SCIENCE TEACHERS ASSOCIATION VICTORIA 2024

TRIAL EXAMINATION

QUESTION AND ANSWER BOOK

Total writing time:
2 hours 30 minutes

CHEMISTRY
UNITS 3 & 4

Student name	

Student ID									**Letter**	

Structure of the trial examination

Section	Number of questions	Number of marks
A	30	30
B	10	90
	Total	**120**

- Students are permitted to bring into the trial examination room: pens, pencils, highlighters, erasers, sharpeners, rulers and a scientific calculator.
- Students are NOT permitted to bring mobile phones and/or any other unauthorized electronic devices into the trial examination room.

Materials supplied

- Questions of 31 pages
- Separate multiple-choice answer sheet.
- Separate data book

Instructions

- Write your name and student number in the space provided on this page and on the multiple-choice answer sheet.
- Unless otherwise indicated, the diagrams in this trial examination are **not** drawn to scale.
- All written responses must be in English.

At the end of the trial examination

- Hand in your trial examination answers and your multiple-choice answer sheet.

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Section A − Multiple-choice questions

Instructions

- Answer **all** questions 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

Which of the following statements regarding bioethanol is correct?

A. Bioethanol is derived from fossil fuels.

B. Bioethanol releases more greenhouse gases than petrol when combusted.

C. Bioethanol releases fewer greenhouse gases than fossil fuel-derived ethanol when combusted.

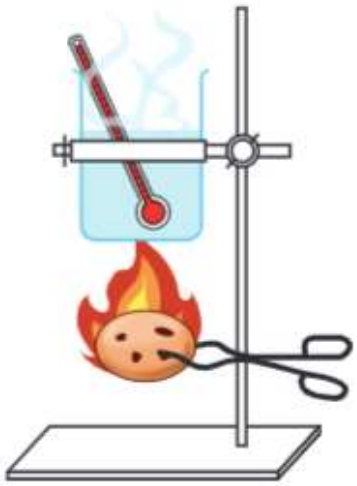
D. Bioethanol is derived from plants such as sugar cane.

Question 2

When 2.00 mol of propane is completely combusted at SLC, which of the following is released?

	mass of CO_2 (g)	energy (kJ)
A.	88.0	2220
B.	88.0	4440
C.	264	2220
D.	264	4440

Use the following information to answer Questions 3 and 4.



3.40 g of biscuit was burnt under a beaker containing 85.24 g of water as shown on the left.

Initial temperature of the water: 22.50°C

Final temperature of the water: 38.25°C

Question 3

The calculated energy content, in kJ g^{-1}, of the biscuit is closest to

A. 0.224

B. 1.65

C. 3.28

D. 19.1

Question 4

What would be the least important source of error in this experiment?

A. lack of insulation

B. the thermometer touching the bottom of the beaker

C. not stirring the water

D. the resolution of the measuring cylinder

Question 5

A packet of sliced cheese provides the following information.

Nutritional information Servings per package: 30 Serving size: 17 g (one slice)	
	Average quantity per 100 g
protein	24.2 g
fat, total	35.3 g
carbohydrate, total	1.4 g

When one slice of cheese is completely digested, the energy provided by the protein is closest to

A. 14 kJ

B. 24 kJ

C. 70 kJ

D. 411 kJ

Question 6

The correct order of increasing boiling point of the following compounds is

A. propanoic acid, propan-1-ol, propan-1-amine, propane

B. propanoic acid, propan-1-amine, propan-1-ol, propane

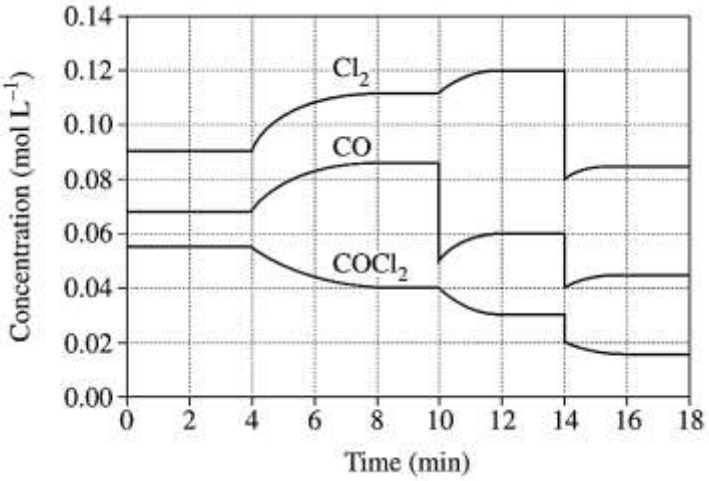
C. propane, propan-1-amine, propan-1-ol, propanoic acid

D. propane, propan-1-ol, propan-1-amine, propanoic acid

Question 7

The graph below shows a concentration-time graph for the following reaction.

$$CoCl_2(aq) \rightleftharpoons Cl_{2(g)} + CO(g) \quad \Delta H = +108 \text{ kJ mol}^{-1}$$



Which of the following changes were made at 4, 10 and 14 mins, respectively?

A. temperature increase; removal of some CO(g); increased volume of container

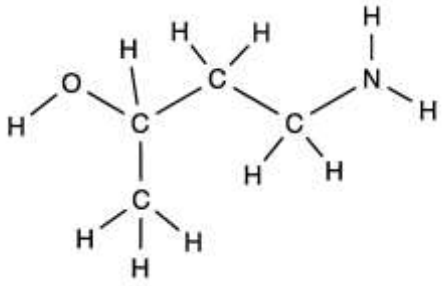
B. temperature increase; removal of some CO(g); decreased volume of container

C. temperature decrease; removal of some CO(g); increased volume of container

D. temperature decrease; removal of some CO(g); decreased volume of container

Question 8

What is the correct IUPAC name of the following molecule?



