NESA STUDENT NUMBER

2022

Year 12 Chemistry

Trial Examination

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen.
- Draw diagrams using pencil.
- Show all relevant working in questions involving calculations.
- NESA approved calculators may be used.

Total marks: 100

Section 1 – Multiple Choice **20 marks**
- Attempt Questions 1–20

Section 2A – Written Response **53 marks**
- Attempt Questions 1–10

Section 2B – Written Response **20 marks**
- Attempt Questions 1–4

Section 2C – Written Response **7 marks**
- Attempt Question 1

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Section 1

20 marks

- Attempt Questions **1–20.**
- Use the multiple-choice answer sheet at the **back of section 2A** to answer the multiple-choice questions for Section 1.

S1

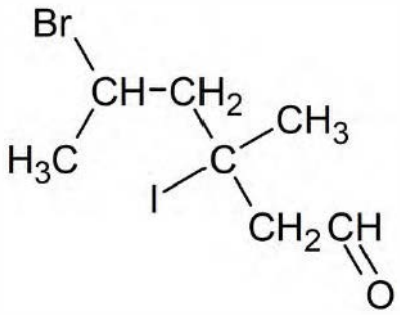
Question 1 (1 mark)

Which of the following correctly identifies the number of isomer(s) that butan-1-ol has?

	Position isomer	Chain isomer
(A)	1	1
(B)	1	2
(C)	2	1
(D)	2	2

Question 2 (1 mark)

The structure of a molecule is given below.



What is the IUPAC name for the structure?

(A) 5-bromo-3-iodo-3-methylhexanal

(B) 3-iodo-3-methyl-5-bromohexanal

(C) 2-bromo-4-iodo-4-methylhexanal

(D) 5-bromo-3-iodo-3-methylhexan-1-one

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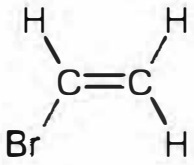
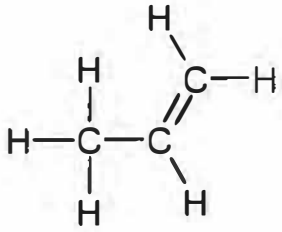
Question 3 (1 mark)

Consider the following structural formulae.

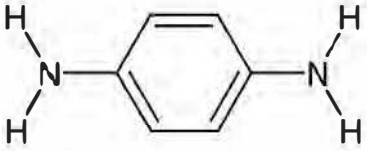
I



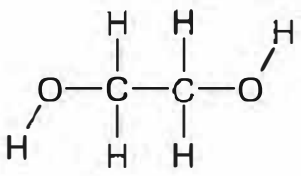
II



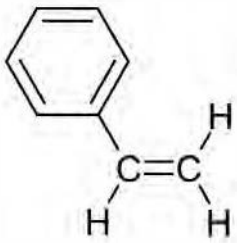
III



IV



V



Which of the following options contains compounds that can form addition polymers?

(A) **I** and **IV**.

(B) **II** and **III**.

(C) **III** and **IV**.

(D) **II** and **V**.

Question 4 (1 mark)

A chemist found two unlabelled bottles and deduced that they were propan-1-ol and butan-1-ol.

Without the use of reference spectra, which of the following instrumental techniques would be LEAST useful in distinguishing the two compounds?

(A) ^{1}**H** NMR spectroscopy

(B) ^{13}C NMR spectroscopy

(C) Infrared spectroscopy

(D) Mass spectrometry

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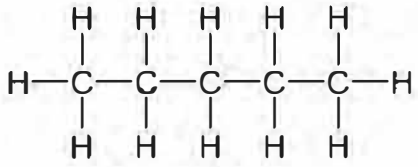
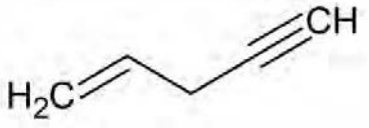
Question 5 (1 mark)

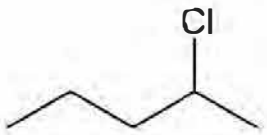
The structures of four organic compounds are shown as follows.



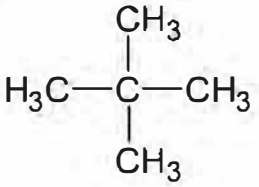
A



B



C



D

What of the following is most likely to be correct?

(A) Compounds **A** and **C** are functional group isomers.

(B) Compound **D** has a lower melting point than **A.**

(C) Compound **D** is more reactive than compound **B.**

(D) Compound **C** is less soluble in water than compound **A.**

Question 6 (1 mark)

Consider the following reaction:

$$Fe_2O_3(s) + 3CO(g) \rightleftharpoons 2Fe(s) + 3CO_2(s)$$

Which of the following row best describes the system at static equilibrium and dynamic equilibrium for the above reaction, respectively?

	Static equilibrium	**Dynamic equilibrium**
(A)	1 mole CO and 1 mole CO_2	1 mole CO and 1 mole CO_2
(B)	1 mole Fe_2O_3 and 2 moles Fe	1 mole Fe_2O_3 and 2 moles CO_2
(C)	3 moles Fe_2O_3 and 9 moles CO	2 moles Fe_2O_3 and 1 mole Fe
(D)	1 mole Fe_2O_3 and 4 moles CO	2 moles Fe and 3 moles CO_2

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Question 7 (1 mark)

The K_a values of some weak acids are shown below.

Acid	K_a
HOBr	2.3×10^{-9}
HOCl	3.5×10^{-8}
HF	7.2×10^{-4}
HCOOH	1.8×10^{-4}

Which of the following acids would produce the strongest conjugate base?

(A) HOBr

(B) HOCl

(C) HF

(D) HCOOH

Question 8 (1 mark)

Which of the following changes takes place when 500 mL of water is added to 500 mL of 1.00 mol L^{-1} acetic acid?

(A) pH increases and percentage ionisation increases.

(B) pH increases and percentage ionisation does not change.

(C) pH decreases and percentage ionisation does not change.

(D) pH decreases and percentage ionisation decreases.

Question 9 (1 mark)

A spirit burner used 26.6 g of ethanol to change 1.00 L of water at 23.5°C to 100.0°C. The molar heat of combustion of ethanol is 1367 kJ mol^{-1}.

What percentage of heat produced from the burner was lost to the environment?

(A) 1.1%

(B) 40.5%

(C) 59.5%

(D) 98.9%

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Question 10 (1 mark)

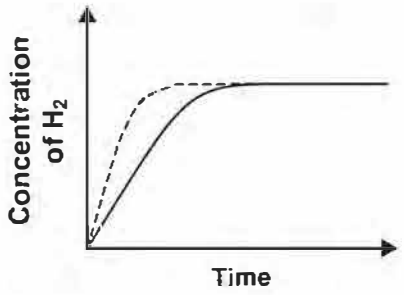
The following reaction is used in some industries to produce hydrogen gas.

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

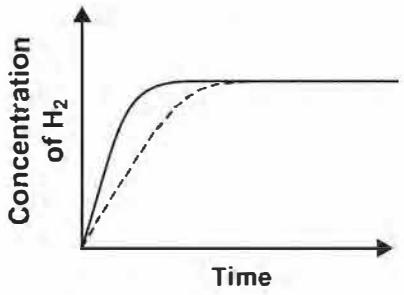
In trials, the reaction is carried out with a catalyst (shown by - - - - - - - line) and without a catalyst (shown by ——— line) in the sealed container. All other conditions are unchanged.

Choose the graph representing the change in hydrogen gas concentration with time between an uncatalysed and a catalysed reaction.

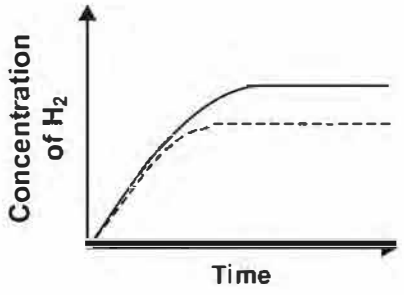
(A)



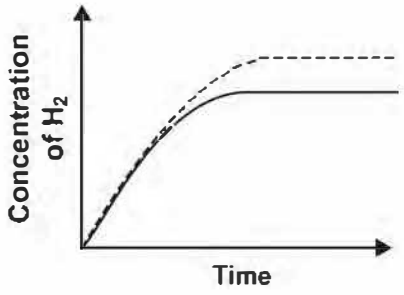
(B)



(C)



(D)



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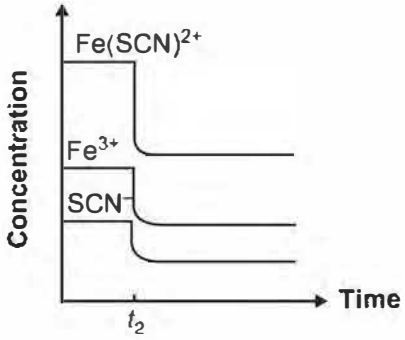
Question 11 (1 mark)

$Fe^{3+}(aq)$ + $SCN^{-}(aq)$ ⇌ $Fe(SCN)^{2+}(aq)$

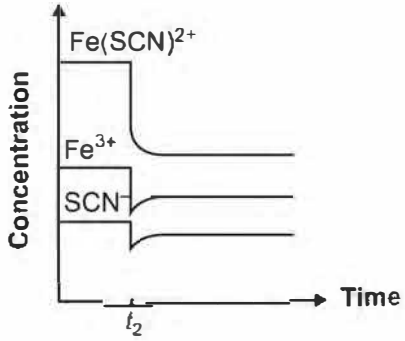
(yellow) (colourless) (red)

Which one of the following best represents the changes in concentration of the above iron(III) chloride and potassium thiocyanate equilibrium mixture, when water was added to the equilibrium mixture at time t_2?

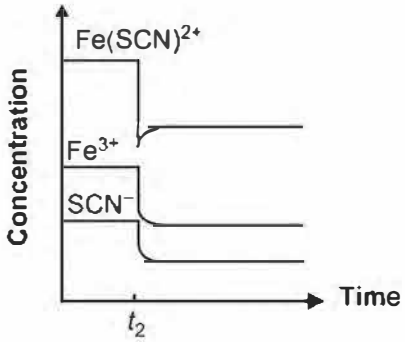
(A)



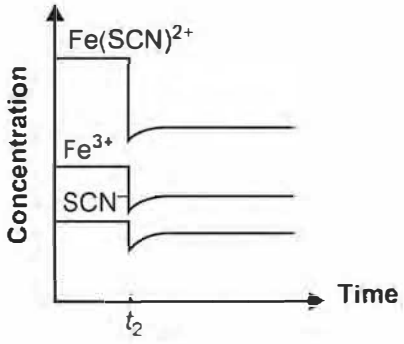
(B)



(C)



(D)



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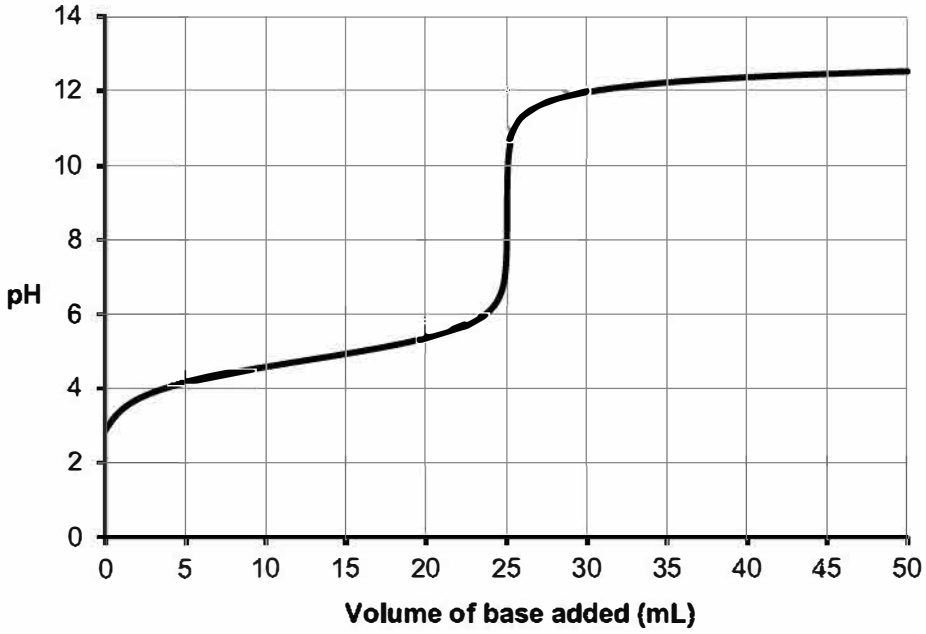
Use the following information to answer Questions 12 and 13.

The diagram below represents the titration curve between a particular acid and a particular base.



Question 12 (1 mark)

Which indicator would be best suited for this titration?

	Indicator	Colour change range (pH)
(A)	Bromophenol blue	6.2 – 7.6
(B)	Magdala red	3.0 – 4.0
(C)	Phenolphthalein	8.2 – 10.0
(D)	Chlorophenol red	5.2 – 6.8

Question 13 (1 mark)

The buffer region for this titration curve may contain:

(A) NaCl and NaOH.

(B) CH_3COOH and CH_3COONa.

(C) NH_3 and NH_4Cl.

(D) NH_3 and CH_3COONH_4.

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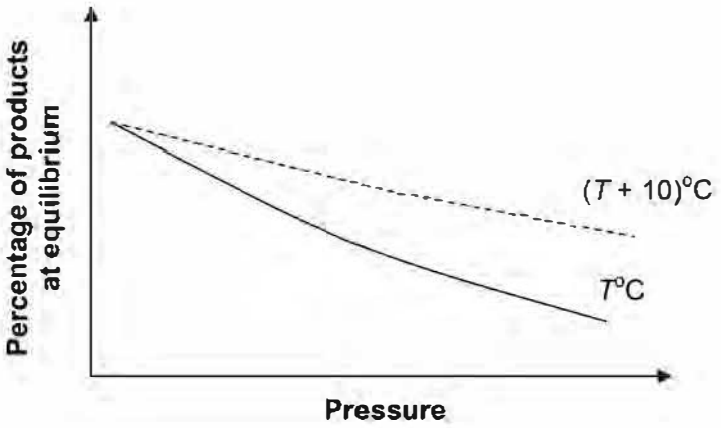
Question 14 (1 mark)

The graph below contains two sets of data to show the variation of the percentage of gaseous products present at equilibrium, with temperature and pressure for a reversible chemical reaction.



Which one of the following chemical reactions could be represented by the data plotted on the graph?

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

(B) $3O_2(g) + 4NH_3(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$ $\Delta H = -1248$ kJ mol^{-1}

(C) $2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g)$ $\Delta H = +82$ kJ mol^{-1}

(D) $CO_2(g) + C(s) \rightleftharpoons 2CO(g)$ $\Delta H = +173$ kJ mol^{-1}

Question 15 (1 mark)

Colourless nitrous oxide (N_2O) reacts with oxygen gas to form brown nitrogen dioxide gas, according to the following equilibrium:

$$2N_2O(g) + 3O_2(g) \rightleftharpoons 4NO_2(g) \qquad \Delta H = -32 \text{ kJ mol}^{-1}$$

0.27 mol of N_2O was placed in a 4.00 L vessel with 0.42 mol of oxygen. The system was allowed to reach equilibrium. At equilibrium 0.15 mol of N_2O remained. The temperature of the vessel was monitored over this time.

Calculate a value for the equilibrium constant at a given temperature.

(A) 10.40

(B) 41.61

(C) 42.67

(D) 53.38

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Question 16 (1 mark)

In a titration of a strong base with strong acid, the following procedure was used:

1. A burette was rinsed with water and then filled with the standard acid.
2. A pipette was rinsed with some base solution.
3. A conical flask was rinsed with some base solution.
4. A pipette was used to transfer a measured volume of base solution into the conical flask.
5. Indicator was added to the base solution, and it was titrated to the endpoint with the acid.

Which of the following statements is correct?

(A) The calculated base concentration will be lower than the actual base concentration.

(B) The calculated base concentration will be the same as the actual base concentration.

(C) The calculated base concentration will be higher than the actual base concentration.

(D) No definite conclusion can be drawn about the calculated base concentration.

Question 17 (1 mark)

The K_{sp} of strontium hydroxide is 2.0×10^{-3}.

What is the pH of a saturated solution of strontium hydroxide?

(A) 0.80

(B) 1.35

(C) 12.65

(D) 13.20

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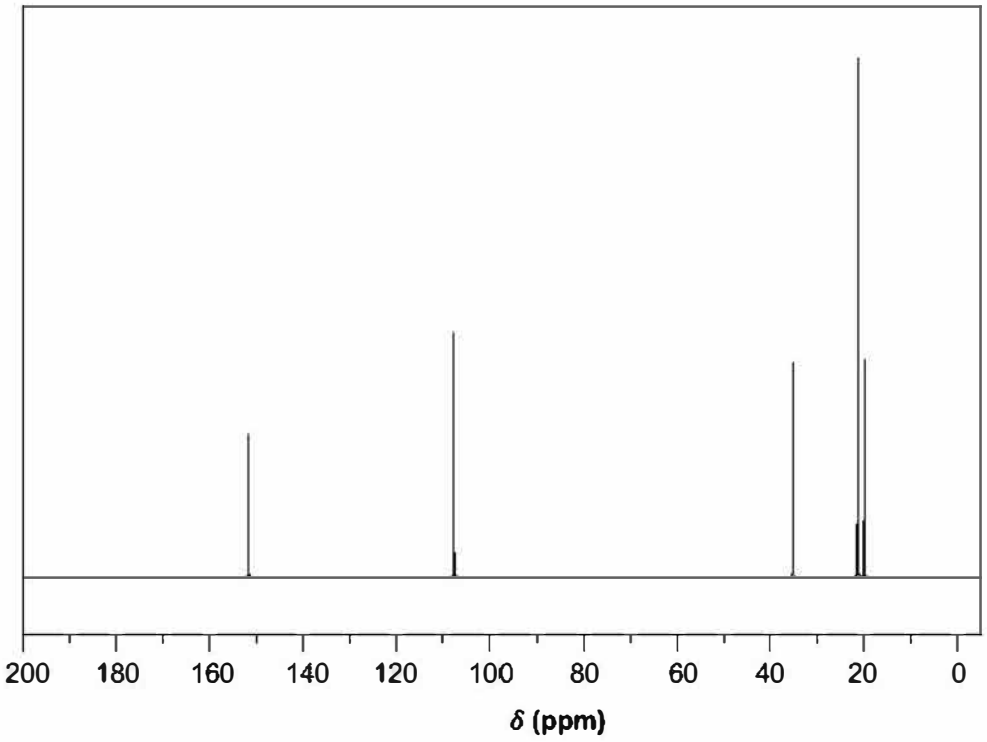
Question 18 (1 mark)

A ^{13}C NMR spectrum is shown.



Which compound gives rise to this spectrum?

(A) Hex-**1**-ene

(B) 2-methylpent-2-ene

(C) 2,3-dimethylbut-**1**-ene

(D) 2,3-dimethylbut-2-ene

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Question 19 (1 mark)

An analytical chemist was provided with a compound **X**. He tested this compound and obtained the following results.

Analysis	**Evidence**
Infrared spectroscopy	Broad absorption at 3385 cm^{-1}
Percentage composition by mass	C = 70.53%, H = 13.81%, O = 15.66%
Mass spectrometry	Molecular ion peak: m/z = 102
Test with acidified potassium dichromate	Orange colour remains upon heating compound **X** with acidified potassium dichromate in a water bath.

Which of the following is a possible structure for the compound **X**?

(A) Hexan-1-ol

(B) 2-methylpentan-3-ol

(C) 3-methylbutanoic acid

(D) 3-methylpentan-3-ol

Question 20 (1 mark)

A sample of 1,2,3,4-tetrachlorobutane was analysed using a mass spectrometer.

The only isotopes present in the compound are hydrogen-1, carbon-12, chlorine-35 and chlorine-37.

Using the above information, determine the number of molecular ion peaks in the mass spectrum of 1,2,3,4-tetrachlorobutane.

(A) 2

(B) 3

(C) 4

(D) 5

END OF SECTION 1

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S2A

2022

Year 12 Chemistry

Trial Examination

Section 2A (53 marks)

Questions 1–10

- Write using a black pen.
- Draw diagrams using pencil.
- Show all relevant working in questions involving calculations.
- NESA approved calculators may be used.

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Section 2A

53 marks

- Attempt Questions 1–10.
- If you use the extra space provided at the back of this exam, clearly indicate which question you are answering.

Marks

Question 1 (6 marks)

Methane and steam can react to form carbon monoxide and hydrogen according to the equation.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +131 \text{ kJ mol}^{-1}$$

4.0 moles of methane and 5.0 moles of steam are placed into a sealed 2.0 litre container which is heated to 450°C and allowed to react until equilibrium is reached.

Measurements show that there are 1.5 moles of methane in the container at equilibrium.

(a) Determine the number of moles of the other gases at equilibrium. **3**

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(b) Write the expression for the equilibrium constant for this reaction. **1**

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(c) Determine the numerical value for the equilibrium constant at 450°C. **2**

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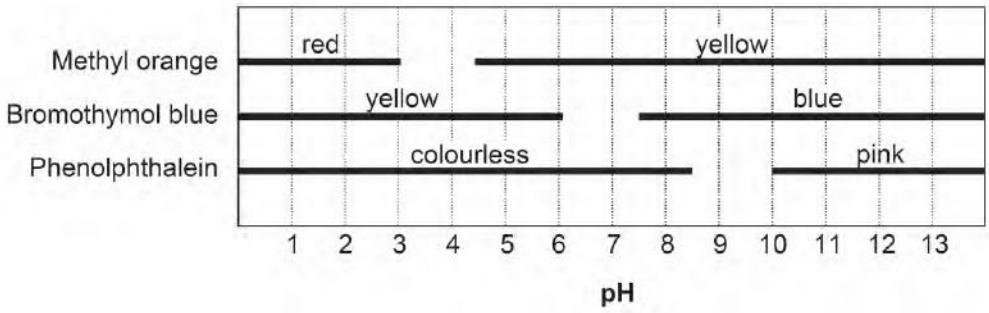
Marks

Question 2 (3 marks)

Maintenance of any swimming pool requires regular monitoring of the pH level of the water. A suitable indicator may be used to ensure that the pH of the pool water is nearly neutral and lies in a very narrow range close to pH = 7. **3**



Ben tested the water in his pool, then used the indicator chart above to make relevant observations.

With reference to each of the indicators in the chart, explain which indicator(s) would be best suited to determine the safety of the pool water.

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Question 3 (4 marks)

Calculate the pH of the resulting solution when 25.0 mL of 0.010 M KOH is mixed with 50.0 mL of 0.20 M H_2SO_4, assuming that sulfuric acid undergoes complete ionisation. **4**

Question 4 (3 marks)

Explain the use of KH_2PO_4 to neutralise strong acid and base spills with reference to its chemical properties. **3**

Support your answer with relevant equations.

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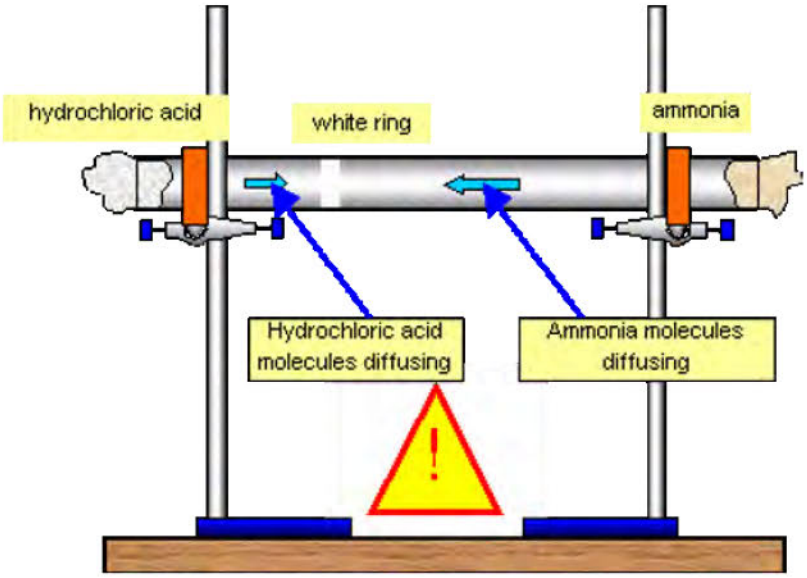
Marks

Question 5 (6 marks)

The Chemistry class of 2022 NBHS conducted an experiment to demonstrate diffusion of gases. The students set up the apparatus as shown below.



Two plugs of cotton wool are put into the ends of a horizontal glass tube. One was soaked with concentrated hydrochloric acid and the other with concentrated ammonia.

After a few minutes, a white ring formed in the tube and the ring was closer to the end of the tube where the hydrochloric acid plug was.

(a) Write a balanced chemical equation that occurs in the above experiment and assess the suitability of Arrhenius' theory to classify it as an acid-base reaction. **2**

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Question 5 continues on the next page

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Marks

Question 5 continued…

(b) The Chemistry Class of 2022 NBHS conducted an experiment where some metallic iron surfaces were cleaned using a process known as pickling. The surfaces had some brown rings due to the formation of rust. **4**

Iron(III) oxide (Fe_2O_3) is a base and the main component of rust. It is insoluble in water but highly soluble in HCl. During pickling the students dipped the steel surfaces in a liquid mixture called pickling liquor containing HCl.

This led to the dissolution of the iron(III) oxide in HCl. The reaction can be shown as:

$$Fe_2O_3(s) + 6HCl(aq) \rightarrow 2FeCl_3(aq) + 3H_2O(l)$$

They were then able to clean off all the brown rings and make the surfaces lustrous.

State whether iron(III) oxide $Fe_2O_3(s)$, can be classified as a Bronsted-Lowry acid/base or an Arrhenius acid/base. Justify your response.

