NESA STUDENT NUMBER

2023

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 **20 marks**
- Attempt Questions 1–4

Section 2B – Written Response **40 marks**
- Attempt Questions 1–8

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

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NBHS Year 12 Chemistry Trial Examination

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

Sample 2 + 4 = (A) 2 (B) 6 (C) 8 (D) 9

A ○ B ● C ○ D ○

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

A ● B ⊗ C ○ D ○

If you change your mind and have crossed out what you consider to be the correct answer, then indicate this by writing the word *correct* and drawing an arrow as follows:

correct

A ⊗ B ⊗ C ○ D ○

1	A ○	B ○	C ○	D ○
2	A ○	B ○	C ○	D ○
3	A ○	B ○	C ○	D ○
4	A ○	B ○	C ○	D ○
5	A ○	B ○	C ○	D ○
6	A ○	B ○	C ○	D ○
7	A ○	B ○	C ○	D ○
8	A ○	B ○	C ○	D ○
9	A ○	B ○	C ○	D ○
10	A ○	B ○	C ○	D ○
11	A ○	B ○	C ○	D ○
12	A ○	B ○	C ○	D ○
13	A ○	B ○	C ○	D ○
14	A ○	B ○	C ○	D ○
15	A ○	B ○	C ○	D ○
16	A ○	B ○	C ○	D ○
17	A ○	B ○	C ○	D ○
18	A ○	B ○	C ○	D ○
19	A ○	B ○	C ○	D ○
20	A ○	B ○	C ○	D ○

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Section 1

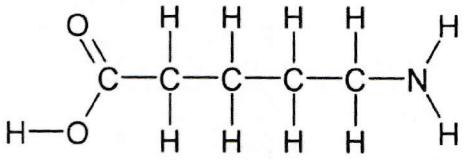
20 marks

- 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)

An organic compound shown below.



Which are the TWO functional groups present in this molecule?

(A) Amide and ester.

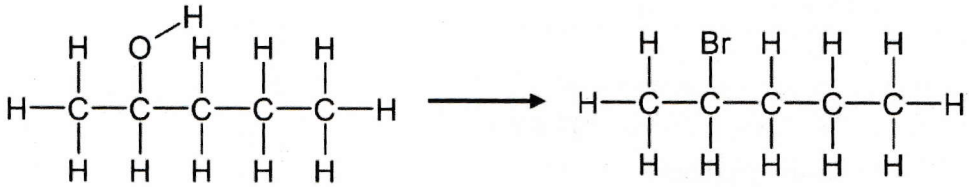
(B) Amide and carbonyl.

(C) Carboxyl and amine.

(D) Alkene and amine.

Question 2 (1 mark)

Which of the following conditions would be appropriate to carry out the following synthesis?



(A) Br_2 and UV light.

(B) Br_2 dissolved in water.

(C) HBr and heat.

(D) HBr and $ZnCl_2$ catalyst.

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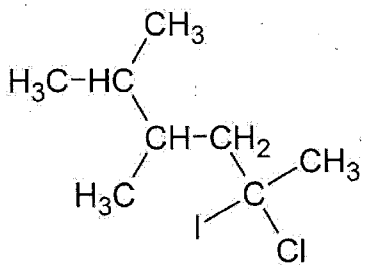
Question 3 (1 mark)

The structure of a compound is shown below.



What is the IUPAC name of this compound?

(A) 2-chloro-2-iodo-4,5-dimethylhexane

(B) 2-iodo-2-chloro-4,5-dimethylhexane

(C) 2,3-dimethyl-5-chloro-5-iodohexane

(D) 5-chloro-5-iodo-2,3-dimethylhexane

Question 4 (1 mark)

The heat of combustion of butan-1-ol is 2676 kJ mol^{-1}.

What is the value of the heat of combustion in kJ g^{-1}?

(A) 30.41

(B) 36.10

(C) 44.60

(D) 47.79

Question 5 (1 mark)

Ethanoic acid (CH_3COOH) is a weak acid with $K_a = 1.74 \times 10^{-5}$ at 25°C. 1.00 L of a solution is prepared by dissolving 0.100 mol of ethanoic acid in distilled water.

What is the pH of the resulting solution?

(A) 2.00

(B) 2.10

(C) 2.80

(D) 2.88

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Question 6 (1 mark)

The table lists some properties of the straight-chained carbon compounds **W**, **X**, **Y** and **Z**.

Compound	Reactivity in bromine water	Solubility in water
W	Rapidly decolourises	Insoluble
X	Unreactive	Insoluble
Y	Unreactive	Soluble
Z	Unreactive	Partially soluble

Which row below best identifies the compounds **W**, **X**, **Y** and **Z**?

	W	X	Y	Z
(A)	C_3H_6	C_3H_8	CH_3OH	C_4H_9OH
(B)	C_3H_8	C_3H_6	CH_3OH	C_4H_9OH
(C)	C_3H_6	C_3H_8	C_4H_9OH	CH_3OH
(D)	C_3H_8	C_3H_6	C_4H_9OH	CH_3OH

Question 7 (1 mark)

The table below shows some data on four acid-base indicators.

Indicator name	pH range	Colour range
methyl orange	3.1–4.4	red–yellow
bromophenol red	3.8–5.4	yellow–blue
methyl red	4.2–6.3	red–yellow
phenol red	6.8–8.4	yellow–red

A solution, labelled **X**, is made by mixing equal volumes of 0.0002 mol L^{-1} sodium hydroxide and 0.0004 mol L^{-1} nitric acid.

Which indicator shown would turn pure yellow when added to a sample of **X**?

(A) Methyl orange

(B) Bromophenol red

(C) Methyl red

(D) Phenol red

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Question 8 (1 mark)

The following organic compounds all have five carbons.

A: 2,2-dimethylbutane

B: 2-methylpentane

C: 4-methylpent-2-ene

Which of the following is most likely to be correct?

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

(B) Compound **A** has a higher melting point than compound **B**.

(C) Compound **B** and compound **C** are functional group isomers.

(D) Compound **A** and compound **B** are positional isomers.

Question 9 (1 mark)

A 3.42 g sample of solid $Mg(OH)_2$ is added to a 200.0 mL solution of 0.600 mol L^{-1} HCl.

What is the final pH of the final mixture?

(A) 0.51

(B) 1.2

(C) 1.9

(D) 2.6

Question 10 (1 mark)

A 50.0 mL sample of 4.0×10^{-3} M $AgNO_3$ solution is added to 50.0 mL of 1.0×10^{-3} M KIO_3 solution at 25°C.

The K_{sp} value for $AgIO_3$ at 25°C is 3.2×10^{-8}.

Which row of the following table correctly predicts if $AgIO_3$ will form a precipitate and the reason for this?

	Will a precipitate form?	Reason
(A)	Yes	$Q_{sp} < K_{sp}$
(B)	Yes	$Q_{sp} > K_{sp}$
(C)	No	$Q_{sp} < K_{sp}$
(D)	No	$Q_{sp} > K_{sp}$

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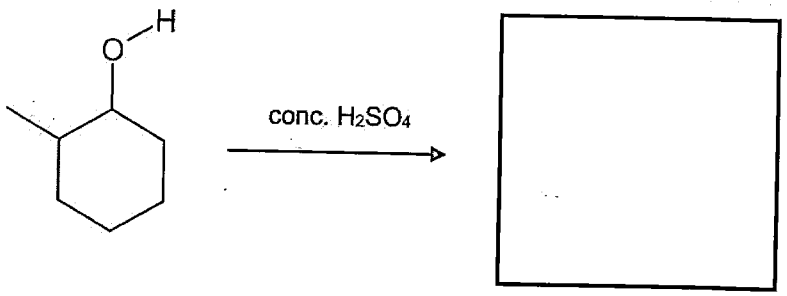
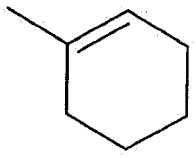
Question 11 (1 mark)

2-methylcyclohexanol is an alcohol and undergoes a dehydration reaction with sulfuric acid as shown.

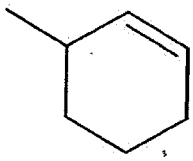


What is the major organic product of this reaction?

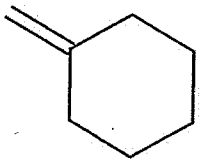
(A)



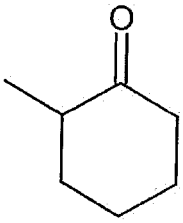
(B)



(C)



(D)



Question 12 (1 mark)

Consider the following equilibrium for a weak base N_2H_4.

$$N_2H_4(aq) + H_2O(l) \rightleftharpoons N_2H_5^+(aq) + OH^-(aq)$$

A 0.75 mol sample of N_2H_4 is placed in a 1.00 L flask. After the system comes to equilibrium, the flask contains 0.45 mol $N_2H_5^+$.

The value of K_b for weak base N_2H_4 is:

(A) 0.27

(B) 0.68

(C) 1.48

(D) 3.70

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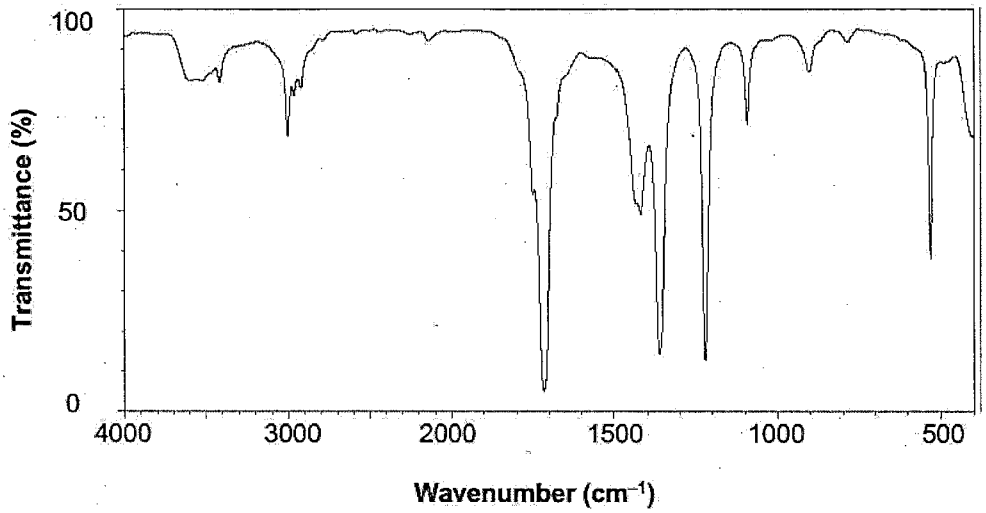
Question 13 (1 mark)

The diagram shows the infrared spectrum of a compound.



Which compound was analysed?

(A) Propane

(B) Propan-1-ol

(C) Propanal

(D) Propan-2-one

Question 14 (1 mark)

A food critic noticed their specialty chicken dish was extremely bland and requested that analysis be carried out to measure the sodium chloride concentration. This was achieved by dissolving the food sample in water and the chloride ion being precipitated by adding an excess of silver nitrate solution. The precipitate was washed and dried.

If the mass of the food sample was 10.0 g and the final precipitate had a mass of 0.188 g, what is the percentage of sodium chloride in the food?

(A) 1.88%

(B) 0.766%

(C) 0.465%

(D) 0.220%

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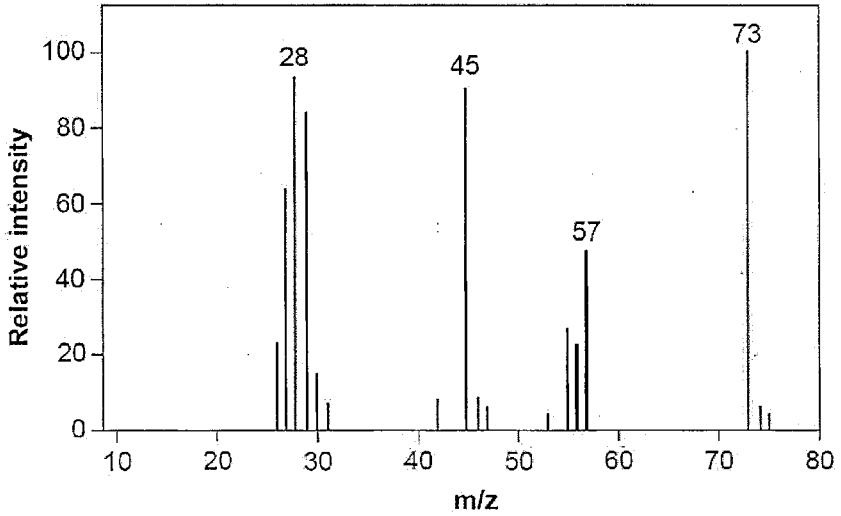
Question 15 (1 mark)

A simplified mass spectrum of butanoic acid is shown.



The peak with the mass-to-charge ratio, m/z, of 73:

(A) has the greatest mass-to-charge ratio.

(B) represents the species $CH_2CH_2COOH^-$.

(C) represents the species CH_2CH_2COOH.

(D) represents the species $CH_2CH_2COOH^+$.

Question 16 (1 mark)

Silver chromate (Ag_2CrO_4) is a yellow solid that dissolves in water to produce a yellow saturated solution containing 2.34×10^{-2} g L^{-1} of silver chromate. The molar mass of silver chromate is 331.8 g mol^{-1}. The chromate ions react with hydrogen ions as shown below:

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightarrow 2HCrO_4^-(aq) + H_2O(l)$$

yellow **orange**

The molar concentration of chromate ions in a saturated solution of silver chromate in 0.183 mol L^{-1} silver nitrate is:

(A) 1.40×10^{-12} g L^{-1}

(B) 4.19×10^{-11} g L^{-1}

(C) 7.05×10^{-3} g L^{-1}

(D) 2.34×10^{-2} g L^{-1}

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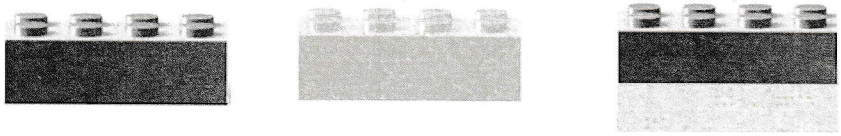
Use the following information to answer questions 17–18.

A student was required to construct a model to help others visualise the composition of a solution of 0.1 M hydrofluoric acid. They were told this acid had a K_a value of 6.7×10^{-4}. The student had access to children's building blocks of various colours, like those shown in the image. The student counted out 25 dark blocks and 25 light blocks and created the following key.

Fluoride ion **Hydrogen ion** **Hydrogen fluoride molecule**



The student used the K_a value provided to determine, via calculation, the appropriate number of dark and light blocks to join to make the number of 'HF molecules' in the model consistent with the K_a value for the acid.

After joining the calculated number of blocks, they finally placed all single and joined blocks into a large beaker. This was presented as the final model.

Question 17 (1 mark)

How many separate dark blocks should the student have placed into the beaker to make the model show the correct percent ionisation for the acid?

(A) 2

(B) 6

(C) 12

(D) 23

Question 18 (1 mark)

Other students assessed the model and were asked to state some of its limitations based on the aim of the modelling exercise. Four statements made are shown below.

I. The model should have included some different coloured blocks to represent the proportion of hydroxide ions also present in the solution.

II. The building blocks used were too big to represent actual ions and molecules.

III. It did not include the most common chemical present in the 0.1 M HF being modelled.

IV. The true nature of the hydrogen ion in aqueous solution is not shown by the model.

Given the aim of the exercise, which of the above statements are significant limitations of the final model presented?

(A) **I** and **II**

(B) **I** and **IV**

(C) **II** and **III**

(D) **III** and **IV**

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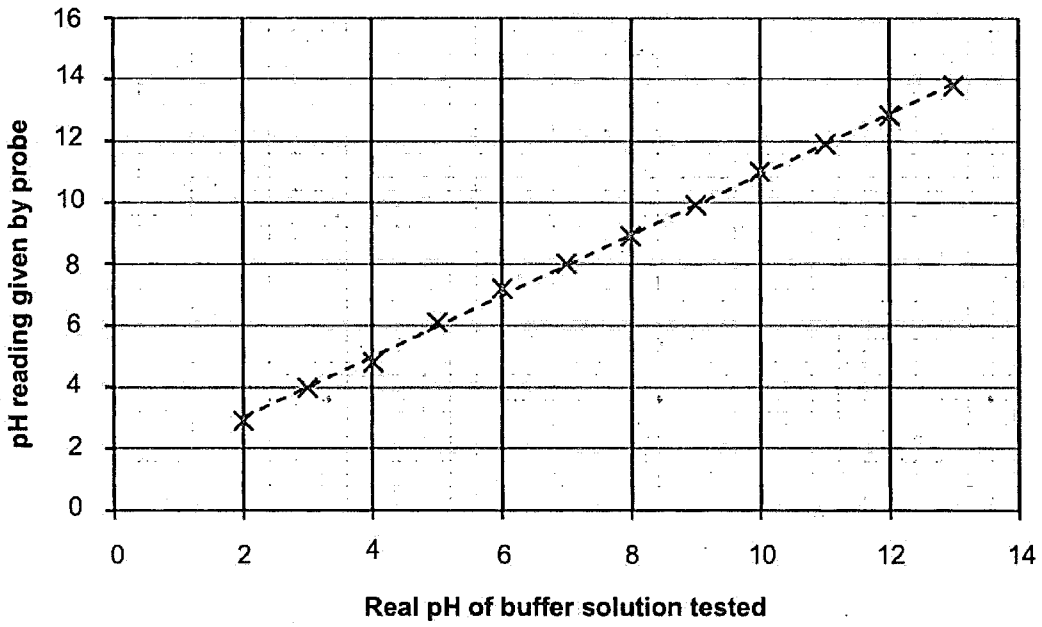
Question 19 (1 mark)

A pH probe is used to measure the pH of several buffers of known pH values to determine if the meter required calibration. The graph below shows the pH readings given by the probe for each of the known (real) pH values of each buffer.

Calibration graph for a pH probe



Which of the following statements is true, based on the data provided in the calibration graph shown?

(A) Using the probe without calibration will affect the reliability of data it gathers.

(B) If the probe were to be placed in a solution with $[OH^-] = [H^+]$ it would read 6.

(C) The equivalent point in a titration, as determined using this probe, will occur approximately one pH unit lower the actual equivalence point.

(D) The $[H^+]$ of a solution, as determined from its pH measured using this probe, will be 10 times lower than the actual $[H^+]$ in the same solution.

Question 20 (1 mark)

A student performed an experiment to determine K_{eq} for the following reaction:

$$Co^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons CoCl_4^{2-}(aq)$$

The student adds a 0.253 g sample of $CoCl_2$ to a solution of 6.0 M NaCl. The value of K_{eq} is 4.8×10^{-4}.

Which of the following is the closest to the percentage of cobalt-containing species that is present as the blue $CoCl_4^{2-}$ ion?

(A) 38%

(B) 46%

(C) 54%

(D) 62%

END OF SECTION 1

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Section 2A

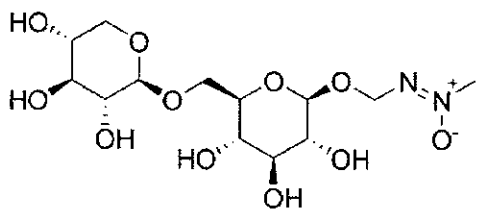
20 marks

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

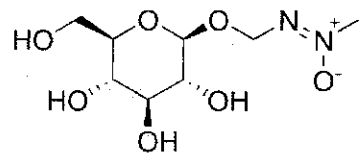
Marks

Question 1 (3 marks)

Cycad fruits have been part of the staple diet of many Indigenous Australian peoples. However, these fruits contain toxins such as cycasin and macrozamin, which are known to cause long-term neurological damage. **3**



macrozamin



cycasin

For safe consumption, the crushed powder from the cycad seeds was placed inside a woven bag. It was noted that running water was more efficient than still water in removing the toxins.

With reference to structural formulae and relevant chemical principles, justify the above observation used to remove the toxins.