A. 1-aminobutan-3-ol

B. 4-aminobutan-2-ol

C. 2-hydroxybutan-4-amine

D. 3-hydroxybutan-1-amine

Question 9

In a protein, hydrogen bonding takes place during the formation of the

A. secondary, tertiary and quaternary structures only.

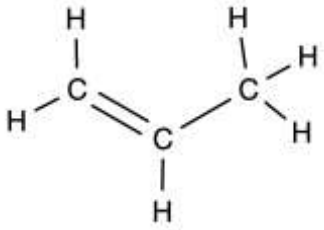
B. primary, secondary and tertiary structures only.

C. tertiary and quaternary structures only.

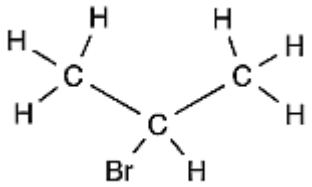
D. primary and tertiary structures only.

Question 10

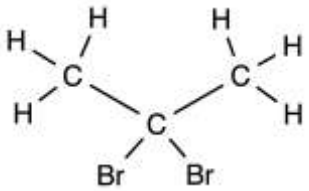
If the following molecule is reacted with Br_2, what would be the expected product?



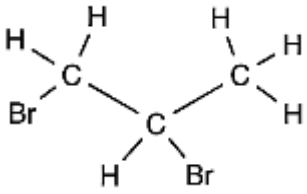
A.



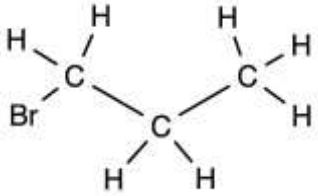
B.



C.



D.



Question 11

A chemist orders three batches of benzoic acid from three different sources. To test their purity, she experimentally measured the melting points of the samples. The melting point of pure benzoic acid is 122.3°C. Her results are shown below.

	Batch 1	**Batch 2**	**Batch 3**
melting point (°C)	122.1 – 122.5	119.7 – 121.1	122.2 – 122.4

The conclusion she can make about the purity of the samples is

A. They all have similar melting points to the expected value so are all pure.

B. Batch 2 contains impurities as its melting point is lower than expected.

C. Batch 2 contains impurities as its melting point is lower than expected and it melts over a larger range.

D. Batch 2 contains impurities as there are fewer types of bonds present in the solid so its melting point is lower than expected.

Question 12

How many signals would the following aldehyde molecule have in ^{1}H and ^{13}C NMR?

$$(CH_3)_3CCH_2CHO$$

A. 3 in ^{1}H and 4 in ^{13}C NMR

B. 5 in ^{1}H and 6 in ^{13}C NMR

C. 5 in ^{1}H and 4 in ^{13}C NMR

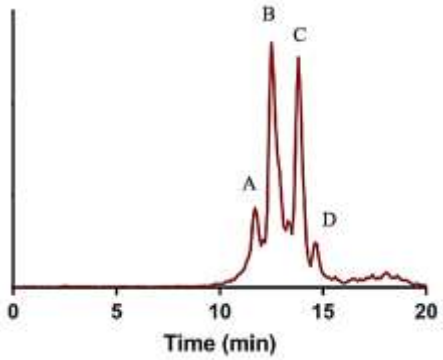
D. 3 in ^{1}H and 6 in ^{13}C NMR

Use the following information to answer Questions 13 and 14.

High performance liquid chromatography (HPLC) was used to detect a performance-enhancing drug in an athlete's urine. A non-polar stationary phase was used.

Question 13

The chromatogram is shown below.

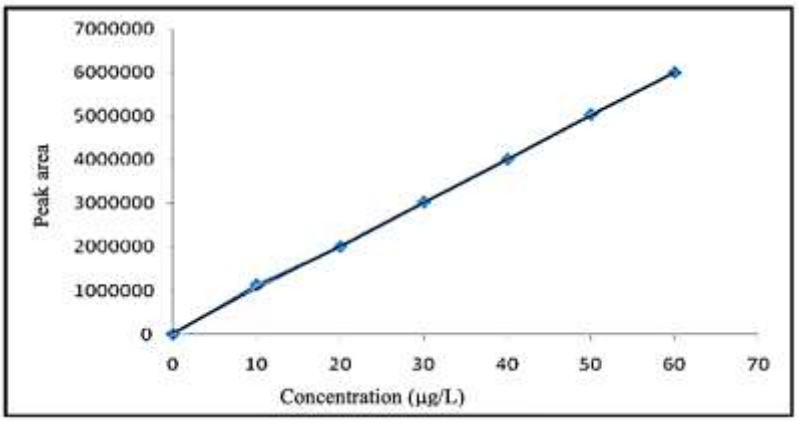


Which of the following statements regarding peaks A − D is correct?

A. Peak A represents the least polar substance.
B. Peak B represents the substance with the lowest concentration in the urine.
C. Peak D represents the least polar substance.
D. Peak A represents the substance with the strongest affinity to the stationary phase.

Question 14

Quantitative analysis on the drug in the athlete's urine was then carried out using HPLC. The calibration curve produced by running standard solutions of the drug through an HPLC column is shown below.



A 10.0 mL aliquot of the urine was diluted to 100.0 mL using deionised water. A sample of the diluted urine was run through the HPLC column under identical conditions to those used to obtain the calibration curve. The peak area obtained for the diluted urine was 2500000.
The mass of the drug, in µg, in 250 mL of the undiluted urine is closest to

A. 6.3
B. 25
C. 63
D. 250

Question 15

Which one of the following molecules has a chiral centre?

A. $CH_3CH_2CH_2CH_2OH$

B. $CH_3CHCHCH_3$

C. $(CH_3)_2CHOH$

D. $CH_3CHOHCH_2CH_3$

Question 16

Consider the following reaction: $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $K = 2.00\ M^{-1}$

What is the value of K for $NO_2(g) \rightleftharpoons NO(g) + ½\ O_2(g)$ at the same temperature?