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Marks

Question 6 (6 marks)

A sample of 25.0 mL of 0.120 mol L^{-1} of standardized solution of ammonium hydroxide was titrated against nitric acid, obtained from an unlabelled bottle. The results were recorded in the table below.

Titration	Volume of nitric acid (mL)
1	18.2
2	18.1
3	21.4
4	18.1

(a) Calculate the concentration of nitric acid solution. **3**

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(b) Using a chemical equation, explain the pH of the resultant salt solution. **3**

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Marks

Question 7 (6 marks)

A special red wine manufacturer from the Hunter region claims its alcohol content as 40.0%(v/v).

Bobby decides to test this claim and conducts a volumetric titration using a sample of the red wine against a standard solution of potassium permanganate, $KMnO_4$, to determine the ethanol content in the red wine.

He transfers a 50.00 mL sample of the above red wine into a 500.0 mL volumetric flask and makes up to the mark with distilled water. He then transfers 20.00 mL aliquot from the volumetric flask into a conical flask, adds an appropriate indicator and titrates against a 0.5022 mol L^{-1} solution of $KMnO_4$.

The reaction is recorded as:

$$4MnO_4^-(aq) + 5C_2H_5OH(aq) + 12H^+(aq) \rightarrow 4Mn^{2+}(aq) + 5CH_3COOH(aq) + 11H_2O(l)$$

The (MnO_4^-) ion has an intense purple colour while the Mn^{2+} ion is colourless. The average of the concordant titres is recorded as 23.22 mL.

(a) The density of ethanol is 0.789 g mL^{-1}. **4**

Calculate the concentration of ethanol in %(v/v) in the red wine that Bobby titrated.

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Question 7 continues on the next page

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Marks

Question 7 continued...

(b) Bobby performed some research and found some interesting information about this titration: **2**

- Mn^{2+} can act as a catalyst for the reduction of MnO_4^- ions.
- A brown solid, most likely MnO_2 forms during this titration, which may have been produced from the incomplete reduction of MnO_4^- ions.
- These MnO_4^- ions would therefore oxidise a smaller amount of ethanol.

Using your explanation, assess the manufacturer's claim.

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NESA STUDENT NUMBER

Marks

Question 8 (6 marks)

Darren conducted a titration between a strong acid HZ and a strong base MOH for investigating titration curves to study characteristic reaction profiles.

He used 0.10 mol L^{-1} of each solution. He added 50 mL of the acid HZ in a clean conical flask and inserted a pH probe to measure the pH of the solution in the conical flask during the titration. He recorded observed values of his experiment in the following table.

#	Volume of MOH added (mL)	pH of HZ
1	0	1.0
2	25	
3	49	
4	50	7.0
5	51	
6	75	12.3

(a) Show relevant calculations in the space given below and **complete the pH values in the above table.** **3**

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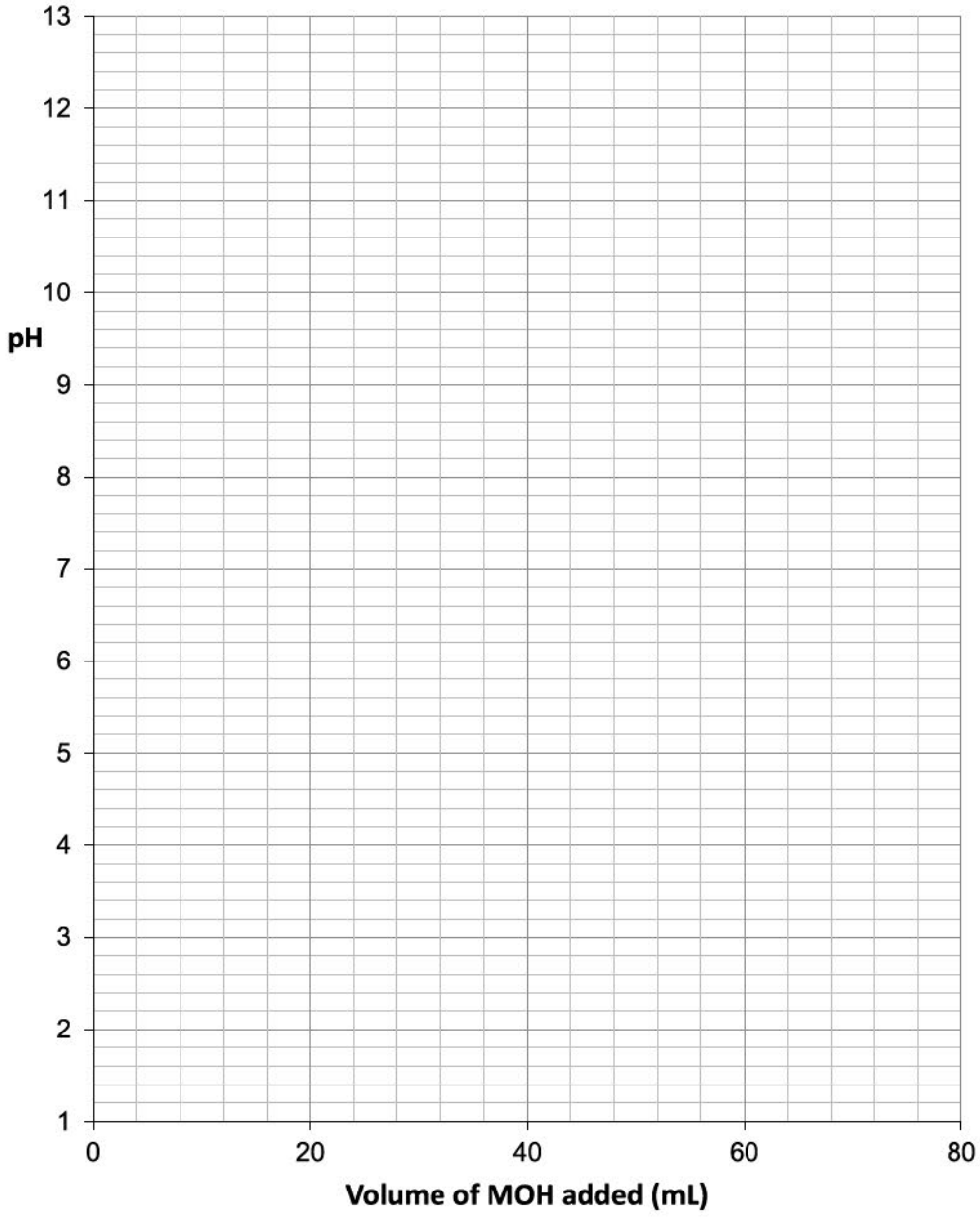
Question 8 continues on the next page

NESA STUDENT NUMBER

Marks

Question 8 continued…

(b) Draw an appropriately labelled titration curve using the above completed table and identify **any TWO** key characteristics of the curve. **3**



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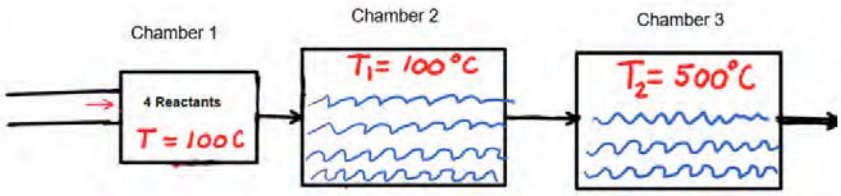
NESA STUDENT NUMBER

Marks

Question 9 (9 marks)



The above diagram represents a section of an industrial process for the manufacture of a chemical present in fertilisers. The optimal condition for the above process is generally represented by:

$$4R(g) \rightleftharpoons 2P(g) \qquad \Delta H < 0 \text{ at } T = 500°C$$

All the required reactants are added to chamber 1 at 100°C and a pressure of 200 atm. The reaction mixture is then allowed to reach equilibrium.

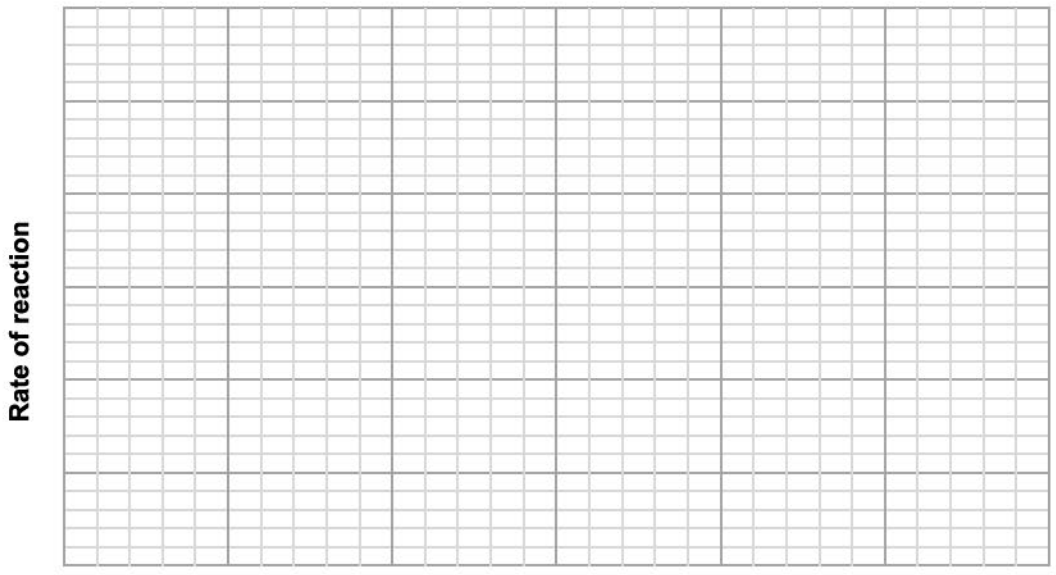
The resultant gas mixture is moved to chamber 2 after 4 hours and the gas mixture is passed over multiple layers of catalyst.

After 8 hours, the gas mixture is then moved to Chamber 3 with same number of catalyst layers and but the temperature is raised to 500°C.

After 12 hours, the gas mixture is finally moved to Chamber 4 where the gas mixture is treated for purification, liquefaction and removal.

(a) On the axes below, draw a sketch of the rate of reaction-time graph, depicting the rate for both forward and backward reactions in each chamber. **4**

Key	
Forward reaction	———
Backward reaction	- - - - - - -



Question 9 continues on the next page

NESA STUDENT NUMBER

Question 9 continued...

(b) Using collision theory and Le Chatelier's Principle, explain the changes in the rate of reaction and concentration of the reaction mixture in chambers 1, 2 and 3 only. **5**

NESA STUDENT NUMBER

Marks

Question 10 (4 marks)

H_3AsO_4 is a weak triprotic acid that releases its hydrogen ions in three steps as shown below: **4**

Step 1: $H_3AsO_4(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + H_2AsO_4^-(aq)$ $pK_{a1} = 2.24$

Step 2: $H_2AsO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HAsO_4^{2-}(aq)$ $pK_{a2} = 6.96$

Step 3: $HAsO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + AsO_4^{3-}(aq)$ $pK_{a3} = 11.50$

Derive the expression for the equilibrium constant (K_{eq}) for the following reaction and calculate its value.

$$H_3AsO_4(aq) + 3H_2O(l) \rightleftharpoons 3H_3O^+(aq) + AsO_4^{3-}(aq)$$

END OF SECTION 2A

NESA STUDENT NUMBER

S2B

2022

Year 12 Chemistry

Trial Examination

Section 2B (20 marks)

Questions 1–4

- Write using a black pen.
- Draw diagrams using pencil.
- Show all relevant working in questions involving calculations.
- NESA approved calculators may be used.

NESA STUDENT NUMBER

Section 2B

20 marks

- Attempt Questions 1–4.
- If you use the extra space provided at the back of this exam, clearly indicate which question you are answering.

Marks

Question 1 (3 marks)

James placed 100 g of glucose ($C_6H_{12}O_6$) into a conical flask, dissolved it in water and added some yeast. He then weighed the conical flask, warmed the mixture to 32°C and left the flask for about 2 days until the reaction has completed. **3**

Afterwards, he re-weighed the flask, and recorded his results as shown below.

- Initial mass of conical flask with mixture = 335.2 g
- Final mass of conical flask with mixture = 319.4 g

Calculate the mass of glucose consumed in the reaction.

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NESA STUDENT NUMBER

Marks

Question 2 (5 marks)

Charlie wanted to make methyl salicylate, a minty smelling flavour. He followed the procedure below. **5**

Method

1. Dissolve 3.0 g of salicylic acid (2-hydroxybenzoic acid) in 20 mL of methanol in a conical flask.
2. Add 1 mL of concentrated sulfuric acid to the reaction mixture and place the conical flask in a hot water bath set up above a Bunsen burner.
3. Monitor the flask by continuously moving it out of the water bath when it is close to boiling, then moving it back in the water bath to heat the mixture up again.
4. Remove the conical flask from the water bath after 10 minutes.
5. Add dilute sodium carbonate solution to the reaction mixture and swirl the flask until it stops reacting.
6. Pour the reaction mixture into a separating funnel and wait until two separate layers form.
7. Discard the bottom layer and keep the top layer as the product, methyl salicylate.

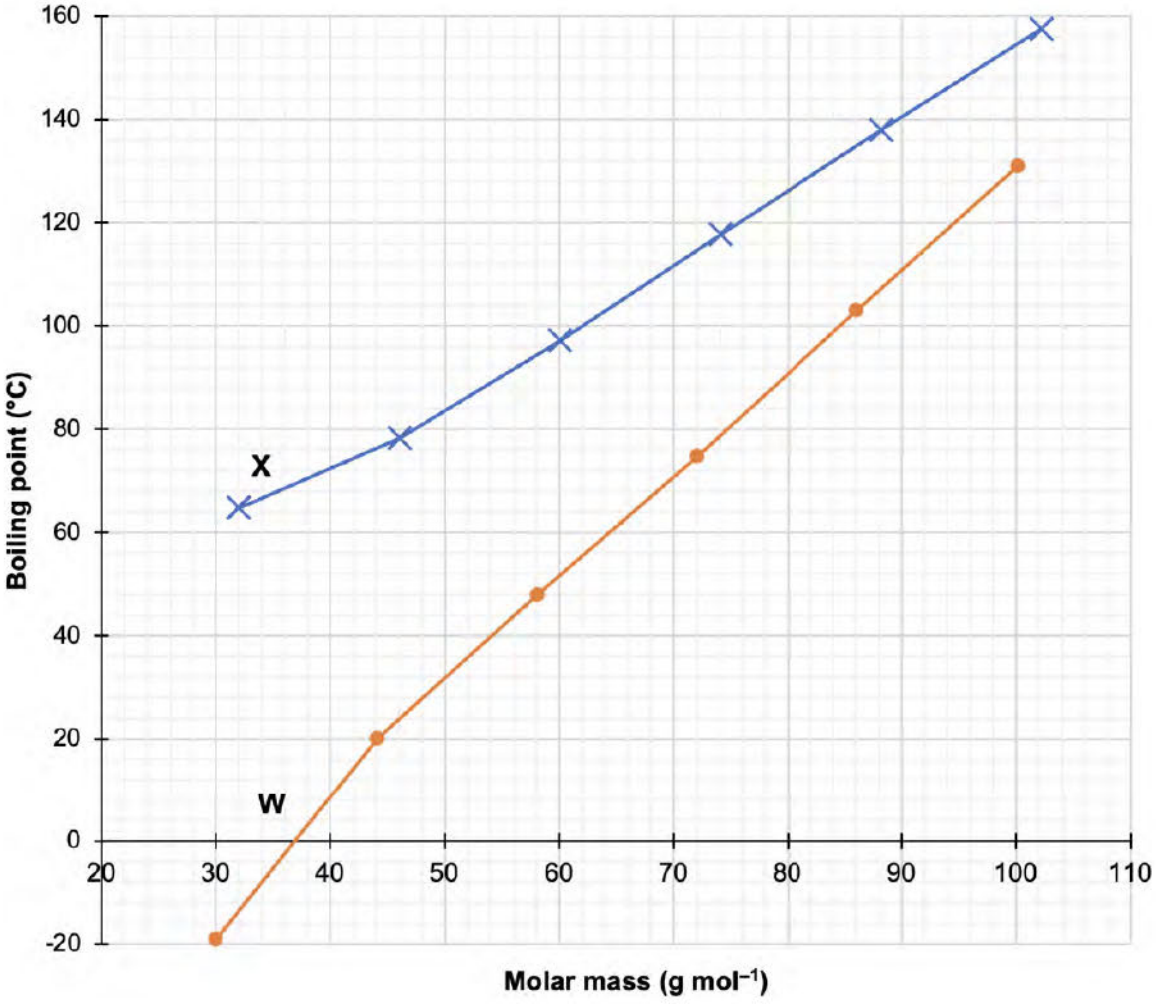
Suggest modifications that could be made to the procedure to improve the production and extraction of pure methyl salicylate. Justify your suggestions.

NESA STUDENT NUMBER

Marks

Question 3 (5 marks)

The graph below shows the boiling points for two different homologous series of organic compounds, straight chained aldehydes and primary alcohols.



Question 3 continued on the next page

NESA STUDENT NUMBER

Marks

Question 3 continued...

(a) Identify the data of **X** and **W** as either aldehydes or alcohols. **1**

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(b) Explain the trends in the data provided. **4**

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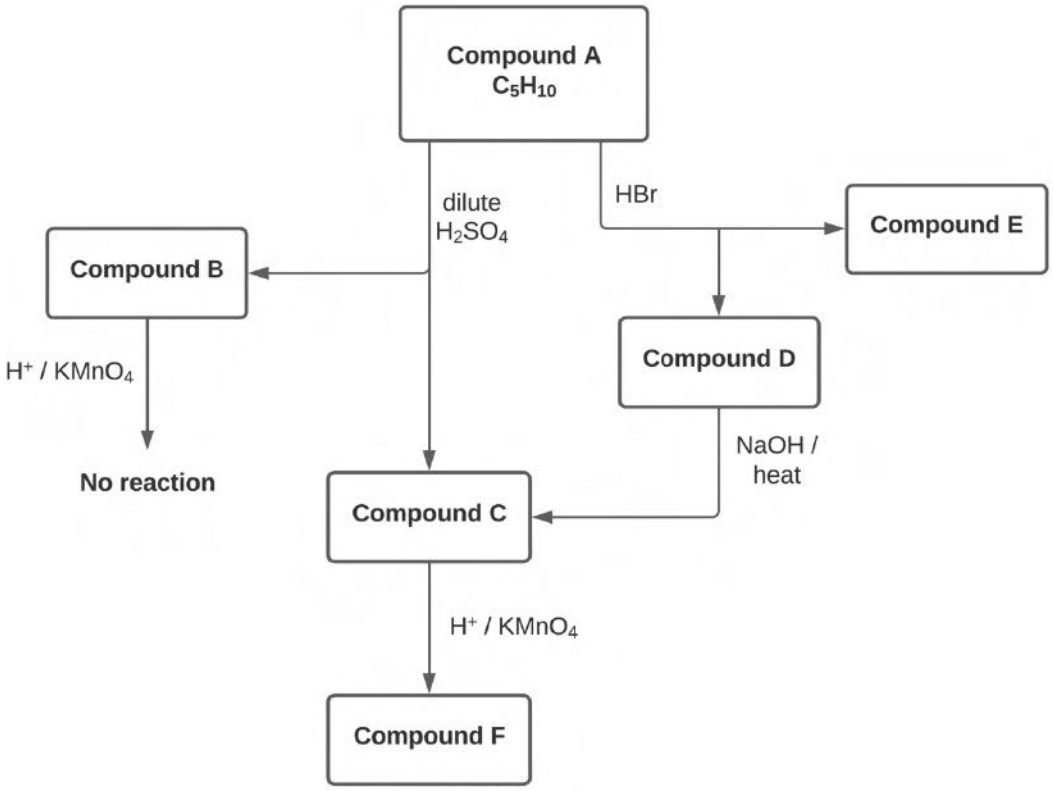
NESA STUDENT NUMBER

Marks

Question 4 (7 marks)

The flowchart below shows reactions involving six different organic compounds (**A** to **F**). Compound **A** has the molecular formula, C_5H_{10}. **7**



Question 4 continued on the next page

NESA STUDENT NUMBER

Marks

Question 4 continued...

Draw the structural formulae and state the IUPAC names of compounds **A** to **F**, justifying your structures with reference to the information provided in the flow chart.

END OF SECTION 2B

NESA STUDENT NUMBER

S2C

2022

Year 12 Chemistry

Trial Examination

Section 2C (7 marks)

Question 1

- Write using a black pen.
- Draw diagrams using pencil.
- Show all relevant working in questions involving calculations.
- NESA approved calculators may be used.

NESA STUDENT NUMBER

Section 2C

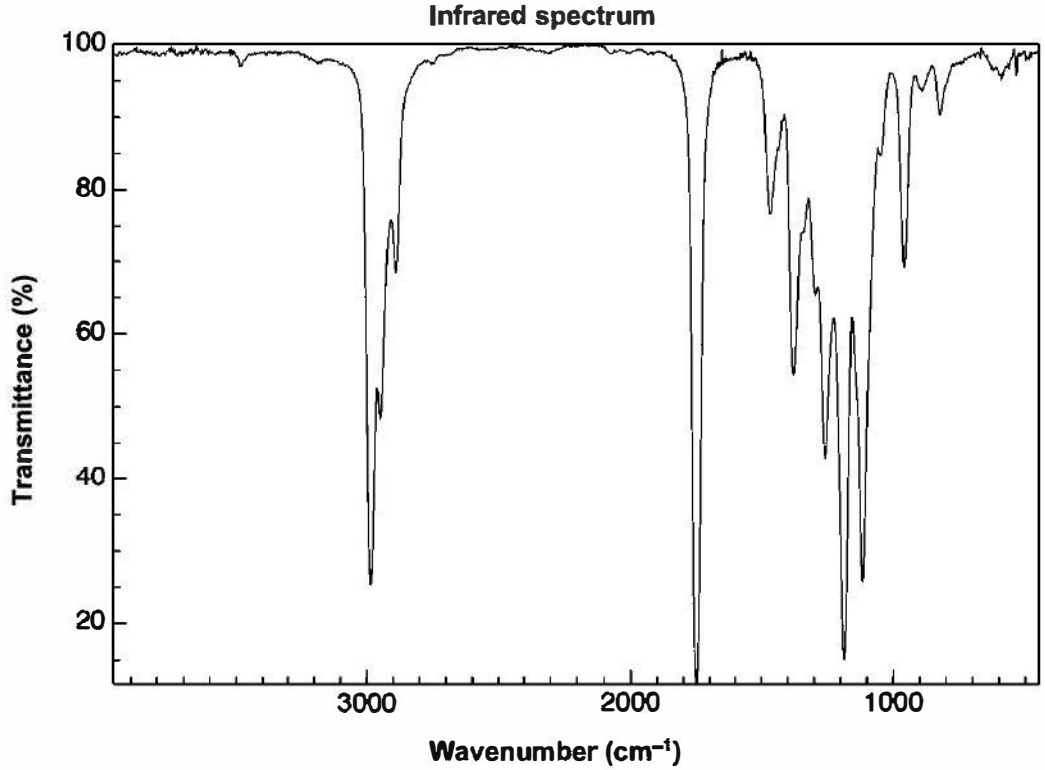
7 marks

- Attempt Question 1.
- If you use the extra space provided at the back of this exam, clearly indicate which question you are answering.

Marks

Question 1 (7 marks)

A chemist discovered a bottle simply labelled '$C_7H_{14}O_2$'. To confirm the molecular structure of the contents of the bottle, a sample was submitted for analysis by infrared spectroscopy and ^1H and ^{13}C NMR spectroscopy. The resulting spectra are shown. **7**



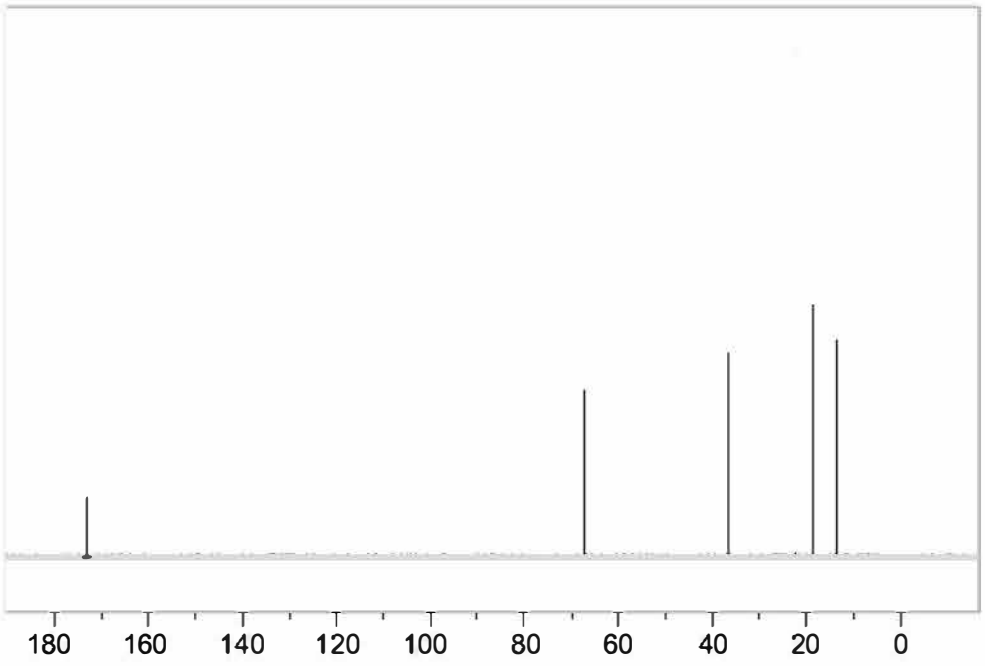
Question 1 continues on the next page

NESA STUDENT NUMBER

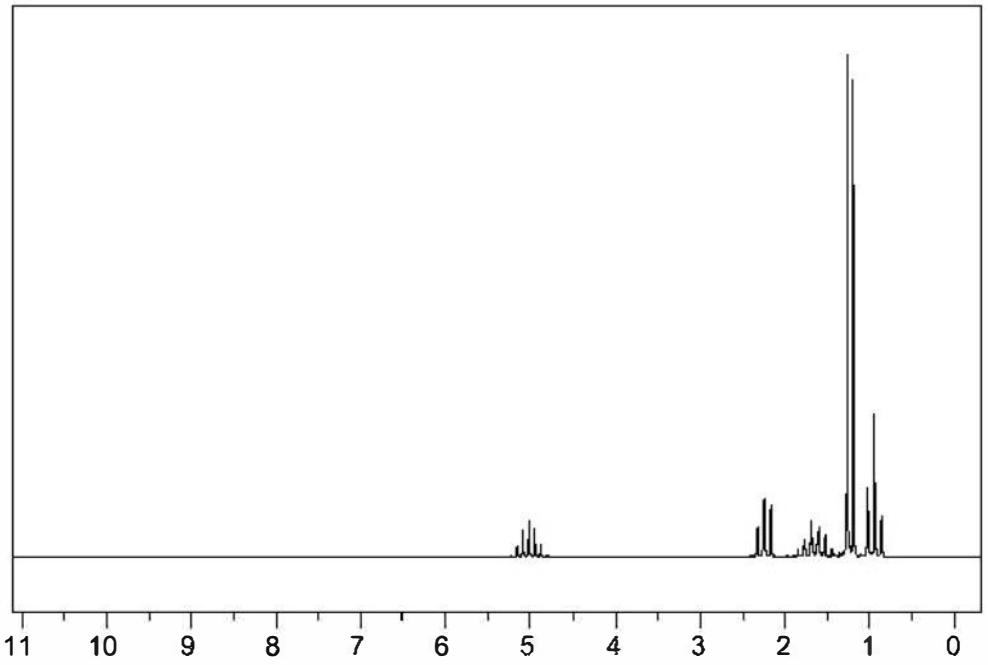
Marks

Question 1 continued...

