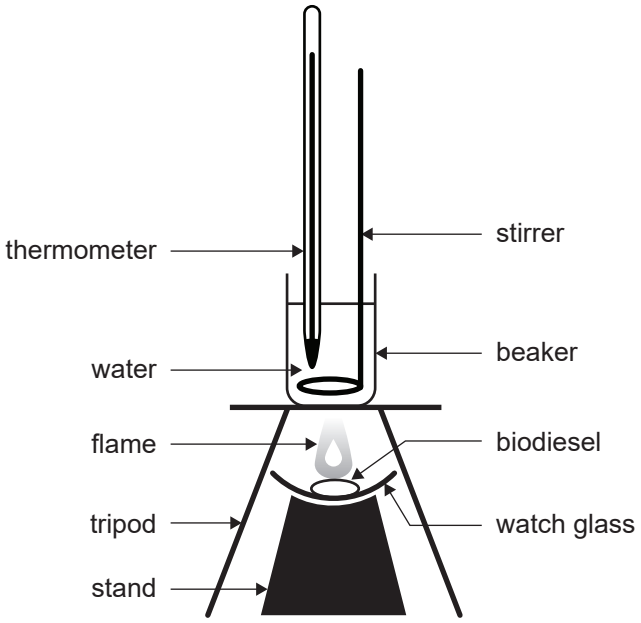
a. Calculate the mass, in grams, of iodine, I_2, that would react with 100 g of this biodiesel. 3 marks

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

c. Transesterification is a reversible reaction.

Explain **one** way that the yield of biodiesel could be maximised. 2 marks

d. The energy content of biodiesel was investigated by two students, Birrani and Jack, using the equipment shown below. They ignited the biodiesel under a beaker containing 200 g of water, which was set on a tripod.



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

Question 4 continues on the next page.

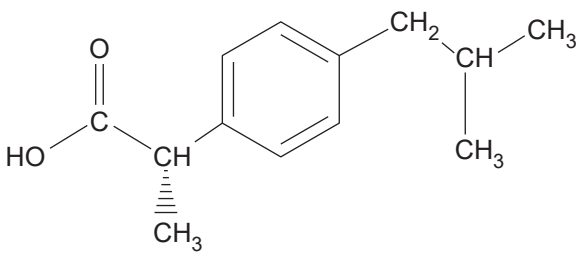
e. The following three molecular formulas represent members of the same homologous series of a fatty acid methyl ester.

$C_{19}H_{36}O_2$ $C_{17}H_{32}O_2$ $C_{15}H_{28}O_2$

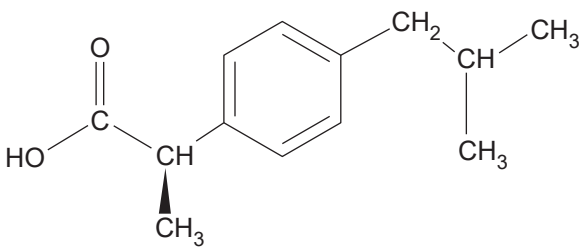
Explain how the viscosity of these compounds will vary. 2 marks

Question 5 (7 marks)

Inflammation is a physiological response that causes swelling to occur around an injury. Ibuprofen is a common anti-inflammatory drug. It can exist in two slightly different forms, shown below. Only the *S*-ibuprofen form is biologically active.



S-Ibuprofen



R-Ibuprofen

When your body feels pain, it responds by producing prostaglandins that then cause inflammation around a pain centre.

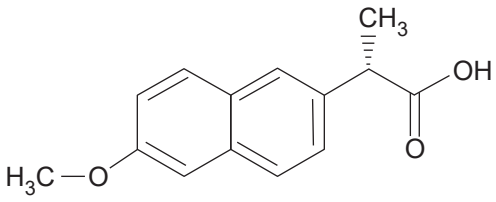
S-ibuprofen is a weak competitive enzyme inhibitor. It inhibits the enzymes that form prostaglandins, which in turn limits inflammation. *R*-ibuprofen has little impact on the body.