A. 0.250

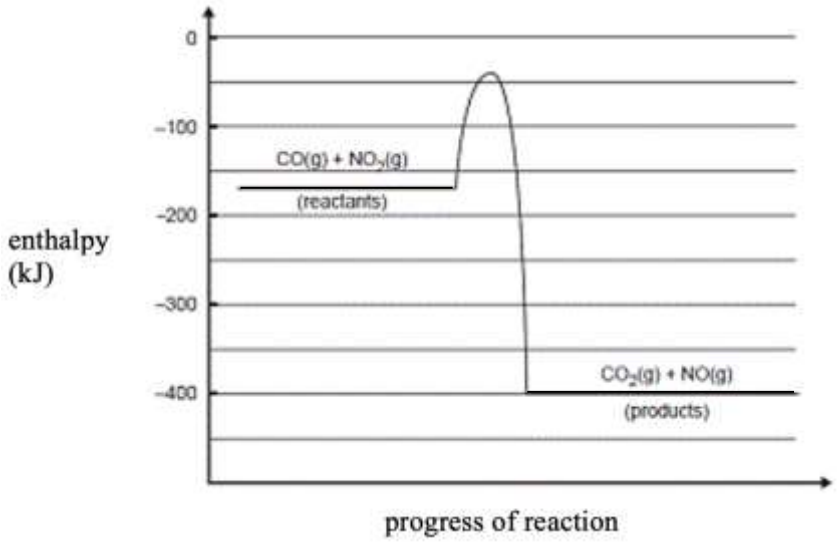
B. 0.707

C. 1.00

D. 1.41

Question 17

A reaction's energy profile diagram is shown below.



The value for the activation energy, in kJ, for the reverse reaction is

A. –130

B. 130

C. –360

D. 360

Question 18

Consider the following unbalanced redox reaction.

$$Ru(s) + Cl^-(aq) + NO_3^-(aq) + xH^+(aq) \rightarrow RuCl_6^{3-}(aq) + NO_2(g) + yH_2O(l)$$

The correct values for x and y in the balanced equation, and the correct identification of the oxidising agent is

A. $x = 3$; $y = 3$; $NO_3^-(aq)$ is the oxidising agent

B. $x = 6$; $y = 3$; $NO_3^-(aq)$ is the oxidising agent

C. $x = 3$; $y = 3$; Ru(s) is the oxidising agent

D. $x = 6$; $y = 3$; Ru(s) is the oxidising agent

Use the following information to answer Questions 19 and 20.

The overall redox reaction in a particular alkaline battery when discharging is

$$Zn(s) + 2MnO_2(s) + H_2O(l) \rightarrow Zn(OH)_2(s) + Mn_2O_3(s)$$

Question 19

The half-equation of the reaction occurring at the positive electrode is

A. $2MnO_2(s) + H_2O(l) + 2e^- \rightarrow Mn_2O_3(s) + 2OH^-(aq)$

B. $2MnO_2(s) + 2H^+(aq) + 2e^- \rightarrow Mn_2O_3(s) + H_2O(l)$

C. $Zn(s) + 2OH^-(aq) \rightarrow Zn(OH)_2(s) + 2e^-$

D. $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

Question 20

The mass of zinc consumed if the battery operates at 550 mA for 10.0 hours is closest to

A. 0.112 g

B. 6.71 g

C. 13.4 g

D. 6.71 kg

Question 21

The following methods can be used to alter reaction rates.

I increase the temperature

II decrease the temperature

III increase the pressure

IV use a catalyst

Which of the above methods will increase the rate of the forward reaction in the following reaction?

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -\text{value}$$

A. I, III and IV only

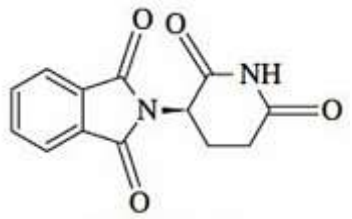
B. II, III and IV only

C. I and IV only

D. I and III only

Question 22

Thalidomide was used as a drug to treat morning sickness but its enantiomer caused terrible birth defects. The structure of thalidomide is shown below.



The molecular formula of thalidomide is

A. $C_{13}H_{10}N_2O_4$

B. $C_{13}H_{16}N_2O_4$

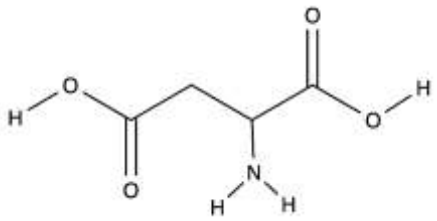
C. $C_{15}H_{10}N_2O_4$

D. $C_{15}H_{16}N_2O_4$

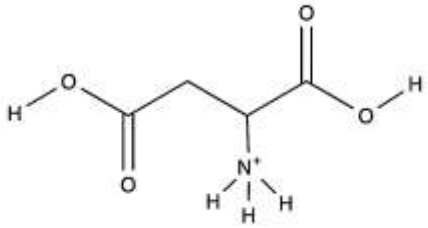
Question 23

Which of the following skeletal structures shows aspartic acid as a zwitterion?

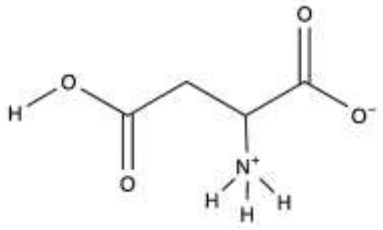
A.



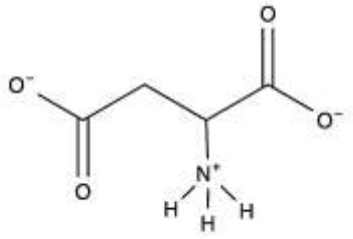
B.



C.



D.



Question 24

When a catalyst is used in a reaction, which of the following is affected?

A. change in enthalpy

B. activation energy

C. equilibrium constant

D. all of the above

Question 25

Consider the following reaction: $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = +value$

Which of the following actions would increase the yield of NO_2?