^{13}C NMR spectrum



^{1}H NMR spectrum



Question 1 continues on the next page

NESA STUDENT NUMBER

Marks

Question 1 continued...

Data from the ^{1}H NMR spectrum

Chemical shift	Relative peak area	Splitting pattern
5.011	1	septet (7)
2.238	2	triplet (3)
1.645	2	sextet (6)
1.229	6	doublet (2)
0.951	3	triplet (3)

^{1}H NMR chemical shift data

	Type of proton	δ (ppm)
$Si(CH_3)_4$	(TMS)	0
R—CH_3		0.7–1.3
R—CH_2—R		1.2–1.5
R—CHR_2		1.5–2.0
H_3C—CO—	(aldehydes, ketones or esters)	2.0–2.5
—CH—CO—	(aldehydes, ketones or esters)	2.1–2.6
H_3C—O—	(alcohols or esters)	3.2–4.0
—CH—O—	(alcohols or esters)	3.3–5.1
R_2—CH_2—O—	(alcohols or esters)	3.5–5.0
R—OH		1–6
R_2C=CHR	(alkene)	4.5–7.0
R—CHO	(aldehyde)	9.4–10.0
R—COOH		9.0–13.0

Question 1 continues on the next page

NESA STUDENT NUMBER

Marks

Question 1 continued...

In the space provided, draw a structural formula for the unknown compound in the space below that is consistent with **all** the information provided.

Justify your answer with reference to the information provided.

Note: The IUPAC name of the unknown compound is not required.

Question 1 continues on the next page

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NESA STUDENT NUMBER

Marks

Question 1 continued…

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END OF SECTION 2C

NESA STUDENT NUMBER

2022

Year 12 Chemistry

Trial Examination

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen.
- Draw diagrams using pencil.
- Show all relevant working in questions involving calculations.
- NESA approved calculators may be used.

Total marks: 100

Section 1 – Multiple Choice **20 marks**
- Attempt Questions 1–20

Section 2A – Written Response **53 marks**
- Attempt Questions 1–10

Section 2B – Written Response **20 marks**
- Attempt Questions 1–4

Section 2C – Written Response **7 marks**
- Attempt Question 1

NESA STUDENT NUMBER

Section 1

20 marks

- Attempt Questions 1–20.
- Use the multiple-choice answer sheet at the **back of section 2A** to answer the multiple-choice questions for Section 1.

S1

Question 1 (1 mark)

Which of the following correctly identifies the number of isomer(s) that butan-1-ol has?

	Position isomer	Chain isomer
(A)	1	1
(B)	1	2
(C)	2	1
(D)	2	2

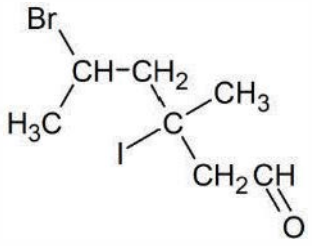
Notes from the Marker

A **position isomer** is differing positions of the same functional group in the molecule. Butan-1-ol has only one other position isomer: **butan-2-ol.**

A **chain isomer** is the different arrangement of a molecule's carbon skeleton. Butan-1-ol has only two other chain isomers: **2-methylpropan-1-ol** and **2-methylpropan-2-ol.**

Question 2 (1 mark)

The structure of a molecule is given below.



What is the IUPAC name for the structure?

(A) 5-bromo-3-iodo-3-methylhexanal

(B) 3-iodo-3-methyl-5-bromohexanal

(C) 2-bromo-4-iodo-4-methylhexanal

(D) 5-bromo-3-iodo-3-methylhexan-1-one

Notes from the Marker

Start with finding the longest carbon chain that includes the highest priority functional group (aldehyde). Number the carbons, where the aldehyde group has the lowest locant.

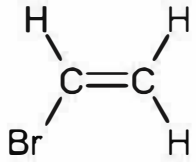
Finally, identify any branches and halogens. These should be named in alphabetical order.

NESA STUDENT NUMBER

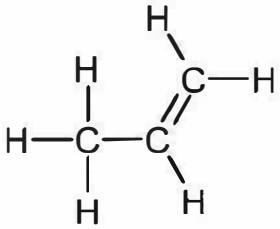
Question 3 (1 mark)

Consider the following structural formulae.

I

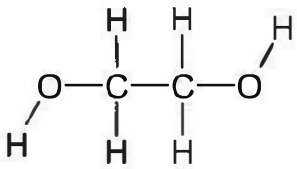


II

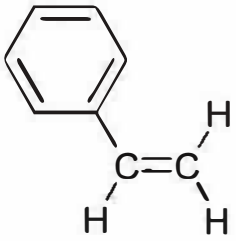


III

IV



V



Which of the following options contains compounds that can form addition polymers?

(A) **I** and **IV**.

(B) **II** and **III**.

(C) **III** and **IV**.

(D) **II** and **V**.

Notes from the Marker

II and **V** forms an addition polymer, where both monomers have double bonds, allowing them to join together.

The other options do not work, as both monomers either do not both have double bonds or cannot eliminate a small molecule such as water (condensation polymer).

NESA STUDENT NUMBER

Question 4 (1 mark)

A chemist found two unlabelled bottles and deduced that they were propan-1-ol and butan-1-ol.

Without the use of reference spectra, which of the following instrumental techniques would be LEAST useful in distinguishing the two compounds?

(A) ^{1}H NMR spectroscopy

(B) ^{13}C NMR spectroscopy

(C) Infrared spectroscopy

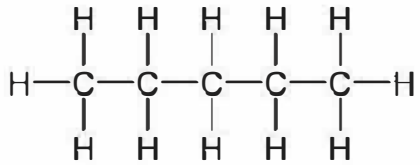
(D) Mass spectrometry

Notes from the Marker

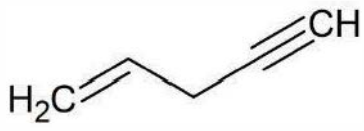
The least useful technique would be infrared spectroscopy as both propan-1-ol and butan-1-ol would a broad absorption between 3230–3550 cm^{-1} due to the O–H bond. The other techniques could be used to distinguish based on the number of peaks, splitting patterns or the masses of fragments produced.

Question 5 (1 mark)

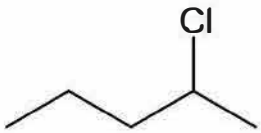
The structures of four organic compounds are shown as follows.



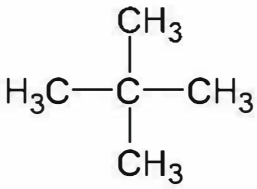
A



B



C



D

What of the following is most likely to be correct?

(A) Compounds **A** and **C** are functional group isomers.

(B) Compound **D** has a lower melting point than **A.**

(C) Compound **D** is more reactive than compound **B.**

(D) Compound **C** is less soluble in water than compound **A.**

Notes from the Marker

Compound **D** has a lower melting point than **A** because it is more compact and can pack together as a solid efficiently. Compound **A** is also an odd numbered carbon chain and does not pack together as efficiently.

NESA STUDENT NUMBER

Question 7 (1 mark)

The K_a values of some weak acids are shown below.

Acid	K_a
HOBr	2.3×10^{-9}
HOCl	3.5×10^{-8}
HF	7.2×10^{-4}
HCOOH	1.8×10^{-4}

Which of the following acids would produce the strongest conjugate base?

(A) HOBr

(B) HOCl

(C) HF

(D) HCOOH

Notes from the Marker

HOBr The acid with the most reactive (strong) conjugate base will be the weakest acid, or the acid with the lowest Ka value.

Question 8 (1 mark)

Which of the following changes takes place when 500 mL of water is added to 500 mL of 1.00 mol L^{-1} acetic acid?

(A) pH increases and percentage ionisation increases.

(B) pH increases and percentage ionisation does not change.

(C) pH decreases and percentage ionisation does not change.

(D) pH decreases and percentage ionisation decreases.

Notes from the Marker

pH increases, percentage ionisation increases

When water is added to a weak acid like ethanoic acid, the number of ethanoic acid molecules that dissociate increases, however, pH increases

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

However, the acetate ion undergoes hydrolysis with water which now instead acts as an acid, reforming acetic acid as well has hydroxide ions:

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$$

OH- will be neutralised by the extra hydronium ions dissociated due to dilution, so as concentration of hydronium reduces, pH increases.

NESA STUDENT NUMBER

Question 9 (1 mark)

A spirit burner used 26.6 g of ethanol to change 1.00 L of water at 23.5°C to 100.0°C. The molar heat of combustion of ethanol is 1367 kJ mol^{-1}.

What percentage of heat produced from the burner was lost to the environment?

(A) 1.1%

(B) 40.5%

(C) 59.5%

(D) 98.9%

Notes from the Marker

$q = mC\Delta T$

$= (1000\ mL) \times (4.18\ J\ g^{-1}\ K^{-1}) \times (100.0 - 23.5\ K)$

$= 319770\ J$

$= 319.770\ kJ$ (heat absorbed by the water)

$n(C_2H_5OH) = m / MM$

$= 26.6 / (2(12.01) + 6(1.006) + 16.00)$

$= 0.5774073109\ mol$

1 mole of ethanol produces 1367 kJ of energy.

In 0.5774073109 moles of ethanol = 1367×0.5774073109

$= 789.316$ kJ of energy is released

Percentage of heat absorbed by the water = $\frac{319.770}{789.316} \times 100$

$= 40.5\ \%$

Percentage of heat lost to the environment = $100\% - 40.5\%$

$= 59.5\%$

NESA STUDENT NUMBER

Question 10 (1 mark)

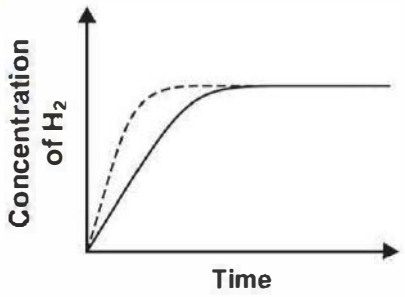
The following reaction is used in some industries to produce hydrogen gas.

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

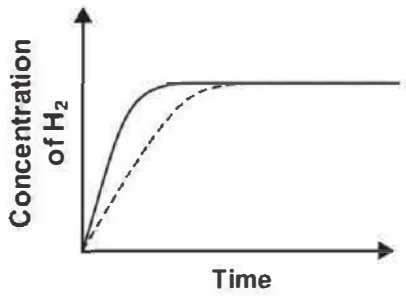
In trials, the reaction is carried out with a catalyst (shown by - - - - - - - line) and without a catalyst (shown by ——— line) in the sealed container. All other conditions are unchanged.

Choose the graph representing the change in hydrogen gas concentration with time between an uncatalysed and a catalysed reaction.

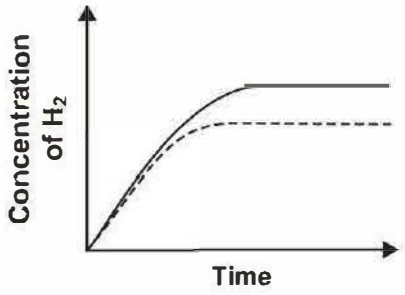
(A)



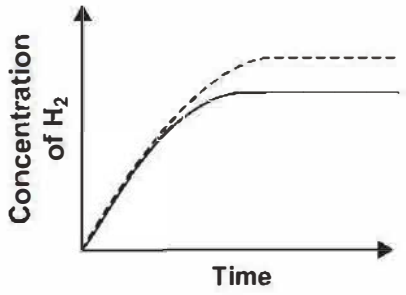
(B)



(C)



(D)



NESA STUDENT NUMBER

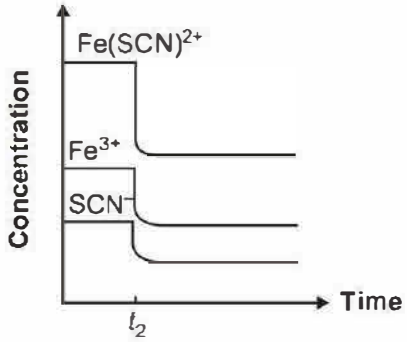
Question 11 (1 mark)

$Fe^{3+}(aq)$ + $SCN^{-}(aq)$ ⇌ $Fe(SCN)^{2+}(aq)$

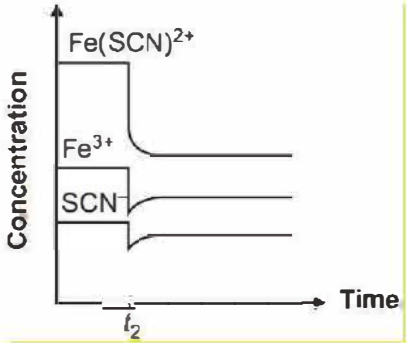
(yellow) (colourless) (red)

Which one of the following best represents the changes in concentration of the above iron(III) chloride and potassium thiocyanate equilibrium mixture, when water was added to the equilibrium mixture at time t_2?

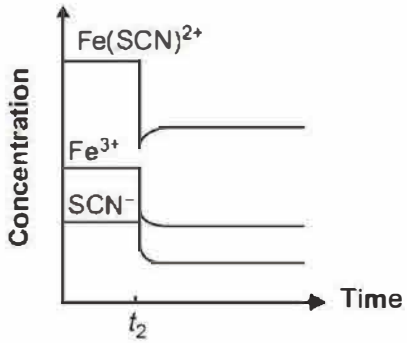
(A)



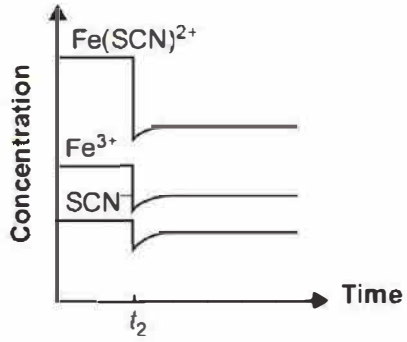
(B)



(C)



(D)



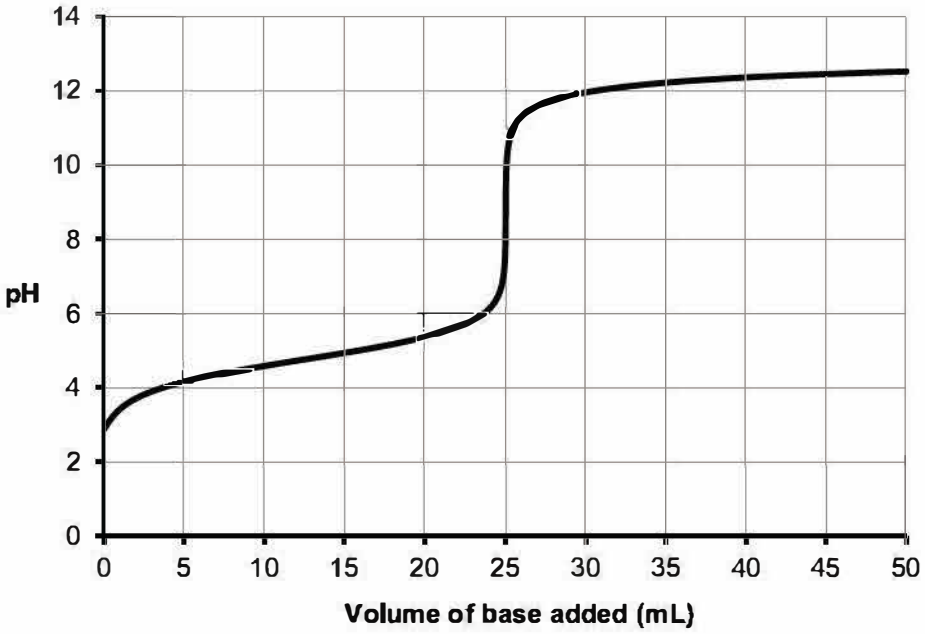
Notes from the Marker

Reduction in concentration due to dilution, followed by shift to the left to increase number of aq moles in solution.

NESA STUDENT NUMBER

Use the following information to answer Questions 12 and 13.

The diagram below represents the titration curve between a particular acid and a particular base.



Question 12 (1 mark)

Which indicator would be best suited for this titration?

	Indicator	Colour change range (pH)
(A)	Bromophenol blue	6.2 – 7.6
(B)	Magdala red	3.0 – 4.0
(C)	Phenolphthalein	8.2 – 10.0
(D)	Chlorophenol red	5.2 – 6.8

Notes from the Marker

Look for BEST suited.

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Question 13 (1 mark)

The buffer region for this titration curve may contain:

(A) NaCl and NaOH.

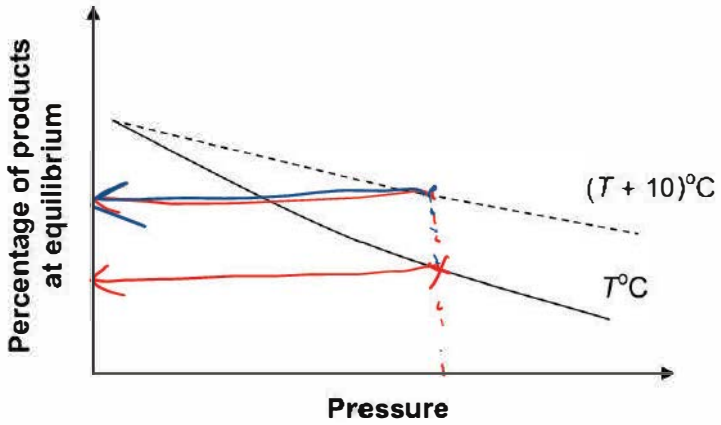
(B) CH_3COOH and CH_3COONa.

(C) NH_3 and NH_4Cl.

(D) NH_3 and CH_3COONH_4.

Question 14 (1 mark)

The graph below contains two sets of data to show the variation of the percentage of gaseous products present at equilibrium, with temperature and pressure for a reversible chemical reaction.



Which one of the following chemical reactions could be represented by the data plotted on the graph?

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

(B) $3O_2(g) + 4NH_3(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$ $\Delta H = -1248$ kJ mol^{-1}

(C) $2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g)$ $\Delta H = +82$ kJ mol^{-1}

(D) $CO_2(g) + C(s) \rightleftharpoons 2CO(g)$ $\Delta H = +173$ kJ mol^{-1}

Notes from the Marker

The graph shows that (T+10)°C has greater % of products than T°C, so forward reaction favoured (supports endothermic reactions), so option A and B is out. For higher pressure at (T+10)°C, increase in concentration occurs so according to LCP, reaction will shift to side with less gas moles (to reduce concentration).

Option C product side is favoured but graph shows reduction in % of products. D is the correct option because reactants are favoured hence % of products reduce which aligns with the explanation.

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Question 15 (1 mark)

Colourless nitrous oxide (N_2O) reacts with oxygen gas to form brown nitrogen dioxide gas, according to the following equilibrium:

$$2N_2O(g) + 3O_2(g) \rightleftharpoons 4NO_2(g) \qquad \Delta H = -32 \text{ kJ mol}^{-1}$$

0.27 mol of N_2O was placed in a 4.00 L vessel with 0.42 mol of oxygen. The system was allowed to reach equilibrium. At equilibrium 0.15 mol of N_2O remained. The temperature of the vessel was monitored over this time.

Calculate a value for the equilibrium constant at a given temperature.

(A) 10.40

(B) 41.61

(C) 42.67

(D) 53.38

Notes from the Marker:

$$2\,N_2O + 3O_2 \rightleftharpoons 4\,NO_2$$

	$2N_2O$	$3O_2$	$4NO_2$
I	0.27	0.42	0
C	-0.12	$-\frac{3}{2}\times 0.12$	$+\frac{4}{2}\times 0.12$
=	-0.12	-0.18	$+0.24$
E	0.15	0.24	0.24

$$K_{eq} = \frac{[NO_2]^4}{[N_2O]^2[O_2]^3} = \frac{\left[\frac{0.24\text{ mol}}{4\text{L}}\right]^4}{\left[\frac{0.15}{4}\right]^2\left[\frac{0.24}{4}\right]^3} = \frac{0.06^4}{0.0375^2 \times 0.0605^3} = 42.67$$

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Question 16 (1 mark)

In a titration of a strong base with strong acid, the following procedure was used:

1. A burette was rinsed with water and then filled with the standard acid.
2. A pipette was rinsed with some base solution.
3. A conical flask was rinsed with some base solution.
4. A pipette was used to transfer a measured volume of base solution into the conical flask.
5. Indicator was added to the base solution, and it was titrated to the endpoint with the acid.

Which of the following statements is correct?

(A) The calculated base concentration will be lower than the actual base concentration.

(B) The calculated base concentration will be the same as the actual base concentration.

(C) The calculated base concentration will be higher than the actual base concentration.

(D) No definite conclusion can be drawn about the calculated base concentration.

Question 17 (1 mark)

The K_{sp} of strontium hydroxide is 2.0×10^{-3}.

What is the pH of a saturated solution of strontium hydroxide?

(A) 0.80

(B) 1.35

(C) 12.65

(D) 13.20

$Sr(OH)_{2(s)} \rightleftharpoons Sr^{+2}_{(aq)} + 2OH^-_{(aq)}$ $K_{sp} = 2.0 \times 10^{-3}\ mol\,L^{-1}$

$x \qquad 2x$

$K_{sp} = x \cdot (2x)^2$

$2.0 \times 10^{-3} = 4x^3$

$\sqrt[3]{\frac{2.0}{4} \times 10^{-3}} = x = 0.079 \simeq 0.08$

$[OH^-] = 2x = 2 \times 0.08 = 0.16$

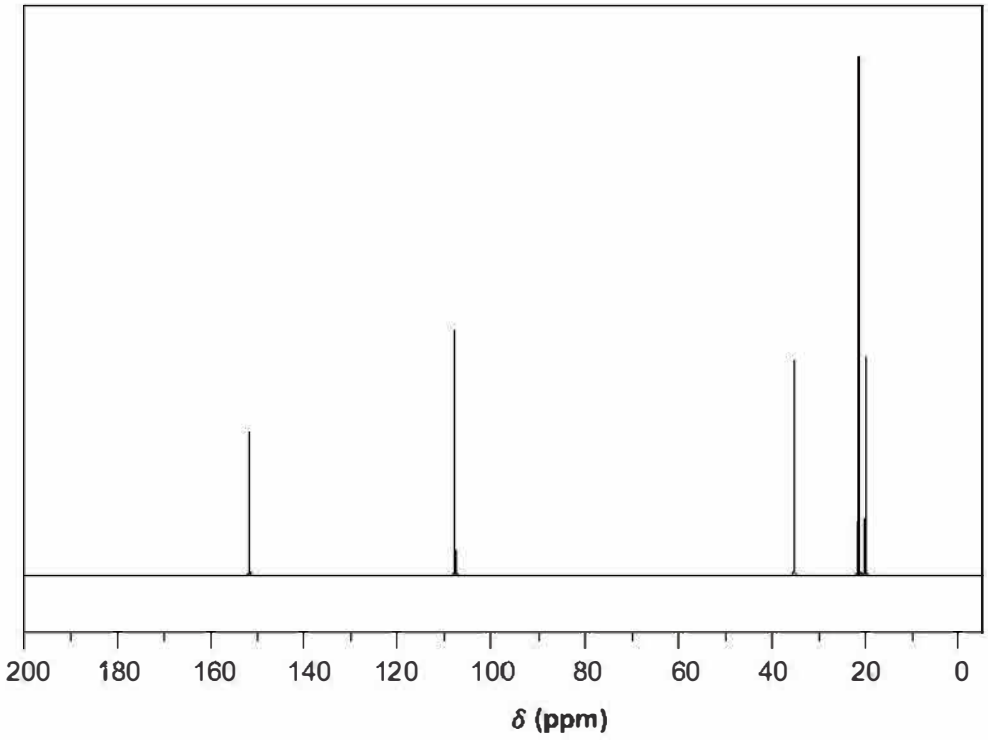
So $pOH = -\log_{10}(0.16) = 0.795$

So $pH = 14 - 0.795 = 13.2$

NESA STUDENT NUMBER

Question 18 (1 mark)

A ^{13}C NMR spectrum is shown.