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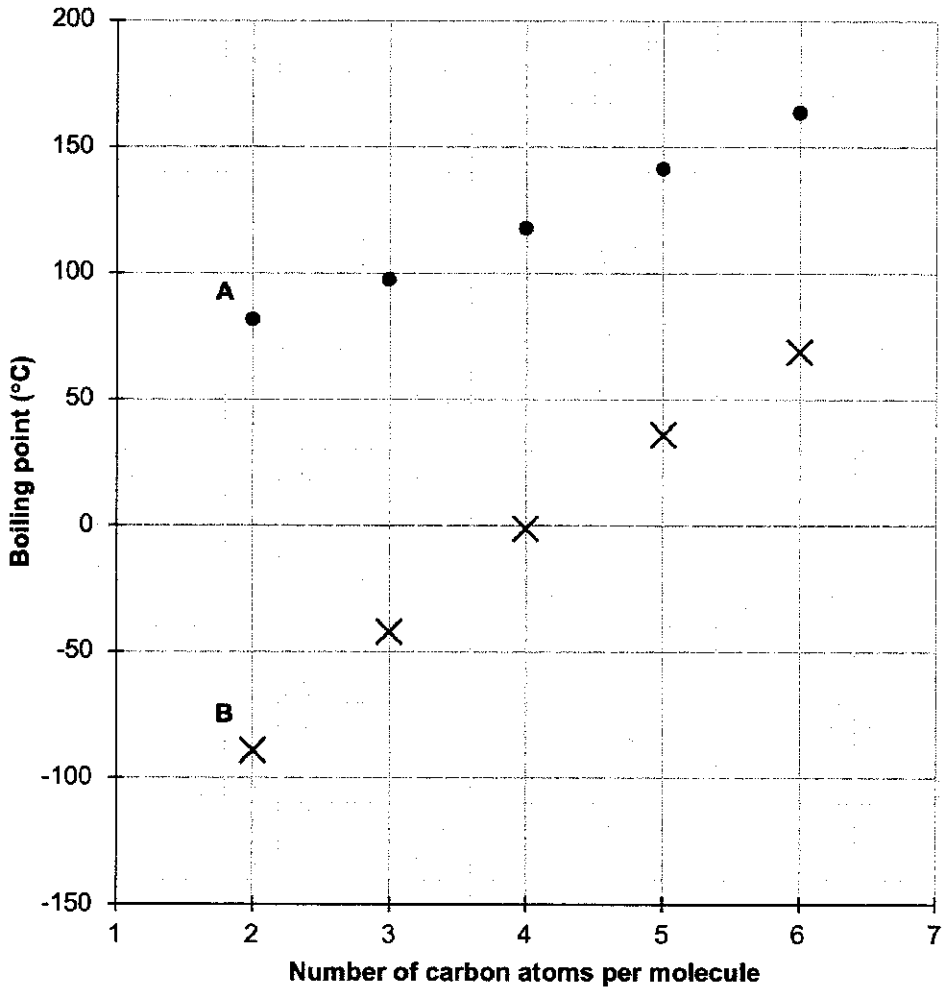
Marks

Question 2 (5 marks)

The graph below shows the boiling points for two different homologous series of organic compounds, straight chained alkanes and straight chained alkane nitriles (R–C≡N).

The two homologous series are labelled on the graph as **A** and **B**.



Question 2 continued on the next page

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Marks

Question 2 continued...

Identify the label of **A** and **B** as either alkanes or alkane nitriles and explain the patterns of the boiling points shown in the graph. **5**

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Marks

Question 3 (5 marks)

A 0.375 g sample of butan-1-ol is burnt to raise the temperature of 150 g of an unknown liquid, using the apparatus shown in **Figure 1**.

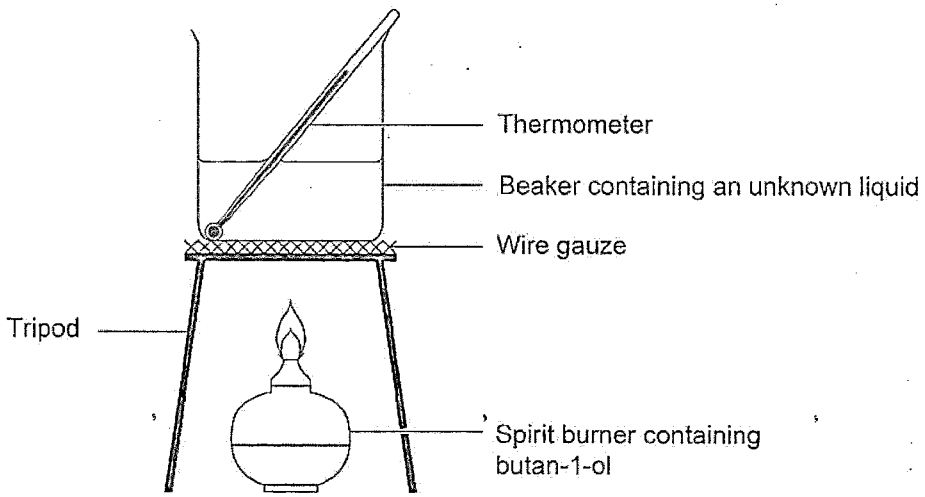

Figure 1 – Apparatus used for the investigation

The temperature changes in the investigation are graphed in **Figure 2**.

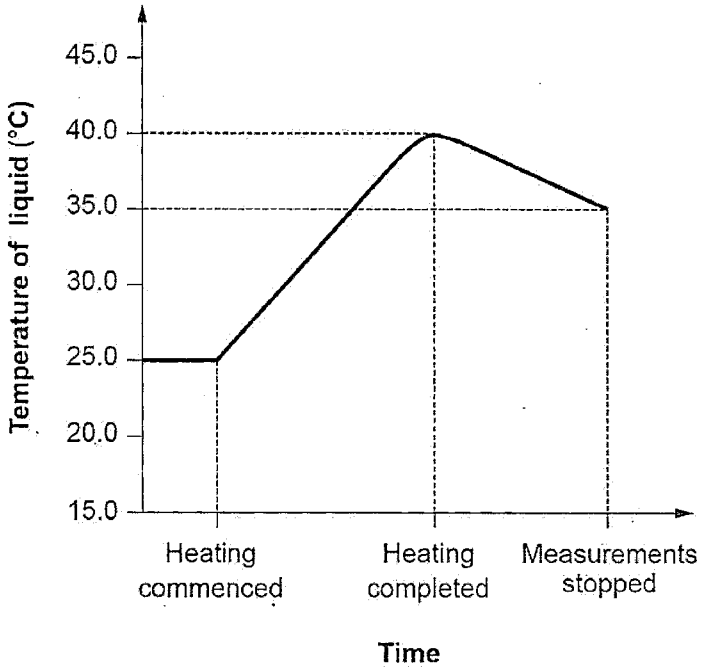

Figure 2 – Changes in the temperature of the unknown liquid during the investigation

Question 3 continues on the next page

NESA STUDENT NUMBER

Marks

Question 3 continued...

(a) The student noted that there was some soot on the base of the beaker. **1**

Outline a reason for this observation.

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(b) Based on prior testing, it was determined that 35.0% of the heat produced by the combustion of butan-1-ol is lost to the surroundings. **4**

Using the information provided, calculate the specific heat capacity of the liquid, given that the heat of combustion of butan-1-ol is 2676 kJ mol^{-1}.

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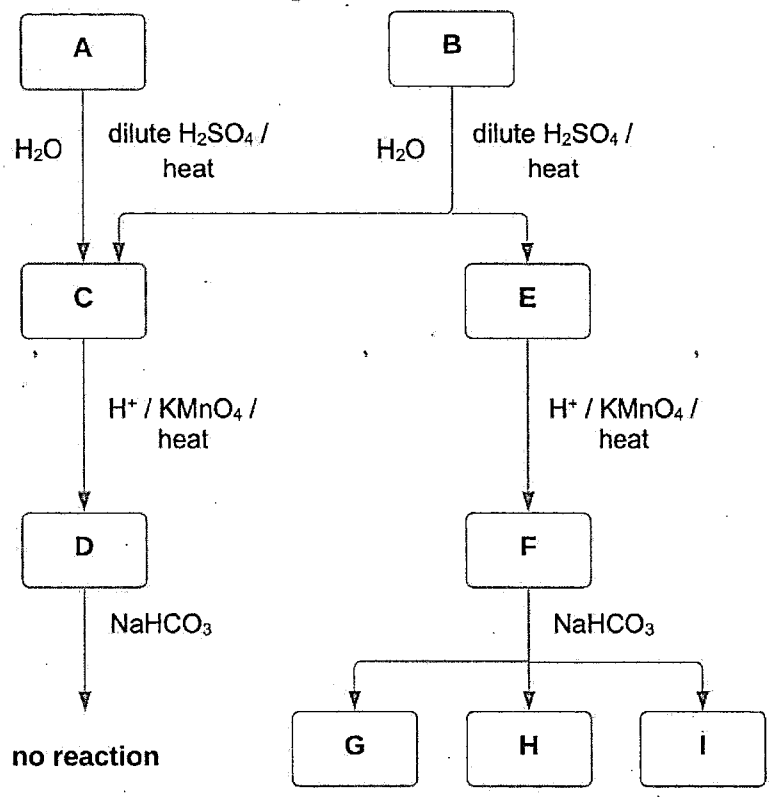
NESA STUDENT NUMBER

Marks

Question 4 (7 marks)

Two different compounds **A** and **B** are isomers with the molecular formula, C_4H_8. **7**

The flowchart below shows reactions involving six different compounds (**A** to **I**).



Question 4 continued on the next page

NESA STUDENT NUMBER

Marks

Question 3 continued...

(a) The student noted that there was some soot on the base of the beaker. **1**

Outline a reason for this observation.

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Using the information provided, calculate the specific heat capacity of the liquid, given that the heat of combustion of butan-1-ol is 2676 kJ mol^{-1}.

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Section 2B

40 marks

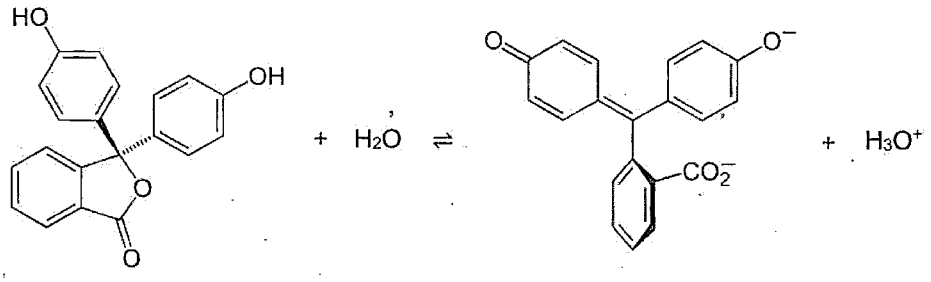
- Attempt Questions 1–8.
- If you use the extra space provided at the back of this exam, clearly indicate which question you are answering.

Marks

Question 1 (3 marks)

Phenolphthalein is a common acid-base indicator with a K_a of 3.0×10^{-10} at 25°C.

When dissolved in water, it undergoes dissociation as shown in the equation below.



phenolphthalein
(colourless)

conjugate base of phenolphthalein
(pink)

(a) Distinct colour change for phenolphthalein occurs when half of the indicator is phenolphthalein, and the other half is its conjugate base. **1**

Given that:

$$pH = pK_a + \log_{10}\frac{[A^-]}{[HA]}$$

calculate the pH at which phenolphthalein shows distinct colour change.

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Question 1 continues on the next page

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Marks

Question 1 continued...

(b) The change of colour for phenolphthalein occurs over a limited range of pH and falls within ±1.00 of the pK_a value. **2**

In an experiment, a solution of a weak acid was titrated against a solution of strong base. It was found that the equivalence point occurred at a pH of 9.30.

Explain if phenolphthalein is a suitable indicator for this titration.

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Marks

Question 2 (4 marks)

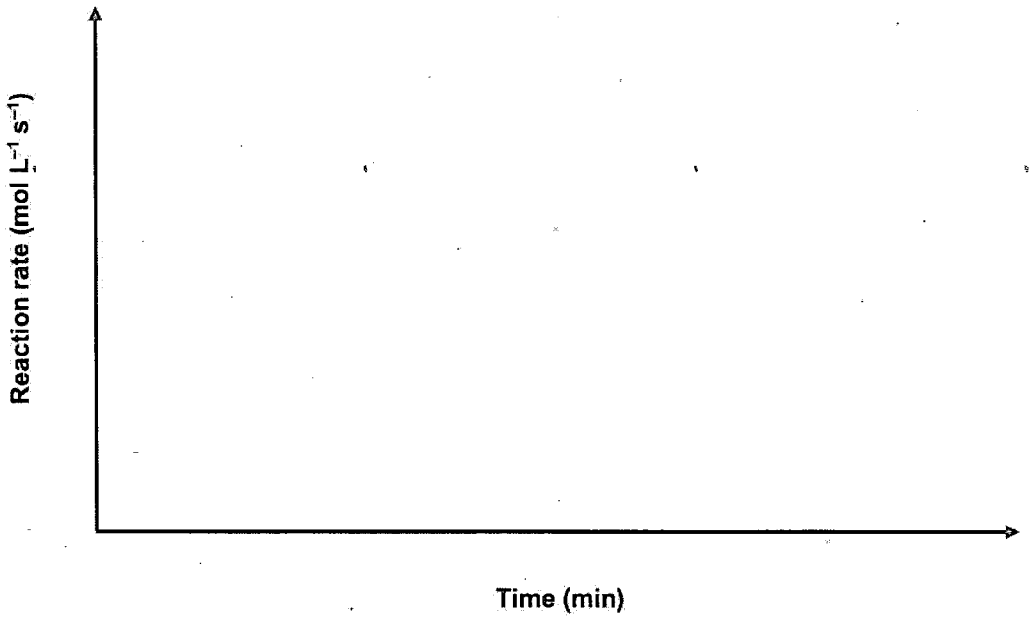
The Haber Process is a method by which ammonia is produced commercially. **4**

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

A vessel contains all three gases at equilibrium.

The vessel is at equilibrium initially, then after 1 minute, the temperature of the vessel is increased. The system re-establishes equilibrium at the 2-minute mark.

Draw a labelled diagram showing the reaction rate-time graph for the above conditions described. Explain with reference to collision theory and Le Chatelier's Principle.



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Marks

Question 3 (5 marks)

Hydrogen gas (H_2) reacts with iodine gas (I_2) in the following reversible reaction: **5**

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

Joseph adds 0.200 mol of H_2 and 0.200 mol of I_2 to a 1.00 L closed container at 400°C. After 2 minutes, the system reaches equilibrium, and 0.316 mol of HI are found in the container.

At the 6-minute mark, how many moles of H_2 gas must be added to the container to increase the amount of HI by 0.050 moles? The system re-establishes equilibrium after 7-minute mark.

NESA STUDENT NUMBER

Marks

Question 4 (4 marks)

The molar enthalpy of neutralisation of two reactions are given: **4**

Reaction 1:

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$ $\Delta H = -57.6$ kJ mol^{-1}

Reaction 2:

$KOH(aq) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O(l)$ $\Delta H = -57.6$ kJ mol^{-1}

Determine if the reaction between solutions of ammonia and hydrochloric acid will produce the same molar enthalpy of neutralisation value as **Reactions 1 and 2**.

Justify your response using your knowledge of acid-base chemistry and include an appropriate chemical equation.

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NESA STUDENT NUMBER

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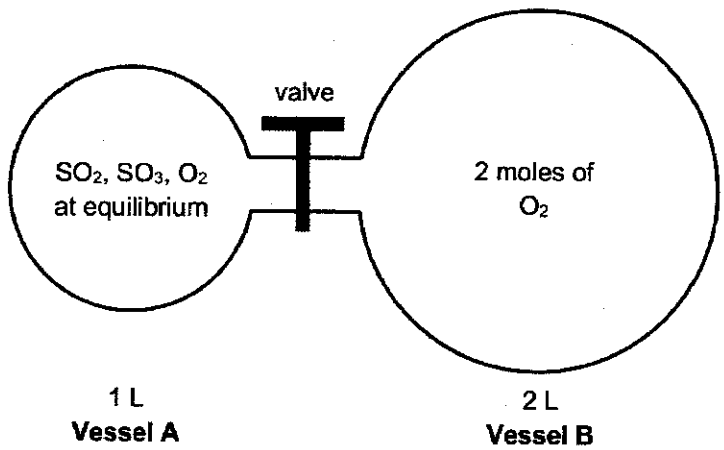
Question 5 (5 marks)

The diagram below shows a closed system with vessels **A** and **B** connected with a small pipe with a valve at the centre. When the valve is closed gases of the two vessels cannot mix with each other. The volume of the small pipe with the valve is assumed to be negligible.



When the valve is closed, vessel **A** is at equilibrium denoted by K_{eq}. When the valve is opened, changes occur to the system in vessel **A**.

(a) Show a relationship between the reaction quotient, Q, and K_{eq} when the valve is closed. **1**

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(b) Explain what happens to the equilibrium position when the valve is opened, using the most appropriate of the following principles. **4**

- Le Chatelier's principle
- Relative rates of the forward and back reactions
- Comparison of Q and K

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NESA STUDENT NUMBER

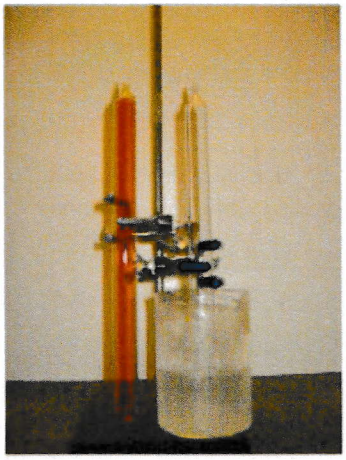
Marks

Question 6 (3 marks)

Consider the following equilibrium system shown.

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

An experiment is conducted to understand the relationship between reversibility, temperature and entropy.



Temperature (°C)	ΔG (kJ)	K_{eq}
100	8.4	0.067
0	–9.2	58
–196	–43.7	3.8×10^{29}

It is known that when $\Delta G = 0$, the reaction is at equilibrium ($K_{eq} = 1$).

Explain the changes that occur when the sealed tube containing the brown NO_2 gas is immersed in liquid nitrogen –196°C, in terms of reversibility, enthalpy and entropy. **3**

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NESA STUDENT NUMBER

Marks

Question 7 (5 marks)

A student prepared two solutions by mixing aqueous sodium hydroxide and ethanoic acid. **5**

- **Solution A** was made by mixing together 25 mL 0.010 mol L^{-1} aqueous sodium hydroxide with 50 mL 0.010 mol L^{-1} ethanoic acid.
- **Solution B** was made by mixing together 25 mL 0.020 mol L^{-1} aqueous sodium hydroxide with 50 mL 0.010 mol L^{-1} ethanoic acid.

Compare the change in pH in **Solutions A** and **B** when a small amount of acid is added to the mixture using equilibrium principles and the Brønsted-Lowry theory.

NESA STUDENT NUMBER

Marks

Question 8 (11 marks)

A manufacturer claims to have 30–32%(v/v) ethanol in most popular brand of red wine. The claim can be verified by determining the concentration of a sample of ethanol from the above red wine, using redox back titration method. The method is given below:

A sample of the red wine is diluted and then oxidised to ethanal using an excess of acidified potassium dichromate solution.

- Pipette 10.0 mL of wine into a 250.0 mL volumetric flask and add distilled water to make up to 250.0 mL and mix thoroughly.
- Pipette 20.0 mL of diluted wine into a conical flask.
- Add 20.0 mL aliquot of 0.040 mol L^{-1} potassium dichromate solution, then add 10 mL of concentrated sulfuric acid (40%).
- Place stopper in flask loosely and heat in a 45°C water bath for 10 minutes then remove from heat.

  All of the ethanol (C_2H_5OH) in the wine sample is oxidised to ethanal (CH_3CHO).

  The flask is stoppered to prevent the ethanol being lost and the overall redox reaction is:

  $$3C_2H_5OH(aq) + Cr_2O_7^{2-}(aq) + 8H^+(aq) \rightarrow 3CH_3CHO(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$$

- Add 2 g of potassium iodide to the flask.