A. adding a catalyst

B. decreasing the volume of the container

C. decreasing the pressure

D. decreasing the temperature

Question 26

An alkaline nickel-metal hydride (NiMH) battery is a rechargeable battery that uses a hydrogen-absorbing alloy (*M*) as one of the electrodes. The following reaction occurs during **recharge**.

$$Ni(OH)_2(s) + M(s) \rightarrow NiO(OH)(s) + MH(s)$$

The equation occurring at the negative electrode during **discharge** is

A. $MH(s) + OH^-(aq) \rightarrow M(s) + H_2O(l) + e^-$

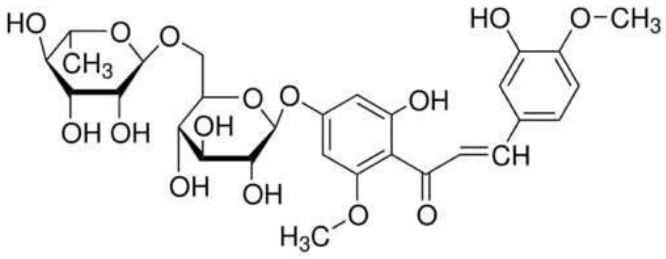
B. $M(s) + H_2O(l) + e^- \rightarrow MH(s) + OH^-(aq)$

C. $NiO(OH)(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq)$

D. $Ni(OH)_2(s) + OH^-(aq) \rightarrow NiO(OH)(s) + H_2O(l) + e^-$

Question 27

Hesperidin methyl chalcone has many antioxidant and anti-inflammatory properties. It has been found in the leaves of several Australian native plants. Its structure is shown below.



The most suitable solvent for its extraction from the leaves is

A. a mixture of water and ethanol

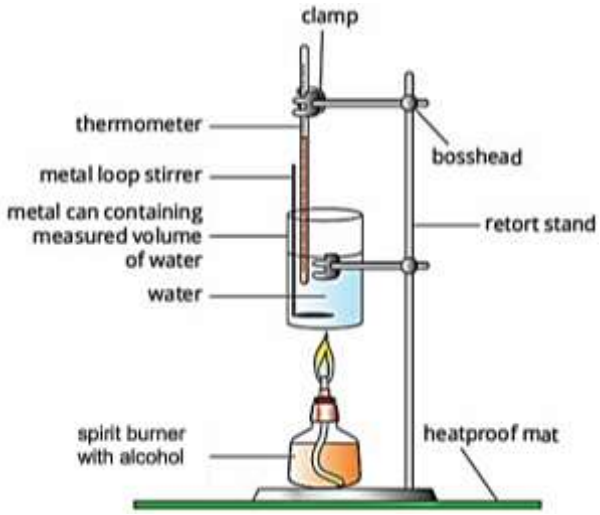
B. tetrachloromethane

C. pentane

D. hexane

Use the following information to answer Questions 28 and 29.

Damian is designing an experiment to determine the heats of combustion of three different alcohols. The set up is shown below.



Question 28

What is the independent variable of his experiment?

A. the amount of water used

B. the temperature change of the water

C. the amount of alcohol used

D. the type of alcohol used

Question 29

To verify the reproducibility of his experiment, Damian should

A. do more repetitions for each type of alcohol.

B. increase the range of alcohols used.

C. get another group of students to repeat his experiment using a similar method.

D. get another group of students to repeat his experiment using different alcohols to him.

Question 30

When the temperature is lower than the optimum temperature of an enzyme, the enzyme activity is decreased because

A. the shape of the active site has been altered so it is no longer complementary to the shape of the substrate.

B. the average kinetic energy of the particles is lower so the frequency of successful collisions between enzyme and substrate is lower.

C. the concentration of the substrate is lower at lower temperatures.

D. the enzyme is denatured at lower temperatures.

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 (9 marks)

Mohammed is investigating an oil, consisting of a triglyceride made from **palmitoleic acid**, and its ability to produce biodiesel.

a. Mohammed reacts a sample of the oil with iodine to check its unsaturation. The molar mass of the triglyceride is 800.0 g mol^{-1}.

Calculate the mass, in grams, of I_2 that would react with 100 g of this oil.

_____

_____

_____

_____

_____

_____

_____

3 marks

b. He then treats another sample of the oil with methanol, using a KOH catalyst, to produce biodiesel. The molar mass of the biodiesel is 268.0 g mol^{-1}.

Write the **semi-structural** formula of the biodiesel molecule.

_____

1 mark

c. Mohammed completely combusts a 14.26 g sample of the biodiesel at SLC.

i. Write a balanced chemical equation for this combustion reaction.

_____

2 marks

ii. Calculate the expected volume of greenhouse gases that would be produced.

_____

_____

_____

_____

_____

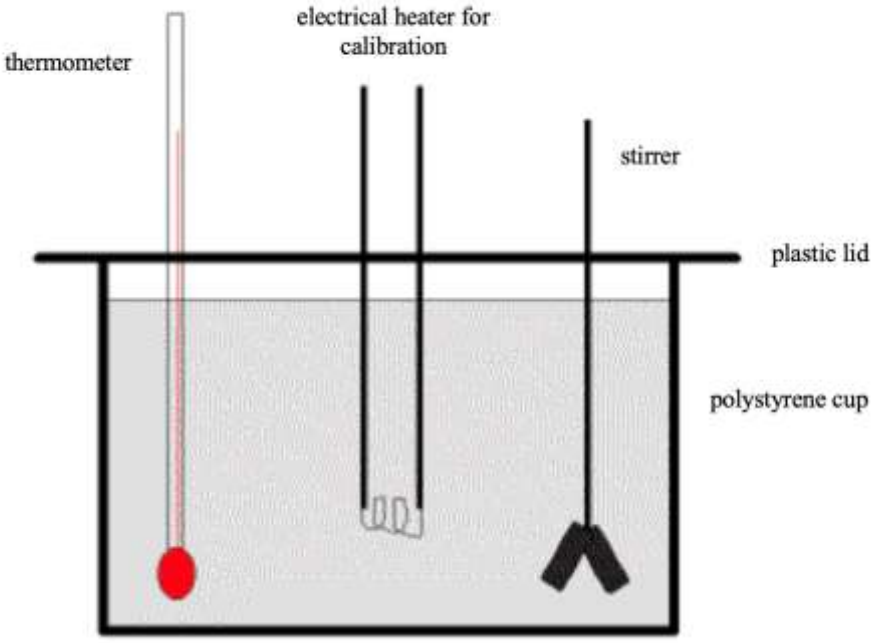
3 marks

Question 2 (7 marks)