Which compound gives rise to this spectrum?

(A) Hex-1-ene

(B) 2-methylpent-2-ene

(C) 2,3-dimethylbut-1-ene

(D) 2,3-dimethylbut-2-ene

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Notes from the Marker

Based on the ^{13}C spectrum, there are five carbon environments. The other options produce:

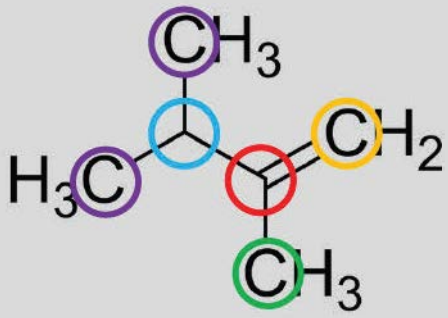
(A) 6 carbon environments

(B) 6 carbon environments

(C) 5 carbon environments

(D) 2 carbon environments

For 2,3-dimethylbut-1-ene, the carbon environments are shown below:



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Question 19 (1 mark)

An analytical chemist was provided with a compound **X.** He tested this compound and obtained the following results.

Analysis	**Evidence**
Infrared spectroscopy	Broad absorption at 3385 cm^{-1}
Percentage composition by mass	C = 70.53%, H = 13.81%, O = 15.66%
Mass spectrometry	Molecular ion peak: m/z = 102
Test with acidified potassium dichromate	Orange colour remains upon heating compound **X** with acidified potassium dichromate in a water bath.

Which of the following is a possible structure for the compound **X**?

(A) Hexan-1-ol

(B) 2-methylpentan-3-ol

(C) 3-methylbutanoic acid

(D) 3-methylpentan-3-ol

Notes from the Marker

Based on the information, the following can be deduced:

- The infrared spectra shows a broad absorption at 3385 cm^{-1} which suggests the presence of an **O–H bond in an alcohol** due to absorption location being between 3230–3550 cm^{-1}.
- The test with acidified potassium dichromate suggests that the substance is either a **tertiary alcohol** or is an **alkanoic acid.** This is not consistent with hexan-1-ol and 2-methylpentan-3-ol as they are primary and secondary alcohols respectively.
- All the above compounds can produce a molecular ion peak at m/z = 102.
- Based on the percentage composition:

	C	**H**	**O**
Mass (g)	70.53	13.81	15.66
Moles (mol)	70.53/12.01 = 5.87261…	13.81/1.008 = 13.70039…	15.66/16.00 = 0.97875
Mole ratio	6	14	1

Therefore, the empirical formula is $C_6H_{14}O$ and this is not consistent with 3-methylbutanoic acid as its empirical formula is $C_5H_{10}O_2$. Hence, the answer must be 3-methylpentan-3-ol.

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Question 20 (1 mark)

A sample of 1,2,3,4-tetrachlorobutane was analysed using a mass spectrometer.

The only isotopes present in the compound are hydrogen-1, carbon-12, chlorine-35 and chlorine-37.

Using the above information, determine the number of molecular ion peaks in the mass spectrum of 1,2,3,4-tetrachlorobutane.

(A) 2

(B) 3

(C) 4

(D) 5

Notes from the Marker

The differing number of molecular ion peaks will depend on the combination of chlorine isotopes in the molecule. Since there are four chlorine atoms in the molecule, the possible m/z ratios are:

- m/z of 1,2,3,4-tetrachlorobutane (4 x Cl-35) = 194
- m/z of 1,2,3,4-tetrachlorobutane (3 x Cl-35 + 1 x Cl-37) = 196
- m/z of 1,2,3,4-tetrachlorobutane (2 x Cl-35 + 2 x Cl-37) = 198
- m/z of 1,2,3,4-tetrachlorobutane (1 x Cl-35 + 3 x Cl-37) = 200
- m/z of 1,2,3,4-tetrachlorobutane (4 x Cl-37) = 202

END OF SECTION 1

Question 1 (6 marks)

Methane and steam can react to form carbon monoxide and hydrogen according to the equation.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +131 \text{ kJ mol}^{-1}$$

4.0 moles of methane and 5.0 moles of steam are placed into a sealed 2.0 litre container which is heated to 450̊C and allowed to react until equilibrium is reached.

Measurements show that there are 1.5 moles of methane in the container at equilibrium.

(a) Determine the number of moles of the other gases at equilibrium.

Marking criteria	***Marks***
Identifies the number of moles using ICE table or other clearly stated method: moles $H_2O(g)$ = 2.5 mol moles CO = 2.5 mol moles H_2 =. 7.5 mol	3
Identifies the number of moles of other gases **without** water moles CO = 2.5 mol moles H_2 =. 7.5 mol	2
Determines the number of moles of **ONE** of the three gases (as above)	1

Q-1 $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H > 0$

Initial	4·0	5·0	0	0
Change	⊖2·5	⊖2·5	⊕2·5	⊕ 3×2·5 = 7·5
Equilibrium	1·5	2·5	2·5	7·5

(a) $n_{H_2O(g)} = 2.5$ | $n_{CO(g)} = 2.5$ | $n_{H_2(g)} = 7.5$

(b) Write the expression for the equilibrium constant for this reaction.

Marking criteria	***Marks***
Provides a correct equilibrium constant expression.	1

$$K_{eq} = \frac{[H_2(g)]^3[CO(g)]}{[CH_4(g)][H_2O(g)]}$$

(c) Determine the numerical value for the equilibrium constant at 450C.

Marking criteria	***Marks***
Show relevant calculations for the **concentration of each of the four** gases **AND** Substitute values into equilibrium constant expression **AND** Determines the value of **K = 70.13 OR 70** with appropriate working **OR** Determines a value of K that is correct for an incorrect answer in b	2
Determines the value of K = 281.25 with values substituted as moles rather than concentrations **OR** **Incorrect calculation**	1

$[CH_4] = 0.75 \frac{mol}{L}$ $[H_2O] = \frac{2.5 \text{ moles}}{2L} = 1.25 \frac{mol}{L}$

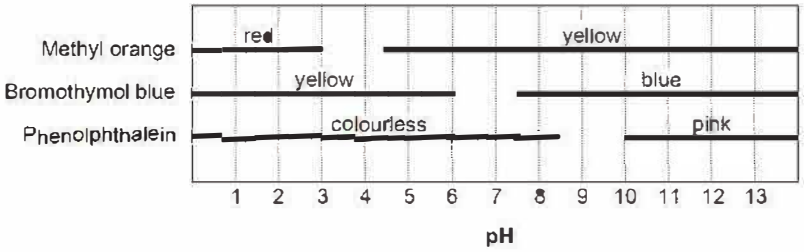
$[CO] = \frac{2.5 \text{ moles}}{2L} = 1.25 M$ $[H_2] = \frac{7.5 \text{ moles}}{2L} = 3.75 M$

$$K_{eq} = \frac{(3.75)^3 \times (1.25)}{(0.75) \times (1.25)} = 70.31$$

$\simeq 70$ (2 sig fig)

Question 2 (3 marks)

Maintenance of any swimming pool requires regular monitoring of the pH level of the water. A suitable indicator may be used to ensure that the pH of the pool water is nearly neutral and lies in a very narrow range close to pH = 7. **3**



Ben tested the water in his pool, then used the indicator chart above to make relevant observations.

With reference to each of the indicators in the chart, explain which indicator(s) would be best suited to determine the safety of the pool water.

Criteria	Marks
Identify the appropriate indicator chosen- bromothymol blue AND Justify the choice-bromothymol blue changes to an intermediate colour in the range is pH = 6.0-7.7 so pH = 7 neutral water lies within this range. AND Justify why the other two indicators were not chosen using the pH range for colour change and the limitation for each.	3
Identify the appropriate indicator chosen- bromothymol blue AND Justify the choice-bromothymol blue colour change range is pH = 6.0-7.7 so pH = 7 lies within this range. OR Justify why the other two indicators were not chosen using the pH range, colour change and the limitation for each.	2
Identify the appropriate indicator chosen- bromothymol blue OR Justify the choice-bromothymol blue colour change range is pH = 6.0-7.7 so pH = 7 lies within this range. OR Justify why the other two indicators were not chosen using the pH range, colour change and the limitation for each.	1

Ben used BB

Neutral water pH = 7 lies closest to the colour change range of bromothymol blue of pH = 6.0 - 7.7

He would not have used Phenolphthalein as it stays colourless in the pH = 7 range and as well as for highly acidic solution where pH < 7.0.

Methyl orange stays yellow as well for pH = 7 range as well as highly basic values for pH >7.7.

(1) Since pH of pool is nearly neutral & lies in a range around 7, a indicator with colour change range around pH 7 should be used.

(2) Bromothymol Blue would be the best indicator as it colour change range is ≈ 6.0 ~ 7.5 as shown on indicator chart, when the solution indicator colour is green, then it indicates a pH in its range, which is close to pH 7, for safety of pool water pH.

(3) Methyl orange's pH colour change range is from ≈ 3.0 - 4.2 pH, which is low, low pH & pool water would always yield yellow result.

(4) Phenolphthalein's pH colour change range is around 8.3 ~ 10.0, which is too basic & not useful in determining a pool water which is usually neutral.

With reference to each of the indicators in the chart, explain which indicator(s) would be best suited to determine the safety of the pool water.

Methyl Orange can determine if the pH is less than 3 (red) or greater than 4.4 (yellow). Thus, it can determine whether the pH is for too acidic, but can't differentiate between neutral and basic.

Bromothymol blue is yellow below pH 6 and blue above ph ≈ 7.5, so it can determine if the pH is slightly too low or high, thus is suited well as it can determine pH slightly too high for to either side, and will appear a mixture of yellow + blue when the pH is correct. Phenolphthalein can determine if the pool is for too basic (pH > 10 it turns pink), however it is colourless from a pH range of 8 ~ 8.6 to 0, and as such cannot determine if the pH is neutral, or acidic. Therefore, the best suited indicator is Bromothymol blue.

Question 3 (4 marks)

Calculate the pH of the resulting solution when 25.0 mL of 0.010 M KOH is mixed with 50.0 mL of 0.20 M H_2SO_4, assuming that sulfuric acid undergoes complete ionisation. **4**

Criteria	Marks
Shows all relevant working, in a clear and logical manner (as shown in sample answer) AND Correct pH value of the resultant solution written to appropriate sig fig/dec places	4
Shows all relevant working, in a clear and logical manner (as shown in sample answer) AND Correct pH value of the resultant solution written to appropriate sig fig/dec places AND One error of some type (Incorrect pH value/ unreasonable sig fig/1 relevant step missing leading to break in the logical flow of working out)	3
Shows most relevant working, AND Correct pH value of the resultant solution written to appropriate sig fig/dec places AND More than One error of some type (Incorrect pH value / unreasonable sig fig/1 relevant step missing leading to break in the logical flow of working out)	2
Shows some relevant steps only AND Multiple errors as stated below (Incorrect pH value/ unreasonable sig fig/1 relevant step missing leading to break in the logical flow of working out)	1

$H_2SO_{4(aq)} + 2KOH_{(aq)} \rightarrow K_2SO_{4(aq)} + 2H_2O_{(l)}$

$n_{H_2SO_4} = 0.20 \frac{mol}{L} \times 0.05 L = 0.01 \text{ moles}$

$n_{KOH} = 0.010 \frac{mol}{L} \times 0.025 L = 2.5 \times 10^{-4}$

$= 0.00025$

~~n_{KOH}~~ = Excess reagent H_2SO_4

2 moles of KOH react with 1 mole H_2SO_4

So 0.00025 moles " " " $\frac{1}{2} \times 0.00025$

$= 1.25 \times 10^{-4}$ moles H_2SO_4

Excess H_2SO_4 left in soln $= 0.01 - 1.25 \times 10^{-4}$

$= 9.875 \times 10^{-3}$

1 mole H_2SO_4 = 2 moles H_3O^+ or H^+

So 9.875×10^{-3} moles H_2SO_4 = ( )x2 = 0.0198 H^+_n

Total volume = 0.075 L

$$[H^+] = \frac{0.0198 \text{ moles}}{0.075 \text{ L}} = 0.2633\ldots$$

$$pH = -\log_{10}(0.2633\ldots) = 0.58 \text{ (2dp)}$$

(2 sig fig)

Student sample

Question 3 (4 marks)

Calculate the pH of the resulting solution when 25.0 mL of 0.010 M KOH is mixed with 50.0 mL of 0.20 M H_2SO_4, assuming that sulfuric acid undergoes complete ionisation. 4

$H_2SO_{4(aq)} + 2KOH_{(aq)} \rightarrow K_2SO_{4(aq)} + 2H_2O_{(l)}$ ✓

$n(KOH) = 0.01 \times 25 \times 10^{-3}$ $\quad n(H_2SO_4) = 0.2 \times 50 \times 10^{-3}$

$= 2.5 \times 10^{-4}$ mol ✓ $\quad = 0.01$ mol ✓

✓$n(H_2SO_4) > \frac{1}{2} n(KOH)$ ∴ KOH is limiting 3 ✓✓

$n(H_2SO_4)$ excess $= 0.01 - \frac{1}{2}(2.5 \times 10^{-4})$

$= 9.875 \times 10^{-3}$ mol ✓

$[H_2SO_4]_{final} = \frac{n}{V} = \frac{9.875 \times 10^{-3}}{(25+50) \times 10^{-3}}$ ✓ $= 0.1316\ldots$ M

$[H^+] = 2[H_2SO_4]_{final}$ ✓ (complete ionisation)

$= 0.26\ldots$ M ✓

$pH = 0.58$ (2sf → 2dp) ✓

Question 4 (3 marks)
Explain the use of KH_2PO_4 to neutralise strong acid base spills with reference to its chemical properties. Support your answer with relevant equations.

Criteria	**Marks**
Identify $H_2PO_4^-$ as amphiprotic substance AND Using relevant equation show $H_2PO_4^-$ as BL acid in strong base spill and explain its role AND Using relevant equation show $H_2PO_4^-$ as BL base in strong acid spill and explain its role	3
Identify $H_2PO_4^-$ as amphiprotic substance AND Using relevant equation show $H_2PO_4^-$ as BL acid in strong base spill and explain its role AND/ OR Using relevant equation show $H_2PO_4^-$ as BL base in strong acid spill and explain its role OR Some errors in equations or sound explanation with no link to role as BL acid or BL base	2
Incorrect equations and multiple errors OR general explanation	1

Sample answer: KH_2PO_4 solution dissociates as below:

$$KH_2PO_4(aq) \rightarrow K^+(aq) + H_2PO_4^-(aq)$$

$H_2PO_4^-$ is an amphiprotic ion that can act as a proton donor (BL acid) when reacted with a basic substance. It can act as a proton acceptor (BL base) when reacted with an acidic substance.

During a strong acid spill, the $H_2PO_4^-$ reacts with the H_3O^+ released from the strong acid & reaction occurs as follows:

$$H_2PO_4^-(aq) + H_3O^+ \rightarrow H_3PO_4(aq) + H_2O(l)$$

($H_2PO_4^-$: BL base, proton acceptor; H_3O^+: from acid)

So the strong spilled acid is neutralised completely when excess KH_2PO_4 is added.

During a strong base spill ($NaOH$), $H_2PO_4^-$ reacts with the OH^- released by the base as follows:

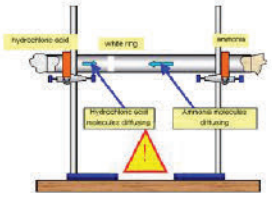
$$H_2PO_4^-(aq) + OH^-(aq) \rightarrow HPO_4^{-2}(aq) + H_2O(l)$$

BL acid, proton donor

Marker' comment: Most students could not score full marks although they knew the concept due to lack of skill in writing scientific explanations. They did not link the equations to specific BL acid's characteristics as a proton donor. Instead, gave general recall-based explanation.

Question 5 (6 marks)

The Chemistry class of 2022 NBHS conducted an experiment to demonstrate diffusion of gases. The students set up the apparatus as shown below.



Two plugs of cotton wool are put into the ends of a horizontal glass tube. One was soaked with concentrated hydrochloric acid and the other with concentrated ammonia.

After a few minutes, a white ring formed in the tube and the ring was closer to the end of the tube where the hydrochloric acid plug was.

(a) Write a balanced chemical equation that occurs in the above experiment and assess the suitability of Arrhenius' theory to classify it as an acid-base reaction. **2**

Criteria	**Marks**
Correct reaction with states AND Identifies ARH not suitable AND provides one justification linking to ARH definition of acid and base AND linking to the stimulus provided.	2
Correct reaction with states OR Identifies ARH not suitable AND provides one justification linking to ARH definition of acid and base	1

$HCl(g) + NH_3(g) \rightarrow NH_4Cl(s)$ 1 mark for correct reaction with states
According to Arrhenius theory, acids release H^+ ions in solution and bases release OH^- in solution.
Arrhenius not suitable because acid-base reaction occurring in non-aqueous environment.

where the hydrochloric acid plug was.

(a) Write a balanced chemical equation that occurs in the above experiment and assess the suitability of Arrhenius' theory to classify it as an acid-base reaction. 2

$HCl_{(g)} + NH_4OH_{(g)} \rightarrow NH_4Cl_{(s)} + H_2O_{(g)}$

Arrhenius theory suggests that acids and bases produce H^+ and OH^- ions in solution (respectively) the above procedure does not prove such as the reaction occurs between gaseous molecules. Therefore arrhenius theory is not suitable to explain the above procedure as and acid-base

very good

Question 5 (4 marks)

(b) The Chemistry Class of 2022 NBHS conducted an experiment where some metallic iron surfaces were cleaned using a process known as pickling. The surfaces had some brown rings due to the formation of rust.

Iron(III) oxide (Fe_2O_3) is a base and the main component of rust. It is insoluble in water but highly soluble in HCl. During pickling the students dipped the steel surfaces in a liquid mixture called pickling liquor containing HCl.

This led to the dissolution of the iron (III) oxide in HCl. The reaction can be shown as:

$$Fe_2O_3(s) + 6HCl(aq) \rightarrow 2FeCl_3(aq) + 3H_2O(l)$$

They were then able to clean off all the brown rings and make the surfaces lustrous.

State whether iron (III) oxide $Fe_2O_3(s)$, can be classified as a Bronsted-Lowry acid/base or an Arrhenius acid/base. Justify your response.

Criteria	Marks
Provides a comprehensive explanation given while maintaining a chronological order as to why the Bronsted/Lowry definition of acids and bases is more applicable than the Arrhenius theory for Fe_2O_3 by: Linking Arrhenius theory to the given reaction AND Linking Bronsted/Lowry theory to the given reaction AND Concluding iron (III) oxide $Fe_2O_3(s)$ as a BL base No chemical/ionic reaction needs to be written	4
Shows a sound understanding (Key terminology and understanding of each theory shown at superficial level only) as to why the Bronsted/Lowry definition is more applicable than the Arrhenius theory Outlining Arrhenius theory to given stimulus AND Linking Bronsted/Lowry theory to the given reaction AND/or Concluding iron (III) oxide $Fe_2O_3(s)$ as a BL base No chemical/ionic reaction needs to be written	3
Shows understanding of the difference between the Bronsted/Lowry and Arrhenius theories and shows a basic understanding of how they relate to Fe_2O_3	2
Provides some relevant information about the Bronsted/Lowry definition of acids and bases and the Arrhenius theory	1

Sample answer:

The Arrhenius theory states that acids are chemicals that donates a H^+ ion into solution, and bases donate OH^- ions into solution.

Iron (III) oxide (Fe_2O_3) is composed of Fe^{3+} and O^{2-} ions, neither of which would dissociate into solution because iron (III) oxide is insoluble in water.

Therefore, the Arrhenius theory, which narrows the definition of "base" to compounds that donate OH^- ions into solution, would not cover the basic properties of iron (III) oxide.

The Bronsted/Lowry theory states that acids are proton donors and bases are proton acceptors.

The Bronsted/Lowry theory satisfactorily explains the basic nature of Fe_2O_3, in that the O^{2-} ions are shown to accept protons from HCl in the dissolution of Fe_2O_3 in a solution of HCl.

The O^{2-} ion accepts 2 protons (H^+) from HCl to form H_2O.

Fe_2O_3 (s) + $6H^+$ (aq) → 2 Fe^{3+} (aq) + 3 H_2O (l)

A **Brønsted-Lowry base** is any species that is capable of accepting a proton, which requires a lone pair of electrons to bond to the H^+.

https://www.khanacademy.org/science/chemistry/acids-and-bases-Lowry%20base.

Conclusion: Hence, the Bronsted/Lowry theory is more suitable in explaining the basic properties of iron (III) oxide.

In the pickling process, the 3HCl acp donates $3H^+$ to Fe_2O_3 to form Fe^{2+} & $3H_2O_{(l)}$. This is an example of Bronsted-Lowry acid & base. B-L definition, acids are proton donors & bases are proton acceptors in ~~base~~ B-L acid-base reaction. Since HCl donates H^+, it is an B-L acid, & Fe_2O_3 is accepting H^+ & reacting with it, it is B-L base, ∴ Fe_2O_3 can be classified as B-L base. Again, the above reaction cannot be classified as an Arrhenius acid & base reaction because Fe_2O_3 is not an aqeous species, ~~not~~ nor can it release OH^- (absense of H atom), hence it cannot be an Arrhenius acid or base.

∴ Reaction of B-L base Fe_2O_3 & B-L acid HCl, was able to dissolve Fe_2O_3 in form of $FeCl_3$ acp after B-L acid/base reaction.

Question 6 (6 marks)

A sample of 25.0 mL of 0.120 mol L^{-1} of standardized solution of ammonium hydroxide was titrated against nitric acid, obtained from an unlabelled bottle. The results were recorded in the table below.

(a) Calculate the concentration of nitric acid solution. 3

Criteria	Marks
Balanced reaction AND Correct titre = 18.13 mL calculated AND Correct calculation and all relevant steps to calculate concentration of nitric acid = 0.33M **Sig fig not considered here**	3
All steps correctly shown but one error from the following: Balanced reaction AND Correct titre = 18.13 mL calculated AND Correct calculation and all relevant steps to calculate concentration of nitric acid = **Sig fig not considered here**	2
Incorrect equations and multiple errors	1

Sample answer

Titration	Volume of nitric acid (mL)
1	18.2
2	18.1
3	21.4
4	18.1

$NH_4OH(aq) + HNO_3(aq) \rightarrow NH_4NO_3(aq) + H_2O(l)$ (1)

1 : 1

$n_{NH_4OH} = \frac{25}{1000}\,L \times 0.12\,\frac{mol}{L} = 0.003$ moles

$n_{NH_4OH} : n_{HNO_3} = 1:1 = 0.003$ moles

average titre $= \frac{18.1 + 18.2 + 18.1}{3} = \frac{54.4}{3} = 18.13$ mL (1)

$= 0.01813\,L$

$C_{HNO_3} = \frac{n}{V} = \frac{0.003\ moles}{0.01813\,L} = 0.165\,mol\,L^{-1}$ (1)

or

0.1655

(b) Using a chemical equation, explain the pH of the resultant salt solution. **3**

Criteria	Marks
Identify the pH of the salt solution AND Detailed **scientific explanation for hydrolysis** AND **1 or more correct equations linked** to the explanations	3
Correct scientific explanation for hydrolysis with reference to pH of salt solution AND Equation/s not linked to explanation	2
Outlined explanation for hydrolysis AND/OR Correct equation with some errors	1

NH_4NO_3 dissociates in solution during titration as

$$NH_4NO_3(aq) \rightarrow NH_4^+(aq) + NO_3^-(aq)$$

Nitrate ions are neutral but NH_4^+ ion undergoes hydrolysis further in water as follows:

$$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$$

(BL acid, proton donor)

pH < 7

The H_3O^+ makes the solution acidic so pH < 7.

.....

(b) Using a chemical equation, explain the pH of the resultant salt solution. 3

The resultant salt NH_4NO_3 dissociates into the neutral NO_3^- ion and the NH_4^+ ion. ✓

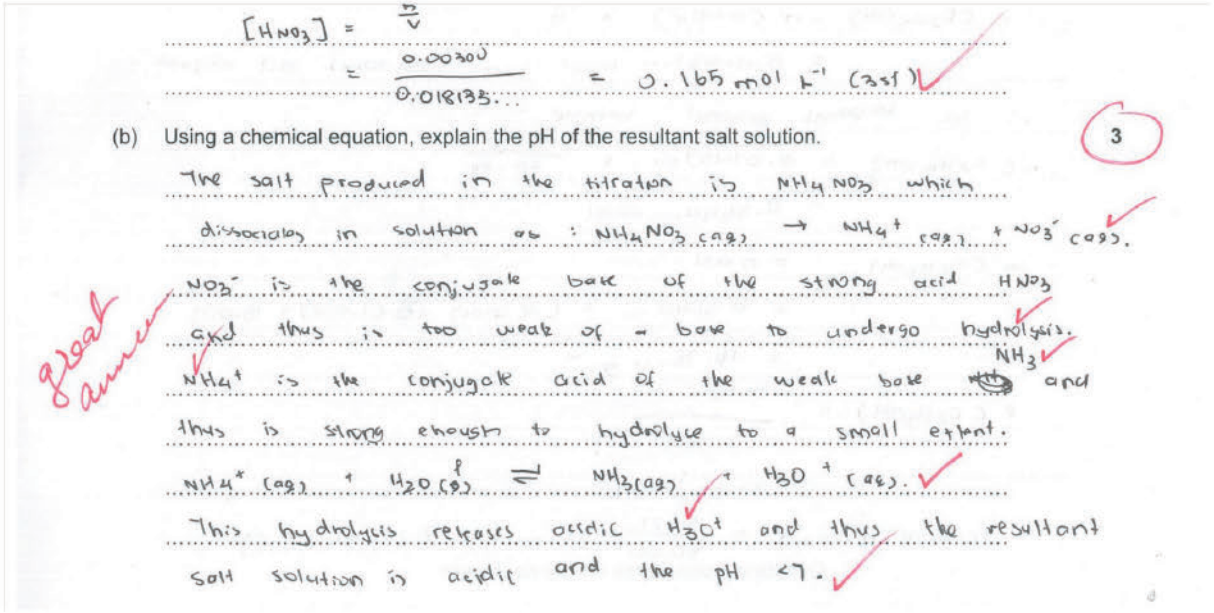
∴ NH_4^+ is the weak conjugate acid of weak base NH_3 as seen in: $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ ✓

undergoes hydrolysis

NH_4^+ must therefore ionise in solution to form H^+ or H_3O^+ as it is an acid: $NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$

∴ The solution has H_3O^+, it is acidic ✓

⇒ pH < 7 ✓



$[HNO_3] = \frac{n}{V}$

$= \frac{0.00300}{0.018135...} = 0.165 \text{ mol } L^{-1}$ (3sf) ✓

(b) Using a chemical equation, explain the pH of the resultant salt solution. 3

The salt produced in the titration is NH_4NO_3 which dissociates in solution as: $NH_4NO_3(aq) \rightarrow NH_4^+(aq) + NO_3^-(aq)$. ✓

NO_3^- is the conjugate base of the strong acid HNO_3 and thus is too weak of a base to undergo hydrolysis. ✓

NH_4^+ is the conjugate acid of the weak base NH_3 ✓ and thus is strong enough to hydrolyse to a small extent.