  The excess dichromate ions will oxidise iodide ions:

  $$2I^-(aq) \rightarrow I_2(aq) + 2e^-$$

  While the iodide ions reduce the dichromate ions to chromium (III) ions:

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

  The overall redox reaction equation and the solution will look rather brown due to the presence of I_2.

  $$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6I^-(aq) \rightarrow 2Cr^{3+}(aq) + 7H_2O(l) + 3I_2(aq)$$

- Titrate the above solution containing iodine with 0.010 mol L^{-1} sodium thiosulfate solution until the solution clears:

  $$I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$$

  Thiosulfate ions act as a reducing agent, reducing I_2 to colourless I^- and thereby removing the brown colour from the solution.

- Record the volume of sodium thiosulfate (the titre).
- Repeat procedure on several samples of the diluted wine until concordant titres are achieved.

Question 8 continued on the next page

NESA STUDENT NUMBER

Marks

Question 8 continued...

The results of the experiment are shown below.

Sample	Volume of sodium thiosulfate (mL)
A	31.92
B	29.63
C	29.61
D	29.62

(a) Given the density of ethanol is 0.789 g mL^{-1}, does the sample verified meet the manufacturer's claim? **7**

Support your answer at least one relevant equation and all relevant calculations.

Question 8 continued on the next page

NESA STUDENT NUMBER

Marks

Question 8 continued...

(b) A NBHS group of students performed some research after the previous volumetric analysis and has found the following pieces of information. They used the findings to alter the volumetric titration.

An extract from the students' logbook is shown below:

Volumetric analysis of ethanol in a given sample of the red wine bottle

Procedure:

- Volume of wine extracted – 50.00 mL
- Wine diluted to 500.0 mL
- 20.00 mL aliquot pipetted to a conical flask, titrated against 0.5022 M $KMnO_4$ solution which is a very powerful oxidising agent.

Observations (chemicals):

- Wine diluted till clear fluid but MnO_4^- ions are intensely purple

Observations (titrations):

- **Titration #1** – Add first drop of titrant, contents of reaction flask turn pink immediately, then after a few seconds turn clear. Add a second drop of titrant, contents turn pink and immediately turns clear. Add titrant in a slow stream, contents remain a very slight pink colour, stop stream - contents turn clear immediately. Bubbles of carbon dioxide observed on the surface of the solution. Titrant added dropwise until colour change is persistent for 10 seconds.
- **Titration #2** – as for titration #1
- **Titration #3** – titrant added as a stream initially. Contents turn from pink immediately before turning clear. Brown solid observed on the bottom of the flask.

Careful research into the above observations led to the following findings.

- In the presence of a very powerful oxidising agent, ethanoic acid oxidises to carbon dioxide, thus inhibiting the reaction of $KMnO_4$ with ethanol.
- Mn^{2+} may be present as well and it acts as a catalyst, thus can cause an incomplete reduction of MnO_4^- ions and the reduction product is MnO_2, a brown suspension.

Question 8 continued on the next page

NESA STUDENT NUMBER

Marks

Question 8 continued...

Using the observations on the previous page, suggest reasons as to why the data collected may or may not be accurate. **4**

In your response, include improvements to the experimental design.

END OF SECTION 2B

NESA STUDENT NUMBER

Section 2C

20 marks

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

Marks

Question 1 (6 marks)

An unknown compound, **X**, is analysed and shown to have a composition of 69.7% carbon, 18.6% oxygen and the remainder is hydrogen. The following incomplete mass spectrometry, infrared spectroscopy data and chemical test data was collected.

Spectral data

Mass spectrum	Infrared spectrum
• M+1 peak at m/z = 87.0 • Fragment ion peak at m/z = 28	• Sharp peak at 1705 cm^{-1} • No broad peak around 3200 cm^{-1}

Chemical test data

- When Fehling's reagent (contains Cu^{2+} ions) is added to a sample of **X** in a test tube, no colour change is observed when the test tube is placed in a warm water bath.
- When Tollen's reagent (contains Ag^{+} ions) is added to a sample of **X** in a test tube, no silver mirror is produced.

Question 1 continues on the next page

NESA STUDENT NUMBER

Marks

Question 1 continued...

(a) Calculate the molecular formula of compound **X**. **2**

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(b) Using the data above, identify two possible isomers for compound **X**. Justify your response by including an explanation proving your two possible isomers and disproving one other isomer. **4**

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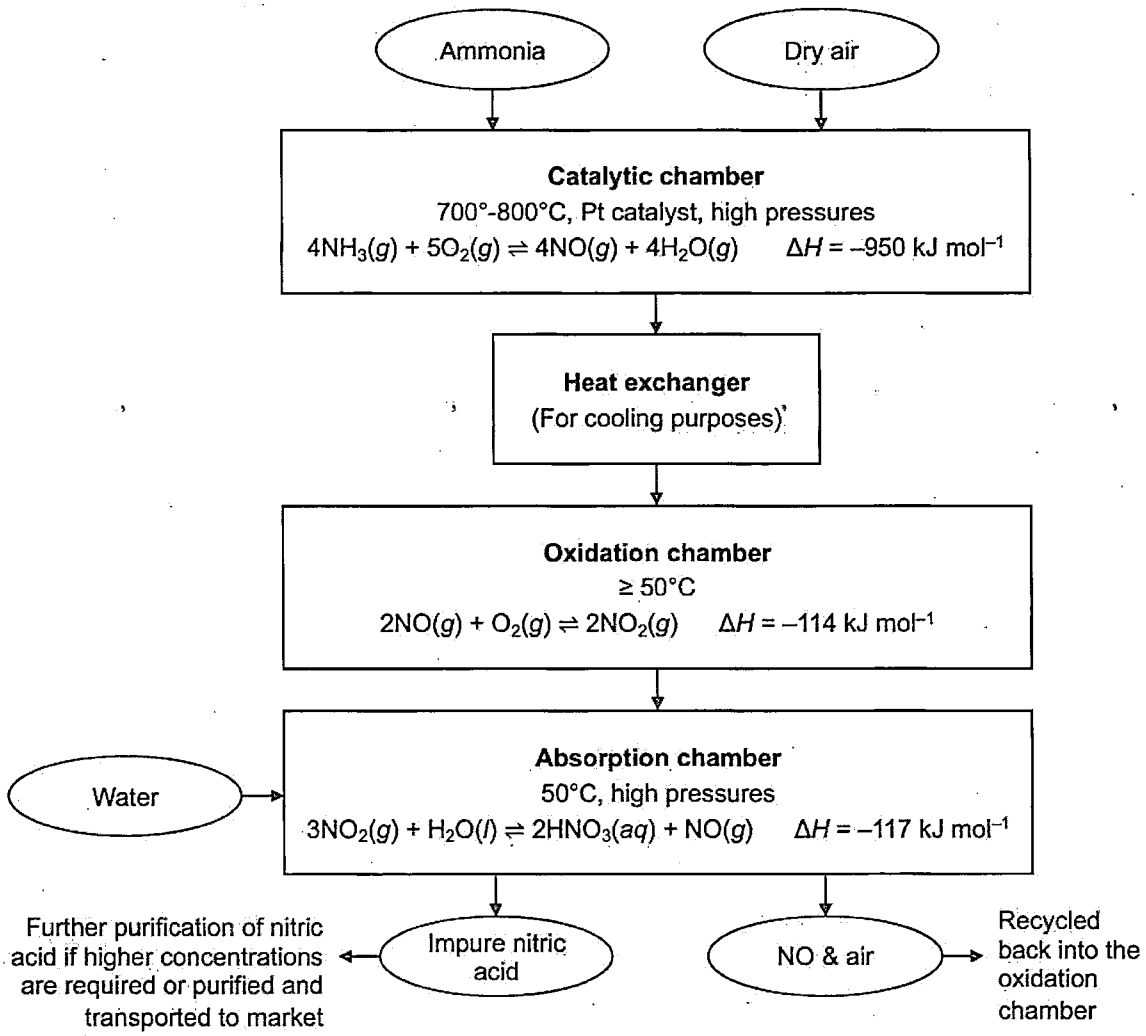
NESA STUDENT NUMBER

Marks

Question 2 (4 marks)

The flow chart summarises an industrial process for the synthesis of nitric acid.



Question 2 continues on the next page

NESA STUDENT NUMBER

Marks

Question 2 continued...

Explain THREE factors that may have been considered in the design of this industrial process. Make specific reference to the flow chart. **4**

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NESA STUDENT NUMBER

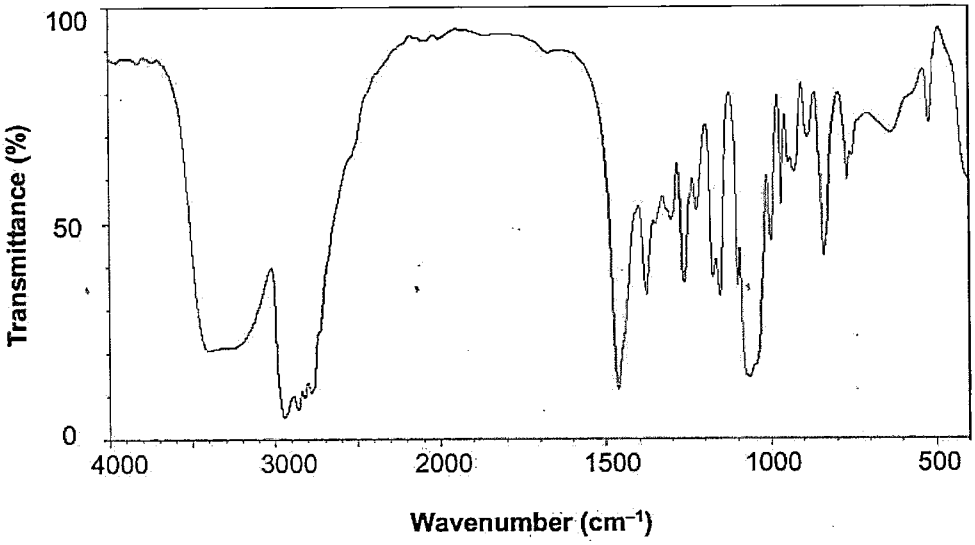
Marks

Question 3 (7 marks)

A chemist discovered a bottle simply labelled '$C_5H_{13}NO$'. **7**

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.

Infrared spectrum



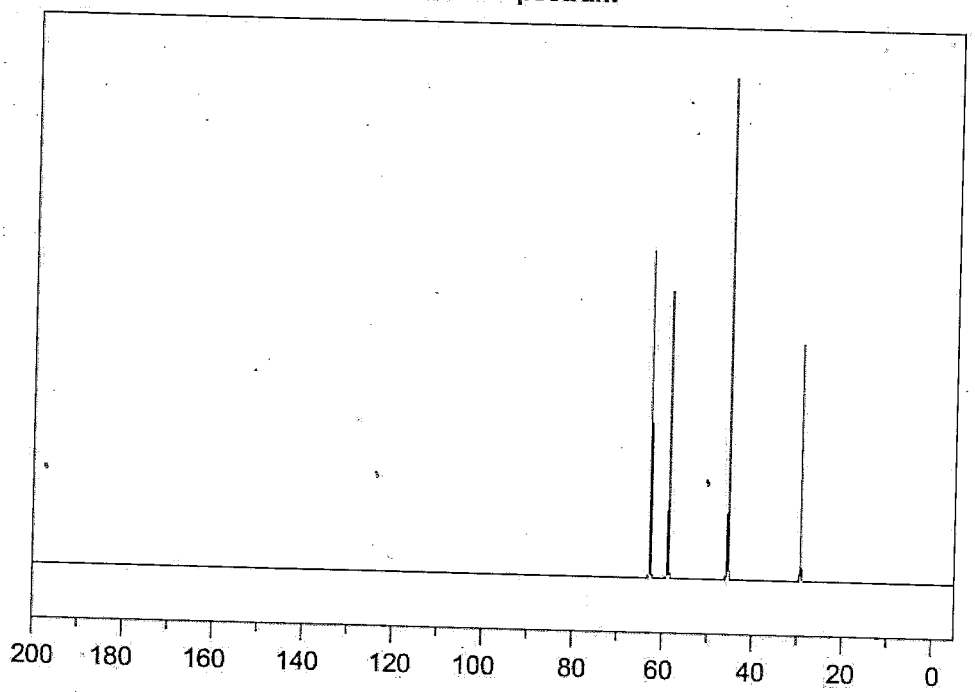
Question 3 continues on the next page

NESA STUDENT NUMBER

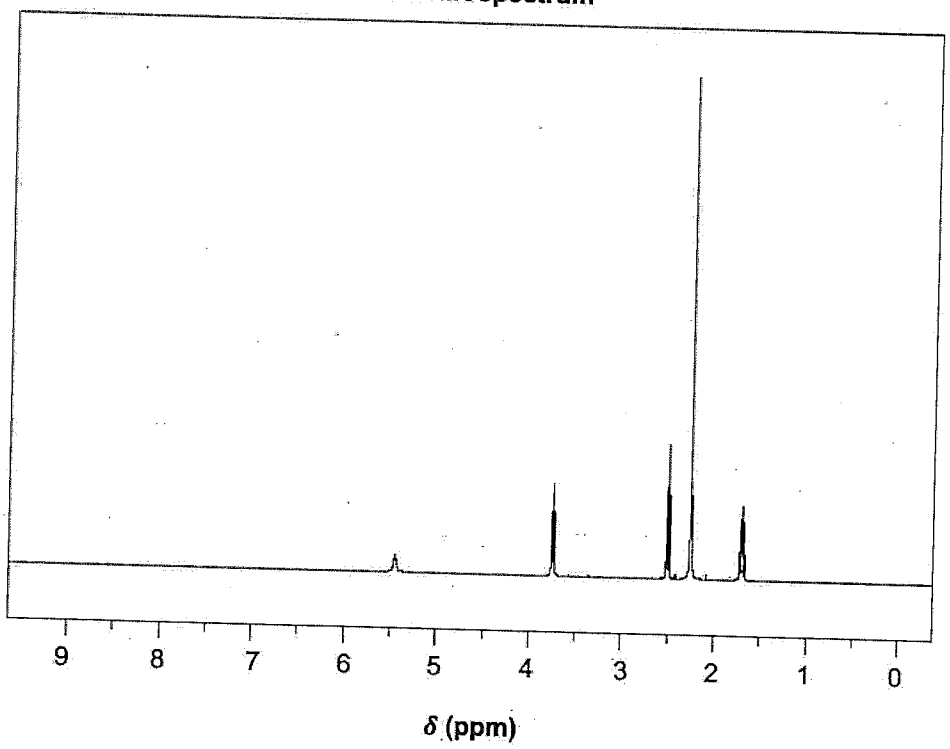
Marks

Question 3 continued...

^{13}C NMR spectrum



^{1}H NMR spectrum



Question 3 continues on the next page

NESA STUDENT NUMBER

Marks

Question 3 continued...

Data from the ^{1}H NMR spectrum

Chemical shift	Relative peak area	Splitting pattern
5.45	1	singlet (1)
3.75	2	triplet (3)
2.50	2	triplet (3)
2.25	6	singlet (1)
1.70	2	quintet (5)

^{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 3 continues on the next page

NESA STUDENT NUMBER

Marks

Question 3 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 3 continues on the next page

NESA STUDENT NUMBER

Marks

Question 3 continued...

NESA STUDENT NUMBER

Marks

Question 4 (3 marks)

Calcium compounds such as calcium fluoride and calcium hydroxide are sparingly soluble in water. **3**

To investigate the solubility of calcium fluoride in calcium hydroxide, a student prepared a saturated solution consisting of calcium fluoride, calcium hydroxide and water. It had a pH of 12.0.

The student noted that the K_{sp} of calcium fluoride at 25°C is 3.45×10^{-11}.

Calculate the molar solubility of calcium fluoride in the above solution at 25°C.

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END OF SECTION 2C

Normanhurst Boys High School

2023 Year 12 Chemistry Trial Examination

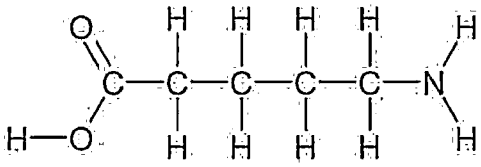
Sample Answers & Notes from the Marker

S1

Section 1 (20 marks)
Written Response

Question 1 (1 mark)

An organic compound shown below.



Which are the TWO functional groups present in this molecule?

(A) Amide and ester.

(B) Amide and carbonyl.

(C) Carboxyl and amine.

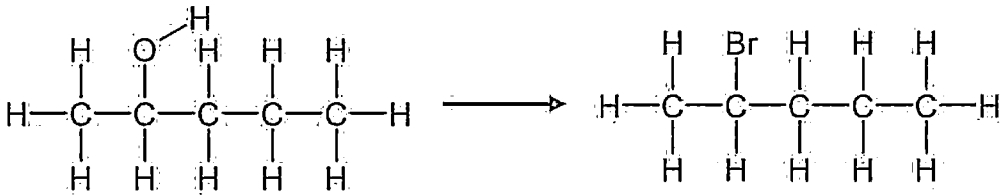
(D) Alkene and amine.

Notes from the Marker

The two functional groups are on the ends of this molecule, the carboxyl group (–COOH) and the amine group ($–NH_2$).

Question 2 (1 mark)

Which of the following conditions would be appropriate to carry out the following synthesis?



(A) Br_2 and UV light.

(B) Br_2 dissolved in water.

(C) HBr and heat.

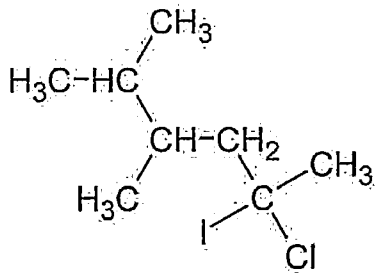
(D) HBr and $ZnCl_2$ catalyst.

Notes from the Marker

Substitution reaction of secondary alcohols with HBr and heat.

Question 3 (1 mark)

The structure of a compound is shown below.



What is the IUPAC name of this compound?

(A) 2-chloro-2-iodo-4,5-dimethylhexane

(B) 2-iodo-2-chloro-4,5-dimethylhexane

(C) 2,3-dimethyl-5-chloro-5-iodohexane

(D) 5-chloro-5-iodo-2,3-dimethylhexane

Notes from the Marker

Start with finding the longest carbon chain, in this case is hexane. Number the carbon chain so that each substituent is given a locant.

There are two possible ways to number the carbon chain:

- From left to right: 2, 3, 5, 5
- From right to left: 2, 2, 4, 5

First point of difference rule will then apply, where the assigned locants will be chosen based on the first substituent locant that has the lowest locant, hence: 2, 2, 4, 5.

The substituents should also be named in alphabetical order.

Question 4 (1 mark)

The heat of combustion of butan-1-ol is 2676 kJ mol^{-1}.

What is the value of the heat of combustion in kJ g^{-1}?

(A) 30.41

(B) 36.10

(C) 44.60

(D) 47.79

Notes from the Marker

To convert $\Delta H = 2676$ kJ mol^{-1} into kJ g^{-1}, divide ΔH by the molar mass of butan-1-ol (C_4H_9OH), since molar mass has units of g mol^{-1}.

$$\frac{\Delta H}{MM} = \frac{2676}{4(12.01) + 10(1.008) + 16.00}$$

$$= 36.10 \text{ kJ g}^{-1}$$

Question 5 (1 mark)

Ethanoic acid (CH_3COOH) is a weak acid with $K_a = 1.74 \times 10^{-5}$ at 25°C. 1.00 L of a solution is prepared by dissolving 0.100 mol of ethanoic acid in distilled water.

What is the pH of the resulting solution?

(A) 2.00

(B) 2.10

(C) 2.80

(D) 2.88

Notes from the Marker

$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$

$[CH_3COOH] = 0.100$ M

$$K_a = \frac{[CH_3COOH][H_3O^+]}{[CH_3COOH]}$$

$$= \frac{[H_3O^+]^2}{[CH_3COOH]} \text{ (since } [CH_3COO^-] = [H_3O^+])$$

$$1.74 \times 10^{-5} = \frac{[H_3O^+]^2}{0.100}$$

$[H_3O^+] = 1.319 \times 10^{-3}$ M

$pH = -\log_{10}(1.319 \times 10^{-3})$

$= 2.88$

Question 6 (1 mark)

The table lists some properties of the straight-chained carbon compounds **W**, **X**, **Y** and **Z**.