Anna used a polystyrene cup to act as a solution calorimeter to determine the molar enthalpy change for the reaction between hydrochloric acid and magnesium metal. The thermochemical equation for this reaction is

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \qquad \Delta H = -457 \text{ kJ mol}^{-1}$$

A set-up of the experiment is shown below.



a. She calibrated the solution calorimeter by passing a potential difference of 5.45 V with a current of 1.80 A for 6.00 minutes through the 100 mL of water. The temperature of the water increased by 6.9°C.

Calculate the calibration factor of the calorimeter in kJ $°C^{-1}$.

_____

_____

_____

_____

_____

2 marks

b. Anna reacted 100 mL of 0.20 M HCl with 0.18 g of Mg in the calorimeter and measured the temperature increase. The temperature of the solution increased by 5.1°C.

i. Determine which reactant is limiting. Show all working.

_____

_____

_____

_____

_____

2 marks

ii. Calculate the experimental molar enthalpy change for this reaction based on Anna's results.

_____

_____

_____

_____

_____

2 marks

iii. State a potential reason for the difference between the experimental and published ΔH values.

_____

_____

1 mark

Question 3 (7 marks)

Consider the following reaction.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad K = 0.052\ M^{-2} \text{ at } 400°C$$

a. A mixture in a 2.0 L container was found to have 2.0 mol N_2, 1.8 mol H_2 and 0.50 mol NH_3.

Is this mixture at equilibrium? Show all working.

3 marks

b. Would increasing or decreasing the pressure of an equilibrium mixture of this reaction increase the yield of NH_3? Explain your choice, referring to Le Chatelier's Principle.

3 marks

c. Some $NH_3(g)$ was removed from an equilibrium mixture of this reaction. Will this lead to an increase or decrease in the rate of the forward reaction as equilibrium is re-established?

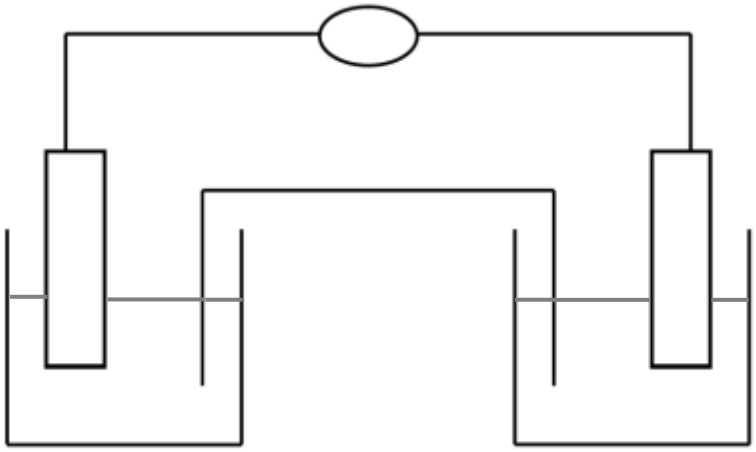
1 mark

Question 4 (8 marks)

A galvanic cell, shown below, was set up using $Ag^{+}(aq)$ / Ag(s) (left hand side) and $Pb^{2+}(aq)$ / Pb (s) (right hand side) half-cells at standard conditions.

a. On the diagram below, label the
- anode and cathode and their polarity
- electrode materials
- electrolytes
- direction of electron flow
- possible salt bridge composition and direction of ion flow

5 marks



b. Determine the expected cell potential difference.

_____

1 mark

c. Less than this voltage was observed. Give **two** reasons this may be the case.

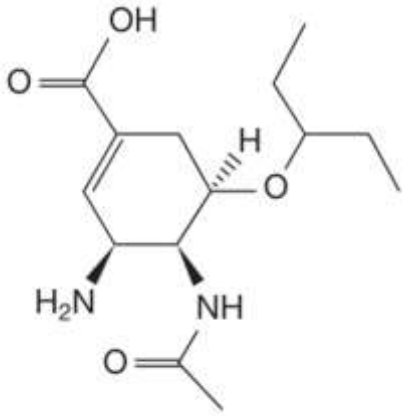
_____

_____

2 marks

Question 5 (10 marks)

Tamiflu, shown below, is a drug that has been developed to treat influenza.



a. Circle and name **three** different functional groups on the Tamiflu molecule above.

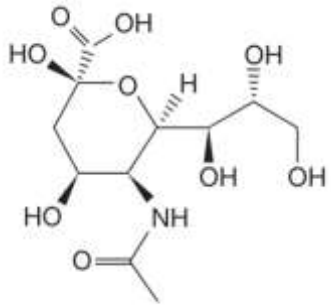
3 marks

b. How many chiral centres are there per molecule? _____

1 mark

c. Tamiflu is a competitive inhibitor of the neuraminidase enzyme on the surface of the influenza viral particles in the lungs. It stops the process of viral replication so the viruses cannot spread to more cells.

The natural substrate of the enzyme is sialic acid, shown below. Explain how Tamiflu acts as a competitive inhibitor of the enzyme. You may use diagrams as part of your response.