$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$. ✓

This hydrolysis releases acidic H_3O^+ ✓ and thus the resultant salt solution is acidic and the pH <7. ✓

great answer

Marker's comment: Most students did part a well. A lot of misconceptions about pH of salt solutions and the effect of hydrolysis of salts. Revise BL theory well.

Question 7 (6 marks)

A special red wine manufacturer from the Hunter region claims its alcohol content as 40.0%(v/v). Bobby decides to test this claim and conducts a volumetric titration using a sample of the red wine against a standard solution of potassium permanganate, $KMnO_4$, to determine the ethanol content in the red wine.
He transfers a 50.00 mL sample of the above red wine into a 500.0 mL volumetric flask and makes up to the mark with distilled water. He then transfers 20.00 mL aliquot from the volumetric flask into a conical flask, adds an appropriate indicator and titrates against a 0.5022 mol L^{-1} solution of $KMnO_4$.
The reaction is recorded as:

$$4MnO_4^-(aq) + 5C_2H_5OH(aq) + 12H^+(aq) \rightarrow 4Mn^{2+}(aq) + 5CH_3COOH(aq) + 11H_2O(l)$$

The (MnO_4^-) ion has an intense purple colour while the Mn^{2+} ion is colourless. The average of the concordant titres is recorded as 23.22 mL.

(a) The density of ethanol is 0.789 g mL^{-1}. **4**

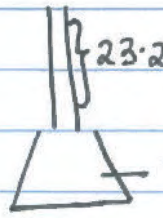
Calculate the concentration of ethanol in %(v/v) in the red wine that Bobby titrated.

Criteria	Marks
Correctly calculates the **moles of Ethanol = 0.014576355** AND Relevant steps to calculate the **original concentration of Ethanol = 7.2881775M** AND Relevant steps to calculate Ethanol content in % (v/v) = 42.55%9(v/v) or 42.6% (v/v) AND Appropriate significant figures	4
Any one error resulting in final wrong value in the following: Correctly calculates the moles of Ethanol = 0.014576355 And/or Relevant steps to calculate the original concentration of Ethanol = 7.2881775M And/or Relevant steps to calculate Ethanol content in % (v/v) = 42.55%9(v/v) or 42.6% (v/v) AND /or Appropriate significant figures	3
Two or more errors or relevant steps missing but correct answer in the following: Correctly calculates the moles of Ethanol = 0.014576355 And/or Relevant steps to calculate the original concentration of Ethanol = 7.2881775M And/or Relevant steps to calculate Ethanol content in % (v/v) = 42.55%9(v/v) or 42.6% (v/v) AND /or Appropriate significant figures	2
Any one step correct only **OR** Multiple errors with incorrect answer	1

$n(MnO_4^-) = 0.5022 \frac{mol}{L} \times 0.02322 = 0.011661084\ mol$

$n(C_2H_5OH) = n(MnO_4^-) \times \frac{5}{4} = (\downarrow) \times \frac{5}{4}$

$n(C_2H_5OH) = 0.014576355\ moles$



Dilution factor $= \frac{500}{50} = 10$

$[C_2H_5OH]_{dil} = \frac{n}{V} = \frac{0.014576355}{0.02\ L}$

$= 0.72881775\ mol\ L^{-1}$

$[C_2H_5OH]_{original} = [C_2H_5OH]_{dil} \times 10$

$= \frac{7.2881775\ mol}{1L}$

$= \frac{7.2881775\ mol}{1000\ ml} \times 100$

$= \frac{0.7288\ mol}{100mL}$

mass: $m(C_2H_5OH) = n \times M = 0.72881775 \times (2 \times 12.01 + 6 \times 1.008 + 16) =$ [illegible] g

density:

density of $C_2H_5OH = 0.789\ g/mL$

mass of C_2H_5OH in 100 mL $= 0.7288 \times Mw = 33.574\ g$

Mass = Volume x density $\Rightarrow$ M ÷ d = volume

volume of $C_2H_5OH = \frac{33.574\ g}{0.789\ g/mL} = 42.55\%\ (v/v)$

Ethanol content is 42.6% (v/v)

NESA STUDENT NUMBER

Marks

Question 7 (6 marks)

A special red wine manufacturer from the Hunter region claims its alcohol content as 40.0%(v/v).

Bobby decides to test this claim and conducts a volumetric titration using a sample of the red wine against a standard solution of potassium permanganate, $KMnO_4$, to determine the ethanol content in the red wine.

He transfers a 50.00 mL sample of the above red wine into a 500.0 mL volumetric flask and makes up to the mark with distilled water. He then transfers 20.00 mL aliquot from the volumetric flask into a conical flask, adds an appropriate indicator and titrates against a 0.5022 mol L^{-1} solution of $KMnO_4$.

The reaction is recorded as:

$$4MnO_4^-(aq) + 5C_2H_5OH(aq) + 12H^+(aq) \rightarrow 4Mn^{2+}(aq) + 5CH_3COOH(aq) + 11H_2O(l)$$

The (MnO_4^-) ion has an intense purple colour while the Mn^{2+} ion is colourless. The average of the concordant titres is recorded as 23.22 mL. $V(KMnO_4) = 0.02322\ L$

(a) The density of ethanol is 0.789 g mL^{-1}. **4**

Calculate the concentration of ethanol in %(v/v) in the red wine that Bobby titrated.

$n(KMnO_4) = cxv = 0.5022 \times 0.02322 = 0.011661084$ mol

$n(MnO_4^-) = n(KMnO_4) = 0.011661084$ mol (1:1 mole ratio)

$\therefore n(C_2H_5OH) = n(MnO_4^-) \times \frac{5}{4} = 0.011661084 \times \frac{5}{4} = 0.014576355$ mol (4:5 mole ratio)

$\rho = \frac{m}{V}$

$0.789 = \frac{m}{0.05}$

$m =$

$[C_2H_5OH] = \frac{n}{V} = \frac{0.014576355}{0.02}$

$= 0.72881775\ mol\ L^{-1}$

$[C_2H_5OH]_{undiluted} = [C_2H_5OH] \times 10$

$= 7.2881775\ mol\ L^{-1}$

$m(C_2H_5OH) = n \times M$

$= 7.2881775 \times (2(12.01) + 6(1.008) + 16.00)$

$= 335.7517611\ g$

$= \frac{7.2881775\ mol}{1\ L}$

$\therefore \%(v/v) = \frac{425.5408886\ mL}{1000\ mL} \times 100$

$= 42.55\%$ (4 s.f.)

$= 42.6\%$ (3 s.f.)

$\rho = \frac{m}{V}$

$V = \frac{m}{\rho} = \frac{335.7517611\ g}{0.789} = 425.5408886\ mL$

Question 7 continues on the next page

(b) Bobby performed some research and found some interesting information about this titration: **2**

- Mn^{2+} can act as a catalyst for the reduction of MnO_4^- ions.
- A brown solid, most likely MnO_2 forms during this titration, which may have been produced from the incomplete reduction of MnO_4^- ions.
- These MnO_4^- ions would therefore oxidise a smaller amount of ethanol.

Using your explanation, assess the manufacturer's claim.

Criteria	Marks
Correct assessment supported with correct justification	
Correct assessment OR correct justification	

A brown solid $MnO_2$was formed during titration from the incomplete reduction of MnO_4^- ions. A smaller amount of ethanol would have been oxidised by these MnO_4^- ions.

This means a greater amount of MnO_4^- ions would have been required to react with all the ethanol, which would lead to higher titre volume obtained. So the calculated value is higher than the actual ethanol content.

Conclusion

The ethanol content in the vodka was determined to be 42.5% (v/v), higher than the manufacturer's quoted value of 40.0% (v/v).

Answers may vary but justification needs to support the claim.

Using your explanation, assess the manufacturer's claim.

(1) Since Mn^{2+} may reduce MnO_4^- to MnO_2 solid ppte, a lower no. mole MnO_4^- will participate in oxidising ethanol.

(2) Hence more titre of MnO_4^- will be required to oxidise all of ethanol in conical flask & will result in experimental calculation values to result in a greater than actual concentration of ethanol.

(3) From a), 42.6% (v/v) ethanol is only slightly higher than the manufacturer's claim & combined with inaccuracy, the result may be affect, indicating the actual ethanol concentration is very close to 40% (v/v).

(4) ∴ the manufacturer's claim are valid for 40% (v/v) ethanol.

Using your explanation, assess the manufacturer's claim.

The reduction of MnO_4^- dilutes the $[MnO_4^-]$ during the titration. As a result more volume of MnO_4^- solution is required to meet the no. of moles needed to neutralise all CH_3OH. Hence the percentage concentration of C_2H_5OH (42.55%) is likely to be higher than the actual.

Hence the manufacturer's claim could be correct due to $[C_2H_5OH] < 42.55\%$ (v/v).

Question 8 (6 marks)

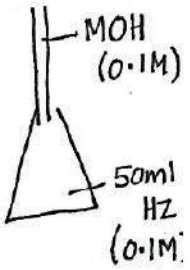
Darren conducted a titration between a strong acid HZ and a strong base MOH for investigating titration curves to study characteristic reaction profiles.

He used 0.10 mol L^{-1} of each solution. He added 50 mL of the acid HZ in a clean conical flask and inserted a pH probe to measure the pH of the solution in the conical flask during the titration. He recorded observed values of his experiment in the following table.

(a) Show relevant calculations in the space given below and **complete the pH values in the above table.**

Criteria	Marks
All pH values correctly filled in the table as 1.5,3.0 and 11.0 **AND** **Relevant calculations correctly shown for #2** **AND** **Relevant calculations correctly shown for #3** **AND** **Relevant calculations correctly shown for #5**	**3**
All of above correct with ONE error or one calculation incomplete **OR** **Most steps correctly done with incomplete relevant steps in all OR steps difficult to follow** **OR** **All Relevant calculations correctly shown BUT pH values have some incorrect values**	**2**
Multiple errors in calculations with incorrect pH values in table	**1**

#	Volume of MOH added (mL)	pH of HZ
1	0	1.0
(2)	25	1.5
3	49	3.0
4	50	7.0
5	51	11.0
6	75	12.3



(a) Show relevant calculations in the space given below and **complete the pH values in the above table.** 3

$HZ_{(aq)} + MOH_{(aq)} \rightarrow MZ_{(aq)} + H_2O_{(l)}$

(2) $n(HZ)$ initial $= 0.10 \times 0.050 = 0.0050$ moles

Base added $n(MOH) = 0.10 \times 0.0250 = 0.00250$ moles

$n(H^+)$ remaining $= 0.0050 - 0.00250 = 0.00250$ moles

Volume $= 0.0750$ L

$[H^+] = \frac{0.00250}{0.0750} = 0.033$ $\quad pH_2 = -\log 0.033 = 1.5$

(3) $n(MOH\ added) = 0.10 \times 0.0490 = 0.00490$ moles

$n(HZ)$ remaining $= n(H^+) = 0.0050 - 0.00490 = 0.00010$ moles

Volume $= 0.0990$ L $\quad [H^+] = \frac{0.00010}{0.099} = 1.01 \times 10^{-3}$ or 0.00101

$pH_3 = -\log 0.00101 = 3.0$

50ml HZ & 51ml

Question 8 continues on the next page

1ml MOH added

(5) $n(OH^-) = 0.1M \times 0.001L = 0.0001$ moles $\quad V = 0.101$ L

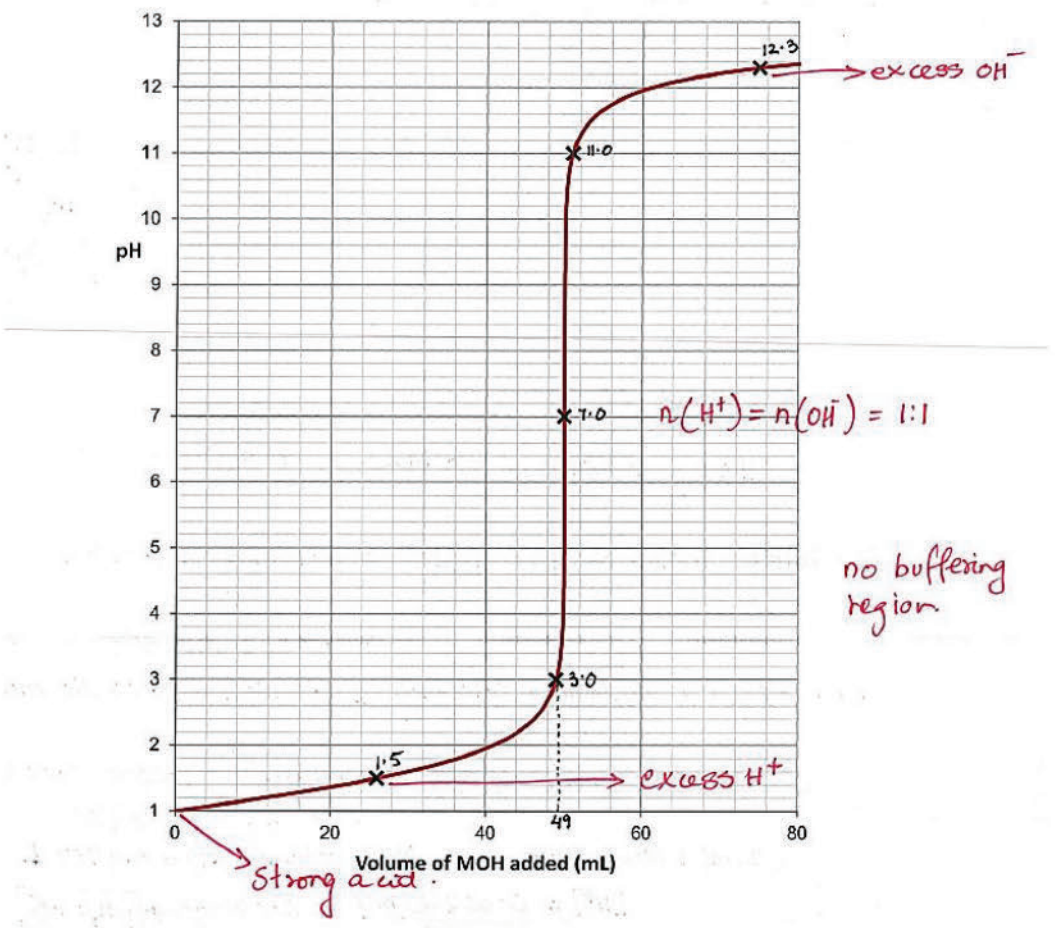
$[OH^-] = 0.0001/0.101 = 0.00099$, $pOH = -\log 0.00099 = 3$

So $pH = 14 - 3 = 11.0$

Question 8

(b) Draw an appropriately labelled titration curve using the above completed table and identify **any TWO key** characteristics of the curve.

Criteria	Marks
All points plotted correctly according to calculations and table values. AND Trendline similar to strong acid/base titration curve AND Two characteristics stated based on drawn titration curve	3
Most points plotted correctly AND Curve described rather than characteristics stated	2
Trendline correct OR some of the above correct	1



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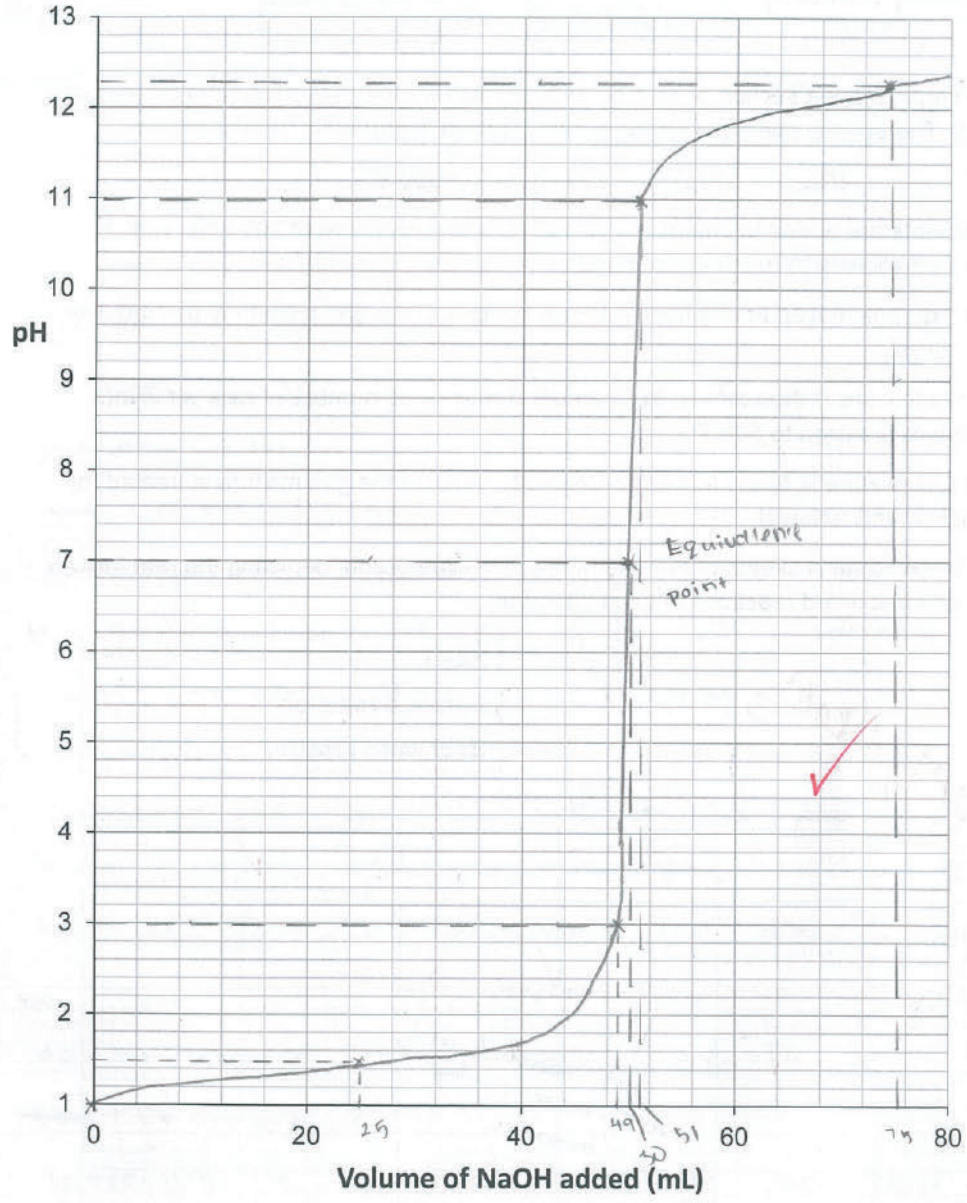
Marks

Question 8 continued...

(b) Draw an appropriately labelled titration curve using the above completed table and identify **any TWO** key characteristics of the curve. **3**



excellent.

1. At the equivalence point, pH is 7.0, curve is vertical almost here

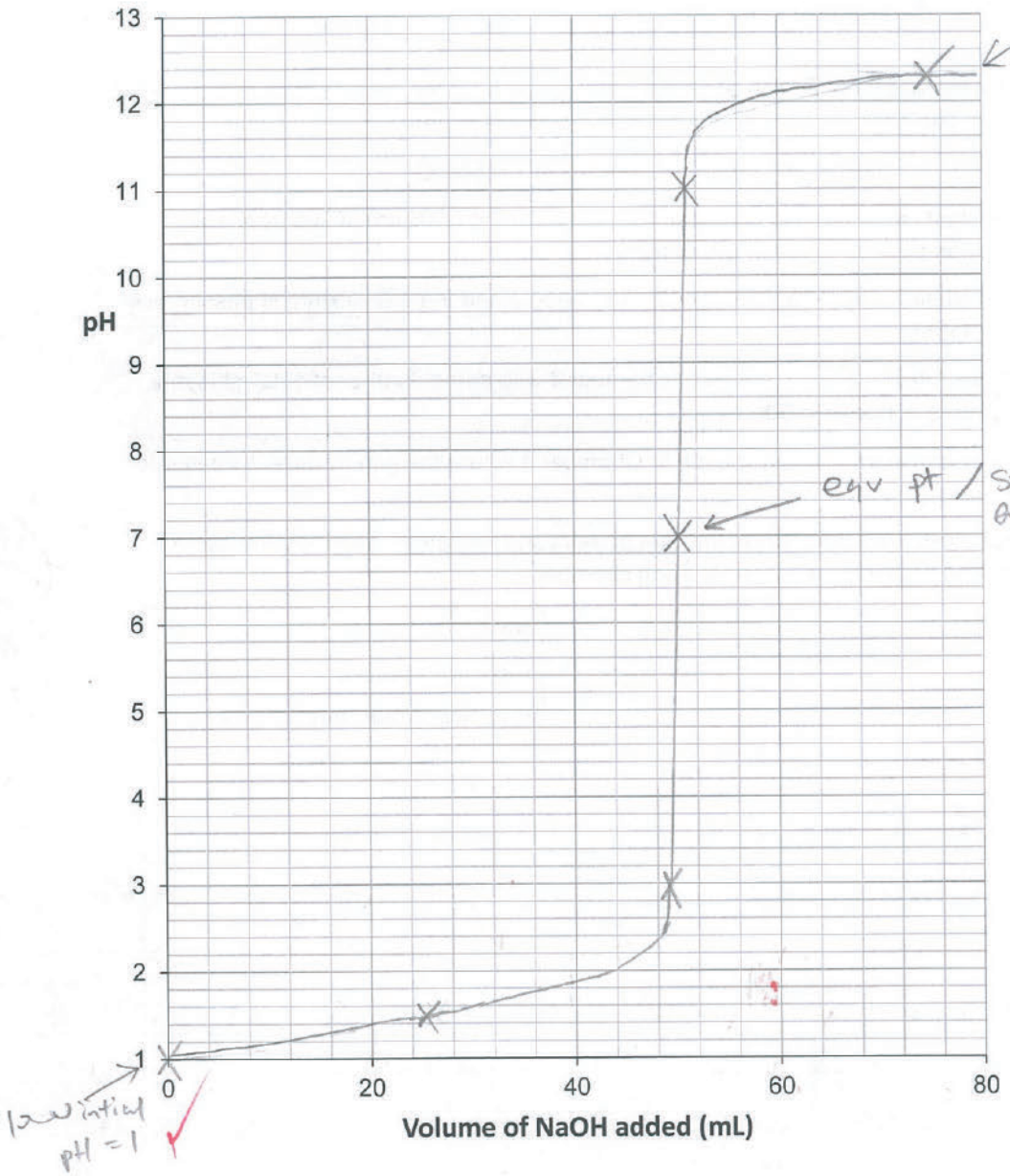
2. pH reach is very slowly increasing near the beginning of the titration (0 - 49mL) but shoots up drastically at 49-51 mL. From (51 - 80mL), pH is very slowly increasing again.

NESA STUDENT NUMBER

Marks

Question 8 continued...

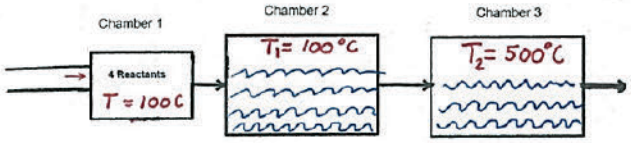
(b) Draw an appropriately labelled titration curve using the above completed table and identify **any TWO** key characteristics of the curve. 3



very good.