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

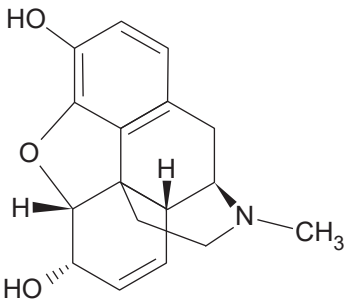
b. Explain, by referring to substrate–enzyme interactions, what is meant by the description of *S*-ibuprofen as a 'competitive inhibitor of an enzyme'. You may use diagrams in your answer. 2 marks

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

d. The structures of naproxen and morphine are shown below. Like ibuprofen, these drugs can be used for pain relief.



naproxen



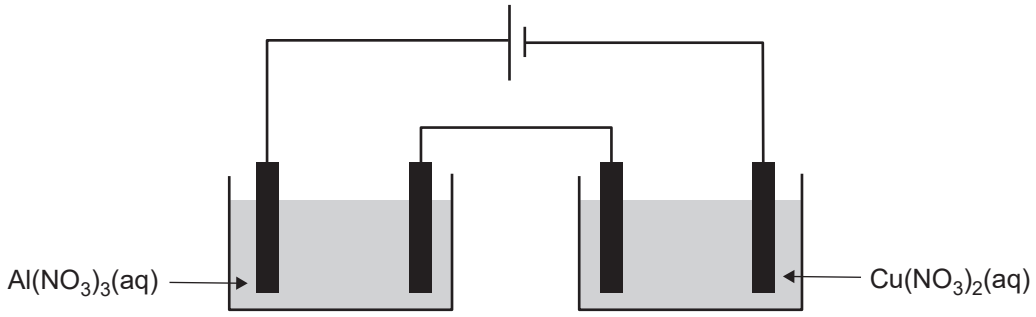
morphine

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

Question 6 (6 marks)

Kelly connected two electrolytic cells in series to the same power supply, as shown in the diagram below.

The electrolytes are, respectively, 0.1 M solutions of $Al(NO_3)_3$ and $Cu(NO_3)_2$. Both cells use inert electrodes.



Kelly set up the cells so that all the gas produced at the anodes is collected and stored at 25.0 °C in a single gas container.

Kelly passed a current of 10.0 A through this circuit for exactly 5.00 minutes.

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

b. Determine the mass of aluminium produced. 1 mark

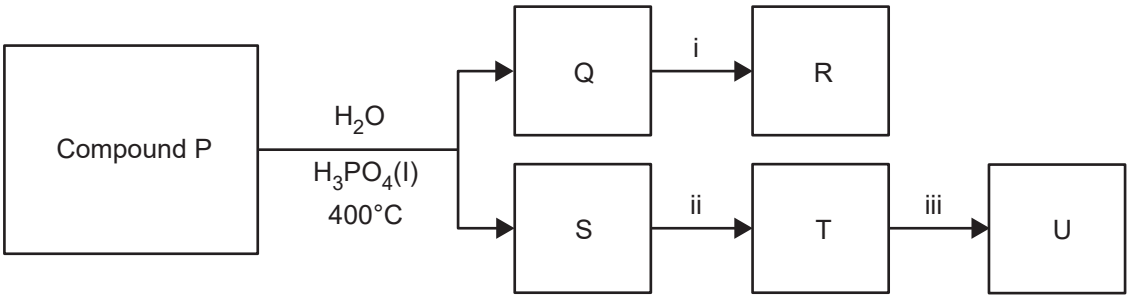
c. Identify the gas being produced at both anodes. 1 mark

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

Question 7 (14 marks)

Compound P is a linear (unbranched) hydrocarbon containing only four carbons and a single functional group.

Compound P was reacted via the pathway shown below.



In this reaction flowchart, the same oxidising agent was used for reactions indicated by i, ii and iii.

In a separate test, when Compound P was reacted with bromine, a colourless solution was produced.

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

b. After Compound P was reacted with steam, two different organic products, Q and S, were obtained. Compounds Q and S both contain a hydroxyl group and are structural isomers of each other.