Sialic acid

_____

_____

_____

_____

_____

2 marks

d. A pharmacologist wants to test the effectiveness of a new neuramidase inhibitor drug in humans. Before human trials, she plans to incubate the medicine with the enzyme and observe the effect on enzyme activity.

i. Apart from how the dependent variable is measured and the concentration or amount of the enzyme, state **two** reaction conditions that will need to be kept constant and state the approximate value for these conditions she should use.

_____

_____

2 marks

ii. Explain what would happen if these conditions are not controlled.

_____

_____

_____

_____

2 marks

Question 6 (8 marks)

The ethanol content of a sample of wine was determined by a redox titration with acidified potassium dichromate. The ethanol is oxidised to ethanoic acid.

A 25.00 mL sample of wine was diluted to 250.0 mL in a volumetric flask. 20.00 mL aliquots of the diluted wine were titrated against a 0.175 M acidified potassium dichromate solution. The average concordant titre was 18.20 mL.

a. The ionic half-equation for the reduction reaction is

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$$

Write the half-equation for the oxidation reaction and the balanced equation for the overall reaction.

_____

_____

_____

_____

2 marks

b. Calculate the amount, in moles, of $Cr_2O_7^{2-}$ in the average concordant titre.

_____

_____

1 mark

c. Calculate the amount, in moles, of ethanol in the 20.00 mL aliquot of diluted wine.

_____

_____

1 mark

d. Calculate the amount, in moles, of ethanol in the 250.0 mL volumetric flask of diluted wine.

_____

_____

1 mark

e. Calculate the concentration of ethanol in the undiluted wine in mol L^{-1}.

_____

_____

1 mark

f. The students rinsed the volumetric flask with the undiluted wine before pipetting in the 25.00 mL sample. Would their calculated concentration of ethanol be higher or lower than the expected value due to this error? Explain, stating the effect it would have on the titre values.

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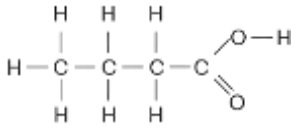
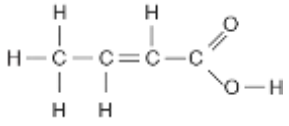
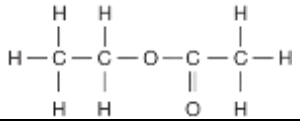
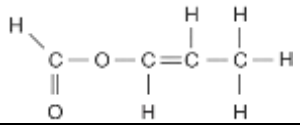
2 marks

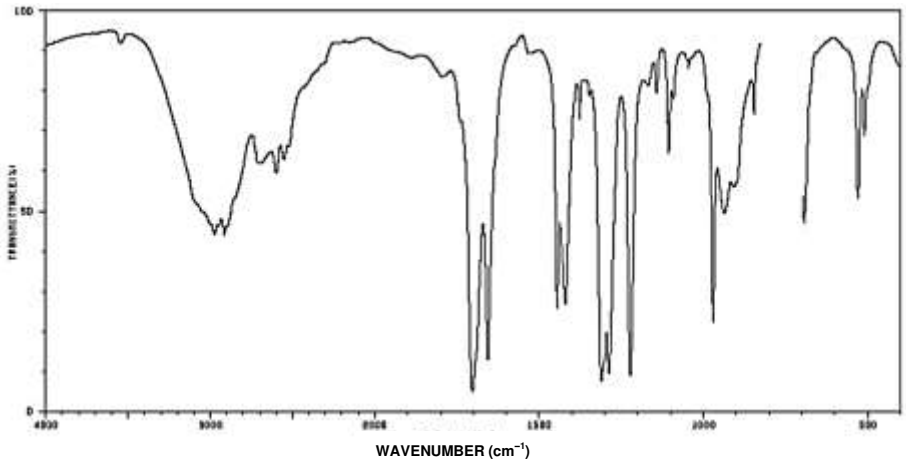
Question 7 (9 marks)

A chemist finds an unlabelled container of a chemical and needs to determine its identity. She has decided it could be one of the following four compounds.

A) 	B) 
C) 	D) 

She performed IR spectroscopy, ^{1}H and ^{13}C NMR, and mass spectrometry on the sample in order to determine its structure therefore identity.

a. The infrared spectrum is shown below.



Using just the region of the IR spectrum 2000 – 4000 cm^{-1}, she narrowed it down to two possible compounds. Give the letters (A − D) of these two compounds, outlining your reasoning with evidence from the spectrum.

_____

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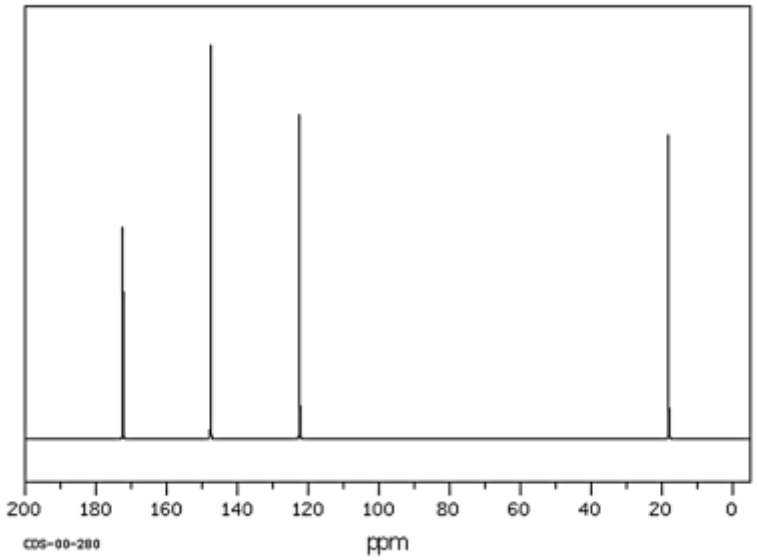
_____

3 marks

b. The ^{13}C NMR spectrum is shown below. She used this spectrum to further narrow it down to one possible compound.



Give the letter (A − D) of this compound, outlining your reasoning with evidence from the spectrum.