Compound	Reactivity in bromine water	Solubility in water
W	Rapidly decolourises	Insoluble
X	Unreactive	Insoluble
Y	Unreactive	Soluble
Z	Unreactive	Partially soluble

Which row below best identifies the compounds **W**, **X**, **Y** and **Z**?

	W	X	Y	Z
(A)	C_3H_6	C_3H_8	CH_3OH	C_4H_9OH
(B)	C_3H_8	C_3H_6	CH_3OH	C_4H_9OH
(C)	C_3H_6	C_3H_8	C_4H_9OH	CH_3OH
(D)	C_3H_8	C_3H_6	C_4H_9OH	CH_3OH

Notes from the Marker

- **W** is an alkene, C_3H_6 (propene), which decolourises bromine water due to the presence of a double bond. It is also non-polar and insoluble in water.
- **X** is an alkane, C_3H_8 (propane), so is unreactive in bromine water, as it is saturated. It is also non-polar and insoluble in water.
- **Y** is a small alcohol, CH_3OH (methanol), so is unreactive in bromine water, as it is saturated. It also contains a polar hydroxyl group with a very short hydrocarbon chain, so is soluble in water, since the hydroxyl group can form hydrogen bonds with water.
- **Z** is a longer chained alcohol, C_4H_9OH, so is unreactive in bromine water, as it is saturated. It also contains a polar hydroxyl group, which can form hydrogen bonds with water. However, the hydrocarbon chain is longer and is non-polar, hence decreasing the solubility of the alcohol, making it partially soluble.

Question 7 (1 mark)

The table below shows some data on four acid-base indicators.

Indicator name	pH range	Colour range
methyl orange	3.1–4.4	red–yellow
bromophenol red	3.8–5.4	yellow–blue
methyl red	4.2–6.3	red–yellow
phenol red	6.8–8.4	yellow–red

A solution, labelled **X**, is made by mixing equal volumes of 0.0002 mol L^{-1} sodium hydroxide and 0.0004 mol L^{-1} nitric acid.

Which indicator shown would turn pure yellow when added to a sample of **X**?

(A) Methyl orange

(B) Bromophenol red

(C) Methyl red

(D) Phenol red

Notes from the Marker

$NaOH(aq) + HNO_3(aq) \rightarrow H_2O(l) + NaNO_3(aq)$

If 1 L of each reactant were added together:

$n(NaOH) = 0.0002 \times 1$

$= 0.0002$ mol

$n(HNO_3) = 0.0004 \times 1$

$= 0.0004$ mol

Due to 1:1 mole ratio, the left-over moles after the reaction:

$n(H_3O^+) - n(OH^-) = 0.0004 - 0.0002$

$= 0.0002$ mol of H_3O^+

$[H_3O^+] = n/V$

$= 0.0002 / 2$

$= 0.0001$ M

$pH = -\log_{10}(0.0001)$

$= 4$

Hence, for the indicator to be pure yellow, it must be phenol red, as it will be yellow for pH < 6.8.

Question 8 (1 mark)

The following organic compounds all have five carbons.

A: 2,2-dimethylbutane

B: 2-methylpentane

C: 4-methylpent-2-ene

Which of the following is most likely to be correct?

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

(B) Compound **A** has a higher melting point than compound **B**.

(C) Compound **B** and compound **C** are functional group isomers.

(D) Compound **A** and compound **B** are positional isomers.

Notes from the Marker

The surface area of compound **A** is lower than the surface area of compound **B**, due to more branches. Compound **A** is therefore easier to pack together and has a higher melting point compared to compound **B**.

Question 9 (1 mark)

A 3.42 g sample of solid $Mg(OH)_2$ is added to a 200.0 mL solution of 0.600 mol L^{-1} HCl.

What is the final pH of the final mixture?

(A) 0.51

(B) 1.2

(C) 1.9

(D) 2.6

Notes from the Marker

$$n(Mg(OH)_2) = \frac{m}{MM}$$

$$= \frac{3.42}{24.31 + 2(16.00) + 2(1.008)}$$

$$= 0.0586359428 \text{ mol}$$

$Mg(OH)_2(aq) \rightarrow Mg^{2+}(aq) + 2OH^-(aq)$

$n(OH^-) = 0.0586359428 \times 2$ (due to 1:2 mole ratio)

$= 0.1172718856$ mol

$n(HCl) = c \times V$

$= 0.600 \times 0.200$

$= 0.1200$ mol

Hence, H^+ will be in excess:

$n(H^+)_{excess} = 0.1200 - 0.1172718856$

$= 0.0027281144$ mol

$[H^+] = n/V$

$$= \frac{0.0027281144}{0.200}$$

$= 0.01364$ M

$pH = -\log_{10}(0.01364)$

$= 1.9$

Question 10 (1 mark)

A 50.0 mL sample of 4.0×10^{-3} M $AgNO_3$ solution is added to 50.0 mL of 1.0×10^{-3} M KIO_3 solution at 25°C.

The K_{sp} value for $AgIO_3$ at 25°C is 3.2×10^{-8}.

Which row of the following table correctly predicts if $AgIO_3$ will form a precipitate and the reason for this?

	Will a precipitate form?	Reason
(A)	Yes	$Q_{sp} < K_{sp}$
(B)	Yes	$Q_{sp} > K_{sp}$
(C)	No	$Q_{sp} < K_{sp}$
(D)	No	$Q_{sp} > K_{sp}$

Notes from the Marker

$AgNO_3(aq) \rightarrow Ag^+(aq) + NO_3^-(aq)$

$n(AgNO_3) = 4.0 \times 10^{-3} \times 0.050$

$= 0.0002$ mol

$[Ag^+]_{mixed} = \frac{0.0002}{0.100}$

$= 0.002$ M

$KIO_3(aq) \rightarrow K^+(aq) + IO_3^-(aq)$

$n(KIO_3) = 1.0 \times 10^{-3} \times 0.050$

$= 0.00005$ mol

$[IO_3^-]_{mixed} = \frac{0.00005}{0.100}$

$= 0.0005$ M

$AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)$

$Q_{sp} = [Ag^+][IO_3^-]$

$= (0.002)(0.0005)$

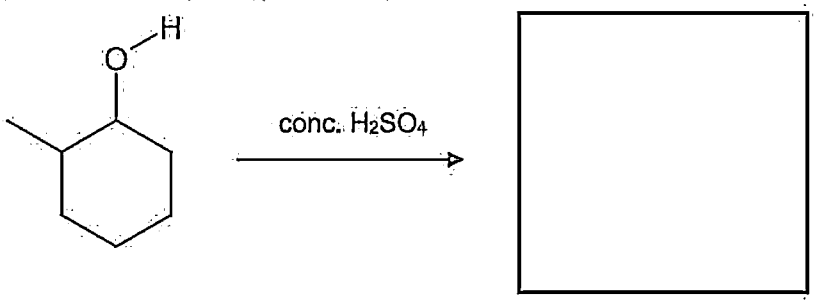
$= 1.0 \times 10^{-6}$ M

$Q_{sp} > K_{sp}$

Therefore, a precipitate will form.

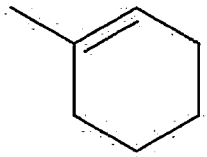
Question 11 (1 mark)

2-methylcyclohexanol is an alcohol and undergoes a dehydration reaction with sulfuric acid as shown.

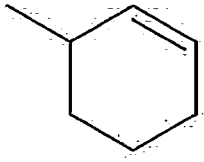


What is the major organic product of this reaction?

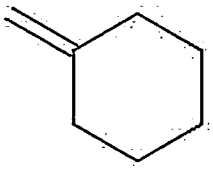
(A)



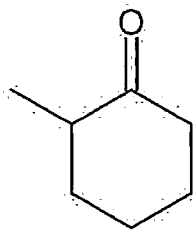
(B)



(C)



(D)



Notes from the Marker

In a dehydration reaction, the hydroxyl group and a hydrogen atom from an adjacent carbon is removed to form an alkene and water. This results in the products of option (A) and (B) that can be produced.

The major product, however, is the alkene with most carbons directly attached (i.e. most highly substituted alkene), hence option (A) is the major product.

Question 12 (1 mark)

Consider the following equilibrium for a weak base N_2H_4.

$$N_2H_4(aq) + H_2O(l) \rightleftharpoons N_2H_5^+(aq) + OH^-(aq)$$

A 0.75 mol sample of N_2H_4 is placed in a 1.00 L flask. After the system comes to equilibrium, the flask contains 0.45 mol $N_2H_5^+$.

The value of K_b for weak base N_2H_4 is:

(A) 0.27

(B) 0.68

(C) 1.48

(D) 3.70

Notes from the Marker

$[N_2H_4] = \frac{0.75}{1.00}$

$= 0.75\ M$

	$[N_2H_4]$	$[N_2H_5^+]$	$[OH^-]$
Initial	0.75	0.00	0.00
Change	–0.45	+0.45	+0.45
Equilibrium	0.30	0.45	0.45

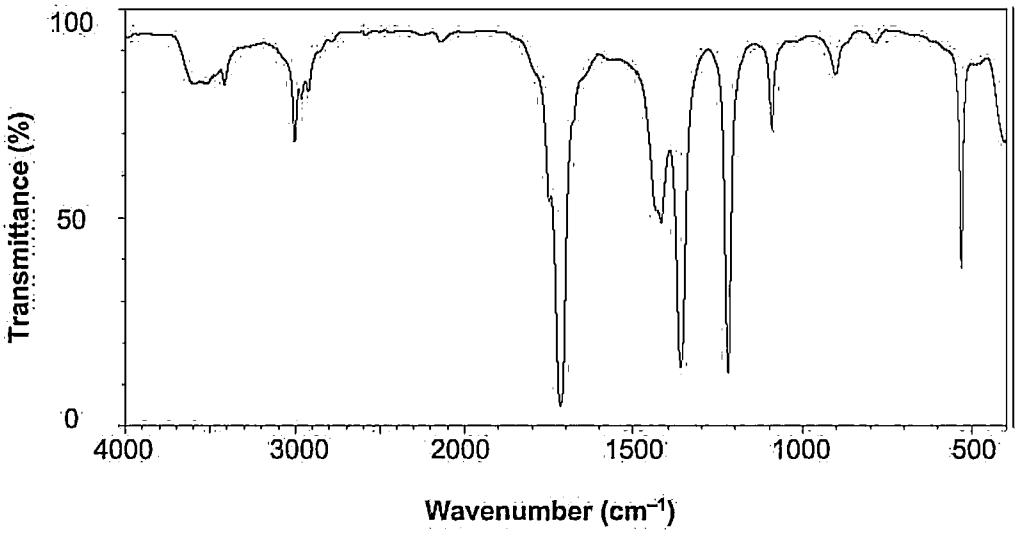
$K_b = \frac{[N_2H_5^+][OH^-]}{[N_2H_4]}$

$= \frac{(0.45)(0.45)}{0.30}$

$= 0.68$

Question 13 (1 mark)

The diagram shows the infrared spectrum of a compound.



Which compound was analysed?

(A) Propane

(B) Propan-1-ol

(C) Propanal

(D) Propan-2-one

Notes from the Marker

The C–H bond is detected at ~3000 cm^{-1} and the C=O bond is detected at ~1700 cm^{-1}. These bonds are present in propanal and propan-2-one.

Question 14 (1 mark)

A food critic noticed their specialty chicken dish was extremely bland and requested that analysis be carried out to measure the sodium chloride concentration. This was achieved by dissolving the food sample in water and the chloride ion being precipitated by adding an excess of silver nitrate solution. The precipitate was washed and dried.

If the mass of the food sample was 10.0 g and the final precipitate had a mass of 0.188 g, what is the percentage of sodium chloride in the food?

(A) 1.88%

(B) 0.766%

(C) 0.465%

(D) 0.220%

Notes from the Marker

m(AgCl) = 0.188 g

n(AgCl) = m/MM

$$= \frac{0.188}{107.9 + 35.45}$$

= 0.00131147541 mol

$n(Cl^-)$ = 0.00131147541 mol

In NaCl:

n(NaCl) = 0.00131147541 mol

m(NaCl) = n x MM

= 0.00131147541 x (22.99 + 35.45)

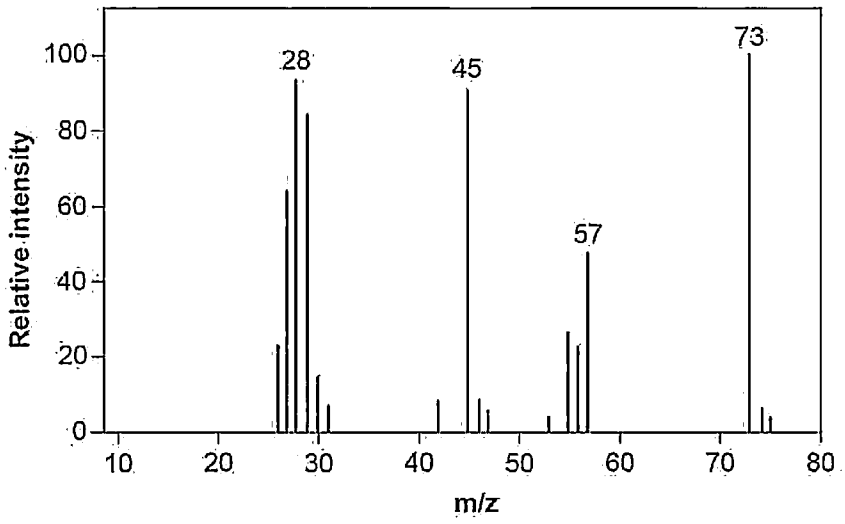
= 0.07664 g

$$\%(NaCl) = \frac{0.07664}{10.0} \times 100$$

= 0.766%

Question 15 (1 mark)

A simplified mass spectrum of butanoic acid is shown.



The peak with the mass-to-charge ratio, m/z, of 73:

(A) has the greatest mass-to-charge ratio.

(B) represents the species $CH_2CH_2COOH^-$.

(C) represents the species CH_2CH_2COOH.

(D) represents the species $CH_2CH_2COOH^+$.

Notes from the Marker

The $CH_2CH_2COOH^+$ species has a mass of 73 and only positively charged species can be detected in a mass spectrometer.

Question 16 (1 mark)

Silver chromate (Ag_2CrO_4) is a yellow solid that dissolves in water to produce a yellow saturated solution containing 2.34×10^{-2} g L^{-1} of silver chromate. The molar mass of silver chromate is 331.8 g mol^{-1}. The chromate ions react with hydrogen ions as shown below:

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightarrow 2HCrO_4^-(aq) + H_2O(l)$$

yellow **orange**

The molar concentration of chromate ions in a saturated solution of silver chromate in 0.183 mol L^{-1} silver nitrate is:

(A) 1.40×10^{-12} mol L^{-1}

(B) 4.19×10^{-11} mol L^{-1}

(C) 7.05×10^{-3} mol L^{-1}

(D) 2.34×10^{-2} mol L^{-1}

Notes from the Marker

$Ag_2CrO_4(s) \rightleftharpoons 2Ag^+(aq) + CrO_4^{2-}(aq)$

Solubility of $Ag_2CrO_4 = 2.34 \times 10^{-2}$ g L^{-1}

$MM(Ag_2CrO_4) = (107.9 \times 2) + (52.00) + (16.00 \times 4)$

$= 331.8$ g mol^{-1}

$$[Ag_2CrO_4] = \frac{2.34 \times 10^{-2} \text{ g L}^{-1}}{331.8 \text{ g mol}^{-1}}$$

$= 7.05 \times 10^{-3}$ mol L^{-1}

$K_{sp} = [Ag^+]^2[CrO_4^{2-}]$

$= (2 \times 7.05 \times 10^{-3})^2 (7.05 \times 10^{-3})$

$= 1.40 \times 10^{-12}$ (3 s.f.)

To determine molar concentration of chromate ions in a saturated solution of silver chromate in 0.183 mol L^{-1} silver nitrate.

$[AgNO_3] = 0.183$ M

$[Ag^+] = [NO_3^-] = 0.183$ M

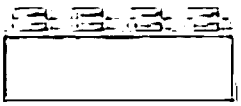
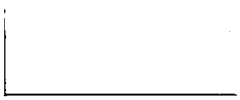
Let $[CrO_4^{2-}] = s$

$1.4 \times 10^{-12} = (0.183)^2 \times s$

$s = 4.19 \times 10^{-11}$ mol L^{-1}

Use the following information to answer questions 17–18.

A student was required to construct a model to help others visualise the composition of a solution of 0.1 M hydrofluoric acid. They were told this acid had a K_a value of 6.7×10^{-4}. The student had access to children's building blocks of various colours, like those shown in the image. The student counted out 25 dark blocks and 25 light blocks and created the following key.

Fluoride ion	Hydrogen ion	Hydrogen fluoride molecule
		

The student used the K_a value provided to determine, via calculation, the appropriate number of dark and light blocks to join to make the number of 'HF molecules' in the model consistent with the K_a value for the acid.

After joining the calculated number of blocks, they finally placed all single and joined blocks into a large beaker. This was presented as the final model.

Question 17 (1 mark)

How many separate dark blocks should the student have placed into the beaker to make the model show the correct percent ionisation for the acid?

(A) 2

(B) 6

(C) 12

(D) 23

Notes from the Marker

$HF(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + F^-(aq)$

$$K_a = \frac{[H_3O^+]^2}{[HF]}$$

$$6.7 \times 10^{-4} = \frac{[H_3O^+]^2}{0.1}$$

$[H_3O^+] = 0.00818535$ M

$$\text{Percent ionisation} = \frac{0.00818535}{0.1} \times 100$$

$= 8\%$

25 blocks of HF x 8% = 2 blocks

Question 18 (1 mark)

Other students assessed the model and were asked to state some of its limitations based on the aim of the modelling exercise. Four statements made are shown below.

I. The model should have included some different coloured blocks to represent the proportion of hydroxide ions also present in the solution.

II. The building blocks used were too big to represent actual ions and molecules.

III. It did not include the most common chemical present in the 0.1 M HF being modelled.

IV. The true nature of the hydrogen ion in aqueous solution is not shown by the model.

Given the aim of the exercise, which of the above statements are significant limitations of the final model presented?

(A) **I** and **II**

(B) **I** and **IV**

(C) **II** and **III**

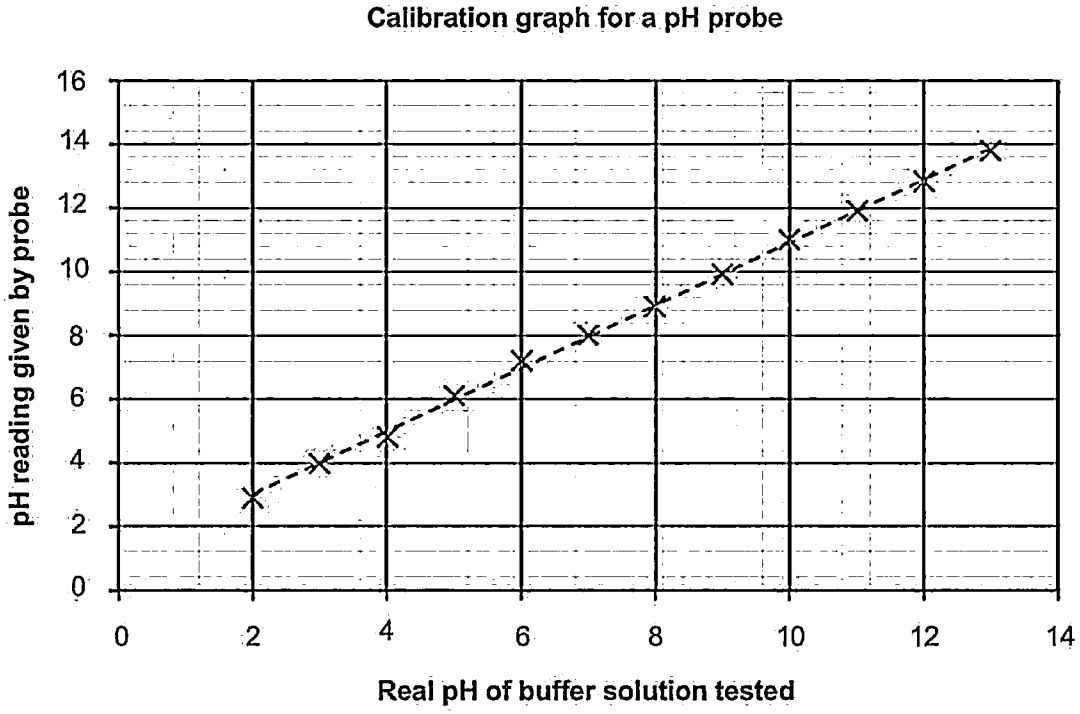
(D) **III** and **IV**

Notes from the Marker

- **III** is a limitation, as the model did not include chemicals such as H_2O, which is a relevant in showing the composition of the acid solution as well as the behaviour of the acid.
- **IV** is a limitation, as the true nature of the hydrogen ion, being the hydronium ion (H_3O^+) was not shown by the model.

Question 19 (1 mark)

A pH probe is used to measure the pH of several buffers of known pH values to determine if the meter required calibration. The graph below shows the pH readings given by the probe for each of the known (real) pH values of each buffer.



Which of the following statements is true, based on the data provided in the calibration graph shown?

(A) Using the probe without calibration will affect the reliability of data it gathers.

(B) If the probe were to be placed in a solution with $[OH^-] = [H^+]$ it would read 6.

(C) The equivalent point in a titration, as determined using this probe, will occur approximately one pH unit lower the actual equivalence point.

(D) The $[H^+]$ of a solution, as determined from its pH measured using this probe, will be 10 times lower than the actual $[H^+]$ in the same solution.

Notes from the Marker

A difference in a pH of 1 represents a 10-fold change in the acidity/basicity of a solution.

The pH readings given by the probe is always 1 pH higher than the real pH of the buffer solution tested. The pH probe therefore measures the $[H^+]$ as 10 times lower than the actual $[H^+]$ in the same solution.

Question 20 (1 mark)

A student performed an experiment to determine K_{eq} for the following reaction:

$$Co^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons CoCl_4^{2-}(aq)$$

The student adds a 0.253 g sample of $CoCl_2$ to a solution of 6.0 M NaCl. The value of K_{eq} is 4.8×10^{-4}.

Which of the following is the closest to the percentage of cobalt-containing species that is present as the blue $CoCl_4^{2-}$ ion?

(A) 38%

(B) 46%

(C) 54%

(D) 62%

Notes from the Marker

$$K_{eq} = \frac{[CoCl_4^{2-}]}{[Co^{2+}][Cl^-]^4}$$

$$= 4.8 \times 10^{-4}$$

In the 6.0 M solution of NaCl, $[Cl^-] = 6.0$ M

0.253 g of $CoCl_2$ is added to this, introducing both Co^{2+} and Cl^-. To determine how much of each ion is added:

$n(CoCl_2) = m/MM$

$$= \frac{0.253}{58.93 + 2(35.45)}$$

$$= 0.001949 \text{ mol}$$

$n(Co^{2+}) = 0.001949$ mol

$n(Cl^-) = 0.001949 \times 2$

$= 0.003897$ mol

Hence, before equilibrium is established:

$[Co^{2+}] = n/V$

$$= \frac{0.001949}{0.500}$$

$= 0.003897$ M

To find total $[Cl^-]$ in solution initially:

$n(Cl^-)_{total} = n(Cl^-)_{initial} + n(Cl^-)_{added}$

$= (6.0 \times 0.500) + 0.003897$

$= 3.0 + 0.003897$

$= 3.0$ mol

$[Cl^-] = n/V$

$$= \frac{3.0}{0.500}$$

$= 6.0$ M

Note that the amount of Cl^- added from the $CoCl_2$ is negligible.

Use an ICE table to determine how much of Co^{2+} initially becomes $CoCl_4^{2-}$:

	$[Co^{2+}]$	$[Cl^-]$	$[CoCl_4^{2-}]$
Initial	0.003897	6.0	0.0
Change	$-x$	$-4x$	$+x$
Equilibrium	$0.003897 - x$	$6.0 - 4x$	x

Since $x << 6.0$, $[Cl^-] \approx 6.0$ M (assuming x is negligible compared to 6.0 M).

$$K_{eq} = \frac{[CoCl_4^{2-}]}{[Co^{2+}][Cl^-]^4}$$

$$4.8 \times 10^{-4} = \frac{[CoCl_4^{2-}]}{[Co^{2+}] \times 6.0^4}$$

$$\frac{[CoCl_4^{2-}]}{[Co^{2+}]} = 4.8 \times 10^{-4} \times 6.0^4$$

$$= 0.62$$

$[CoCl_4^{2-}] = 0.62 \times [Co^{2+}]$

This means that for every 100 $CoCl_4^{2-}$, we have only ~62 Co^{2+} ions. Thus, out of a total of 162 cobalt-containing species, 62 of these would be Co^{2+} ions.

The percentage would therefore be:

$$\frac{62}{162} \times 100 = 38\%$$

2022

NBHS Year 12 Chemistry Trial Examination

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

Sample 2 + 4 = (A) 2 (B) 6 (C) 8 (D) 9

A ○ B ● C ○ D ○

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

A ● B ⊗ C ○ D ○

If you change your mind and have crossed out what you consider to be the correct answer, then indicate this by writing the word *correct* and drawing an arrow as follows:

correct

A ⊗ B ⊗ ← C ○ D ○

1	A ○	B ○	C ●	D ○
2	A ○	B ○	C ●	D ○
3	A ●	B ○	C ○	D ○
4	A ○	B ●	C ○	D ○
5	A ○	B ○	C ○	D ●
6	A ●	B ○	C ○	D ○
7	A ○	B ○	C ○	D ●
8	A ○	B ●	C ○	D ○
9	A ○	B ○	C ●	D ○
10	A ○	B ●	C ○	D ○
11	A ●	B ○	C ○	D ○
12	A ○	B ●	C ○	D ○
13	A ○	B ○	C ●	D ●
14	A ○	B ●	C ○	D ○
15	A ○	B ○	C ○	D ●
16	A ○	B ●	C ○	D ○
17	A ●	B ○	C ○	D ○
18	A ○	B ○	C ○	D ●
19	A ○	B ○	C ○	D ●
20	A ●	B ○	C ○	D ○

Normanhurst Boys High School

2023 Year 12 Chemistry Trial Examination

Marking Responses, Sample Answers & Notes from the Marker

S2A **Section 2A** (10 marks)

Question 1

Marking Criteria	Marks
Identifies that macrozamin and cycasin can form bonds with water, with reference to the relevant structural group (hydroxyl). AND States the equilibrium reaction that can occur with the toxins in water (either described in words or written as an equation). AND Justifies the observation to remove toxins by: • Describing the difference between **running water** (open system) and **still water** (closed system, equilibrium forms) OR states why **still water** would not be efficient by relating to equilibrium. • Relating to the efficiency of running water in removing toxins through LCP. **Response shows a good understanding of principles involving dissolving and equilibrium.**	3
Identifies that macrozamin and cycasin can form bonds with water. AND Justifies the observation to remove toxins by: • Relating to the efficiency of running water in removing toxins through LCP. OR: Justifies the observation to remove toxins by: • Describing the difference between running water (open system, no equilibrium) and still water (closed system, equilibrium forms) • Relating to the efficiency of running water in removing toxins through LCP. OR States the equilibrium reaction that can occur with the toxins in water. AND Justifies the observation to remove toxins by: • Relating to the efficiency of running water in removing toxins through LCP. **Response shows a sound understanding of principles involving dissolving and equilibrium.**	2
Provides some relevant information, such as ONE of the following: • Identifies that the toxins can form hydrogen bonds with water. • States the equilibrium reaction that can occur with the toxins in water. • Provides a reason for why running water is more efficient than still water • Stated a reason for the crushed powder = to increase surface area to be more efficient at dissolving.	1

Sample Response

The toxins macrozamin and cycasin have multiple **polar hydroxyl groups**, which allow for multiple **hydrogen bonding to occur with water.** This allows the toxins to **dissolve** in water, forming an equilibrium, for example:

$$\text{cycasin}(s) \rightleftharpoons \text{cycasin}(aq)$$

Still water would form an equilibrium as it is a **closed system**, while running water is an **open system** so the **dissolved toxins do not reach equilibrium.** As a result, running water is more efficient than still water in removing the toxins, as it allows the dissolved toxins to be flushed out. It ensures that the equilibrium is shifted to the right, as per Le Chatelier's principle, as the dissolved toxins are constantly removed. This results in more toxins being dissolved and continually flushed away, eventually removing the toxins.

Notes from the Marker

- Better responses.
  - showed a good understanding in the concept of dissolving and specified the intermolecular forces formed with the toxins and water.
  - were clear when relating the above observation to equilibrium principles, specifying how running water would affect the equilibrium.
- Weaker responses:
  - did not show a good understanding in the concept of dissolving, stating that a chemical reaction is occurring instead of the intermolecular forces formed with water.
  - did not address the comparison of running water to still water. These responses need to be explicit to show why running water is **more** efficient.

Student sample (student scored 3/3)

With reference to structural formulae and relevant chemical principles, justify the above observation used to remove the toxins.

Cycasin and macrozamin can form hydrogen bonds with water, allowing it to dissolve, the cycasin to the high presence of polar O-H bonds.

cycasin(s) ⇌ cycasin(aq) and macrozamin(s) ⇌ macrozamin(aq)

When placed in still water, the toxins exert to establish equilibrium, thus there is a lower amount accumulated of cycasin left in the solid, hence cycasin is still present in the solid when equilibrium is formed. Placing the bag under running water shifts the equilibrium right. As the system is open, the leaves cycasin is unable to form solid cycasin as it is removed from the system by the running water, thus this process will eventually leach out all the solid cycasin while more reacts; thus is more efficient than in still water method. ✓

thus the water must be constantly replaced to fully remove toxin.

Question 2

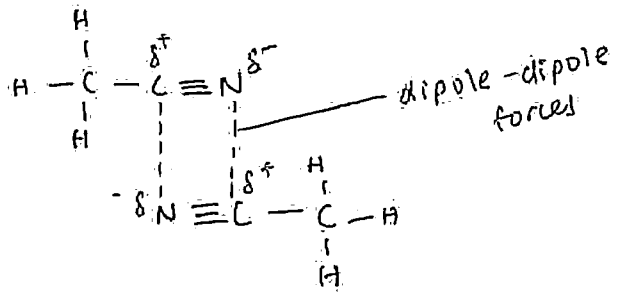
Marking Criteria	Marks
Correctly identifies group A and B. AND Identifies the **THREE** trends in the graph. AND Explicitly relates the **structure** of alkanes and alkane nitriles to their **intermolecular forces** (i.e. non-polar, polar, specific bonds). AND Explains EACH of the trends by relating 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. **Response is coherent, uses correct terminology, links to the stimulus provided and explanations demonstrate a deep understanding of how intermolecular forces influence boiling point.**	5
Correctly identifies group A and B. AND Identifies at least TWO–THREE trends in the graph. AND Relates the structure of alkanes and alkane nitriles to their intermolecular forces. AND Explains at least TWO 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.**	4
Correctly identifies group A and B. AND Identifies at least ONE–TWO trends in the graph. AND Relates the relevant molecules to their intermolecular forces. AND **Sound** explanation of at least ONE 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.	3
Correctly identifies group A and B. AND Identifies at least ONE trend from the graph. AND Relates the structure of the molecules to their intermolecular forces. AND/OR Relates the strength of the intermolecular forces to boiling point. AND **Responses shows a limited understanding of the intermolecular forces that caused the trend.**	2

Provides some relevant information, such as ONE of the following: • Identifies at least ONE trend from the graph AND outlines a reason for the trend. • Identifies the intermolecular forces present in alkanes and alkane nitriles.	1

Sample Response

A shows the data points for alkane nitriles and **B** shows the data points for alkanes.

Alkane nitriles would have a higher boiling point than alkanes because they can form **dipole-dipole forces** between molecules due to the **C≡N bond**, as shown. There is also greater **electron density** at the triple bond, making this portion of the molecule **polar.**



Alkanes however, only form **dispersion forces** between molecules, as the molecules are **non-polar.** Since **dipole-dipole forces are stronger than dispersion forces**, alkane nitrile molecules **require more energy to break** these intermolecular forces, resulting in a **higher boiling point.**

As the chain length increases for both alkanes and alkane nitriles, the boiling point for both groups also increase. This is due to **stronger dispersion forces** between the carbon chain length, due to a **greater electron clouds** and greater surface area between molecules, therefore resulting in a higher boiling point.

As chain length increases, the difference in boiling points between the two groups also decreases, as shown with the 2 carbon chain length alkane and alkane nitrile with a difference in boiling point of around 170°C, while the 6 carbon chain length molecules have a difference in boiling point of around 100°C between the two groups. This is due to the **dipole-dipole forces** between alkane nitrile molecules having a smaller contribution to the overall intermolecular forces and is **outweighed by the contribution of dispersion forces** from the longer carbon chains.

Notes from the Marker

- Better responses:
  - were explicit and provided specific details, such as linking the strength of intermolecular forces to boiling point and related the two structures to its intermolecular forces.
  - made specific references to the stimulus by providing specific values.
  - were coherent and showed a deep understanding in their explanations of the trends and application of their knowledge.
- 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).
  - incorrectly showed where the intermolecular forces are between alkane nitriles, where the dipole-dipole forces were incorrectly shown as N bonded to the H of the non-polar part of the alkane nitrile.
  - incorrectly stated that alkane nitriles can form hydrogen bonds instead of dipole-dipole forces.
  - provided incorrect information, such as describing "rate" when interpreting the graph.

Student sample 1

Identify the label of **A** and **B** as either alkanes or alkane nitriles and explain the patterns of the boiling points shown in the graph.

5

Label: A: alkane nitriles B: alkanes

Trend 1: For the same number of carbons, the boiling point (BP) of alkane nitriles is significantly higher than that of alkanes. This is because alkane nitriles contain a polar $C \equiv N$ group which allows the molecule to form strong dipole-dipole forces between each other. Additionally as well as dispersion forces. As a result, more energy is required to separate molecules so B.P is higher seen in graph where for 2 carbons, BP(alkanes) = -90°C which is less than BP(alkane nitriles) = 80°C.

Trend 2: As the number of carbons increases, the boiling point for both molecules increases. This is because the addition of more C atoms, introduces more electrons which increase the electron cloud more polarizable, allowing stronger ~~dipole~~ dispersion forces to form, which require more energy to separate. Thus a higher boiling point seen in graph where BP(alkanes) increases from -90°C to 70°C from 2 to 6 C atoms and BP(alkane nitriles) increases from 80°C to 165°C from 2 to 6 C atoms.

Trend 3 As the number of C atoms increases, the difference in boiling point between two molecules decreases.

This is because, adding more carbons increases strength of dispersion forces ONLY. The polar end of the molecule in alkane nitriles remains the same, so the dipole-dipole forces contribute less to overall intermolecular forces, which means as number of C atoms ↑ from 2 - 6, difference in BP decreases from 170°C to 95°C because the difference in energy required to separate molecules decreases.

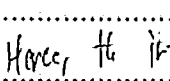
Student sample 2

5

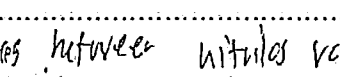
Identify the label of **A** and **B** as either alkanes or alkane nitriles and explain the patterns of the boiling points shown in the graph.

Alkanes are non-polar and bond with weak dispersion forces, while nitriles have polar C≡N bonds, which allow them to form stronger dipole-dipole forces and dispersion interactions

propane: −40°C BP



propane nitrile: 118°C BP.



(capable of dipole-dipole)

1. Hence, the intermolecular forces between nitriles require more thermal energy to break compared to alkanes of the same length, resulting in a higher BP.

2. As chain length increases, the number of electrons in both nitriles and alkanes increases, resulting in stronger dispersion forces in both. The more as chain length increases, both alkanes and nitriles see an increase in BP (5 carbon nitrile has a BP of 97°C compared to 2 carbon nitrile with a BP of −89°C)

3. As chain length increases, the strength of dispersion forces in nitriles increases while the strength of its dipole-dipole forces remain the same. Hence, the difference in boiling point compared to alkanes decreases due to the smaller proportional increase in intermolecular strength. (compared to alkanes. as chain length increases. (as shown in graph.) the difference in boiling point of C=5 is 109°, less than the difference at C=2 (170°C)

Question 3(a)

Marking Criteria	Marks
Provides an appropriate reason for the observation of soot.	1

Sample Response

Incomplete combustion may have occurred from the burner flame, which produces soot.

Notes from the Marker

- Better responses were specific in being able to identify that incomplete combustion resulted in the formation of soot.
- Weaker responses:
  - restated the information from the question, such as stating that soot was formed.
  - were not specific in the reason for soot, instead stating "insufficient oxygen".

Question 3(b)

Marking Criteria	Marks
Correctly calculates the moles of butan-1-ol. AND Relevant steps to calculate the total quantity of heat released. AND Relevant steps to calculate the quantity of heat measured after heat loss. AND Correctly calculates the specific heat capacity of the liquid, including units, to appropriate significant figures. **Response shows a thorough understanding of heat of combustion.**	4
All correct steps with any ONE error.	3
Correct steps with incorrect answer and multiple errors.	2
Any ONE step correct only.	1

Sample Response

$$n(C_4H_9OH) = \frac{m}{MM}$$

$$= \frac{0.375}{4(12.01) + 10(1.008) + 16.00}$$

$$= 0.00505936319 \text{ mol}$$

$\Delta H = 2676 \text{ kJ mol}^{-1}$

$$\Delta H = \frac{q}{n}$$

$q_{total} = \Delta H \times n$

$= 2676 \times 0.00505936319$

$= 13.53885591 \text{ kJ}$

$= 13538.86 \text{ J}$

35% heat loss, so 65% heat absorbed:

$q_{measured} = 13538.86 \times 0.65$

$= 8800.256 \text{ J}$

$q = mC\Delta T$

$8800.256 = 150 \times C \times (40.0 - 25.0)$

$C = 3.91 \text{ J g}^{-1} \text{ K}^{-1}$

Notes from the Marker

- Better responses:
  - showed clear working out by showing each step and calculating their answers at each step.
  - were able to interpret the stimulus correctly and determined the change in temperature using the graph and applied the heat loss correctly.
- Weaker responses:
  - did not apply the percentage of heat loss correctly, where they did not multiply the heat by 65.0%, which was the heat measured (since the question stated that 35.0% of heat was lost to the environment).
  - showed an incorrect conceptual understanding of the heat loss. To account for the heat loss, it should be applied to either q or ΔH; however, some responses applied it to the temperature change, which is conceptually and practically incorrect.
  - did not show clear working out and took many shortcuts. These responses resulted in incorrect answers and not enough steps shown in the working out. Each step should be clearly shown and calculated.
  - rounded up numbers on the periodic table when calculating molar mass, which resulted in an incorrect final answer.

Student sample

(a) The student noted that there was some soot on the base of the beaker. (1)

Outline a reason for this observation.

Incomplete combustion of butan-1-ol occurred due to limited oxygen supply thus forming soot on the beaker.

(b) Based on prior testing, it was determined that 35.0% of the heat produced by the combustion of butan-1-ol is lost to the surroundings. (4)

Using the information provided, calculate the specific heat capacity of the liquid, given that the heat of combustion of butan-1-ol is 2676 kJ mol^{-1}.

$n(C_4H_9OH) = \frac{m}{MM}$

$= \frac{0.375}{4(12.01)+10(1.008)+16.00}$

$= 0.005059...$ mol

$q = \Delta H n$

$= 2676 \times 0.005059...$ mol

$= 13.53885591$ kJ

$= 13538...$ J

$q_{actual} = 0.65 \times 13538.8...$

$= 8800.256341$ J

$q = mc\Delta T$

$8800.256341 = 150 \times c \times (40-25)$

$c = \frac{8800.256341}{150 \times (40-25)}$

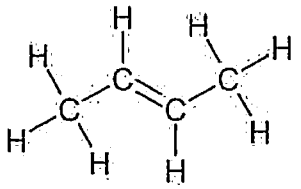
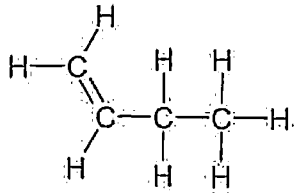
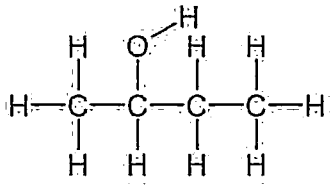
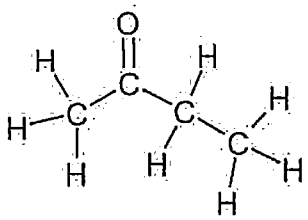
$= 3.91$ $Jg^{-1}K^{-1}$

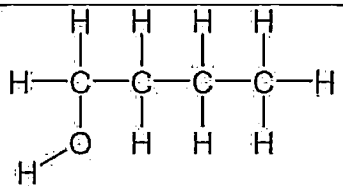
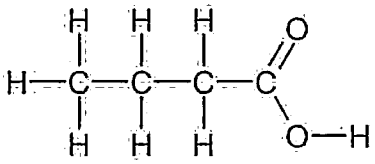
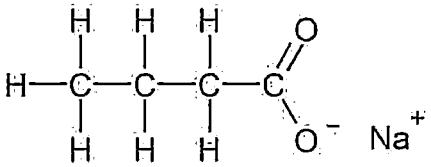
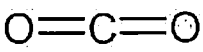
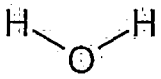
Question 4

Marking Criteria	Marks
All correct structures and correct IUPAC names for compounds A, B, C, D, E, F, G, H and I. AND Correct justifications for all compounds A to I, including: • A and B being isomers • how compound A is determined to be symmetrical with a double bond. • hydration reaction to produce alcohols • oxidation of alcohol shows it is either primary or secondary • the reaction with $NaHCO_3$ determines the presence of the acid F • acid carbonate reaction to produce G, H and I AND Key terms used in justification. AND Makes **explicit 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, F, G, H and I. AND Correct justifications for all compounds A to I, including: • how compound A is determined to be symmetrical with a double bond. • hydration reaction to produce alcohols • oxidation of alcohol shows it is either primary or secondary • the reaction with $NaHCO_3$ determines the presence of the acid F AND Key terms used in justification. 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 used when naming, a few key terms missing) OR all of the above criteria but 1–2 minor types of errors.	6
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 1-5 incorrect or missing structures or names and justifications incomplete. OR 4 correct structures with names and appropriate justifications	4
Response contains at least 5 errors. OR Some structures or names are incorrect but some correct justifications. OR 1-6 incorrect or missing structures or names, with very limited justifications. OR	3

3 correct structures with names and appropriate justifications	
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 reactions/pathways in flowchart).	2
Some correct/relevant information and shows limited understanding in following the reactions in the flowchart, such as ONE of the following: • Shows understanding in ONE of the reactions. • Identifies the structure of any ONE compound. • Identifies a structure of the C_4H_8 compound.	1

Sample Response

Compound	Structure and Name	Justification
A	but-2-ene 	Compound A undergoes **hydration** with **dilute H_2SO_4** to produce **only one alcohol product.** It is therefore a **symmetrical,** unsaturated hydrocarbon with the double bond at the second carbon, with the **formula C_4H_8.**
B	but-1-ene 	The hydration of compound B with dilute H_2SO_4 produces **two possible alcohol products,** so it is **unsymmetrical,** with the double bond on first carbon, since one of the product, C, is also produced by A. It is therefore a straight chained **isomer of A.**
C	butan-2-ol 	Compound C **can oxidise** when **acidified $KMnO_4$** is added and since the double bond is at the second carbon, it is a **secondary alcohol.**
D	butan-2-one 	Compound D is the **product of the oxidation reaction** of butan-2-ol. It also **does not react with $NaHCO_3$** so it is a **ketone, not a carboxylic acid.**
E	butan-1-ol	Compound E is the other product (major product) of the **hydration with dilute H_2SO_4** reaction of compound B.

		
F	butanoic acid 	Since compound E is the **primary alcohol**, it **oxidises** to produce a **carboxylic acid** (compound F) when acidified $KMnO_4$ is added.
G	sodium butanoate 	From the **acid-carbonate reaction** between compound F and $NaHCO_3$, a salt, carbon dioxide and water are produced.
H	carbon dioxide 	
I	water 	

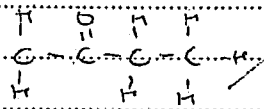
Notes from the Marker

- Better responses:
  - made specific references to the stimulus information, included key terms and provided sufficient detail to justify their structures.
  - correctly provided the IUPAC name for each structure and correctly drew all the structures.
- Weaker responses:
  - needed more specific references to the stimulus and required more key terms in their justification. They also needed more detail to justify their compounds.
  - did not state the IUPAC names of all of the compounds or incorrectly stated the IUPAC names.
  - incorrectly drew their structural formulae and did not expand out the bonds (such as between O–H), did not include all the H's on the hydrocarbon chain, or incorrectly showed a 5 bonded carbon.
  - incorrectly drew the structure of carbon dioxide and sodium butanoate.

Student sample

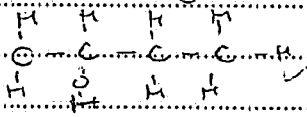
Draw the structural formulae and state the IUPAC names of compounds A to I, justifying your compounds with reference to the information provided in the flow chart.

(P) does not react with $NaHCO_3$ but does oxidise from alcohol C. This means that D could only possibly be a ketone with 4 carbon atoms



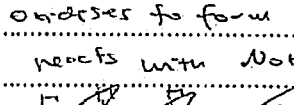
Butan-2-one (or Butanone...)

(C) oxidised to give D (which is a ketone) so C must be a secondary alcohol with 4 carbon atoms

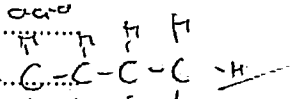


Butan-2-ol

(E) must be a primary alcohol with 4 carbon atoms as it oxidises to form F, which is a carboxylic acid as it reacts with $NaHCO_3$

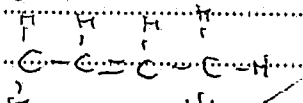


Butanoic acid



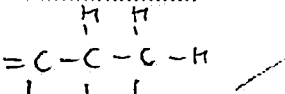
Butan-1-ol

(A) must be an alkene (as C_4H_8 is same as CnH_{2n} for alkenes) with the double bond on the secondary carbon as it undergoes hydration (H_2O with H_3PO_4 catalyst) to form only one product



But-2-ene

(B) Hence must be the carbon on the 1st carbon on the alkene as it forms 2 products, major and minor depending on how the -OH from the water is added

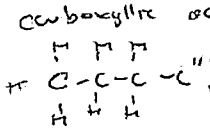


But-1-ene

END OF SECTION 2A

17

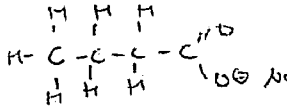
(F) is a carboxylic acid from the oxidation of primary alcohol E



Butanoic acid

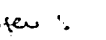
React with $NaHCO_3$:

(G) is

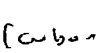


Sodium Butanoate

(H) is Water:



(I) is Carbon dioxide:



Normanhurst Boys High School

2023 Year 12 Chemistry Trial Examination

Marking Responses, Sample Answers & Notes from the Marker

S2B

Section 2C (40 marks)

Written Response

Question 1(a)

Marking Criteria	Mark
• All relevant steps shown clearly AND correct answer to appropriate decimal places (i.e. to 2 decimal places).	1
• Correct answer with no working OR non attempts.	0

Sample Response

$\frac{[A^-]}{[HA]} = \frac{1/2}{1/2} = 1$ $\quad pK_a = -\log_{10}(3.0 \times 10^{-10}) = 9.52$

$pH = 9.52 + \log_{10} 1 = \boxed{9.52}$ (2 d.p)

Marker Feedback:

The number of decimal places in pH should equal to the number of significant figures in concentration.

Question 1(b)

Marking Criteria	Marks
• Identifies range for colour change AND links choice of indicator to the given range	2
• Correct answer with no working OR non attempts	1

Sample Response

Range for change of colour = $pK_a \pm 1.00 = 9.52 \pm 1$

Range: $8.52 - 10.52$ — (1)

pH of 9.30 falls in the above range

So HPH is a suitable indicator as its colour change falls within $8.52 - 10.52$. — (1)

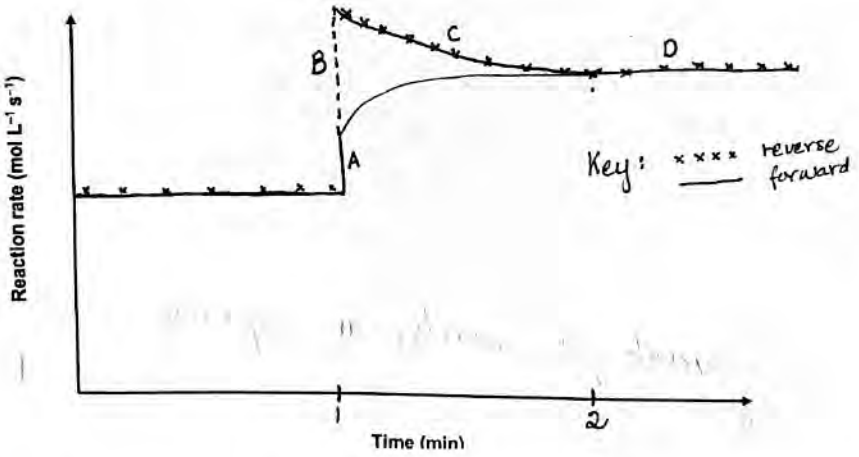
Marker Feedback:

- You cannot score for repeating statements from part (a).
- Question was well answered. Most students understand the use/choice of indicators. Some students lost marks for not showing all working.

Question 2

Marking Criteria	Marks
• Draws a correct graph, neat, using most of the given space with appropriate key for reverse and forward reaction pathway. AND • Explains parts A, B C AND D using both collision theory and LCP where most appropriate AND • Explanation written using all key terminology AND • Explanation is succinct and maintains chronological manner	4
• All the above EXCEPT One key feature missing OR • Section A or B not explained AND uses collision theory AND/OR LCP in detail and draws correct graph	3
• Incorrect graph AND Section B NOT explained AND • A, C, D outlined using collision theory AND/OR LCP OR • Correct graph and any two sections not explained in detail	2
• Correct graph OR • Any one section explained correctly using Collision Theory AND/OR LCP OR • All sections outlined with limited detail	1

Sample Response



① A expln Increase in T, increases reaction rate (A) for the whole reaction.
Coll/LCP This is due to excess heat energy absorbed by the system
① This in turn increase KE, hence greater collisions between particles. This increase successful collisions for all molecules therefore both reactant formation (reverse rate) and product formation (forward rate) increases. The endothermic reverse reaction absorbs heat energy to a greater extent (B) than
① B & C the exothermic forward reaction. Thus $[N_2, H_2]$ will increase
expln more than $[NH_3]$. The system will counter this by shifting equilibrium to the right in an attempt to reduce the $[N_2, H_2]$. Thus the rate of forward reaction will increase while the rate of reverse will slow down
LCP and at $t = 2$ min equilibrium will be re-established. (LCP)

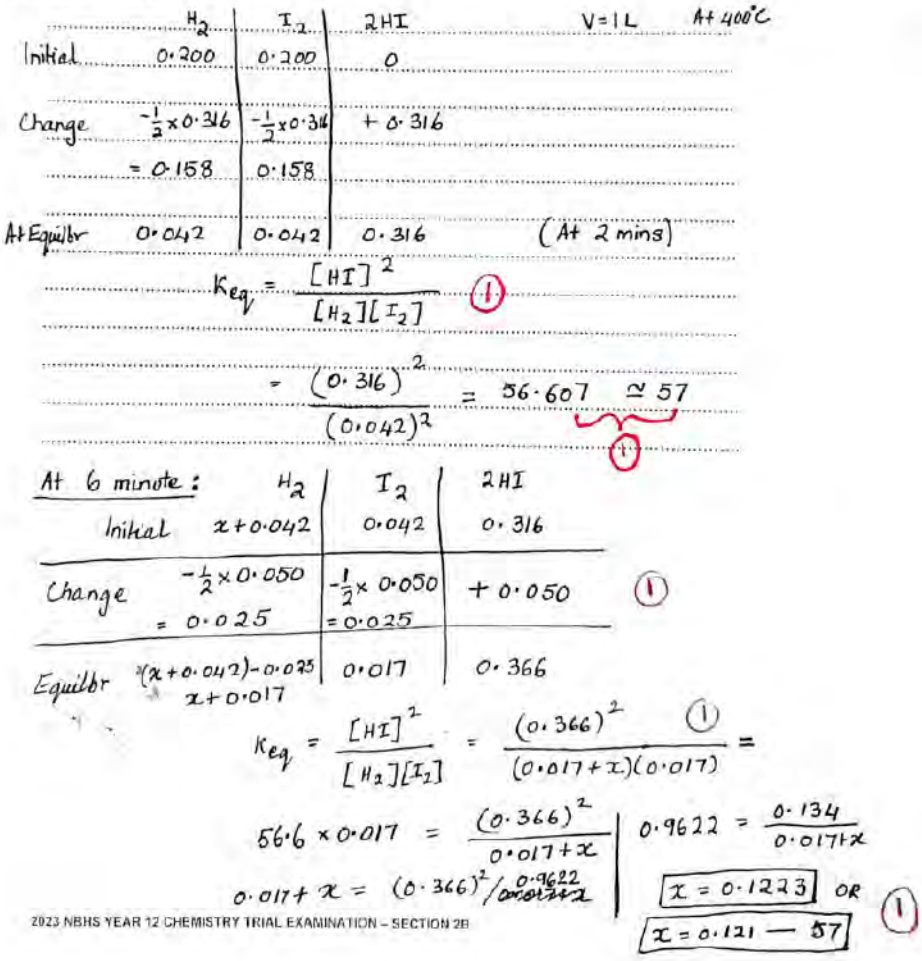
Marker's Feedback:

- Question was well answered. Most students explained well. Graphs require further practice in neatness, use of full space, using key and labelling.
- Labelled sections from the graph should be used to support explanation.
- Some students failed to explain section B. There is NO requirement to state LCP. Collision theory and LCP should used to explain only. Therefore, key terminologies are critical to score full marks.

Question 3

Marking Criteria	Marks
• Uses ICE table 1 accurately AND sets up correct K_{eq} expression AND calculates the value of K_{eq} = 57 AND • Shows all relevant values for ICE table 2 at 6 minutes AND • Sets up correct K_{eq} expression for table 2 AND • Solves algebraic equation and calculates the moles of hydrogen added (shown as x). **x = 0.1223 OR 0.121.**	5
• All relevant steps correct with any ONE calculation error.	4
• Uses ICE table 1 accurately AND sets up correct K_{eq} expression AND calculates the value of K_{eq} = 57 AND • Error in ICE table 2 AND error in algebraic calculation leading to two significant errors AND • Incorrect value for x.	3
• Uses ICE table 1 accurately AND sets up correct Keq expression AND calculates the value of K_{eq} = 57.	2
• Any one step of calculation or expression correct.	1

Sample Response



Question 4

Marking Criteria	Marks
• Uses B-L Theory labels such as proton donor (BL acid) and BL base (proton acceptor) (acid-base chemistry) to explain reaction between strong acids and strong bases AND • Shows equation for neutralization as $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$ only for all above neutralisation AND • Justifies above equation to support ΔH = –57.6 kJ mol^{-1} for all strong acid/base neutralisations AND • Identifies NH_3 as weak base and explains its ionization in water using B-L theory AND • Shows **ALL** relevant equations OR writes all word equations AND • Explains HCl reacting directly with ammonia instead of OH^- OR • Explains correctly differently why NH_3 with HCl leads to a different ΔH *value*	4
• Outlines or explains B-L Theory labels to explain reaction between strong acids and strong bases AND • Outlines/explains the reaction between strong acids such as HCl and NH_3 AND • Uses one/two relevant equations only related to any one of the above	3
• Provides detailed justification for strong acid/base neutralisation with appropriate equation as $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$ AND/OR • Provides correct equation for ammonia and HCl as $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$ but no explanation for ammonia and HCl is provided OR • Incorrect justification ammonia and HCl is provided	2
• Explains any one of the above concepts well OR • Outlines both concepts with NO chemical equation/incorrect equation with multiple errors in understanding OR • No explanation but one correct equation only OR • Outlines both concepts but no chemical equation	1

Sample Response

Explaining same enthalpy of neutralisation for strong acids with strong bases:

When solutions of a strong acid (such as HCl/HNO_3) are mixed with a strong base (such as NaOH /KOH), H_3O^+ and OH^- ions are undergoing neutralisation due to 100% ionisation **only**, all other ions are such as Cl^-, Na^+, NO_3^- are spectators.

Hence, strong acid/base neutralisation reaction is always as:

$$H_3O^+(aq) + OH^-(aq) \rightarrow 2\,H_2O(l)$$

(proton donor) (proton acceptor)

The value for the enthalpy of neutralisation when NaOH reacts with HCl and between HNO_3 and KOH are therefore the same and are equal to **−57.6 kJ mol^{-1}.**

Explaining the difference in enthalpy of neutralisation for strong acid HCl with weak base ammonia NH_3:

NH_3 is a **weak base (proton acceptor).** The reaction equation for the reaction that occurs when NH_3 is dissolved in water is shown below:

$$NH_3(aq) + H_2O(l) \leftrightarrow NH_4^+(aq) + OH^-(aq) \qquad \Delta H_1$$

Therefore, a solution of NH_3 would **only contain a small amount of OH^-** and NH_4^+ ions, only occurs to a small extent. There would be a significant amount of NH_3 remaining in this solution.

Since ammonia is a weak base, **the ionisation of ammonia requires energy** as some of the energy is consumed in breaking the N–H bonds.

HCl is a strong acid (B-L proton donor) and as per B-L theory, HCl **donates its proton** and becomes Cl^-.

Hence, when HCl is added to this solution, most of the HCl will react **directly** with the NH_3, instead of OH^-.

NH_3 **accepts the proton** and becomes NH_4^+. Hence, the reaction equation will be:

$$HCl(aq) + NH_3(aq) \rightarrow NH_4^+(aq) + Cl^-(aq) \qquad \Delta H_2$$

This leads to a **different chemical reaction** than the one referenced in the enthalpy of neutralisation.

Hence, the value of enthalpy of this reaction will be the sum of ΔH_1 and ΔH_2 and therefore **different.**

Note: There is no requirement to state if the value is higher or lower since it can only be determined by complex thermodynamic calculation (beyond the HSC syllabus).

Question 5

Marking Criteria	Marks
• Shows correct relationship for $Q = K_{eq} = 1$ when valve is closed	1
• Uses stoichiometric relationship for the chemical equation to derive $Q = K_{eq} = 1$ and/or writes a balanced chemical equation AND • Identifies TWO changes when valve is opened • AND uses correct analysis (principles of validity and lack of sufficient information) to and reject LCP and collision theory AND • Choose the most appropriate principle as comparison of Q and K to derive $Q_{before} = Q_{after} = K_{eq}$ AND • Correct conclusion: Position of K_{eq} does not change	4
• Uses stoichiometric relationship for the chemical equation to derive $Q = K_{eq} = 1$ and/or writes a balanced chemical equation AND/OR • Identifies TWO changes when valve is opened AND uses correct analysis (principles of validity and lack of sufficient information) to and reject LCP and Collision Theory AND • Choose the most appropriate principle as comparison of Q and K to derive $Q_{before} = Q_{after} = K_{eq}$ AND • Correct conclusion: Position of K_{eq} does not change	3
• Uses stoichiometric relationship for the chemical equation to derive $Q = K_{eq} = 1$ and/or writes a balanced chemical equation AND/OR • Identifies TWO changes when valve is opened AND uses correct analysis (principles of validity and lack of sufficient information) to and reject LCP and collision theory AND/OR • Choose the most appropriate principle as comparison of Q and K to derive $Q_{before} = Q_{after} = K_{eq}$ AND • Correct conclusion: Position of K_{eq} does not change	2
• Two partial correct statements OR • One complete correct statement	1

Sample Response

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

n 2 : 1 : 2 when V = 1L

Valve closed: Let number of moles be at above ratio

$$Q_{Before} = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(\frac{2}{1})^2}{(\frac{2}{1})^2(1)} = 1$$

$Q_{Before} = K_{eq} = 1$ at any point of time

When valve is opened two changes occur.

(1) Volume of vessel 1L ⟶ 3L so concentration of all gases decrease to $\frac{1}{3}$.

(2) Extra 2 moles of O_2 is introduced, the concentration $[O_2] = \frac{3 \text{ moles}}{3L} = 1M$ (unchanged)

[Note: Addition of reactant must occur at constant volume]

Validity

- Hence LCP cannot be applied because this principle works for one imposed change only at a time.

OR

- Relative rates of reaction cannot be applied, due to insufficient information. Increase in volume decreases all conc of gases, but the extent of reduction for each reaction cannot be determined.

- Comparing Q and K as follows: (Best to use)

Tap opened: $[SO_2]_{After} = \frac{2}{3}$ $[SO_3] = \frac{2}{3}$ $[O_2] = \frac{3}{3} = 1$

$$Q_{After} = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(\frac{2}{3})^2}{(\frac{2}{3})^2 \cdot 1} = 1$$

So $Q_{Before} = Q_{After} = K_{eq}$

(i) Position of equilibrium does not change.

Question 6

Marking Criteria	Marks
• Uses given stimuli (table and image) to *explain*. • Reversibility: using K value to derive forward reaction favoured $K_{eq} = 3.8 \times 10^{29}$ (large) N_2O_4 favoured AND • Enthalpy: uses the equation $2NO_2(g) \leftrightharpoons N_2O_4(g)$ and the given information to derive that forward reaction is exothermic $\Delta H < 0$ AND • Links entropy to spontaneity: Lower entropy, lower disorder, lower temperature (–196°C) $\Delta G < 0$, reaction spontaneous AND • Maintains chronological order	3
• Any TWO explained well and no reference to stimuli. OR • All three outlined with detail missing. OR • All three explained well but no reference to spontaneity	2
• Anyone explained well as above OR • Errors in conceptual understanding in one or more aspects	1

Sample Response

(1) $2NO_2(g) \rightleftharpoons N_2O_4(g) + H$ $\Delta H < 0$
Brown Colourless ↓

when T = 100, $\Delta G > 0$, K_{eq} is very small. This is a non spontaneous reaction that favours reactant (NO_2) and requires external heat energy to drive the reaction forward.

System will be at equilibrium rate of formation of NO_2 is equal to rate of formation of N_2O_4 when $K_{eq} = 1$

As T is lowered to -196°C, reaction becomes spontaneous

(1) and K_{eq} increases to 3.8×10^{29} indicating shift of equilibrium to favour products N_2O_4 (colourless). Increase in $[N_2O_4]$ proves forward reaction is exothermic ($\Delta H < 0$) as system tries to heat up the system (LCP) by favouring the exothermic side.

(1) Entropy is lowering T = -196, reduces entropy as shift occurs from 2 gaseous moles to 1 gaseous mole leading to $\Delta G < 0$ a spontaneous re

Question 7

Criteria	Marks
• Shows deep understanding of buffers AND • Uses a chemical equation and relevant calculations to explain in detail solution A is as buffer AND • Uses BL theory and LCP and links relevant chemical equations to explain the role of buffer (CH_3COOH/CH_3COONa) when a small amount of acid(H_3O^+) is added and its resistance to change in pH when pH = -log$[H^+]$AND • Justifies with relevant calculations, relevant equation with reference to BL theory and/or LCP why solution B is NOT a buffered solution in detail AND • Explains the hydrolysis of basic salt CH3COONa for solution B and its drastic drop in pH when small amount of acid is added AND compares the change in pH when small amount of acid is added.	5
• Student shows very good understanding of buffers AND • Uses a chemical equation and relevant calculations to explain solution A is as buffer AND • Uses BL theory OR LCP and links relevant chemical equations to explain the role of buffer (CH_3COOH/CH_3COONa) when a small amount of acid(H_3O^+) is added and its resistance to change in pH when pH = -log$[H^+]$ AND • Justifies with relevant calculations, relevant equation with reference to BL theory and/or LCP why solution B is NOT a buffered solution AND • Provides an outline the hydrolysis of basic salt CH3COONa for solution B and its drastic drop in pH when small amount of acid is added. • (Detail lacking, 1 chemical equation only, no calculation and hydrolysis not mentioned no error)	4
• Detail lacking for explanation for solution A OR solution B AND/OR one error AND • Limited chemical equations but correct calculations AND/OR • Limited OR No calculation AND • Hydrolysis not addressed OR • Solution explained in detail but solution B outlined only or vice versa	3
• Detail Lacking and limited equations OR calculations OR • No equations and/or no calculation OR • No explanation in reference to LCP or BL theory AND pH not determined using pH = -log$[H^+]$ AND/OR Hydrolysis not addressed • OR Incorrect explanation	2
• Any one correct step (either one calculation, one explanation OR one chemical equation)	1

Sample Response

Soln A: $NaOH_{(aq)} + CH_3COOH_{(aq)} \rightarrow CH_3COONa_{(aq)} + H_2O_{(l)}$

V x C	0.025 L of 0.010 M	0.05 L x 0.010	
n	= 0.00025 (OH^-) (Lt Rgt)	= 0.0005 (H^+)	≃ 0.00025 formed

excess CH_3COOH left in soln = 0.00025

Note: % ionisation has been ignored as value not provided.

0.00025 moles NaOH will neutralise CH_3COOH and produce 0.00025 moles of CH_3COONa in given solution.

Total volume = 0.075 L

$$[CH_3COONa] = \frac{0.00025 \text{ moles}}{0.075 \text{ L}} = 0.003 \text{ M}$$

$$[CH_3COOH] \simeq \frac{0.00025 \text{ (excess)}}{0.075 \text{ L}} = 0.003 \text{ M}$$ (0.003M)

(1)

Since weak acid CH_3COOH and its conjugate base CH_3COO^- (salt) are in equimolar ratio, soln A is a buffer solution.

When a small amount of acid (H^+) is added to the buffer solution, the $[H_3O^+]$ goes up, pH goes down.

(1) BLTh

$CH_3COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$

BL acid: proton donor; amphiprotic: proton acceptor; H_3O^+: strong proton donor; CH_3COO^-: conjugate base

(1) Acc to LCP, equilibrium shifts left & favours the formation of CH_3COOH (reverse reaction) in order to reduce $[H_3O^+]$ & counter the imposed change. Thus it resists further decrease in pH & the pH is maintained in a small range.

Soln B: $NaOH_{(aq)} + CH_3COOH_{(aq)} \rightarrow CH_3COONa_{(aq)} + H_2O_{(l)}$

V x C = n	$0.025L \times 0.020M$	$0.05L \times 0.010M$	
	$0.0005\ OH^-$	$0.0005\ H^+$	0.0005 salt

0.0005 moles of CH_3COOH will react with 0.0005 moles of NaOH to produce 0.0005 moles of the salt CH_3COONa with no excess CH_3COOH left in soln.

So after the neutralisation is complete solution B is a basic solution with a $pH > 7$ due to the basic salt CH_3COONa.

$$[CH_3COONa] = \frac{0.0005 \text{ moles}}{0.075L} = 0.006\dot{6}\ M$$

(1) Since there is no corresponding weak acid left this is not a buffer solution. (Soln B)

CH_3COONa dissociates in water as: $CH_3COONa_{(aq)} \rightarrow CH_3COO^-_{(aq)} + Na^+_{(aq)}$

Hydrolysis of CH_3COO^- in water can be written as

$$CH_3COO^-_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COOH_{(aq)} + OH^-_{(aq)}$$

conjugate base

Here $K_b > K_a$ hence a basic solution $\boxed{pH > 7}$

(1) when a small amount of acid (H_3O^+) is added (say x) it will react with x amount of CH_3COO^- & equilibrium will shift right to produce CH_3COOH. This reaction

$H_3O^+ + OH^- \rightarrow H_2O_{(l)}$ or $CH_3COO^-_{(aq)} + H_3O^+_{(aq)} \rightarrow CH_3COOH_{(aq)} + OH^-$

will occur till all acetate ions are consumed, then $pH < 7$

→ as small amounts of acid are added pH will drop drastically.

Question 8(a)

Marking Criteria	Marks
• All relevant and correct calculations shown in detail AND • One chemical equation relevant to back titration mole ratio AND • Claim verified correctly: Invalid claim 16.1% (v/v) instead of 30-32% (v/v).	7
• All relevant and correct calculations shown in detail BUT ONE error AND • One chemical equation relevant to back titration mole ratio AND • Claim verified correctly: Claim justified appropriately and supported by above calculations.	6
• All relevant and correct calculations shown in detail BUT TWO errors AND • One chemical equation relevant to back titration mole ratio AND • Claim verified correctly: Claim justified appropriately and supported by above calculations.	5
• More than two errors and relevant calculations NOT shown in detail AND • Claim justified appropriately and supported by above calculations. OR • All relevant steps & equations NOT shown.	4
• Multiple errors in calculations and relevant steps missed AND equation not provided AND • Invalid claim.	3
• Any two correct steps with one chemical equation AND/OR valid claim based on calculations.	2
• Any one relevant calculation correctly shown such as average titre = 0.02962L OR • One correct and relevant chemical equation.	1

Sample	Volume of sodium thiosulfate (mL)
A	31.92 ✗
B	29.63 ✓
C	29.61 ✓
D	29.62 ✓

(a) Given the density of ethanol is 0.789 g mL^{-1}, does the sample verified meet the manufacturer's claim? 7

Support your answer at least one relevant equation and all relevant calculations.

1. titre ave = $(29.63 + 29.61 + 29.62) \div 3 = 29.62$ mL = 0.02962 L (1)

2. $n_{Na_2S_2O_3} = c \times v = 0.010 \frac{mol}{L} \times 0.02962 L = 0.0002962$
$= 2.962 \times 10^{-4}$ moles

$n_{S_2O_3^{2-}} = 2.962 \times 10^{-4}$ moles

So $n_{I_2} = \frac{1}{2} \times n_{S_2O_3^{-2}} = 0.0001481$ moles

During titration (1) $n_{Cr_2O_7^{2-}}$ (remaining or excess) $= \frac{1}{3} \times 0.0001481 = 4.94 \times 10^{-5}$

(1) $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6I^-(aq) \rightarrow 2Cr^{+3}(aq) + 7H_2O(l) + 3I_2(aq)$ ↓

Initial Moles of $Cr_2O_7^{-2}$ added to diluted wine at the start = $c \times v$
$= 0.040 \frac{mol}{L} \times 0.02 L = 0.0008$ moles

(1) So moles of $Cr_2O_7^{-2}$ reacted with EtOH = Initial − Remaining
$= 0.0008 - 0.0000494 = 7.51 \times 10^{-4}$

Relevant Equation:

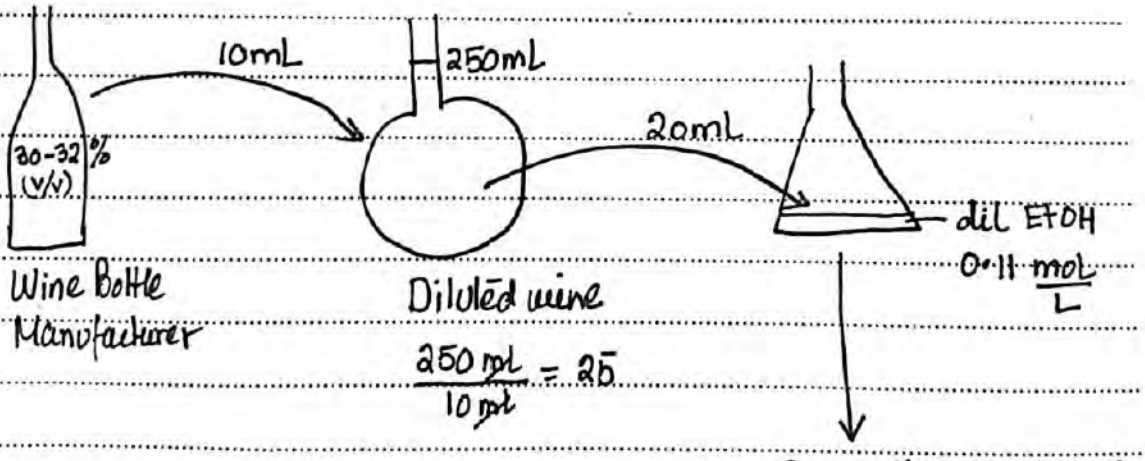
$3C_2H_5OH(aq) + Cr_2O_7^{-2}(aq) + 8H^+(aq) \rightarrow 3CH_3CHO(aq) + 2Cr^{+3}(aq) + 7H_2O(l)$

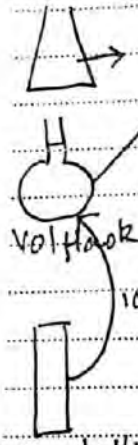
$n(Cr_2O_7^{2-}) : n_{EtOH} = 1 : 3$

$n_{EtOH} = 3 \times 7.51 \times 10^{-4}$ moles

$= 2.25 \times 10^{-3}$ moles C_2H_5OH (1)

Working Out for dilution





20 mL EtOH contains 2.25×10^{-3} moles

250 ml Vol. flask " $2.25 \times 10^{-3} \times \left(\frac{250}{20} = 12.5\right)$

250 ml = 0.028125 moles

10 ml EtOH was transferred to vol flask then topped up to 250 ml with dH_2O

Implies # of moles from wine bottle (10 ml) to vol. flask (250 ml) is the same.

$\Rightarrow$ 10 mL contains 0.028125 moles (!)

$M_w(C_2H_5OH) = 12.01 \times 2 + 1.008 \times 6 + 16 = 46.07 \ \frac{g}{mol}$

$n = \frac{mass}{M_w} \Rightarrow n \times M_w = mass$

$= 0.028125 \times 46.07 = 1.296 g$

$Mass = Vol \times density \Rightarrow density = \frac{mass}{volume}$

$Volume = \frac{1.296 g}{0.789 g\,ml^{-1}}$

So 10 mL (bottle) contains 1.64 ml EtOH = 1.64 mL

Then 100 mL (bottle) " $\frac{1.64}{10} \times 100 = 16.4\ \%\ (v/v)$ (1)

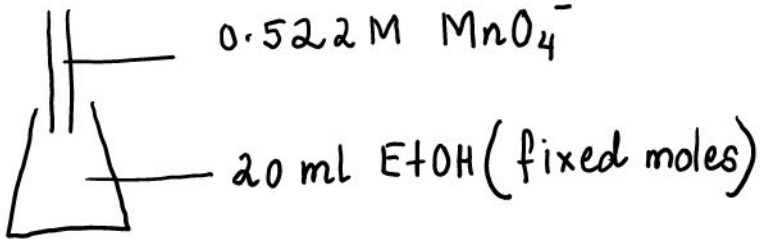
Question 8(b)

Marking Criteria	Marks
• Two observations (O1, O2) linked to inaccuracies in data and provides detailed improvement with justification for both errors in methodology (Im) • Succinct well explained (Ex), maintains chronological order.	4
• Any one of the two observations AND explains inaccurate data in detail and outlines one improvement.	3
• One relevant observation outlined with some justification and improvement	1–2

Sample Response

Observation 1

Bubbles were visible during the titrations, which may be attributed to the formation of CO_2 in the conical flask from the oxidation of ethanoic acid to carbon dioxide, thus inhibiting the reaction of $KMnO_4$ with ethanol. For the complete neutralisation of ethanol to occur, greater amount of permanganate, and therefore a greater titre volume, would be required to react with all the ethanol moles in the conical flask and reach the endpoint (slightly higher than equivalence point).



Inaccurate data 1: Higher titre volume will lead to a **higher calculated value of EtOH content** thus overestimating the manufacturer's claim.

Observation 2

The wine may contain Mn^{2+} which acts as a **catalyst**, thus can cause an **incomplete reduction of MnO_4^-** ions. A brown solid MnO_2 was formed in titration #3. This implies the Mn^{2+} catalyst speeds up the reaction and reacts faster with the permanganate ions. Since these MnO_4^- ions have been incompletely reduced, a **smaller amount of ethanol** would have been oxidised by these MnO_4^- ions.

Inaccurate data 2: This means a greater amount of MnO_4^- ions would have been required to react with all the ethanol, which would explain the very high titre volume obtained.

Observation 3

The reaction rate increased after addition of the first drop of titrant. The endpoint itself occurs when there is excess permanganate in the conical flask, it would occur just after the equivalence point.

Inaccurate data 3: Using **one full drop** for each titration rather than **use of half-drops** in the methodology towards the end of the titration, **increases the risk of overshooting** the endpoint.

Improvements to the methodology:

1. If CO_2 formation had occurred, this issue could be rectified by the use of a weaker oxidising agent than permanganate ions, one that would not react with ethanoic acid (but would with ethanol) such as $K_2Cr_2O_7$. This would remove the systematic error caused by the presence of very strong oxidising agent.
2. By changing the oxidising agent, the catalyst effect and formation of brown solid can be avoided.
3. The use of half-drops (or even quarter-drops) would decrease the risk of overshooting the endpoint.

Normanhurst Boys High School

2023 Year 12 Chemistry Trial Examination

Marking Responses, Sample Answers & Notes from the Marker

S2C

Section 2C (20 marks)

Written Response

Question 1(a)

Marking Criteria	Marks
• Determines the correct molecular formula WITH appropriate working and reasoning.	2
• Determines the correct molecular formula WITHOUT appropriate working and reasoning. OR • States the correct molecular formula without working.	1

Sample Response

The empirical formula of the compound is:

	C	H	O
Mass (g)	69.7	11.7	18.6
Moles (mol)	$\frac{69.7}{12.01} = 5.8035...$	$\frac{11.7}{1.008} = 11.6071...$	$\frac{18.6}{16.00} = 1.1625$
Mole ratio	$\frac{5.8035...}{1.1625} \approx 5$	$\frac{11.6071...}{1.1625} \approx 10$	$\frac{1.1625}{1.1625} = 1$

Since the empirical formula has a molecular mass of 86, and the molecular ion peak has a charge to mass ratio of 86, the molecular formula of the compound is $C_5H_{10}O$.

Notes from the Marker

- Better responses were able to determine the empirical formula and demonstrated evidence of correctly using the mass spectrum data to determine the molecular formula of the unknown compound.
- Weaker responses assumed that the m/z of the M+1 peak was the molar mass of the compound. It should be noted that the M+1 peak is caused by the presence of the ^{13}C isotope in the molecule.

Question 1(b)

Marking Criteria	Marks
• Determines plausible TWO possible isomers and excludes ONE possible isomer with ALL of the following features, with extensive detail: ○ interprets the mass spectrum data and proposes how this relates to the isomers ○ interprets the IR spectrum data and proposes how this correlates to the isomers AND/OR excludes other isomers ○ interprets chemical tests and proposes how this correlates to the isomers AND excludes other isomers ○ proposes TWO possible isomers and excludes ONE isomer based on ALL of the valid interpretation of the proposed data	4
• Determines TWO possible isomers and excludes ONE possible isomer but makes ONE error. OR • Determines plausible TWO possible isomers and excludes ONE possible isomer with ALL of the above features with a good level of detail.	3
• Determines ONE possible isomer and excludes ONE possible isomer but makes ONE error with appropriate reasoning. OR • Determines plausible TWO possible isomers and excludes ONE possible isomer with TWO of the above features with some reasoning.	2
• Provides some relevant information.	1

Sample Response

The three possible structures for the compound are pentanal, pentan-2-one and pentan-3-one. This is because the:

- sharp IR peak at 1720 cm^{-1} corresponds to a C=O bond which suggests that the compound could be an aldehyde or a ketone
- molecular ion peak has a m/z of 86 which corresponds to a molar mass of approximately 86 g mol^{-1}
- fragment ion peak at m/z = 28 has come from a fragment such as $[C=O]^+$

However, based on the chemical tests using Fehling's reagent and Tollen's reagent, both of the negative results suggest that the unknown compound is a ketone, as an aldehyde would lead to a positive result due to its oxidation to pentanoic acid. Hence, the unknown compound could be pentan-2-one and pentan-3-one and not pentanal.

Notes from the Marker

- Better responses were able to utilise all of the data in order to deduce potential isomers and to rule out one possible isomer. Students are reminded
- Weaker responses assumed that the m/z of the M+1 peak was the molar mass of the compound. It should be noted that the M+1 peak is caused by the presence of the ^{13}C isotope in the molecule.

Question 2

Marking Criteria	Marks
• Extensively explains THREE relevant factors with reference to how that factor benefits the production of nitric acid. • Makes specific reference to the flow chart for EACH factor.	4
• Explains TWO relevant factors with some reference to the flow chart. OR • Explains ONE relevant factor and outlines TWO other relevant factors with some reference to the flow chart. OR • Explains THREE relevant factors without specific reference to the flow chart.	3
• Explains ONE relevant factor. OR • Outlines TWO relevant factors.	2
• Provides some relevant information.	1

Sample Response

Use of a catalyst

The use of a Pt catalyst in the catalytic chamber allows the reaction to proceed at lower temperatures as it provides an alternate pathway with a lower activation energy. Combined with the high temperature and high pressure, the rate of reaction is increased to convert the ammonia and oxygen gas into nitric oxide and water vapour due to the increased likelihood of successful collisions between reactant molecules. This maximises the efficiency of this step in the production of nitric acid as the bulk of the reactants have been converted into produced, thus reducing the running costs of this chamber as it is in operation for a shorter period of time.

Use of a heat exchanger

The use of a heat exchanger enables the reaction mixture to be cooled down as the reaction in the catalytic chamber is very exothermic and poses a safety risk if it is not managed. In addition to this, the oxidation chamber utilises low temperatures. By Le Chatelier's principle, when the closed system is disturbed through the use of low temperature (50°C), this favours the forward reaction and the production of nitrogen dioxide in order to counteract this change, thus maximising the yield for this step in the process.

Recycling

Unused reactant gases are recycled after being separated from the reaction mixture. This means that resources are not wasted – making the process more economical as less reactant needs to be produced in the catalytic chamber and the oxidation chamber. This also ensures that these gases are not released into the environment as they have the potential to cause pollution (e.g. contribute to acid rain and photochemical smog).

Access to reactants

The plant would be located so that ammonia and oxygen gases would be easily accessible for use in the catalytic chamber – perhaps near a Haber process plant or road/rail network so that these resources could be transported easily and cheaply. This ensures that profits can be maximised to ensure that the production of nitric acid is economically viable.

Notes from the Marker

- Better responses were able to make explicit reference to the flowchart and link the relevant chemical principles, where appropriate, to the viability of the production of nitric acid in an industrial context.
- Weaker responses assumed links to chemical principles was sufficient and did not explain how their proposed factors were necessary considerations to feasibly produce nitric acid.

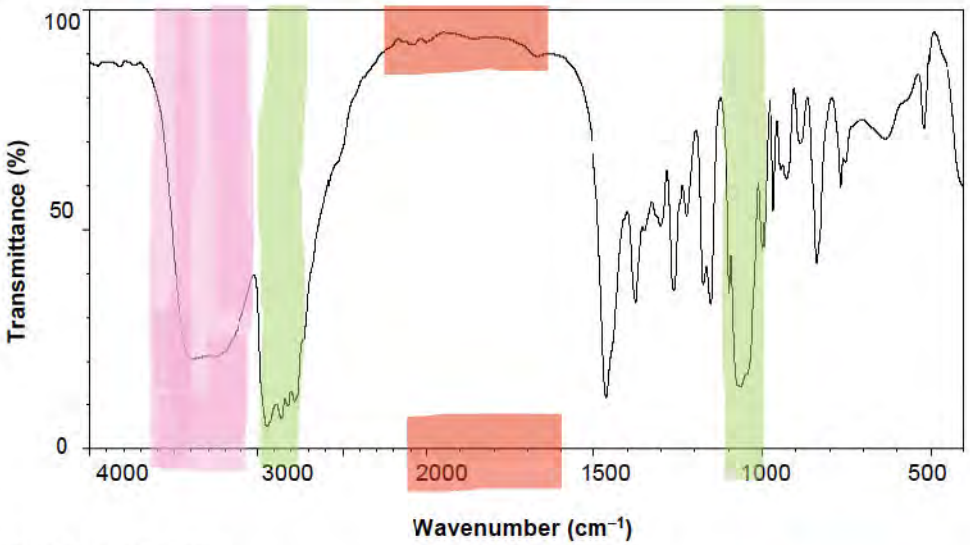
Question 3

Marking Criteria	Marks

• Writes the correct structural formula for the given compound **(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 peak due to the C=O bond addressed to rule out 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 **the given compound (naming not required)** or a structure very close to the correct structure. • 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 BUT **some critical peak analysis missing.**	6
• Shows a sound understanding of the interpretation of spectroscopic data with **critical analysis of data missing.** • 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 Response

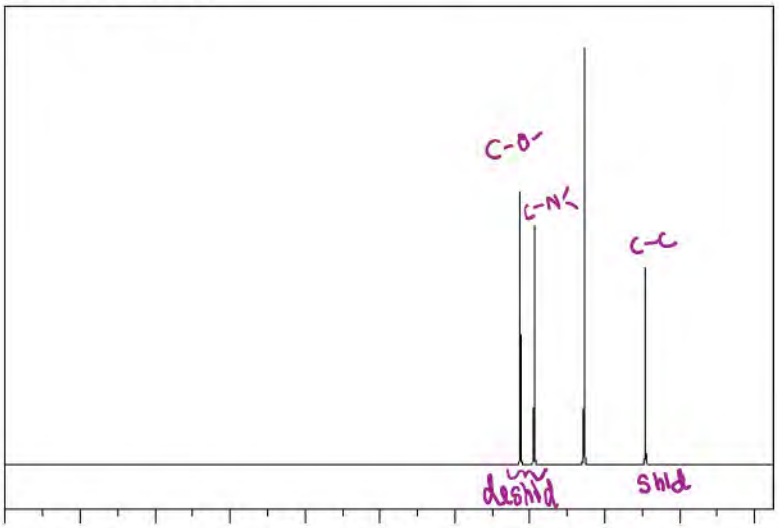


From the infrared spectrum, the:

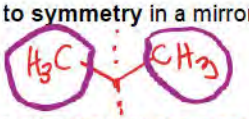
- **strong and broad peak between 3230 - 3500cm^{-1}** suggests that there is a **O-H bond** and /or N-H bond in the structure.
- **Absence of a strong and broad peak at 1733 cm^{-1}** suggests that the organic molecule **does not** contain a **C=O bond in the structure,** hence the molecule may not contain any carbonyl group **due to a carboxylic acid functional group** or ketones.
- **Fingerprint region (less than 1500 cm^{-1})** cannot be conclusively analysed due to the overlapping of peaks due to different bonds, however there is a clear and strong absorption at 1000 cm^{-1}. **This could be possibly due to a C–O bond.**

2

^{13}C NMR spectrum

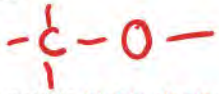


From the ^{13}C spectrum, there are four **unique carbon environments**. As there are 5 C atoms, this suggests that **two C atoms are in the same environment due to symmetry** in a mirror plane.



The peak(s) at:

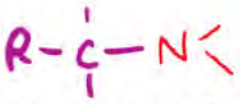
- The peak at 63 ppm to the extreme left has the highest chemical shift and corresponds to a C atom single bonded to an O atom as shown below.



This is most de-shielded due to the carbon next to highly electronegative O atom resulting in the peak being downfield.

- Peak at 60 ppm corresponds to a C atom singly bonded to an N atom as shown below.

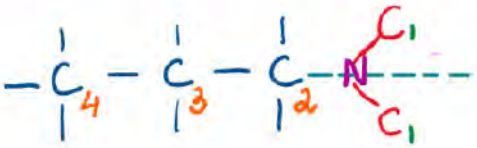
1



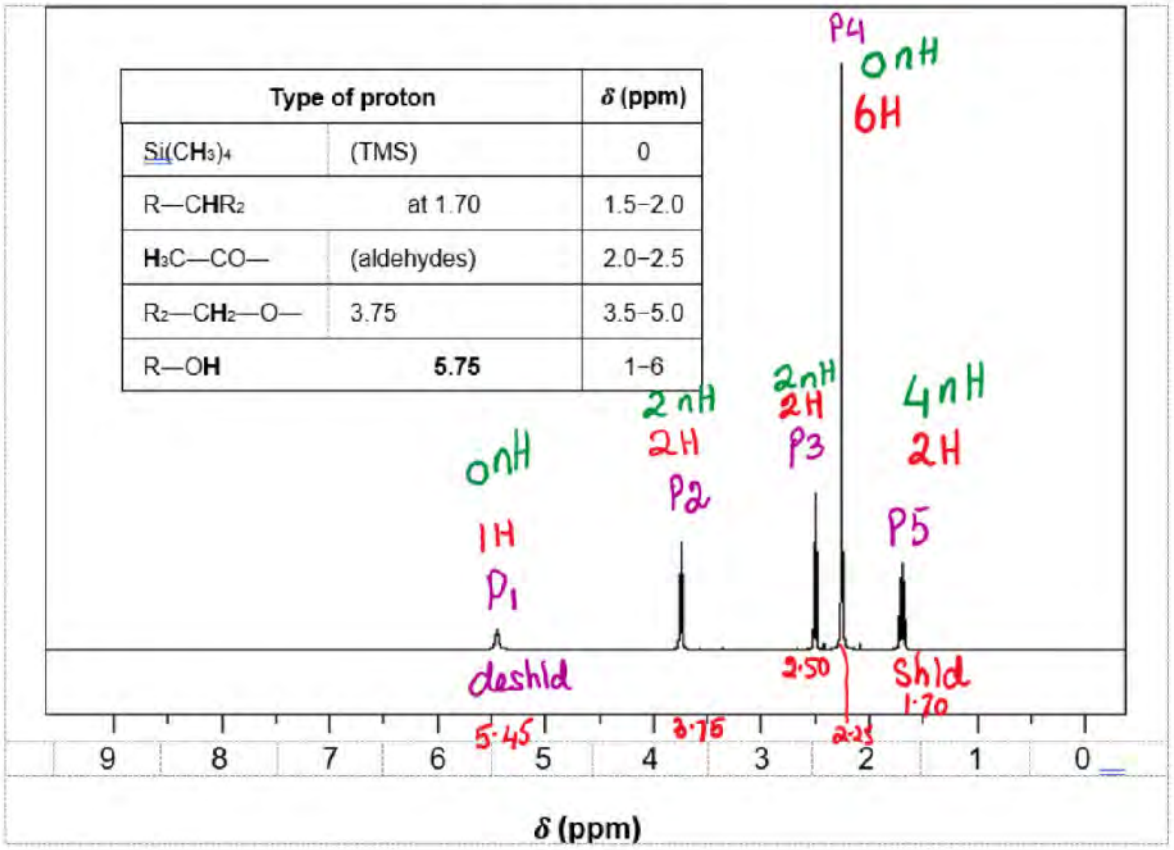
This is de-shielded as well due to the carbon next to the electronegative N atom resulting in the peak being reasonably downfield. (not required use this this term in Chemistry exam)

- Peak at 46 ppm corresponds to **C atom bonded to the N in an alkyl group** which is consistent with chemical shift between 25–60 ppm.
- Peak at 29 ppm correspond to **C atoms bonded to the C in an alkyl group** which is consistent with chemical shift between 5–40 ppm.

Possible structure so far:



^{1}H NMR spectrum



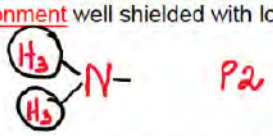
Type of proton		δ (ppm)
$Si(CH_3)_4$	(TMS)	0
R—C**H**R_2	at 1.70	1.5–2.0
H$_3$C—CO—	(aldehydes)	2.0–2.5
R_2—C**H**$_2$—O—	3.75	3.5–5.0
R—O**H**	**5.75**	1–6

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:

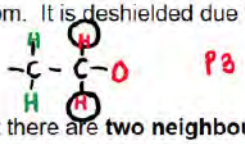
- **Singlet** at 5.45 ppm indicates that there are **no neighbouring H atoms,** relative peak area of 1 corresponds to **one H atom** in the following environment. It is highly de-shielded due to the neighbouring O atom.

- **Singlet** at 2.25 ppm indicates that there are **no neighbouring H atoms,** the relative peak area of 6 corresponds to **6 H atoms** in the environment well shielded with low chemical shift.

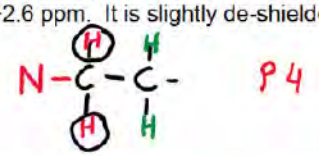


3

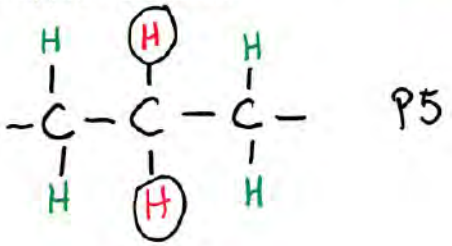
- **triplet peak** at 3.75 ppm indicates that there are **two neighbouring H atoms**, most likely in a **neighbouring –CH_2 group**. The relative peak area of 2 corresponds to **2 H atoms** in the environment as the shift occurs between 2.1−2.6 ppm. It is deshielded due to the nearby O atom.



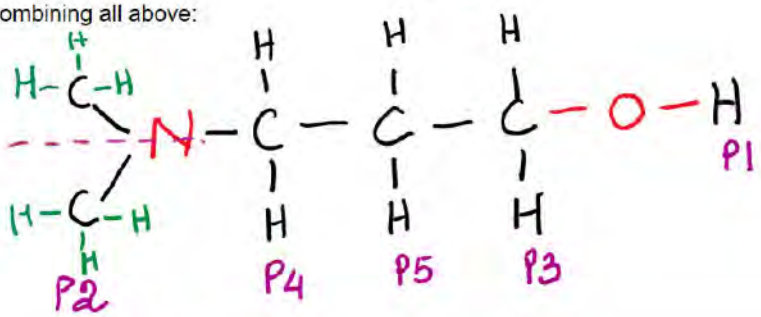
- **triplet peak** at 2.50 ppm indicates that there are **two neighbouring H atoms**, most likely in a **neighbouring –CH_2 group**. The relative peak area of 2 corresponds to **2 H atoms** in the environment as the shift occurs between 2.1−2.6 ppm. It is slightly de-shielded due to the nearby N atom.



- **Quintet peak at 1.70 ppm** indicates that there are **four neighbouring H atoms**, most likely in two **neighbouring –CH_2 group**. The relative peak area of 2 corresponds to **2 H atoms** in the environment as the shift occurs between 1.5 −2.0 ppm, most shielded.



Combining all above:



1

Correct Structure

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.

Question 4

Marking Criteria	Marks
• Calculates the molar solubility of calcium fluoride in the solution with ALL of following features: ○ determines the concentration of hydroxide ions in solution ○ calculates the calcium ion concentration based on calcium hydroxide ○ calculates the calcium fluoride solubility using the fluoride ion concentration.	3
• Calculates the molar solubility of calcium fluoride in the solution with TWO of the above features.	2
• Provides some relevant information by determining the concentration of hydroxide ions in solution.	1

Sample Response

At pH = 14.0:

$$\text{pH} + \text{pOH} = 14.0$$
$$\text{pOH} = 14.0 - 12.0$$
$$= 2.0$$
$$\therefore [\text{OH}^-] = 10^{-2.0}$$
$$= 1.0 \times 10^{-2} \text{ mol L}^{-1}$$

For $Ca(OH)_2$:

$$K_{sp} = [\text{Ca}^{2+}][\text{OH}^-]^2$$
$$5.02 \times 10^{-6} = [\text{Ca}^{2+}] \times (1.00 \times 10^{-2})^2$$
$$[\text{Ca}^{2+}] = \frac{5.02 \times 10^{-6}}{(1.00 \times 10^{-2})^2}$$
$$= 0.0502 \text{ mol L}^{-1}$$

For CaF_2:

$$K_{sp} = [\text{Ca}^{2+}][\text{F}^-]^2$$
$$3.45 \times 10^{-11} = 0.0502 \times [\text{F}^-]^2$$
$$[\text{F}^-] = \sqrt{\frac{3.45 \times 10^{-11}}{0.0502}}$$
$$= 2.621547 \times 10^{-5} \text{ mol L}^{-1}$$

Therefore, the molar solubility of CaF_2 in this solution is:

$$[\text{CaF}_2] = \frac{1}{2} \times 2.621547\ldots \times 10^{-5}$$
$$= 1.310773\ldots \times 10^{-5}$$
$$= 1.3 \times 10^{-5} \text{ mol L}^{-1}$$

Notes from the Marker

- Better responses showed evidence of understanding how the common ion effect can be applied in calculations and ensured that all working out is shown and logically ordered.
- Weaker responses did not utilise the information provided in the question and did not utilise the K_{sp} value of calcium hydroxide provided on the data sheet.

Question 3

Marking Criteria	Marks
• Uses ICE table 1 accurately AND sets up correct K_{eq} expression AND calculates the value of $K_{eq} = 57$ AND • Shows all relevant values for ICE table 2 at 6 minutes AND • Sets up correct K_{eq} expression for table 2 AND • Solves algebraic equation and calculates the moles of hydrogen added (shown as x). $x = 0.1223$ **OR** 0.121.	5
• All relevant steps correct with any ONE calculation error.	4
• Uses ICE table 1 accurately AND sets up correct K_{eq} expression AND calculates the value of $K_{eq} = 57$ AND • Error in ICE table 2 AND error in algebraic calculation leading to two significant errors AND • Incorrect value for x.	3
• Uses ICE table 1 accurately AND sets up correct Keq expression AND calculates the value of $K_{eq} = 57$.	2
• Any one step of calculation or expression correct.	1

Sample Response

	H_2	I_2	$2HI$	$V = 1L$ At 400°C
Initial	0.200	0.200	0	
Change	$-\frac{1}{2} \times 0.316 = 0.158$	$-\frac{1}{2} \times 0.316 = 0.158$	$+0.316$	
At Equilbr	0.042	0.042	0.316	(At 2 mins)

$$K_{eq} = \frac{[HI]^2}{[H_2][I_2]} \quad (1)$$

$$= \frac{(0.316)^2}{(0.042)^2} = 56.607 \simeq 57 \quad (1)$$

At 6 minute:	H_2	I_2	$2HI$
Initial	$x + 0.042$	0.042	0.316
Change	$-\frac{1}{2} \times 0.050 = 0.025$	$-\frac{1}{2} \times 0.050 = 0.025$	$+0.050$ (1)
Equilbr	$(x + 0.042) - 0.025 = x + 0.017$	0.017	0.366

$$K_{eq} = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.366)^2}{(0.017 + x)(0.017)} \quad (1)$$

$$56.6 \times 0.017 = \frac{(0.366)^2}{0.017 + x}$$

$$0.017 + x = (0.366)^2 / 0.9622$$

$$0.9622 = \frac{0.134}{0.017 + x}$$

$x = 0.1223$ OR $x = 0.121$ — 57 (1)

Question 4

Marking Criteria	Marks
• Uses B-L Theory labels such as proton donor (BL acid) and BL base (proton acceptor) (acid-base chemistry) to explain reaction between strong acids and strong bases AND • Shows equation for neutralization as $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$ only for all above neutralisation AND • Justifies above equation to support $\Delta H = -57.6$ kJ mol^{-1} for all strong acid/base neutralisations AND • Identifies NH_3 as weak base and explains its ionization in water using B-L theory AND • Shows **ALL** relevant equations OR writes all word equations AND • Explains HCl reacting directly with ammonia instead of OH^- OR • Explains correctly differently why NH_3 with HCl leads to a different ΔH *value*	4
• Outlines or explains B-L Theory labels to explain reaction between strong acids and strong bases AND • Outlines/explains the reaction between strong acids such as HCl and NH_3 AND • Uses one/two relevant equations only related to any one of the above	3
• Provides detailed justification for strong acid/base neutralisation with appropriate equation as $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$ AND/OR • Provides correct equation for ammonia and HCl as $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$ but no explanation for ammonia and HCl is provided OR • Incorrect justification ammonia and HCl is provided	2
• Explains any one of the above concepts well OR • Outlines both concepts with NO chemical equation/incorrect equation with multiple errors in understanding OR • No explanation but one correct equation only OR • Outlines both concepts but no chemical equation	1