1. Eqv pt / Stochiometric eqlpt is at pH = 7 (neutral)
∴ Both acid & base are Strong ⇒ the salt product will be neutral
2. low initial pH = 1
the acid is Strong ⇒ 100% ionised ⇒ conc. of acid = 0.1M
⇒ $[H^+]$ initial = 0.1M
$pH = -\log[H^+]$ ⇒ initial pH = 1

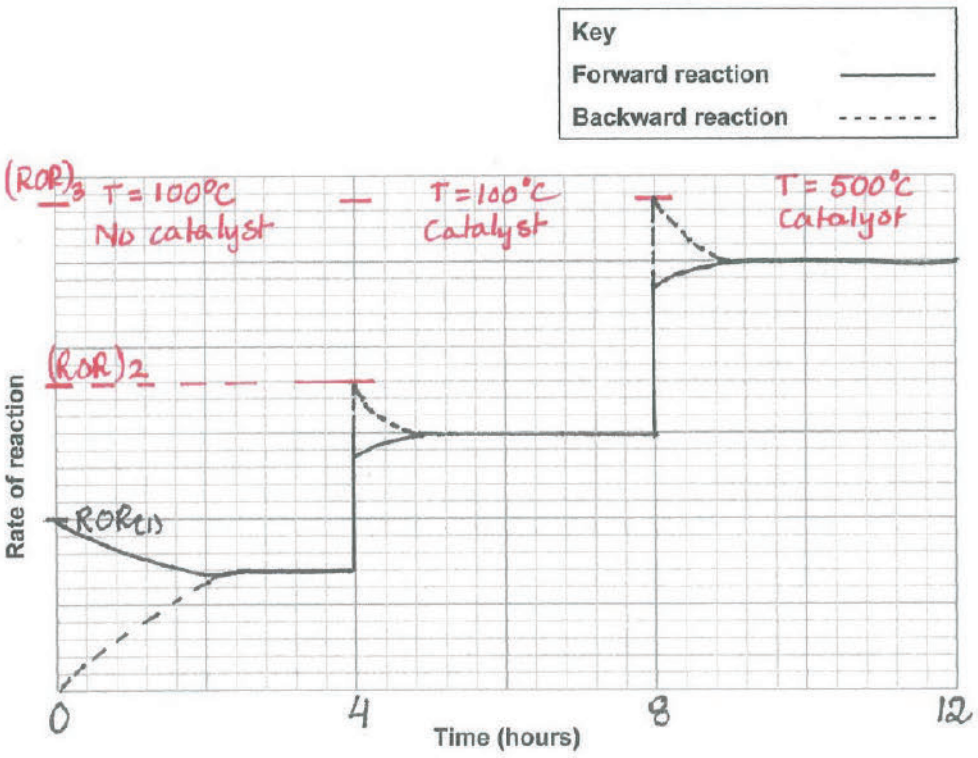
Question 9 (9 marks)

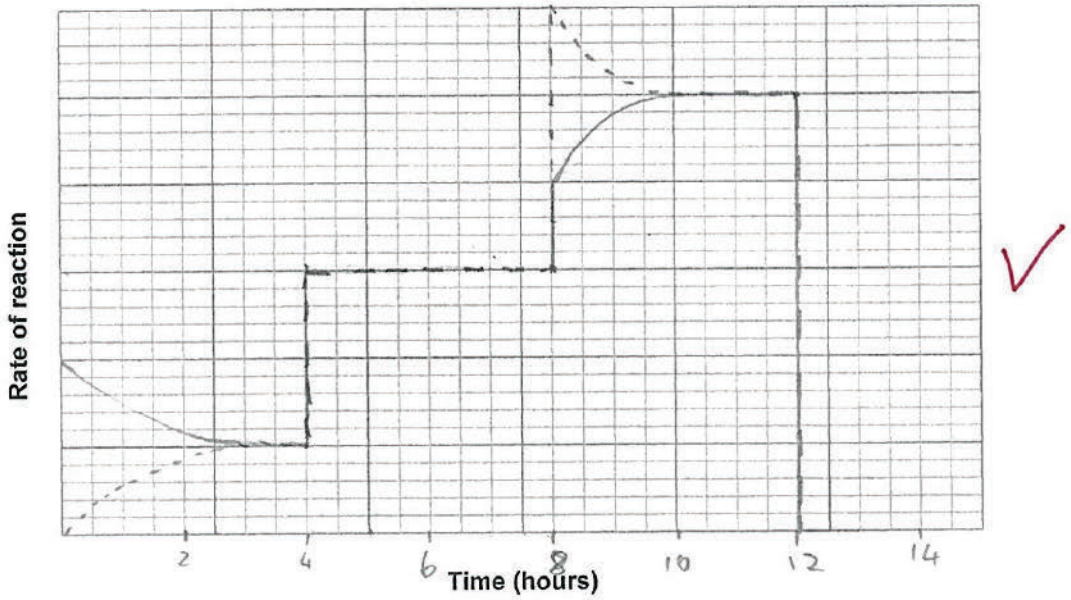


The above diagram represents a section of an industrial process for the manufacture of a chemical present in fertilisers. The optimal condition for the above process is generally represented by:

$$4R(g) \rightleftharpoons 2P(g) \qquad \Delta H < 0 \text{ at } T = 500°C$$

Criteria	Marks
Rate of reaction (ROR)	
Sketch for chamber 1 correctly drawn AND Sketch for chamber 2 correctly drawn (Straight line only accepted since volume of chamber not to scale) AND Sketch for chamber 3 correctly drawn AND Rate of reaction $(ROR)_1 < (ROR)_2 < (ROR)_3$	4
All trendlines correct with One Error	3
All trendlines have some correct sections **AND** Rate of reaction (ROR) of at least TWO in order $(ROR)_1 < (ROR)_2$ OR $(ROR)_2 < (ROR)_3$	2
All trendlines have some correct section AND ROR of AT LEAST TWO in order	1





(b) Using collision theory and Le Chatelier's Principle, explain the changes in the rate of reaction and concentration of the reaction mixture in chambers 1, 2 and 3 only.

Criteria	Marks
1. Explains $(ROR)_1$ in CH1 with reference to stimulus/graph drawn in terms of LCP and/or Collision Theory AND 2. Explains $(ROR)_2$ in CH2 with reference to stimulus/graph drawn in terms of LCP and/or Collision Theory AND explaining the role of catalyst AND 3. Explains $(ROR)_3$ in CH3 with reference to stimulus/graph drawn in terms of LCP and/or Collision Theory AND explaining changes at t = 8 hours AND T>8 hours AND 4. Maintains good chronological order, uses scientific terminology, and displays deep understanding of LCP AND collision theory and its impact on ROR_{fwd} and ROR_{bwd}	5
1, 2 and 3 all addressed correctly BUT 4 is limited, must have no errors	4
Outline of 1 and/or 2 and/or 3 AND sound explanation in some areas and 4 is lacking in any one component or some errors in 1 of the two components	3
Limited understanding of LCP and/or Collision Theory	2
Any one or two pieces of information correct in explaining LCP and/or Collision Theory	

Marker's comment: part a was poorly done but part b was well answered by most students. Students scoring full marks were able to:

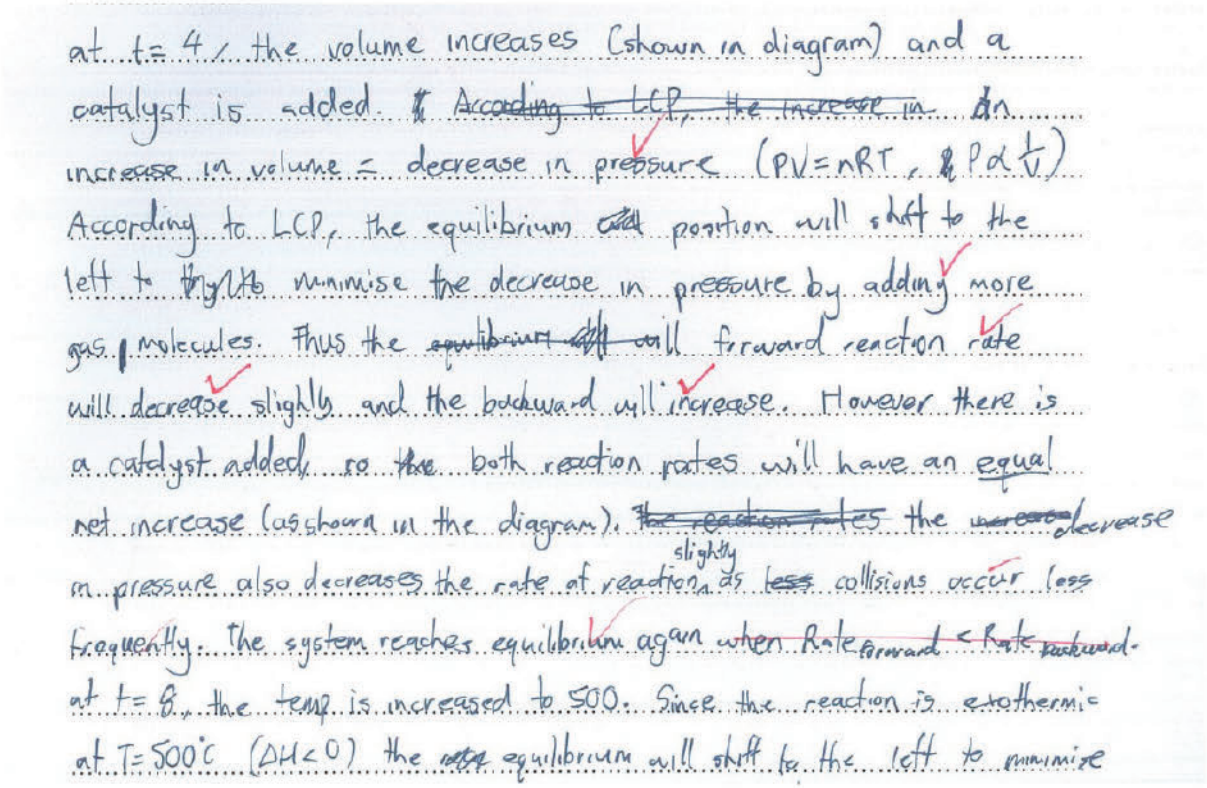
Identify reaction conditions in each chamber, then explain the changes in rate of reaction for forward and backward using either collision theory (chamber 1 and 3) and gas laws (PV=nRT) and LCP mainly for chamber 2.

It was pleasing to see many students justify the increase in volume and its impact on rate of reaction using LCP.

Students explained well increase in temperature favouring endothermic reaction and linked it well to activation energy required and LCP as well.

Students are encouraged to re-attempt the question to get a perfect score if they have not received full marks.

A sample of great explanation from Max Luo:


at t= 4, the volume increases (shown in diagram) and a catalyst is added. ~~According to LCP, the increase in~~ An increase in volume = decrease in pressure (PV=nRT, & P∝1/V) According to LCP, the equilibrium ~~will~~ position will shift to the left to ~~try to~~ minimise the decrease in pressure by adding more gas molecules. Thus the ~~equilibrium will~~ forward reaction rate will decrease slightly and the backward will increase. However there is a catalyst added, so the both reaction rates will have an equal net increase (as shown in the diagram). ~~The reaction rates~~ the ~~increase~~ decrease in pressure also decreases the rate of reaction slightly as ~~less~~ collisions occur less frequently. The system reaches equilibrium again when Rate forward = Rate backward. at t= 8, the temp. is increased to 500. Since the reaction is exothermic at T=500°C (ΔH<0) the ~~new~~ equilibrium will shift to the left to minimize

Question 10 (4 marks)

H_3AsO_4 is a weak triprotic acid that releases its hydrogen ions in three steps as shown below:

Step 1: $H_3AsO_4(aq) + H_2O(l) \leftrightharpoons H_3O^+(aq) + H_2AsO_4^{-1}(aq)$ $pKa_1 = 2.24$

Step 2: $H_2AsO_4^{-1}(aq) + H_2O(l) \leftrightharpoons H_3O^+(aq) + HAsO_4^{-2}(aq)$ $pKa_2 = 6.96$

Step 3: $HAsO_4^{-2}(aq) + H_2O(l) \leftrightharpoons H_3O^+(aq) + AsO_4^{-3}(aq)$ $pK_{a3} = 11.50$

Derive the expression for the equilibrium constant (K_{eq}) for the following reaction and calculate its value.

$$H_3AsO_4 + 3H_2O(l) \leftrightharpoons 3H_3O^+(aq) + AsO_4^{-3}(aq)$$

Criteria	Marks
Shows relevant working to **derive the Keq expression** for $H_3AsO_4 + H_2O(l) \leftrightharpoons 3H_3O^+(aq) + AsO_4^{-3}(aq)$ **AND** **Prove the relationship**: $Keq = Ka_1 \times Ka_2 \times Ka_3$ **AND** Writes the correct expression for each Ka AND Correctly calculates all Ka values for step1, 2 and 3 **AND** Correctly calculates Keq = 2.00×10^{-21}	4
With any one error in the following steps Shows relevant working to **derive the Keq expression** for $H_3AsO_4 + H_2O(l) \leftrightharpoons 3H_3O^+(aq) + AsO_4^{-3}(aq)$ **AND** **Prove the relationship**: $Keq = Ka_1 \times Ka_2 \times Ka_3$ **AND** Writes the correct expression for each Ka AND Correctly calculates all Ka values for step1, 2 and 3 **AND** Correctly calculates Keq = 2.00×10^{-21}	3
Uses **the relationship**: $Keq = Ka_1 \times Ka_2 \times Ka_3$ **AND** Correctly calculates all Ka values for step1, 2 and 3 **AND** Correctly calculates Keq = 2.00×10^{-21}	2
Any one step correct from the following: Shows some relevant working to **derive the Keq expression** **OR** **Uses the relationship**: $Keq = Ka_1 \times Ka_2 \times Ka_3$ **AND** Correctly calculates any one or two Ka values for step1, 2 and 3 **AND/OR** Some correct steps to calculate Keq with incorrect answer	1

Sample answer:

$pKa_1 = 2.24$

$Ka_1 = 10^{-pKa_1} = 5.75 \times 10^{-3}$

$pKa_2 = 6.96$

$ka_2 = 10^{-6.96} = 1.1 \times 10^{-7}$

$pKa_3 = 11.50$

$ka_3 = 10^{-11.50} = 3.16 \times 10^{-12}$

$$Ka_1 = \frac{[H_3O^+][H_2AsO_4^-]}{[H_3AsO_4]} \qquad Ka_2 = \frac{[H_3O^+][HAsO_4^{-2}]}{[H_2AsO_4^-]} \qquad Ka_3 = \frac{[H_3O^+][AsO_4^{-3}]}{[HAsO_4^{-2}]}$$

$$H_3AsO_4(aq) + 3H_2O(l) \rightleftharpoons 3H_3O^+(aq) + AsO_4^{-3}(aq)$$

$$K_{eq} = \frac{[H_3O^+]^3[AsO_4^{-3}]}{[H_3AsO_4]}$$

$$ka_1 \times ka_2 \times ka_3 = \frac{[H_3O^+][H_2AsO_4^-]}{[H_3AsO_4]} \times \frac{[H_3O^+][HAsO_4^{-2}]}{[H_2AsO_4^-]} \times \frac{[H_3O^+][AsO_4^{-3}]}{[HAsO_4^{-2}]}$$

$$= \frac{[H_3O^+]^3[AsO_4^{-3}]}{[H_3AsO_4]} = K_{eq} \text{ Proved}$$

$$= 5.75 \times 10^{-3} \times 1.1 \times 10^{-7} \times 3.16 \times 10^{-12}$$

$$= 1.99 \times 10^{-21} = 2.00 \times 10^{-21}$$

Normanhurst Boys High School

2022 Year 12 Chemistry Trial Examination

Marking Responses, Sample Answers & Notes from the Marker

S2B

Section 2B (20 marks)

Question 1 (3 marks)

James placed 100 g of glucose ($C_6H_{12}O_6$) into a conical flask, dissolved it in water and added some yeast. He then weighed the conical flask, warmed the mixture to 32°C and left the flask for about 2 days until the reaction has completed. **3**

Afterwards, he re-weighed the flask, and recorded his results as shown below.

- Initial mass of conical flask with mixture = 335.2 g
- Final mass of conical flask with mixture = 319.4 g

Calculate the mass of glucose consumed in the reaction.

Question 1

Marking Criteria	Marks
States the balanced chemical equation for the fermentation of glucose. AND Correctly calculates the mass of glucose consumed by: • calculating the moles of CO_2 produced using the mass lost from the mixture. • determining the moles of glucose using the stoichiometric mole ratio. • calculates the mass of glucose consumed.	3
States the balanced chemical equation for the fermentation of glucose. AND Provides the main steps in calculations including the following: • calculates the moles of CO_2 produced using the mass lost from the mixture. • determining the moles of glucose using the stoichiometric mole ratio. **OR** Incorrect chemical equation. AND Correctly calculates the mass of glucose consumed by: • calculating the moles of gas produced using the mass lost from the mixture. • determining the moles of glucose using the stoichiometric mole ratio. • calculates the mass of glucose consumed.	2
Provides some relevant information including at least ONE of the following: • stating the balanced chemical equation for the fermentation of glucose AND determines the difference in mass. • determines the mass lost as CO_2 and calculates the moles of CO_2 produced.	1

Sample Response

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

$m(CO_2) = 335.2 - 319.4$

$= 15.8$ g

$n(CO_2) = \frac{m}{MM}$

$= \frac{15.8}{12.01 + 2(16.00)}$

$= 0.3590093161$ mol

$n(C_6H_{12}O_6)_{consumed} = 0.3590093161 / 2$ (due to 2:1 mole ratio)

$= 0.179504658$ mol

$m(C_6H_{12}O_6)_{consumed} = n \times MM$

$= 0.179504658 \times (6(12.01) + 12(1.008) + 6(16.00))$

$= 32.3$ g

Notes from the Marker

- Better responses:
  - showed clear working out, indicating each step.
  - were able to interpret the question in identifying the mass lost as CO_2 and use stoichiometric calculations to determine the glucose consumed.
- Weaker responses:
  - did not show clear working out or did not show **all** working out and as a result, marks for showing understanding could not be awarded.
  - stated the incorrect chemical equation, where an equilibrium arrow was used or the wrong products were produced.
  - did not understand the question or did not interpret it in a logical, practical sense (e.g. determined the mass remaining in the flask as only glucose left over which did not take into account the ethanol formed also in the flask)

Question 2 (5 marks)

Charlie wanted to make methyl salicylate, a minty smelling flavour. He followed the procedure below. **5**

Method

1. Dissolve 3.0 g of salicylic acid (2-hydroxybenzoic acid) in 20 mL of methanol in a conical flask.
2. Add 1 mL of concentrated sulfuric acid to the reaction mixture and place the conical flask in a hot water bath set up above a Bunsen burner.
3. Monitor the flask by continuously moving it out of the water bath when it is close to boiling, then moving it back in the water bath to heat the mixture up again.
4. Remove the conical flask from the water bath after 10 minutes.
5. Add dilute sodium carbonate solution to the reaction mixture and swirl the flask until it stops reacting.
6. Pour the reaction mixture into a separating funnel and wait until two separate layers form.
7. Discard the bottom layer and keep the top layer as the product, methyl salicylate.

Suggest modifications that could be made to the procedure to improve the production and extraction of pure methyl salicylate. Justify your suggestions.

Question 2

Marking Criteria	Marks
Production Identifies at least TWO features from the given method that can be improved. AND Outlines appropriate modifications for EACH of the identified steps (**including refluxing** and any **ONE** other). AND Justifies each modification by linking to each of the above identified steps and in how it improves the production. AND **Extraction** Identifies at least ONE feature from the given method that can be improved. AND Outlines an appropriate modification to the identified step. AND Justifies the modification by linking to the above identified step and in how it improves the extraction. AND **Response is coherent, uses correct terminology, multiple links to the stimulus provided and justifications demonstrate a deep understanding of the practical methodology involved in refluxing and safety.** ***OR*** All of the above, but with ONE feature for production and TWO features for extraction.	5
Production Identifies at least TWO features from the given method that can be improved. AND Outlines appropriate modifications for the identified step (**including refluxing**). AND Justifies the modification to the identified step. AND **Extraction** Identifies at least ONE feature from the given method that can be improved. AND Outlines an appropriate modification to the identified step. AND Justifies the modification to the identified step. AND **Response is coherent, uses correct terminology, some links to the stimulus provided and justifications demonstrate a good understanding of the practical methodology involved in refluxing.** ***OR*** All of the above, but with ONE feature for production and TWO features for extraction.	4
Production Identifies at least ONE feature from the given method that can be improved. AND Outlines an appropriate modification for the identified step. AND Justifies the modification. AND **Extraction** Identifies at least ONE feature from the given method that can be improved.	3

AND Outlines an appropriate modification to the identified step. AND Justifies the modification. AND **Response uses correct terminology, few links to the stimulus provided and justifications demonstrate a sound understanding of the practical methodology involved.** ***OR*** **Production** Identifies at least TWO features from the given method that can be improved. AND Outlines appropriate modifications for the identified step. AND Justifies the modification. ***OR*** **Extraction** Identifies at least TWO features from the given method that can be improved. AND Outlines appropriate modifications to the identified step. AND Justifies the modification. AND **Response uses correct terminology, few links to the stimulus provided and justifications demonstrate a sound understanding of the practical methodology involved.**	
Production Outlines an appropriate modification. AND Justifies the modification to improve the production of the ester. AND/OR **Extraction** Outlines an appropriate modification. AND Justifies the modification to improve the extraction of the ester. AND **Response demonstrates a basic understanding of the practical methodology involved.**	2
Outlines an appropriate modification for the production of the ester. AND/OR Outlines an appropriate modification for the extraction of the ester. AND/OR Identifies how the modification improves the production/extraction. **Response demonstrates a limited understanding of the practical methodology involved.**	1

Sample Response

Production

- Instead of using a water bath over a Bunsen burner, a **heating mantle** can be used. By removing the presence of a naked flame, it would minimise risks of combustion of organic substances, as they are volatile and flammable.
- Since the substances in the reaction mixture are volatile, they can escape from the flask very easily, when moving the flask in and out of the water bath to heat it up. Instead, a **condenser** can be used to allow for **refluxing**. This ensures the **substances do not escape the vessel when heated, as the vapours are continuously cooled down.** (This would also help with safety and minimising risks of escaped volatile organic substances while heating.)
- The reaction is reversible and a slow process, so 10 minutes of heating it may not produce much yield of methyl salicylate. Instead, the reaction mixture should be **heated for several hours under reflux.** This not only increases the kinetic energy of the molecules (and hence improves the **rate of reaction)**, as it is **heated for longer at higher temperatures**, but also **maintains the forward reaction**, as the **reactants are kept in the vessel, increasing the yield.** Boiling chips should then also be used so that it can be heated for long periods of time, which prevents the mixture from superheating.

Extraction

- After adding enough dilute sodium carbonate to the flask until it has neutralised any acid remaining (salicylic acid and sulfuric acid), **more water can be added to wash the organic layer several times** to ensure any **remaining water-soluble species** (sulfuric acid, methanol, salicylic acid) **are dissolved and separated from the organic layer.**
- A **drying agent** such as anhydrous magnesium sulfate can be added after the organic layer has been separated from the aqueous layer to **further remove any water remaining** in the mixture.
- The resulting product would be impure and should then be **purified through distillation**, where the methyl salicylate can be collected at its boiling point.

Notes from the Marker

- Better responses:
  - were able to link their suggested modifications to the stimulus in order to justify why it improves production and extraction.
  - showed depth to their understanding by providing relevant and specific detail to their justifications.
- Weaker responses:
  - did not link back to the stimulus to justify why the suggested modification is better than the given method.
  - identified what the modification will improve (e.g. yield) or only providing an outline (e.g. condenser prevents vapours from escaping).
  - needed more and specific detail when justifying to demonstrate how the modification improves the production/extraction (e.g. needed more detail on what refluxing helps with and why it improves the yield).
  - provided incorrect justifications and purposes to the features, such as boiling chips.
  - stated modifications that did not relate to their justifications.

Student sample (student scored 4/5 marks)

4/5

Charlie wanted to make methyl salicylate, a minty smelling flavour. He followed the procedure below.

Method

1. Dissolve 3.0 g of salicylic acid (2-hydroxybenzoic acid) in 20 mL of methanol in a conical flask.
2. Add 1 mL of concentrated sulfuric acid to the reaction mixture and place the conical flask in a hot water bath set up above a Bunsen burner.
3. Monitor the flask by continuously moving it out of the water bath when it is close to boiling, then moving it back in the water bath to heat the mixture up again. boiling.
4. Remove the conical flask from the water bath after 10 minutes. wait longer
5. Add dilute sodium carbonate solution to the reaction mixture and swirl the flask until it stops reacting. repeat.
6. Pour the reaction mixture into a separating funnel and wait until two separate layers form.
7. Discard the bottom layer and keep the top layer as the product, methyl salicylate. distill.

Suggest modifications that could be made to the procedure to improve the production and extraction of pure methyl salicylate. Justify your suggestions.

(1) Between steps 2 & 3, it is stated that bunsen burner & hot water bath is used & manual labour to monitor boiling of ~~water~~ mixture. This is inefficient & dangerous (ignition of volatile flammable liquids, eg. methanol). A reflux apparatus should be used to allow prolonged heating at higher temperatures & its condenser will be able to automatically condense any volatile liquid back into mixture, increasing yield of ~~product~~ ester production & rate of reaction. ↳ how? need specific detail to justify

(2). The esterification process, is normally slow & reversible, it is suggested to let reaction proceed for at least 30 min ~~for~~ before removing mixture.

(3). The washing process was poorly done at (6), it ~~was~~ should be washing with Na_2CO_3 (aq) solution at least 3 times or until no more CO_2 effervescence will indicate all acid is removed via neutralisation & discard aqeous layer, improving purity & yield.

(4) Since methanol has some solubility in organic ~~solvent~~ solvent, distill the top organic layer to purify ester methyl salicylate, improving extraction.

/4

Student sample (student scored 4/5 marks)

Suggest modifications that could be made to the procedure to improve the production and extraction of pure methyl salicylate. Justify your suggestions.