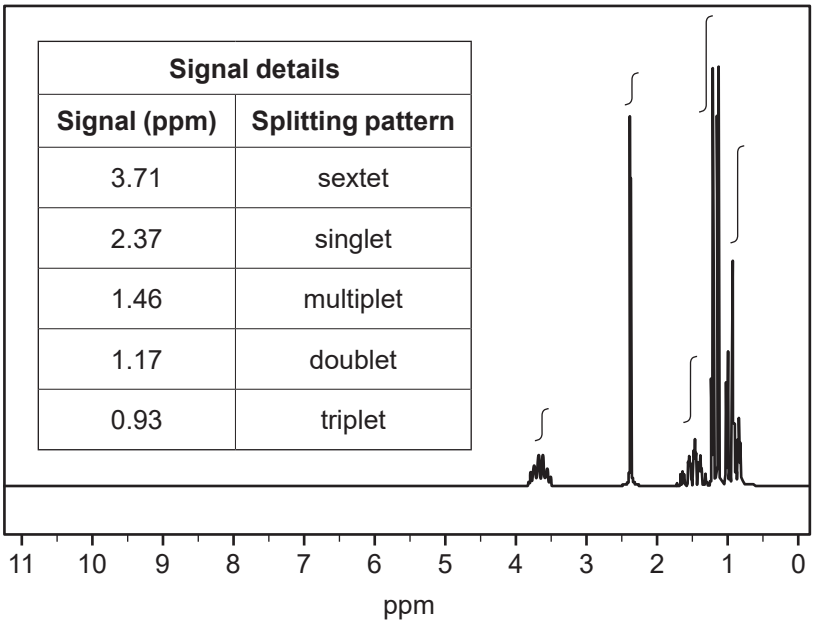
i. Identify a chemical test that can be used to confirm the presence of the hydroxyl functional group through an observable colour change. Describe the expected colour changes that would be observed. 2 marks

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

Question 7 continues on the next page.

c. Compound Q was isolated and a ^{1}H NMR was conducted to determine the structure of the alcohol produced. The table provides the details of the peaks produced.

Signal details	
Signal (ppm)	**Splitting pattern**
3.71	sextet
2.37	singlet
1.46	multiplet
1.17	doublet
0.93	triplet



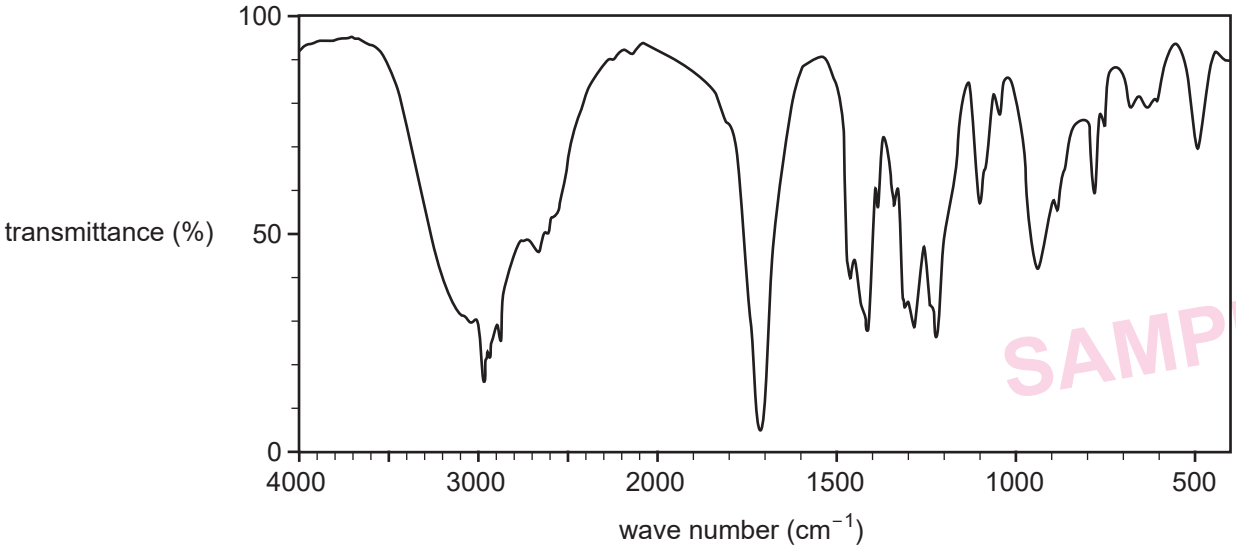
Data: SDBS Web <sdbs.db.aist.go.jp>,
National Institute of Advanced Industrial Science and Technology

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

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

f. An IR spectrophotometer was used to analyse Product U. The spectrum produced is shown below.

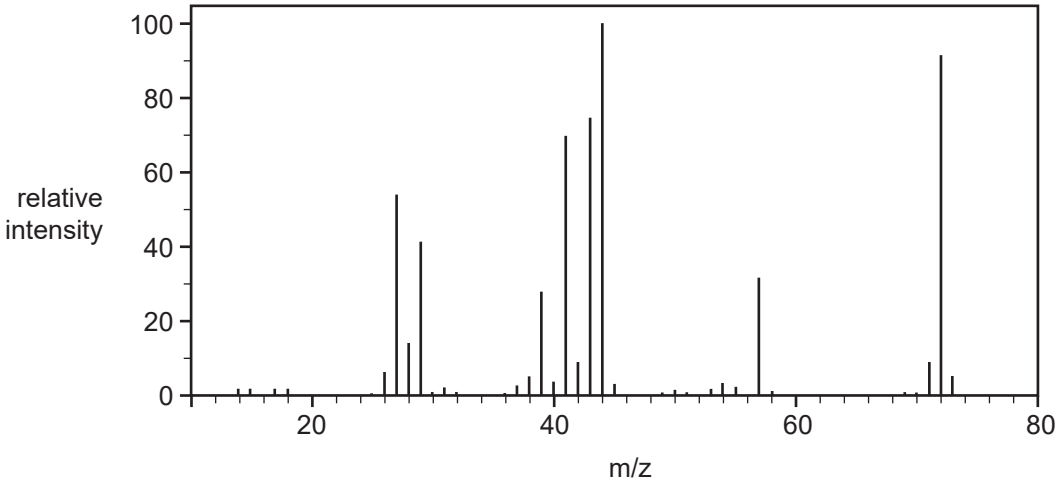


Data: SDBS Web <sdbs.db.aist.go.jp>,
National Institute of Advanced Industrial Science and Technology

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

Question 7 continues on the next page.

g. The mass spectrum of Molecule T is shown below.



Data: SDBS Web <sdbs.db.aist.go.jp>,
National Institute of Advanced Industrial Science and Technology

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

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

Question 8 (12 marks)

The following equation shows the reaction between oxalic acid, $C_2H_2O_4$, and potassium permanganate, $KMnO_4$.

$$2KMnO_4(aq) + 3H_2SO_4(aq) + 5C_2H_2O_4(aq) \rightarrow K_2SO_4(aq) + 2MnSO_4(aq) + 8H_2O(l) + 10CO_2(g)$$

A direct titration between potassium permanganate and oxalic acid is not an effective method of analysis because this reaction is quite slow.

For a student-designed scientific investigation, Sam developed an alternative method for the analysis of oxalic acid.

The following hypothesis was written in Sam's logbook.

> Potassium permanganate is a purple colour. The rate of decrease in purple colour, as measured using a colorimeter, will provide a means of establishing the rate of reaction. If concentration of oxalic acid is increased, then the rate of reaction would increase because there are more particles available to collide with each other.
>
> Therefore, if the new method is valid, a plot of 'Rate of reaction vs $[C_2H_2O_4]$' should show a positive relationship.

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

b. Sam set up a series of experiments.

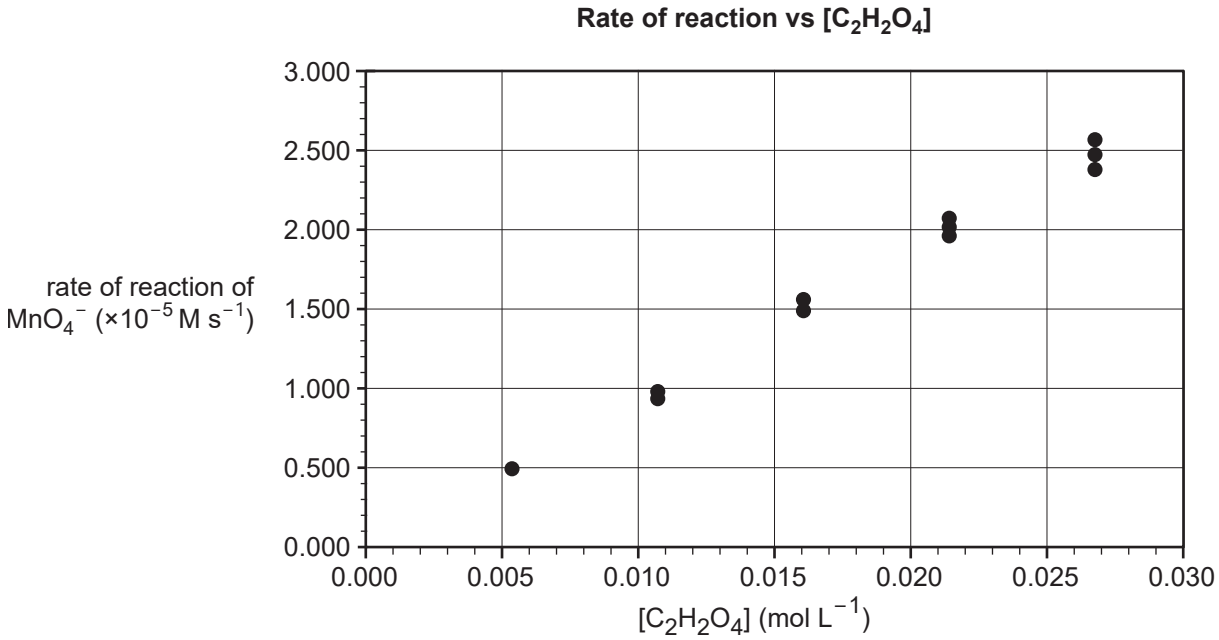
- In each experiment the potassium permanganate and sulfuric acid concentrations were set at a fixed value, and Sam only altered the concentration of oxalic acid.
- Whenever Sam changed the concentration of oxalic acid, the experiment was repeated three times.
- Sam made a total of five changes to the concentration of the oxalic acid.
- In every experiment, the volume of all solutions used was kept constant.

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

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

Question 8 continues on the next page.

c. Sam collated all the data generated, processed the raw data and plotted the resultant values, as shown below.



Sam made the following claim about the plot.

> The plot 'Rate of reaction vs $[C_2H_2O_4]$' shows clear evidence of a good experimental design through:
>
> - the production a very consistent trend in data
> - little variation of data within each trial.

i. Comment on Sam's claim. 2 marks

ii. Justify whether the data shown in the plot 'Rate of reaction vs $[C_2H_2O_4]$' supports Sam's hypothesis. 2 marks

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

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

Question 9 (9 marks)

Hydrogen can help tackle various critical energy challenges. It offers ways to decarbonise a range of sectors – including long-haul transport, chemicals, and iron and steel – where it is proving difficult to meaningfully reduce emissions.

Hydrogen can be extracted from fossil fuels and biomass, from water, or from a mix of both.

Source: Adapted from 'The Future of Hydrogen: Seizing Today's Opportunities', International Energy Agency, Paris (2019)
<www.iea.org/reports/the_future_of_hydrogen>

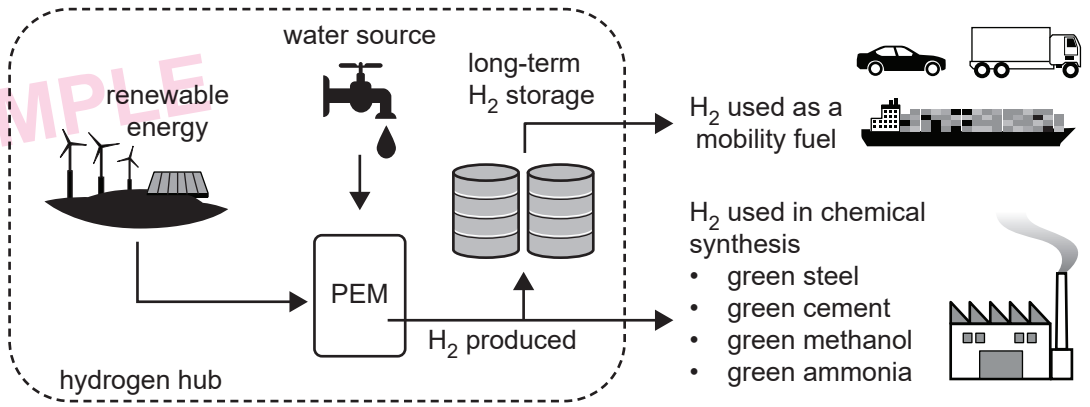
To meet the decarbonisation target of the climate change sustainable development goal (SDG13), global carbon dioxide emissions need to be reduced by 45 per cent by 2030 and reach net-zero emissions by 2050.

Source: Adapted from 'Sustainable Development Goals: Climate Action', United Nations Statistics Division (2023)
<https://unstats.un.org/sdgs/report/2021/goal-13>

The Australian Renewable Energy Agency (ARENA) proposes to establish 'hydrogen hubs', to be built near industries so that the hydrogen gas can be stored and used in a local area.

With more wind and solar coming online, there are times when we have excess energy capacity. Rather than spill this energy, we can store it. Hydrogen is a prospective form of storage.

Source: Adapted from Australian Renewable Energy Agency, <www.arena.gov.au>



a. At the heart of the hub is the polymer electrolyte membrane (PEM) electrolyser.

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

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

b. Using a relevant sustainable development goal that applies to the use of the '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

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

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

Question 10 (6 marks)

Hydrogen is a feedstock for another essential chemical, ammonia, which is used extensively for plastics and fertiliser production, and is also being considered as a means of 'exporting energy'.

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

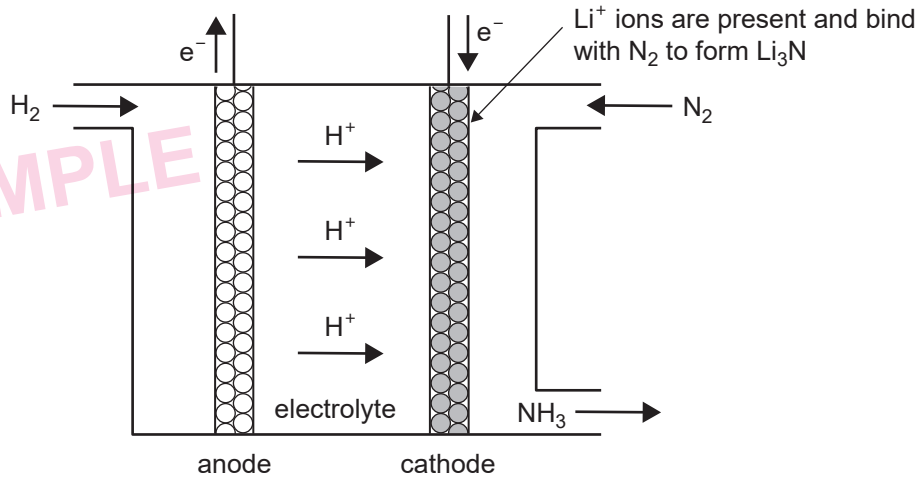
Ammonia is almost exclusively made by the century-old equilibrium-based process, which requires the following conditions:

- pressures of 10 000–25 000 kPa
- temperatures of 400–450 °C
- a porous iron/iron oxide, Fe_3O_4, catalyst.

Even with energy optimisation in place, this one chemical process accounts for 1.5% of global greenhouse gas emissions.

Monash University researchers have recently developed a fuel cell that provides an 'electrochemical synthesis' route to produce ammonia at room temperature and slightly above atmospheric pressure.

A representation of this process is shown below.



Source: Adapted from I Amar et al, 'Solid-state electrochemical synthesis of ammonia: a review', *J Solid State Electrochem* (2011) 15:1845–1860

In this fuel cell, H_2 reacts at the anode to form H^+ ions that are carried across to the cathode by a phosphorus-based compound. At the cathode, N_2 reacts with Li^+ ions to form a lithium-nitride, Li_3N, intermediate that then reacts with the H^+ to form ammonia and the original Li^+ ions. The overall reaction is shown below.

$$N_2(g) + 3H_2(g) \xrightarrow{Li^+} 2NH_3(g)$$

Evaluate whether electrochemical synthesis of ammonia provides a potentially more sustainable method for industry to meet society's needs than the equilibrium-based process.

Your response should include specific reference to:

- the reaction conditions of both the new fuel cell and equilibrium process
- the optimisation of equilibrium reactions for both yield and rate in the equilibrium-based process
- relevant green-chemistry principles.

End of examination questions

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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