_____

_____

_____

_____

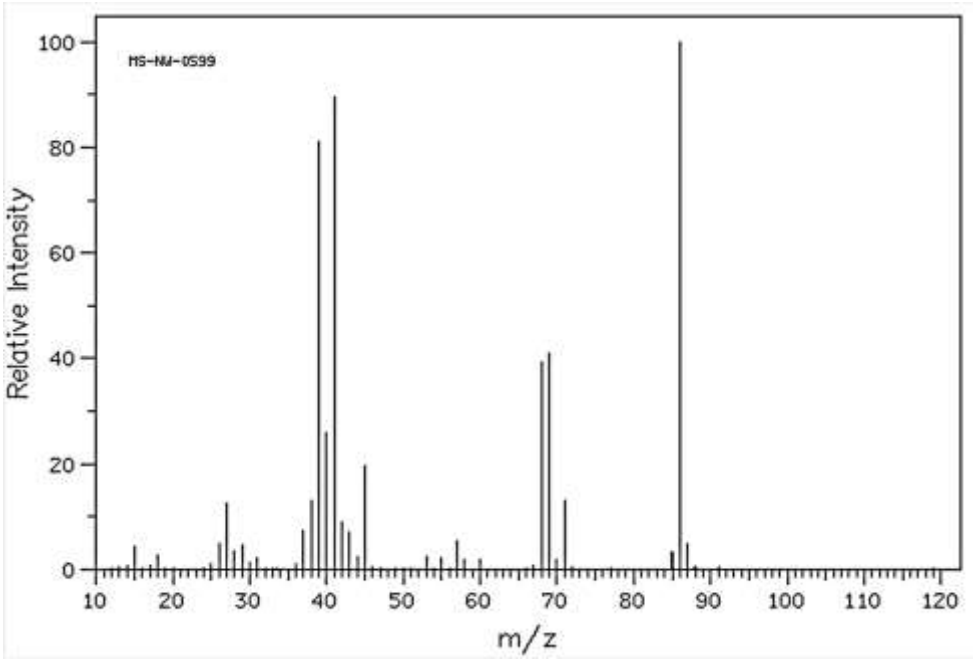
2 marks

c. How many peaks would she have seen on a low-resolution ^{1}H NMR spectrum of this compound?

_____

1 mark

d. The mass spectrum of the compound is shown below.



i. There is a prominent peak at m/z = 41. Identify a possible fragment that has produced this peak.

_____

1 mark

ii. Give one piece of evidence that supports the mass spectrum belonging to the compound you have chosen.

_____

_____

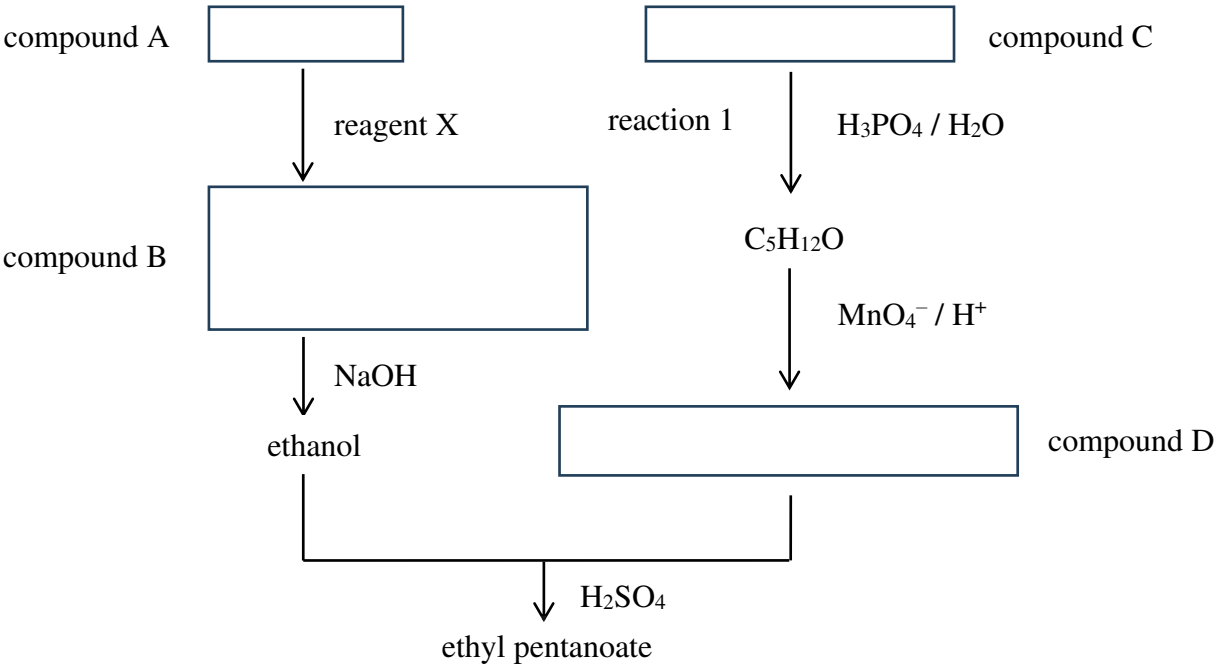
1 mark

e. Draw a skeletal structure for the compound you have chosen.

1 mark

Question 8 (12 marks)

The reaction pathway below represents the synthesis of ethyl pentanoate, an ester commonly used as a food additive to impart the fruity flavour of apples.
Compound A is a alkane.



a. Identify reagent X _____ 1 mark

b. In the appropriate boxes above, write the

i. molecular formula for compound A.

ii. structural formula for compound B.

iii. the systematic IUPAC name for compound C.

iv. the semi-structural formula for compound D. 4 × 1 = 4 marks

c. Reaction 1 produces another structural isomer of $C_5H_{12}O$. The mixture of the two isomers must be separated by fractional distillation.

i. Will the isomer with the lower or higher boiling point condense first?

_____

1 mark

ii. Outline a qualitative test to determine which fraction contains which isomer and the expected results from this test.

_____

_____

_____

_____

2 marks

d. Calculate the % atom economy for the production of ethyl pentanoate from ethanol and compound D.

_____

_____

_____

_____

3 marks

e. Referring to **item 26. ii.** from the Data Book, state one way to make the production of ethyl pentanoate more sustainable.

_____

_____

1 mark

Question 9 (12 marks)

Ayushi wants to observe the effect of current on the production of tin, Sn, metal using electrolysis in a school laboratory as part of her Area of Study 3 student-designed scientific investigation.

Her aim is "To determine if increasing the current increases the percentage yield of tin produced at the cathode during electrolysis".

a. Write a suitable hypothesis for this investigation.

_____

_____

1 mark

An extract from her method reads:

1. Weigh two strips of tin and connect them to the circuit in the electrolytic cell containing 60 mL of 1 M $Sn(NO_3)_2$.
2. Pass a current of 1.35 A through the circuit for 15 minutes.
3. Remove both electrodes (noting which is which), rinse with deionised water and dip into a beaker containing acetone.
4. Allow the electrodes to air-dry for 20 minutes.
5. Reweigh both electrodes.
6. Calculate % yield of tin.

b. Give the relevant half-equations occurring at the electrodes in this electrolytic cell.

i. positive electrode: _____ 1 mark

ii. negative electrode: _____ 1 mark

c. The first trial carrying out this method produced the following results

Initial mass of cathode (g)	13.54
Final mass of cathode (g)	14.12

Calculate the % yield of tin from this trial.

_____

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5 marks

d. Ayushi repeated the experiment twice more at this current and made the following observations in her logbook.

- The current keeps fluctuating during the 15 minutes.
- Some tin falls off the cathode each time I rinse it with water.

i. Is the fluctuating current a source of systematic or random error?

_____

1 mark

ii. Due to the tin consistently falling off the cathode, Ayushi makes the decision to use the mass lost at the anode for her calculations instead and writes her communication statement on her poster based on these calculations.

What should Ayushi do to ensure this altered experiment is valid?

_____

1 mark

e. Ayushi looked up the safety data sheet for acetone and noticed the following hazard statements:

- highly flammable liquid and vapour
- causes serious eye irritation
- may cause drowsiness or dizziness
- frequent skin contact may cause dermatitis

Outline **two** safety precautions Ayushi should take when using acetone.

_____

_____

2 marks

Question 10 (8 marks)

Two Australian-built hydrogen-powered buses are currently being trialled across several Melbourne routes in the west, including route 401 between North Melbourne station and Melbourne University.

https://www.transitsystems.com.au/news/2023/11/28/transit-systems-vaporises-emissions-with-new-aussie-built-hydrogen-buses

'Victoria warned against 'very inefficient' hydrogen buses after trial announced'

The Guardian, Fri Nov 24, 2023

- The production of grey hydrogen releases CO_2 and unreacted methane into the atmosphere. Methane is a potent greenhouse gas.
- David Cebon, a professor of mechanical engineering at the University of Cambridge and a member of the hydrogen science coalition, said hydrogen was inefficient because of the energy-intensive process. "It's very, very inefficient. And that means that you use a lot more energy in that process than if you just took electricity and you put it in a battery and then just ran a battery electric bus."
- Prof Scott Hamilton, from Monash University's department of chemical and biological engineering, said buses should use **green hydrogen**, which needs to be independently certified.
  "If it's not, the emissions profile can end up worse than if you were using petrol or other fuels because of the use of fossil fuels and electricity," he said.
- Hydrogen-fuelled vehicles can travel further than electric vehicles without requiring recharging.

The future plan for hydrogen production in Melbourne is for BOC to produce **green hydrogen** at the old Toyota plant in Altona in a new purpose-built Hydrogen Centre of Excellence. The hydrogen refuelling station will dispense hydrogen produced through electrolysis.

https://www.boc-limited.com.au/en/news_and_media/press_releases/news-20210329-boc-toyota-victoria-first-hydrogen-refuelling-station.html

a. Explain how the hydrogen produced at this site will be considered 'green'.

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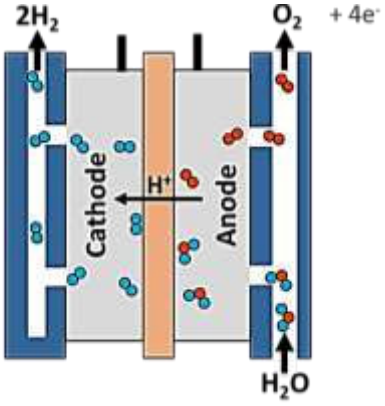
2 marks

b. There are a few possible ways of producing green hydrogen. Two are:

- Electrolysis of purified water using a PEM electrolyser whose electrodes are made from expensive and critically endangered metals such as ruthenium and iridium. Approximately 80% efficient.
- Electrolysis of seawater using a PEM electrolyser whose electrodes are coated in non-precious and cheap catalysts such as cobalt oxide with chromium oxide. Nearly 100% efficient.

Guo J et al (2023) 'Direct seawater electrolysis by adjusting the local reaction environment of a catalyst', Nature Energy, 8(3):264-272.

Diagram of a PEM electrolyser



i. Give the half-equation that occurs at the negative electrode in both types of PEM electrolysers.

_____

1 mark

ii. Referring to the information given above and your own knowledge and understanding of chemistry, decide which of the two methods listed above to produce green hydrogen is the most sustainable. Give a detailed justification for your decision.

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3 marks

c. The traditional method of producing hydrogen is by steam reforming fossil fuels such as natural gas that contains methane. This hydrogen is considered 'grey'.

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H = +206$ kJ mol^{-1}
$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ $\Delta H = -41$ kJ mol^{-1}

Give **two** reasons that the production of green hydrogen is better for the environment than the production of grey hydrogen.

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2 marks

END OF TRIAL EXAMINATION