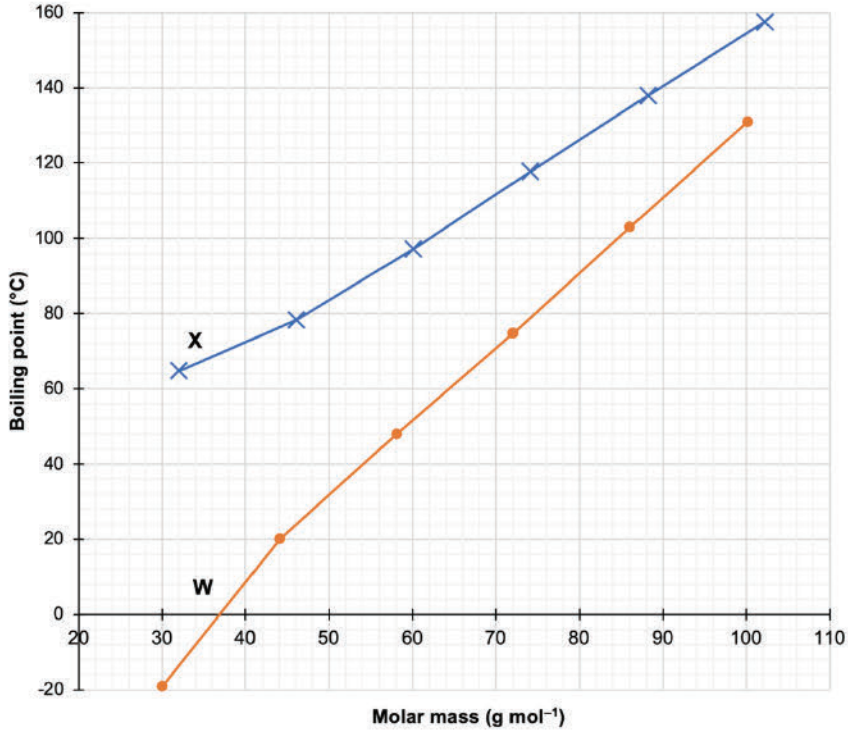
A change to this reaction procedure is to conduct the reaction through heating by reflux rather than the use of a bunsen burner. As salicylic acid and methanol are volatile substances they must be kept away from an open flame and more a water bath is used. However as the reaction requires the removal from the water bath, the reactants will cool and more the rate of reaction will decrease. By heating by reflux, the temperature of the heating mantle can be controlled, volatile reactants and products are contained within the reactor mixture as it is condensed back into solution, and the forward reaction is continually progressing due to the constant recondition of reagents. This would produce a much higher yield of products than using a water bath system.

For the extraction of pure methyl salicylate, the reaction should be washed first initially and the aqueous layer removed by separating funnel as first impurity of the substance. Contaminated ~~H2SO4~~ anhydrous Na_2SO_4 can also be be added to dehydrate any water in the solution, and since it forms a precipitate it can be removed from solution by filtering. The By following the steps choices procedure will be improved in collecting pure methyl salicylate. This assuming we is ~~using laboratory equipment and~~ has access to fractional distillation equipment, that can be utilised to increase the purity of the extraction of pure methyl salicylate due to the differences in boiling point.

why?

Question 3 (7 marks)

The graph below shows the boiling points for two different homologous series of organic compounds, straight chained aldehydes and primary alcohols.



(a) Identify the data of **X** and **W** as either aldehydes or alcohols. **1**

(b) Explain the trends in the data provided. **4**

Question 3(a)

Marking Criteria	Marks
• Correctly identifies that **X** is alcohols and **W** is aldehydes.	1

Sample Response

The data **X** shows alcohols and **W** shows aldehydes.

Notes from the Marker

- Better responses were able to identify the group with the higher boiling point (**X**) as alcohols and the overall lower boiling point (**W**) as aldehydes.
- Weaker responses were not able to determine which homologous group had the higher boiling point and hence identified it incorrectly using the graph.

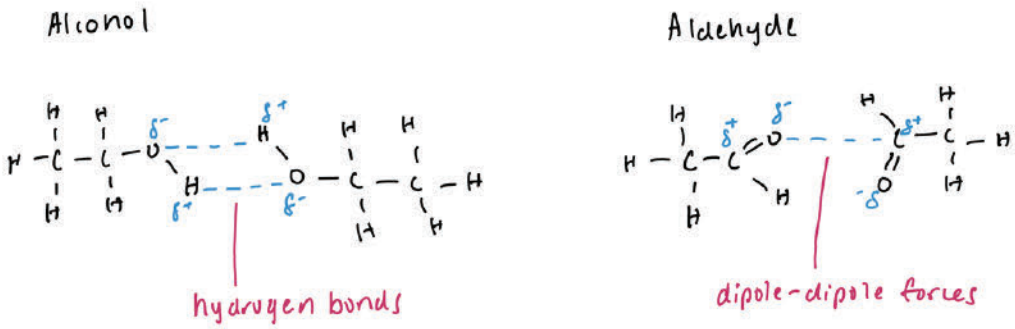
Question 3(b)

Marking Criteria	Marks
Identifies the THREE trends in the graph. AND Relates the structure of alcohols and aldehydes to their intermolecular forces. AND Explains each of the trends by relating to how intermolecular forces influence boiling point. AND Relates the strength of the intermolecular forces to boiling point. AND Explains what effects dispersion forces have on boiling point (when increasing molar mass). AND Relates the effect of different contributions of the intermolecular forces to the trends shown. AND **Response is coherent, uses correct terminology, links to the stimulus provided and explanations demonstrate a deep understanding of how intermolecular forces influence boiling point.**	4
Identifies at least TWO trends in the graph. AND Relates alcohols and aldehydes to their intermolecular forces. AND Explains each of the trends by relating to how intermolecular forces influence boiling point. AND Relates the strength of the intermolecular forces to boiling point. AND/OR Explains what effects dispersion forces have on boiling point (when increasing molar mass). AND/OR Relates the effect of different contributions of the intermolecular forces to the trends shown. **Response uses correct terminology and explanations demonstrate a good understanding of how intermolecular forces influence boiling point.**	3
Identifies at least ONE trend in the graph. AND Relates the relevant molecules to their intermolecular forces. AND Sound explanation of each of the trends by relating to how intermolecular forces influence boiling point by using **correct terminology to identify the intermolecular forces that caused the trend.** AND/OR Relates the strength of the intermolecular forces to boiling point.	2
Identifies at least ONE trend from the graph. AND Relates the structure of the molecules to their intermolecular forces. AND Uses correct terminology to show a limited understanding of the intermolecular forces that caused the trend.	1

Sample Response

Alcohols have a higher boiling point than aldehydes because they can form **hydrogen bonds** between molecules (due to O-H group), while aldehydes mainly form **dipole-dipole forces** (due to C=O group). Since **hydrogen bonds are stronger**, alcohol molecules would therefore require more energy to break these intermolecular forces, resulting in a higher boiling point.

For example:



As the chain length increases for both alcohols and aldehydes (increasing molar mass), the boiling points for both groups also increase. This results in **stronger dispersion forces** between the carbon chain length due to a greater surface are between molecules and greater instantaneous induced dipoles (or more dispersion forces), therefore a higher boiling point.

As chain length increases, the difference in boiling points between the two groups also decreases, as shown with the shortest chain alcohol and aldehyde with a difference in boiling point of around 80°C, while the longest chain alcohol and aldehyde with molar masses of around 100 g mol^{-1} have a difference of around 25°C. This is due to both, the **hydrogen bonding between alcohol molecules and the dipole-dipole forces between aldehyde molecules having a smaller contribution to the total intermolecular forces and is outweighed by the contribution of dispersion forces from the longer carbon chains.**

Notes from the Marker

- Better responses:
  - were able to interpret the graph to explain the three trends shown and made references to the data in the graph.
  - provided explicit and specific details using key terminology to explain the trends.
- Weaker responses:
  - did not explicitly relate the strength of intermolecular forces to boiling point (i.e. linking back to the energy required to break those forces).
  - were not explicit in certain aspects, such as not stating that hydrogen bonds are the strongest intermolecular forces (remember that details such as these should not be implied by the marker).
  - provided incorrect information, such as describing "rate" when interpreting the graph or incorrect diagrams in showing the intermolecular forces between molecules.
  - did not provide relevant information to explain the trends e.g. described the 'packing' of molecules (this is more relevant for melting point).
  - used abbreviations without first defining it (this does not show that the response can communicate using scientific literacy with key terminology to explain).

Student sample

(a) Identify the data of **X** and **W** as either aldehydes or alcohols. 1

X is alcohol

W is aldehyde

(b) Explain the trends in the data provided. 4

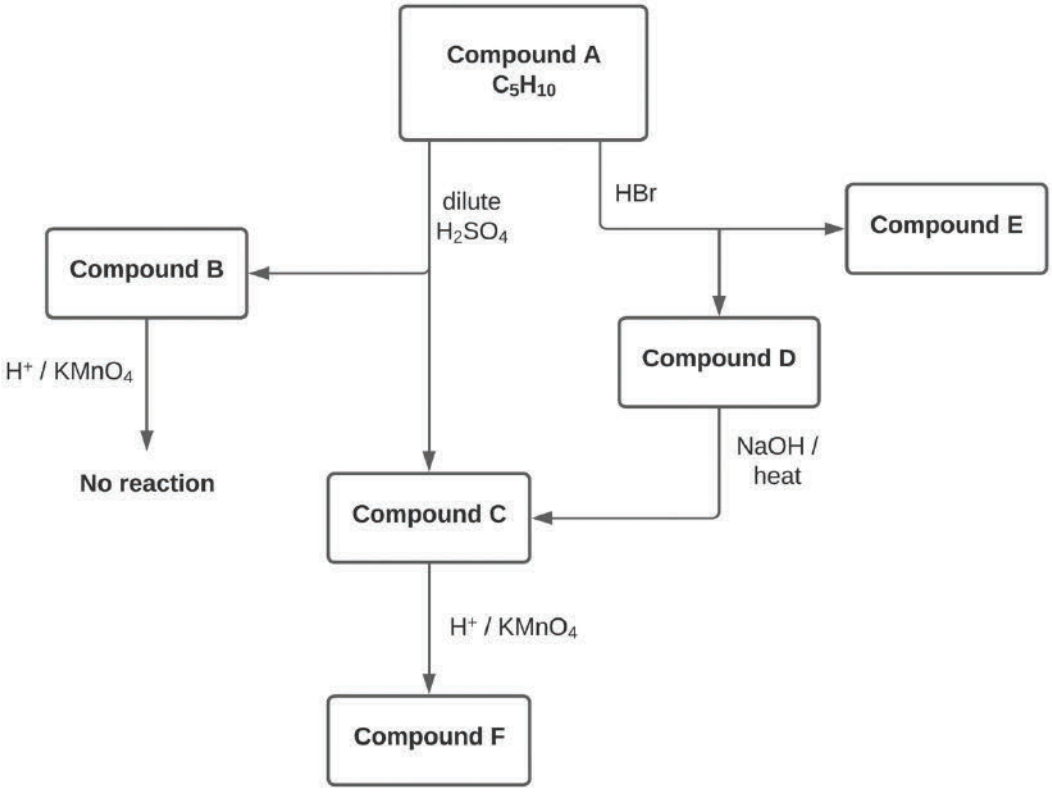
Trend 1: Alcohols have higher boiling points than corresponding aldehydes with similar molar mass. This is due to the difference in intermolecular forces present in each of the molecule, as they have varying strengths. Strong hydrogen bonding, dispersion forces & dipole-dipole forces are found in alcohols, whilst only dipole-dipole forces & dispersion forces are found in aldehydes. Due to this, greater energy is required to break intermolecular forces in order to reach the boiling point. This is observed where MM(alcohol) ≈ 34 gmol^{-1} has a BP of ≈ 65°C, which is much higher than MM(aldehyde) ≈ 30 gmol^{-1} having a BP of ≈ -20°C.

Trend 2: Both alcohols & aldehydes increase in BP as molar mass increases. To An increase in molar mass results in an increase in number of dispersion forces found in both molecules. Due to this, greater energy is required to break IMFs in order to reach boiling point. This is observable where. Alcohol ≈ 34 gmol^{-1} has a BP of ≈ 65°C which is much lower than alcohol ≈ 103 gmol^{-1} with BP ≈ 157°C. Likewise, Aldehyde ≈ 30 gmol^{-1} has a BP of ≈ -20°C, which is much lower than aldehyde ≈ 100 gmol^{-1} with BP of ≈ 130°C.

Trend 3: As molar mass of both aldehydes & alcohol increase, the difference between boiling points decrease. This is due to the increasing strength of dispersion forces being added to the molecule as molar mass increases. Due to this increase, the strength of dispersion forces become closer to overcoming the dominant IMF of alcohols & aldehydes (hydrogen bonding, dipole-dipole respectively). Due to this, the difference between alcohol & aldehyde BP decreases as mass increases. This is observable where the first alcohol & aldehyde have a BP diff. of ≈ 85°C where as the last alcohol & aldehyde have a BP diff of ≈ 27°C, as shown in the graph.

Question 4 (7 marks)

The flowchart below shows reactions involving six different organic compounds (**A** to **F**). Compound **A** has the molecular formula, C_5H_{10}. **7**



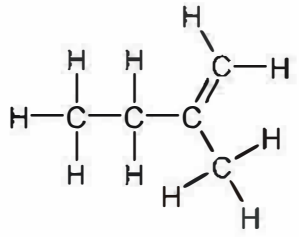
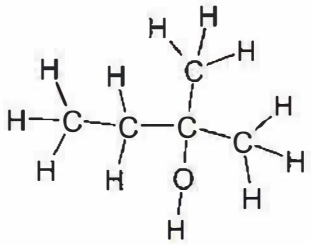
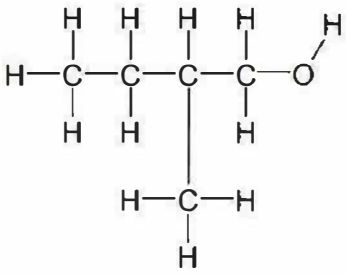
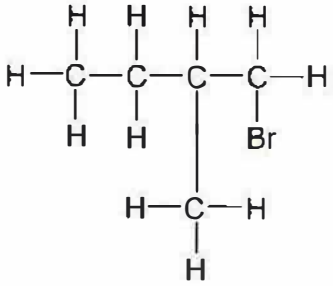
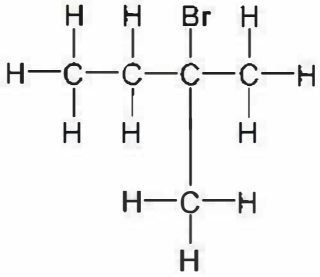
Draw the structural formulae and state the IUPAC names of compounds **A** to **F**, justifying your structures with reference to the information provided in the flow chart.

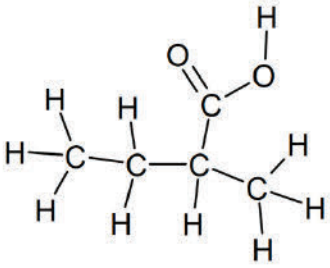
Question 4

Marking Criteria	Marks
All correct structures and correct IUPAC names for compounds A, B, C, D, E and F. AND Correct justifications for all compounds A to F, including: • how compound A is determined to be branched and the locant of the double bond. • the type of alcohol identified from the oxidation tests (for compounds B and C). • identifying compound D from the substitution reaction to form compound C. AND Key terms used in justification. AND Makes references to most of the information provided in the flowchart.	7
All correct structures and correct IUPAC names for compounds A, B, C, D, E and F. AND Correct justifications for all compounds A to F, including: • how compound A is determined to be branched and the locant of the double bond. • the type of alcohol identified from the oxidation tests (for compounds B and C). • identifying compound D from the substitution reaction to form compound C. AND Key terms used in justification.	6

AND Makes limited references to the information provided in the flowchart. **All of the above but contains ONE type of error** (such as incorrect locants used when naming, incorrect commas and dashes used when naming, a few key terms missing).	
All of the above, but contains 2-3 types of errors. AND/OR All IUPAC names and structures mentioned but key terms missing in justification. AND/OR All of the above but missing some names. OR 1 missing structure but correct IUPAC name and correct justification for all other compounds. OR No structures but correct IUPAC names and correct justifications for all compounds.	5
Response contains 2-4 errors. AND/OR Correct structures with no names and some justifications. OR 1-2 incorrect or missing structures or names and justifications incomplete.	4
Response contains at least 5 errors. AND/OR All correct names and structures but no justifications. OR Some structures or names are incorrect but some correct justifications. OR 1-2 incorrect or missing structures or names, with limited justifications.	3
Response contains 5 or more errors. OR Most structures or names are incorrect and limited justifications. OR Structures are incorrect AND/OR have some correct IUPAC names AND shows some understanding in following the reactions in the flowchart and no justification (shows understanding in at least two pathways in flowchart).	2
Some correct/relevant information, such as showing limited understanding in following the reactions in the flowchart.	1

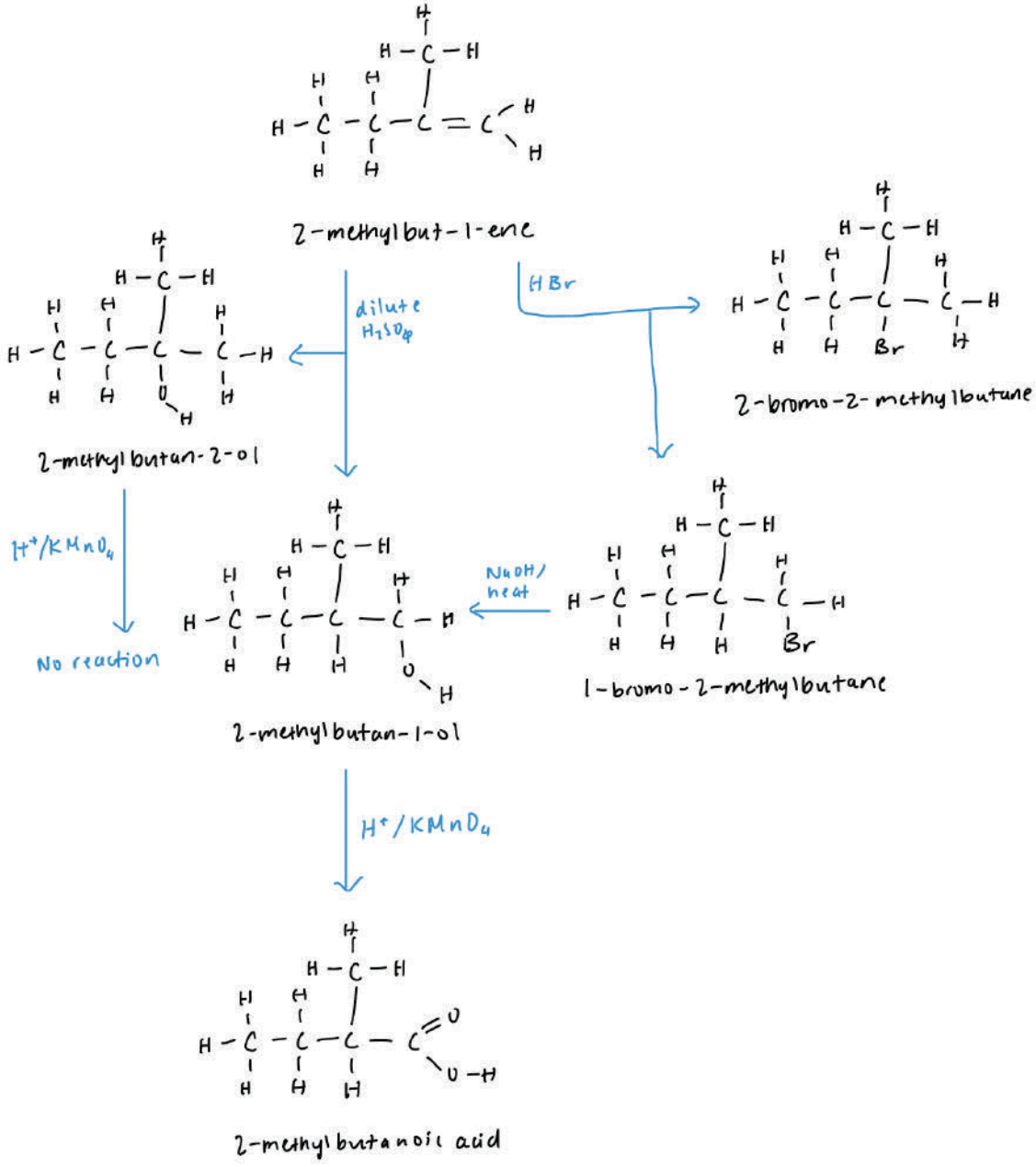
Sample Response

Compound	Structure and Name	Justification
A	2-methylbut-1-ene 	Compound A undergoes hydration with dilute H_2SO_4 to produce alcohol products. Since compound B does not **oxidise** when acidified $KMnO_4$ is added, it is a **tertiary alcohol.** Compound A is therefore an unsaturated, branched hydrocarbon with molecular formula C_5H_{10} (2-methylbut-1-ene). The **double bond is on the same carbon as the branched methyl group** to allow the formation of a tertiary alcohol, when it reacts.
B	2-methylbutan-2-ol 	The reaction of compound A with dilute H_2SO_4 produces two possible alcohol products. Since compound B **does not oxidise**, it is the **tertiary alcohol** formed.
C	2-methylbutan-1-ol 	Compound C is the other product from the reaction of compound A with dilute H_2SO_4. Since it **can oxidise** when acidified $KMnO_4$ is added, this further confirms that it is the **primary alcohol.**
D	1-bromo-2-methylbutane 	Compound A undergoes hydrohalogenation with HBr to produce two products, D and E. Since compound D undergoes substitution reaction with NaOH and heat to produce C (2-methylbutan-1-ol), compound D is therefore 1-bromo-2-methylbutane, where the **Br is replaced by an OH on the first carbon.**
E	2-bromo-2-methylbutane 	Compound E is therefore the other product of the hydrohalogenation of compound A, 2-bromo-2-methylbutane.

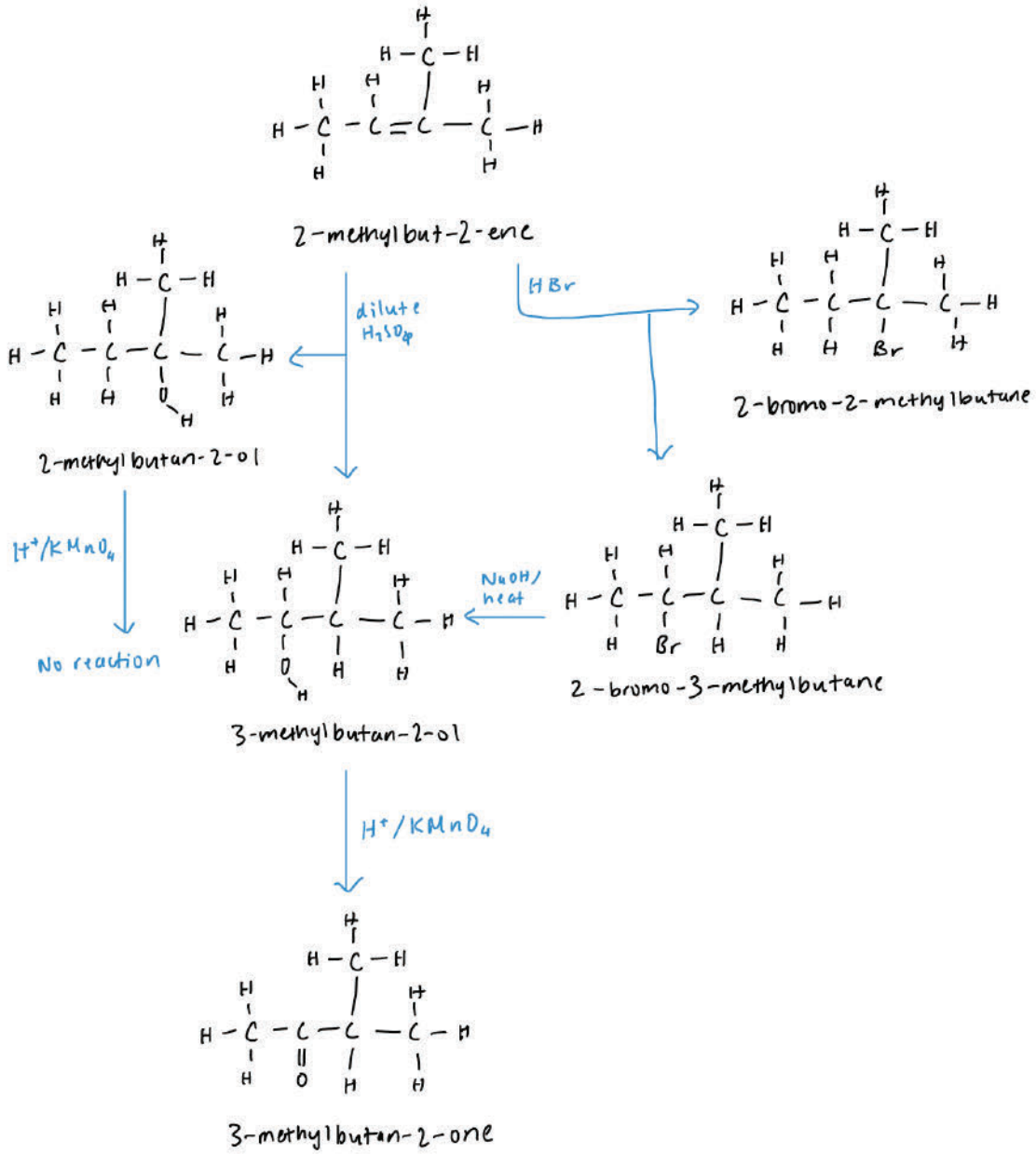
F	2-methylbutanoic acid 	Since compound C is the primary alcohol, it oxidises to produce a carboxylic acid (compound F) when acidified $KMnO_4$ is added.

Note: Two different set of answers were possible in this question.

Set 1



Set 2

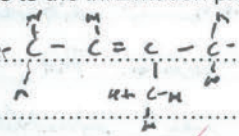


Notes from the Marker

- Better responses constructed correct structural formulae for all compounds with correct IUPAC names and were able to justify each structure with sufficient detail using the information in the flowchart and knowledge on organic reactions.
- Weaker responses:
  - incorrectly constructed their structural formulae, such as:
    - not fully expanding out the structure (i.e. did not show all bond lines).
    - some structures had missing hydrogen atoms.
    - some carbons were shown to have five bonds.
  - provided the incorrect IUPAC name, such as incorrect commas and dashes or incorrect locant numbers (remember to name the compound using the lowest locant numbers, accounting for the functional group).
  - did not justify the structures of each compound and only constructed the structures with IUPAC names (it is recommended to read and highlight key aspects of the question to remember to address it).
  - required more detail in their justifications in order to explicitly relate the structure of each compound to organic reactions and the information in the flowchart.

Student sample (student scored 7/7)

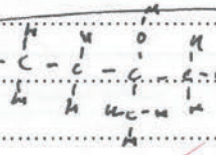
Draw the structural formulae and state the IUPAC names of compounds **A** to **F**, justifying your structures with reference to the information provided in the flow chart.

compound A: 

2-methyl but-2-ene

Explanation

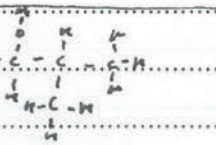
- the compound can undergo both hydration and hydrohalogenation.
- with hydration, it produces a secondary and a tertiary alcohol, hence the double bond must be substituted by three carbon and be in the middle of the molecule.

compound B: 

2-methyl butan-2-ol

- this compound must be the tertiary alcohol product of the hydration of compound A since it does not undergo oxidation.

- major product of hydration of A

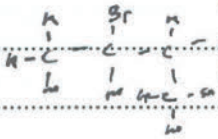
compound C: 

3-methyl buten-2-ol

- this compound must be the secondary alcohol product of the hydration of A since it only reacts with acidified potassium permanganate once.

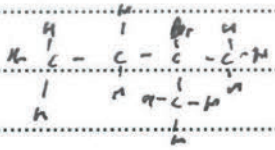
- minor product of hydration of A.

- by considering the right-side reaction pathway, the box should also include NaBr

4.] Compound D: 

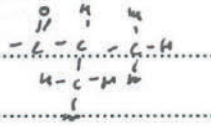
2-bromo-3-methyl butane

- this compound is the minor product of the hydrohalogenation of compound A.
- since the compound can undergo substitution to produce compound C, the bromine must be where it is positioned.

compound E: 

2-bromo-2-methyl butane.

- this compound is the major product of the hydrohalogenation of compound A.
- since compound D must be 2-bromo-3-methyl butane in order to properly account for its substitution reaction into C, this product must be as seen.

compound F: 

3-methyl buten-2-one

- this ~~product~~ compound is a product of the oxidation of compound C.
- Since C is a secondary alcohol, the compound must be a ketone where the carbonyl-group replaces the hydroxyl-group of compound C.

Normanhurst Boys High School

2022 Year 12 Chemistry Trial Examination (Section 2C)

Marking Responses, Sample Answers & Notes from the Marker

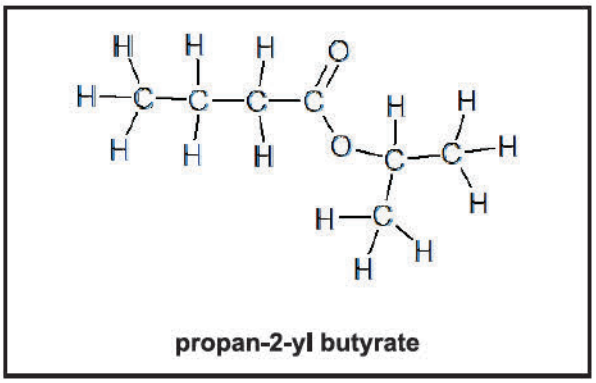
Question 1

Marking Criteria	Marks

• Writes the correct structural formula of propan-2-yl butanoate **(naming not required).**
• Justifies the correct structure showing an extensive understanding of the interpretation of spectroscopic data and refers explicitly to the relevant spectroscopic data.
• Infrared spectrum
  ○ Two peaks shown are addressed in terms of bonds.
  ○ Lack of a very broad peak due to the O–H bond addressed to rule out alcohol and carboxylic acid.
• ^{13}C NMR spectrum
  ○ Number of carbon environments addressed in relation to the molecular formula and symmetry.
  ○ All peaks addressed.
• ^{1}H NMR spectrum
  ○ Number of hydrogen environments addressed in relation to the molecular formula.
  ○ All peaks addressed in relation to data, (n+1) rule and relative peak area with sufficient detail.
	7

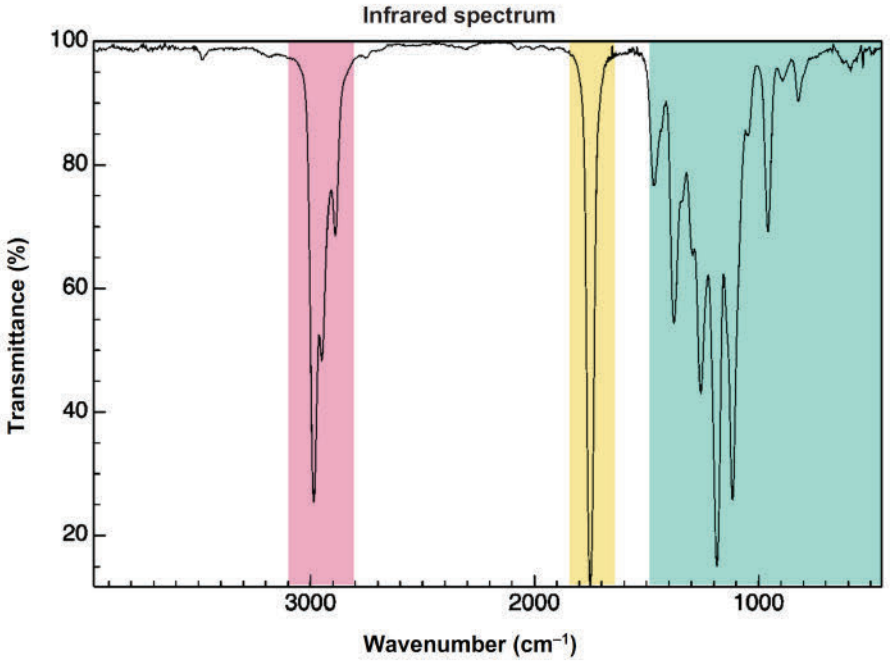
• Writes the correct structural formula for **an isomer of propan-2-yl butanoate (naming not required).** • Justifies the structure showing a thorough understanding of the interpretation of spectroscopic data. • Refers to relevant spectroscopic data. **OR** • Deduces the correct molecule and provides thorough analysis of the spectroscopic data.	6
• Shows a sound understanding of the interpretation of spectroscopic data. • Uses relevant information presented in the question to justify the structure of the chemical. • Provides a structural formula consistent with analysis.	4–5
• Shows some understanding of the interpretation of spectroscopic data.	2–3
• Provides some relevant information.	1

Sample Answer



propan-2-yl butyrate

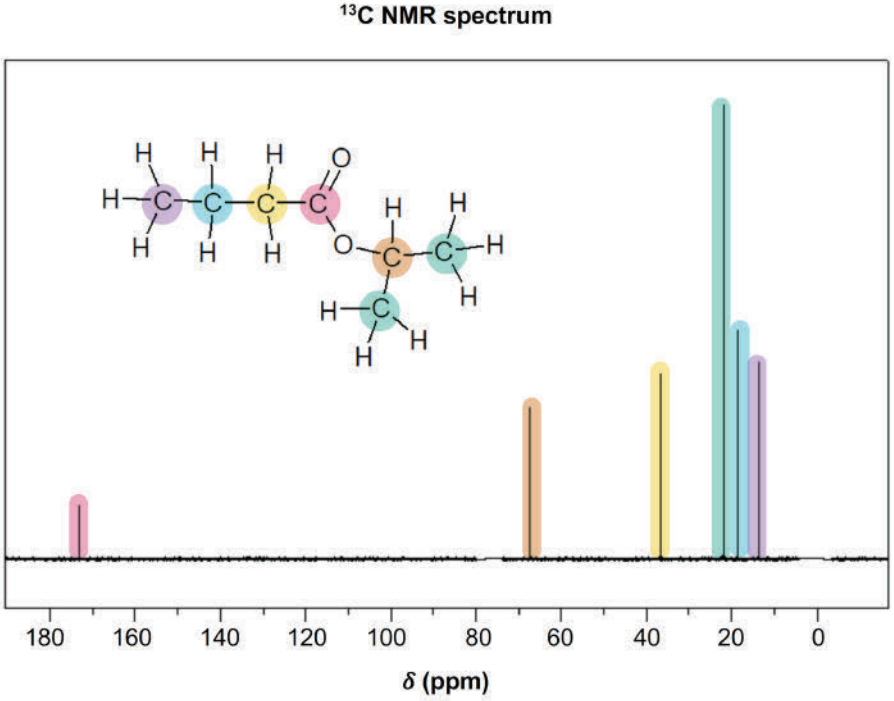
Infrared spectrum



From the infrared spectrum, the:

- **strong peak at 2981 cm^{-1}** suggests that there is a **C–H bond** in the structure.
- **strong peak at 1733 cm^{-1}** suggests that there is a **C=O bond** in the structure.
- **absence of a strong and broad peak between 3230–3550 cm^{-1}** suggests that the organic molecule **does not contain an O–H bond in the structure due to an alcohol functional group.**
- **absence of a strong and very broad peak between 2500–3000 cm^{-1}** suggests that the organic molecule **does not contain an O–H bond in the structure due to an carboxylic acid functional group.**
- **fingerprint region (less than 1500 cm^{-1})** cannot be conclusively analysed due to the overlapping of peaks due to different bonds.

^{13}C NMR spectrum

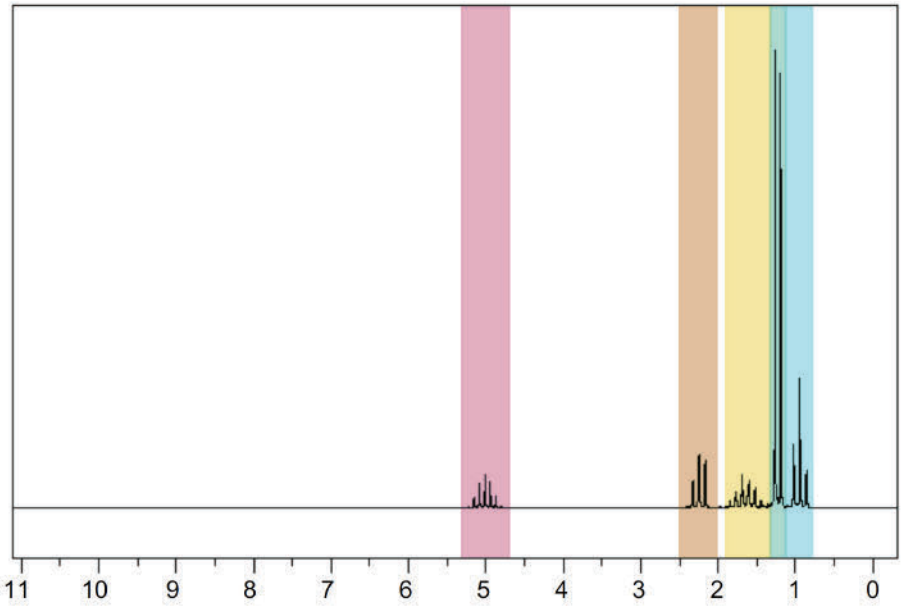


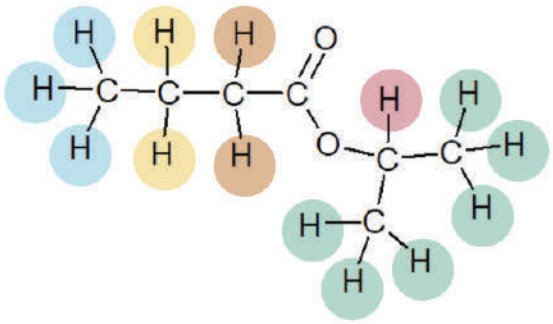
From the ^{13}C spectrum, there are **six unique carbon environments.** As there are 7 C atoms, this suggests that **two C atoms are in the same environment due to symmetry.** The peak(s) at:

- 173 ppm corresponds to a **C atom double bonded to an O atom on the ester group** which is consistent with chemical shift between 160–185 ppm. This is due to the **deshielding of the carbon next to the O atom resulting in the peak being downfield.**
- 67 ppm corresponds to a **C atom singly bonded to an O atom in an ester group** which is consistent with chemical shift between 50–90 ppm. This is due to the **deshielding of the carbon next to the O atom resulting in the peak being downfield.**
- 37 ppm corresponds to a **C atom that is bonded to a C atom double bonded to an O atom** which is consistent with chemical shift between 20–50 ppm.
- 22 ppm, 19 ppm and 17 ppm correspond to **C atoms bonded to the C in an alkyl group** which is consistent with chemical shift between 5–40 ppm.

^{1}H NMR spectrum

^{1}H NMR spectrum





Data from the ^{1}H NMR spectrum

Chemical shift	Relative peak area	Splitting pattern
5.011	1	septet (7)
2.238	2	triplet (3)
1.645	2	sextet (6)
1.229	6	doublet (2)
0.951	3	triplet (3)

From the ^{1}H spectrum, there are **five unique hydrogen environments.** By considering the molecular formula, the **number of H atoms in each environment corresponds to the relative peak area in a 1:1 ratio.**

Through the use of the n+1 rule to analyse the splitting patterns and based on the relative peak area, the:

- **septet peak** at 5.011 ppm indicates that there are **six H neighbouring atoms**, indicating that there are **two neighbouring –CH_3 groups.** The relative peak area of 1 corresponds to **one H atom** in the following environment as the shift occurs between 3.3−5.1 ppm. It is highly deshielded due to the neighbouring O atom.

—C**H**—O—

- **triplet peak** at 2.238 ppm indicates that there are **two H neighbouring atoms**, most likely in a **neighbouring –CH_2 group.** The relative peak area of 2 corresponds to **2 H atoms** in the following environment as the shift occurs between 2.1−2.6 ppm. It is deshielded due to the nearby O atom.

—C**H**—CO—

- **sextet peak** at 1.645 ppm indicates that there are **five H neighbouring atoms**, most likely in a **neighbouring –CH_2 group and –CH_3 group.** The relative peak area of 2 also corresponds to 2 H atoms in this environment and is slightly downfield of the range of 1.2−1.5 ppm due to the deshielding effect of nearby O atoms.

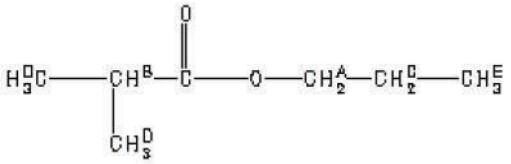
R—C**H_2**—R

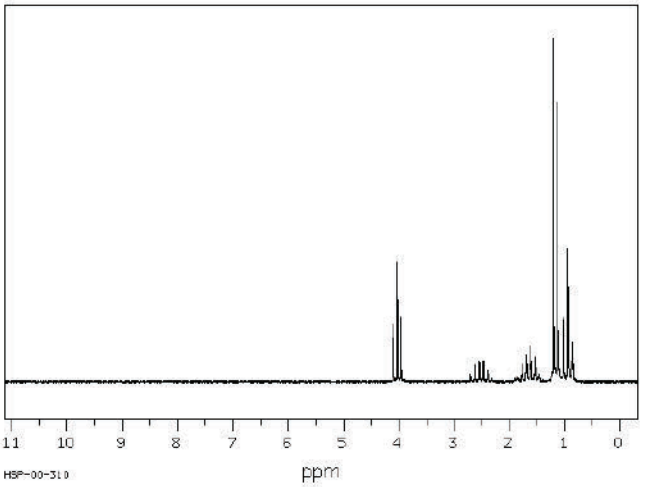
- **doublet peak** at 1.229 ppm indicates that there is **one H neighbouring atom**, most likely in a **neighbouring –CH group.** The relative peak area of 6 corresponds to **6 H atoms** in this environment. The **septet and doublet combination is consistent with the presence of a** —CH(C**H_3**)$_2$ group and is consistent with the chemical shift of 0.7−1.3 ppm.
- **triplet peak** at 0.951 ppm indicates that there are **two H neighbouring atoms**, most likely in a **neighbouring –CH_2 group.** The relative peak area of 3 corresponds to **3 H atoms** in the following environment and is consistent with the chemical shift of 0.7−1.3 ppm.

R—C**H_3**

NOTE

For responses which interpreted the ^1H NMR incorrectly and generated the isomer:





Chemical shift	Relative peak area	Splitting pattern
4.025	2	triplet (3)
2.529	1	septet (7)
1.646	2	sextet (6)
1.169	6	doublet (2)
0.950	3	triplet (3)

From the ^1H spectrum, there are **five unique hydrogen environments.** By considering the molecular formula, the **number of H atoms in each environment corresponds to the relative peak area in a 1:1 ratio.**

Through the use of the n+1 rule to analyse the splitting patterns and based on the relative peak area, the:

- **triplet peak** at 4.025 ppm indicates that there are **two H neighbouring atoms**, most likely in a **neighbouring $–CH_2$ group.** The relative peak area of 2 corresponds to **two H atom** in the following environment as the shift occurs between 3.3–5.0 ppm. It is highly deshielded due to the neighbouring O atom.

$$R_2—CH_2—O—$$

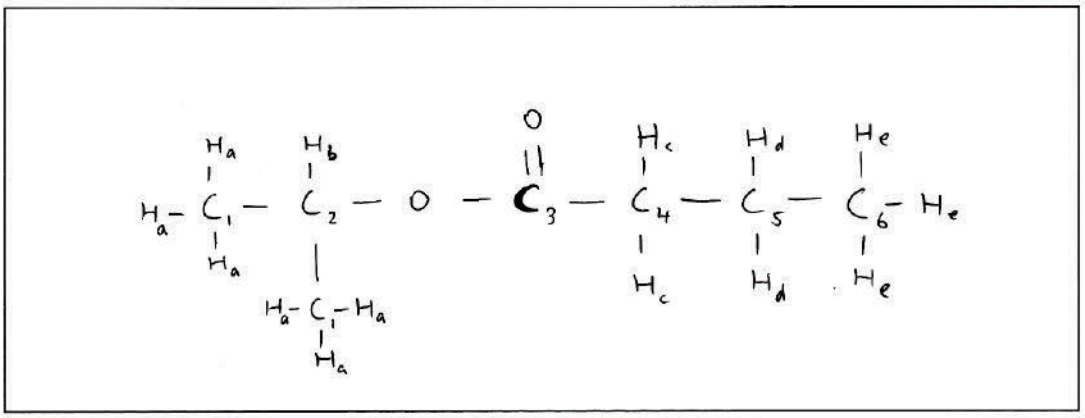
- **septet peak** at 2.529 ppm indicates that there are **six H neighbouring atoms**, indicating that there are **two neighbouring $–CH_3$ groups.** The relative peak area of 1 corresponds to **one H atom** in the following environment as the shift occurs between 2.1–2.6 ppm. It is deshielded due to the neighbouring O atom.

$$—CH—CO—$$

Notes from the Marker

- Better responses had used and explicitly referred to the spectroscopic data to put together the pieces of the puzzle, clearly showed their thinking processes and annotated the spectroscopic data. These responses showed evidence of analysing each peak thoroughly and provided reasoning and explanation for each of the peaks given.
- Weaker responses did not show care when drawing organic molecules and did not show good annotations to the spectra to clearly link this data to H and C environments in the molecule. These responses also did not explain the significance of each peak or explain the relevance of the number of environments clearly. These responses often were not cohesive or relied on partial analysis of the data.

Student Sample 1



IR

1) narrow absorption at ~3000 cm^{-1} => presence of C-H bond

2) strong, narrow absorption at ~1750 cm^{-1} => presence of C=O bond

3) lack of broad absorption at ~3800 cm^{-1} => lack of O-H bonds

All features matches my proposal and the molecular formula $C_7H_{14}O_2$

~~NOT~~

^{13}C NMR

6 shifts => 6 unique C-envs (I labelled from 1 to 6)

shift	type of env.	corresponding Env in my proposal:
173 ppm	[R-C(=O)-] env.	Env 3
67 ppm	[C-O] env.	Env 2
37 ppm	[R-C(=O)-C]	Env 4
22 ppm	[C-C]	Env 1 / Env 5
19 ppm	[C-C]	Env 1 / Env 5
13 ppm	[C-C]	Env 6

ppm too close, I cannot determine which one is shielded more, but does not contradict my proposal in any combination

Question 1 continues on the next page

All features of ^{13}C NMR matches my proposal

^1H NMR

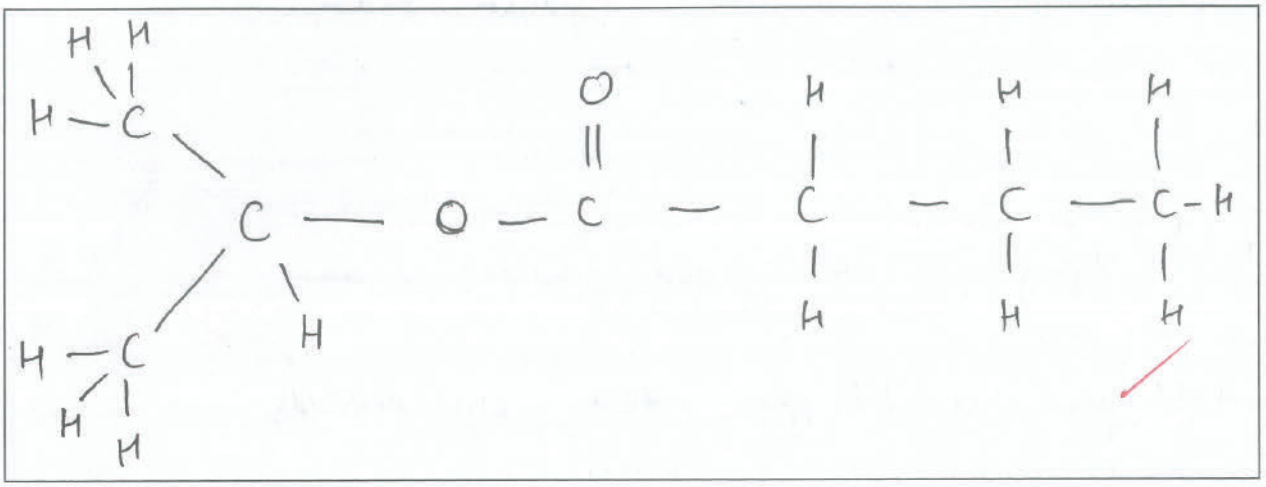
5 shifts ⇒ 5 unique H envs (2 labelled a, b, c, d, e)

Shift (ppm)	splitting	N_H by 'n+1 rule'	no. of H by integrazer	shielding	corresponding Env
5.011	7	6 (from env a)	1	very deshielded (close to δ^-O which is singly bonded)	b
2.238	3	2 (from Env d)	2	very deshielded (close to C=O where O is δ^-)	c
1.645	6	5 (from Env c & e)	2	deshielded (close to C=O	d
1.228	2	1 (from Env b)	6	shielded, far from δO	a
0.951	3	2	3	very shielded (very far from δ^-O)	e

END OF SECTION 2C

∴ all features matches my proposal

Student Sample 2



From IR:

(1) Strong absorbtion at 3000 cm^{-1} indicate presence of C-H bond

(2) Strong absorbpt-en at 1750 cm^{-1} indicate presence of C=O bonds

(3) Strong absorpt- at 1200 cm^{-1} indicate presence of C-O bond

(4) Lack of broad absorpt- around 3000 cm^{-1} to 3500 cm^{-1} and 2500 cm^{-1} to 3000 cm^{-1} indicate lack of O-H bond

∴ Molecule is very likely to be an ester as it has C-H, C=O and C-O bonds

∴ Molecule cannot be alcohol / acid due to the lack of O-H bond, present ∴ both alcohol & acid

From CNMR:

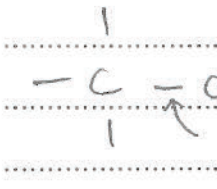
what does this suggest?

· Total of 6 peaks ⇒ 6 unique C environments

The upfield position of peaks (1) to (2), (3), (4)

with low chemical shift around 5 - 40 ppm all represent C atom with low deshielding => they are only bound to other C atom and H atom

(5) Midfield ~~position~~ peak of ~~68~~ 67 ppm indicate medium deshielding due to a connected O atom



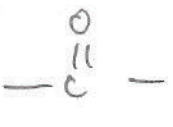
slightly polar bond that deshielded C atom

(6) Downfield peak at 173 ppm indicate high deshielding due to C=O bond in ester

~~polar bond~~ electronegativity difference cause e^- to be closer to O

END OF SECTION 2C

=> C is deshielded

∴ The molecule has both  and  structure, both present in ester.

∴ Molecule is very likely to be ester

1. Relate rel peak area to molecular formula

H NMR

(1) Downfield ^ sp septet peak of 5.011 ppm with relative peak area of 1 indicates environment with 1 H and 6 neighboring H

High chemical shift due to ^ C–O bond close to this environment: R_2-CH_2-O- (high deshielding due to)

(2) Midfield ~~peak~~ triplet peak of 2.231 ppm with area of 2 indicates env with 2 H and 2 neighboring H

Median chemical shift due to ^ C=O bond close to this environment: H_3C-CO- or $-CH-CO-$ (median deshielding due to)

(3) Upfield septet peak of 1.645 ppm with area 2 indicates env with 2 H and 5 neighboring H

Low chemical shift due to low deshielding: $R-CHR_2$

(4) Upfield doublet peak of 1.229 ppm with area 6 indicates env with 6 H and 1 neighboring H

low chemical shift due to low deshielding: $R-CH_2-R$

(5) Upfield triplet peak ~~at~~ at 0.951 ppm with ~~area~~ area 3 indicates env with 3 H and 2 neighboring H

low chemical shift due to low deshielding: $R-CH_3$

~~Hence the molecule is~~ Hence the molecule is: