



2021

**HIGHER SCHOOL CERTIFICATE
TRIAL EXAMINATION**

Name:

Class:

Section I	/20
Section II	/80
Total	/100

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using blue or black pen
Black pen is preferred
- Draw diagrams using pencil
- Board-approved calculators may be used
- A data sheet and a Periodic Table are provided at the back of this paper
- Write your name and class at the top of this page

Total marks – 100

Section I Pages 2 – 10

20 marks

- Attempt Questions 1 – 20
- Allow about 35 minutes for this part

Section II Pages 11 – 29

80 marks

- Attempt Questions 21 – 33
- Allow about 2 hours and 25 minutes for this section

Section I: Multiple Choice Questions (20 marks)

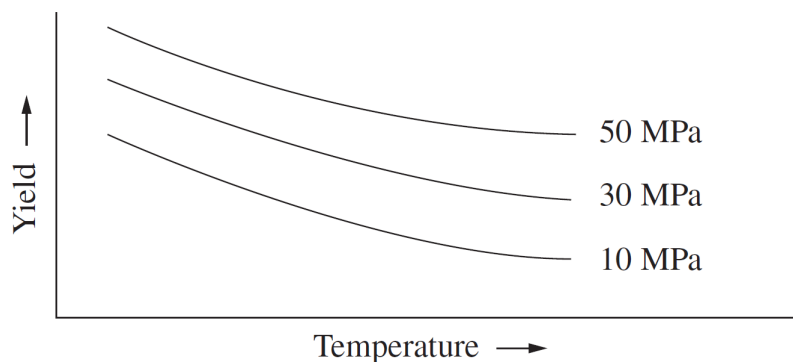
Attempt Questions 1 – 20

Allow about 35 minutes for this section

Use the multiple choice answer sheet for Questions 1 – 20.

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| 18. | <input type="radio"/> A | <input type="radio"/> B | <input type="radio"/> C | <input type="radio"/> D |
| 19. | <input type="radio"/> A | <input type="radio"/> B | <input type="radio"/> C | <input type="radio"/> D |
| 20. | <input type="radio"/> A | <input type="radio"/> B | <input type="radio"/> C | <input type="radio"/> D |

1. Compounds X, Y and Z are in equilibrium. The graph below shows how the equilibrium yield of compound Z changes with variations in temperature and pressure.



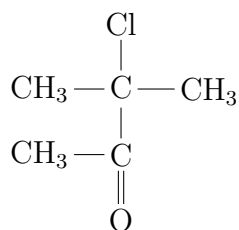
Which equation is consistent with this graph?

- (A) $X_{(g)} + 3 Y_{(g)} \rightleftharpoons 2 Z_{(g)} \quad \Delta H < 0$
(B) $X_{(g)} + 3 Y_{(g)} \rightleftharpoons 2 Z_{(g)} \quad \Delta H > 0$
(C) $2 X_{(g)} \rightleftharpoons 2 Y_{(g)} + Z_{(g)} \quad \Delta H < 0$
(D) $2 X_{(g)} \rightleftharpoons 2 Y_{(g)} + Z_{(g)} \quad \Delta H > 0$
2. Which of the following is a conjugate acid/base pair that contains an amphoteric species?
- (A) HCl/Cl^-
(B) $\text{HPO}_4^{2-}/\text{PO}_4^{3-}$
(C) $\text{H}_2\text{CO}_3/\text{CO}_3^{2-}$
(D) $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$
3. Which of the following compounds are a pair of functional group isomers?
- (A) Hex-1-ene and cyclohexene
(B) Butan-1-ol and 2-methylpropan-2-ol
(C) Pentane and 2-methylbutane
(D) Pentanal and pentan-2-one
4. A sample of solid magnesium hydroxide was added to a sodium hydroxide solution with a pH of 12.00 and only some of the magnesium hydroxide dissolved.

What is the equilibrium concentration of magnesium ions in the resultant solution?

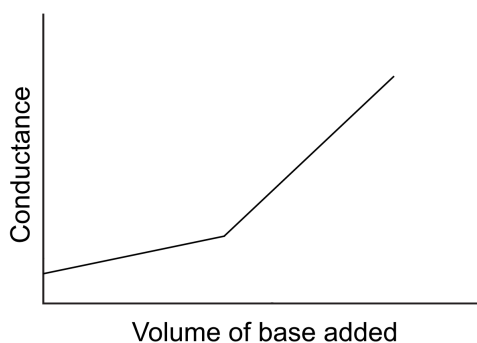
- (A) $5.6 \times 10^{-8} \text{ mol L}^{-1}$
(B) $5.6 \times 10^{-9} \text{ mol L}^{-1}$
(C) $5.6 \times 10^{-10} \text{ mol L}^{-1}$
(D) $5.6 \times 10^{-11} \text{ mol L}^{-1}$

5. Consider the following compound:



What is the systematic name of this compound?

- (A) 2-chloro-2-methylbutanal
(B) 2-chloro-2,2-dimethylpropanal
(C) 3-chloro-3-methylbutan-2-one
(D) 3-chloro-3,3-dimethylpropan-2-one
6. A conductometric acid-base titration was carried out and the following conductivity curve was obtained.



Which row of the following table contains an indicator that would be suitable for this titration?

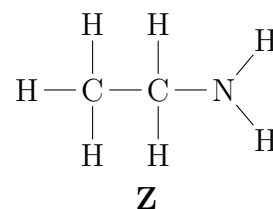
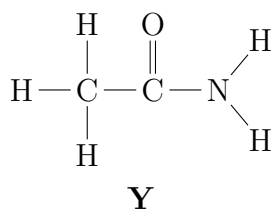
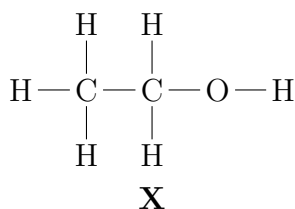
	Indicator	pH range
(A)	Crystal violet	0.0 – 2.0
(B)	Methyl red	4.4 – 6.2
(C)	Cresolphthalein	8.2 – 9.8
(D)	Indigo carmine	11.4 – 13.0

7. A 50.0 mL sample of contaminated water was analysed for its lead ion content. Excess sodium chloride was added to this sample and the lead(II) chloride precipitate that formed was filtered, dried and weighed. It had a mass of 0.110 g.

What is the concentration of lead ions in the water sample?

- (A) 1640 ppm
(B) 1880 ppm
(C) 2120 ppm
(D) 2360 ppm

8. Consider the following compounds which have been labelled as **X**, **Y** and **Z**:



Which of the following arranges these compounds in order of increasing boiling point?

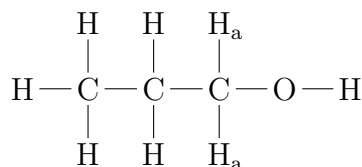
- (A) **X** < **Y** < **Z**
 (B) **X** < **Z** < **Y**
 (C) **Y** < **X** < **Z**
 (D) **Z** < **X** < **Y**
9. A sodium hydroxide solution was prepared by weighing out 1.00 g of solid sodium hydroxide and dissolving it in sufficient distilled water to make a 250.0 mL solution. A hydrochloric acid solution was then titrated with the sodium hydroxide solution using an appropriate indicator. The titration was repeated three more times and the results are shown below.

Titration	Volume of NaOH added (mL)
1	15.20
2	15.15
3	15.10
4	15.10

Which row of the following table best describes the results of this experiment?

	Reliability	Accuracy	Calculated HCl concentration
(A)	Unreliable	Accurate	Correct
(B)	Reliable	Inaccurate	Underestimated
(C)	Reliable	Inaccurate	Overestimated
(D)	Reliable	Accurate	Correct

10. Consider the following compound where one of the ^1H environments has been labelled as H_a :



What would be the splitting pattern of the signal produced by the H_a environment on a ^1H nuclear magnetic resonance (NMR) spectrum under standard conditions?

- (A) Singlet
 (B) Doublet
 (C) Triplet
 (D) Quartet

11. A 40.0 mL solution of 0.20 mol L⁻¹ barium nitrate is mixed with 40.0 mL of 0.20 mol L⁻¹ sodium hydroxide solution at 25°C.

Which row of the following table correctly predicts if barium hydroxide will form as a precipitate and the reason for this?

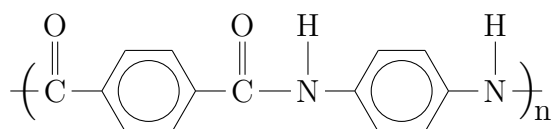
	Will a precipitate form?	Reason
(A)	No	$Q_{\text{sp}} < K_{\text{sp}}$
(B)	No	$Q_{\text{sp}} > K_{\text{sp}}$
(C)	Yes	$Q_{\text{sp}} < K_{\text{sp}}$
(D)	Yes	$Q_{\text{sp}} > K_{\text{sp}}$

12. The table below shows the heat of combustion of three different alcohols in kJ g⁻¹.

Alcohol	Heat of combustion (kJ g ⁻¹)
Methanol	22.7
Ethanol	29.7
Propan-1-ol	33.6

What is the most likely molar heat of combustion of butan-1-ol?

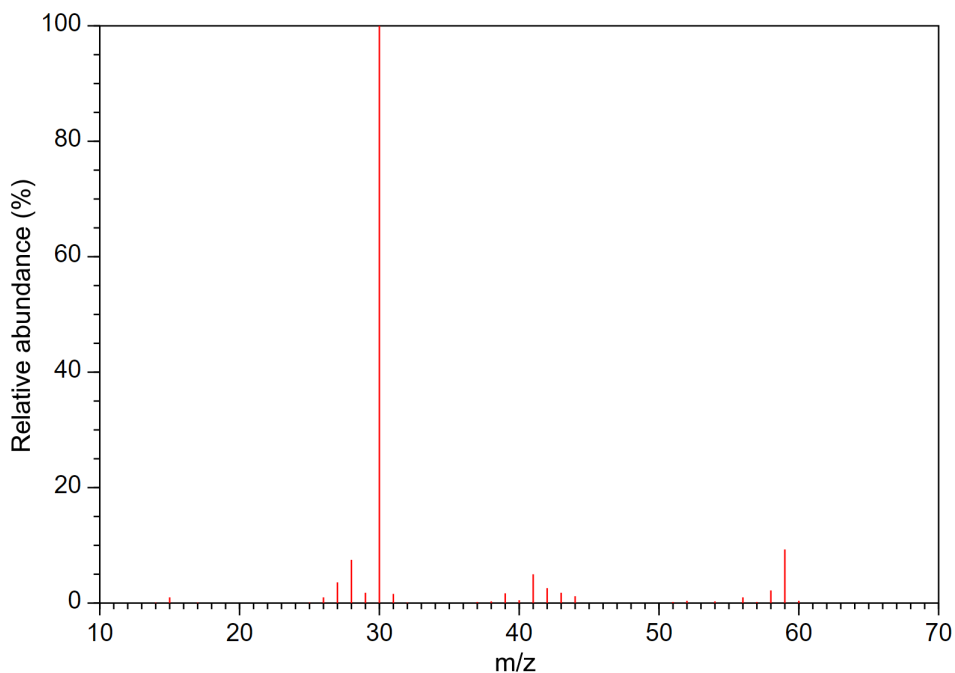
- (A) 2019 kJ mol⁻¹
 (B) 2671 kJ mol⁻¹
 (C) 5286 kJ mol⁻¹
 (D) 36.0 kJ g⁻¹
13. The polymer below can be produced from a reaction between two different monomers.



Which of the following is one of the monomers used to produce the above polymer?

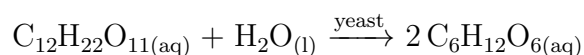
- (A) $\text{H}_2\text{N}-\text{C}_6\text{H}_4-\text{COOH}$
 (B) $\text{HO}-\text{C}_6\text{H}_4-\text{COOH}$
 (C) $\text{H}_2\text{N}-\text{C}_6\text{H}_4-\text{CONH}_2$
 (D) $\text{H}_2\text{N}-\text{C}_6\text{H}_4-\text{NH}_2$

14. The mass spectrum of propan-1-amine is shown below.



Which species is most likely responsible for the base peak on this mass spectrum?

- (A) C_2H_5^+
 - (B) C_2H_6^+
 - (C) CH_2NH_2^+
 - (D) $\text{C}_3\text{H}_7\text{NH}_2^+$
15. A solution of sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) was allowed to undergo fermentation in a conical flask that was stoppered with cotton wool. During this process, yeast enzymes first hydrolyse sucrose into simple carbohydrates according to the following equation:



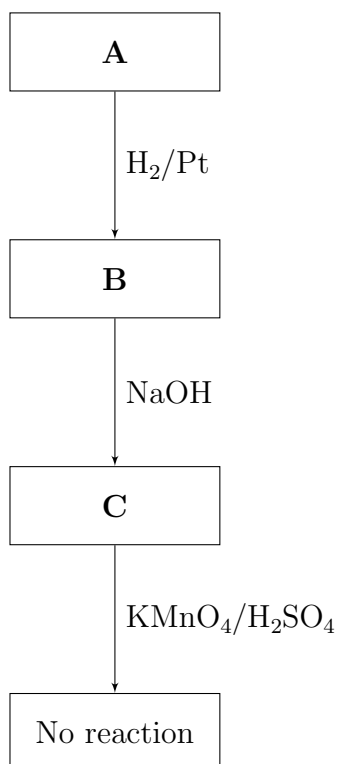
The simple carbohydrates produced are then converted into ethanol and carbon dioxide.

The initial mass of the conical flask with its contents was 365.8 g and after several days, the final mass was found to be 354.3 g.

What is the theoretical mass of sucrose that got consumed during this time period?

- (A) 22.4 g
- (B) 33.6 g
- (C) 44.8 g
- (D) 56.0 g

16. Consider the following series of reactions where **A**, **B** and **C** are different organic compounds.



Based on the above information, a possible identity for compound **A** is:

- (A) 1-bromo-2-methylbut-1-ene
 - (B) 2-bromo-2-methylbut-1-ene
 - (C) 3-bromo-2-methylbut-1-ene
 - (D) 4-bromo-2-methylbut-1-ene
17. A laboratory contains solutions of hydrochloric acid and acetic acid, both at equal volumes with the same pH of 2.00. A chemist made the following statements regarding these solutions:
- (i) Both solutions have the same hydronium ion concentration
 - (ii) A 10-fold dilution of both acids would cause both their pH values to increase by 1 unit
 - (iii) The hydrochloric acid solution would require a smaller volume of 0.10 mol L^{-1} sodium hydroxide solution to be completely neutralised than the acetic acid solution

Which of the above statement(s) are correct?

- (A) (i) only
- (B) (i) and (ii) only
- (C) (i) and (iii) only
- (D) (i), (ii) and (iii)

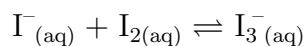
18. The table shows some properties of two organic compounds, X and Y.

Compound	Solubility in water	Litmus paper test
X	Partially soluble	Blue litmus turns red
Y	Soluble	Red litmus turns blue

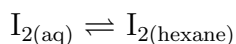
Which row of the following table best identifies compounds X and Y?

	X	Y
(A)	HCOOH	C ₆ H ₁₃ NH ₂
(B)	C ₅ H ₁₁ COOH	CH ₃ NH ₂
(C)	CH ₃ NH ₂	C ₅ H ₁₁ COOH
(D)	C ₆ H ₁₃ NH ₂	HCOOH

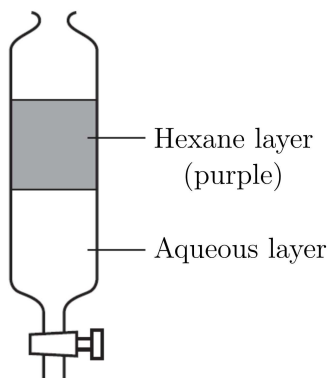
19. In aqueous solution, iodide ions (I⁻) can react with iodine (I₂) to form triiodide ions (I₃⁻) and an equilibrium is established.



When hexane is added to this system, two separate layers form and some iodine dissolves into the hexane layer which becomes purple due to the dissolved iodine. The following distribution equilibrium is then established:



The diagram below shows the appearance of the equilibrium mixture.



Which row of the following table shows the most likely colour changes that would occur in the hexane layer when potassium iodide and silver nitrate are added to the aqueous layer?

	KI added	AgNO ₃ added
(A)	Purple colour fades	Purple colour fades
(B)	Purple colour fades	Purple colour intensifies
(C)	Purple colour intensifies	Purple colour fades
(D)	Purple colour intensifies	Purple colour intensifies

20. A 25.0 mL solution of 0.15 mol L^{-1} nitric acid was mixed with a 20.0 mL solution of 0.10 mol L^{-1} barium hydroxide.

What is the pH of the resultant solution?

- (A) 7.70
- (B) 9.06
- (C) 10.40
- (D) 11.74

Section II: Short Answer Questions (80 marks)

Attempt Questions 21 – 33

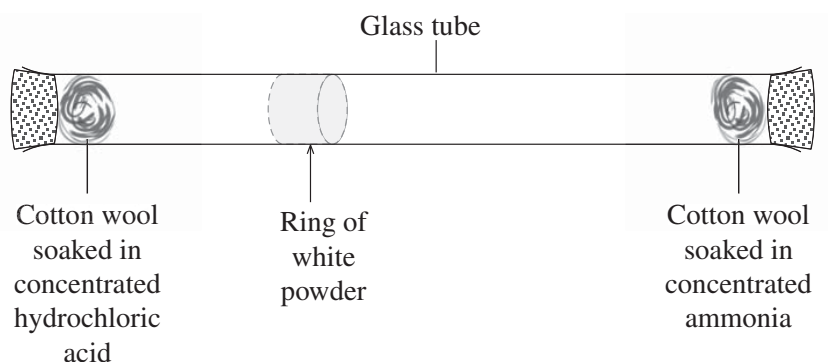
Allow about 2 hours and 25 minutes for this part

Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.

Show all relevant working in questions involving calculations.

Question 21 (4 marks)

A chemist placed two pieces of cotton wool at opposite ends of a sealed horizontal glass tube. One piece of cotton wool was soaked in concentrated ammonia solution, and the other was soaked in concentrated hydrochloric acid solution. Over time, a ring of white powder is formed inside the tube. This is shown in the schematic diagram below.



- (a) Explain why this reaction is well accounted for by the Brønsted-Lowry theory of acids and bases, but not by the Arrhenius theory. Include a relevant chemical equation in your answer.

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- (b) Describe ONE limitation of the Brønsted-Lowry theory of acids and bases.

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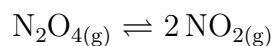
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Question 22 (7 marks)

N_2O_4 is a colourless gas that can dissociate into brown NO_2 gas according to this equation:



- (a) When an equilibrium mixture of N_2O_4 and NO_2 is placed into an ice bath, the brown colour of the mixture fades. **2**

Explain whether the decomposition of N_2O_4 into NO_2 is endothermic or exothermic.

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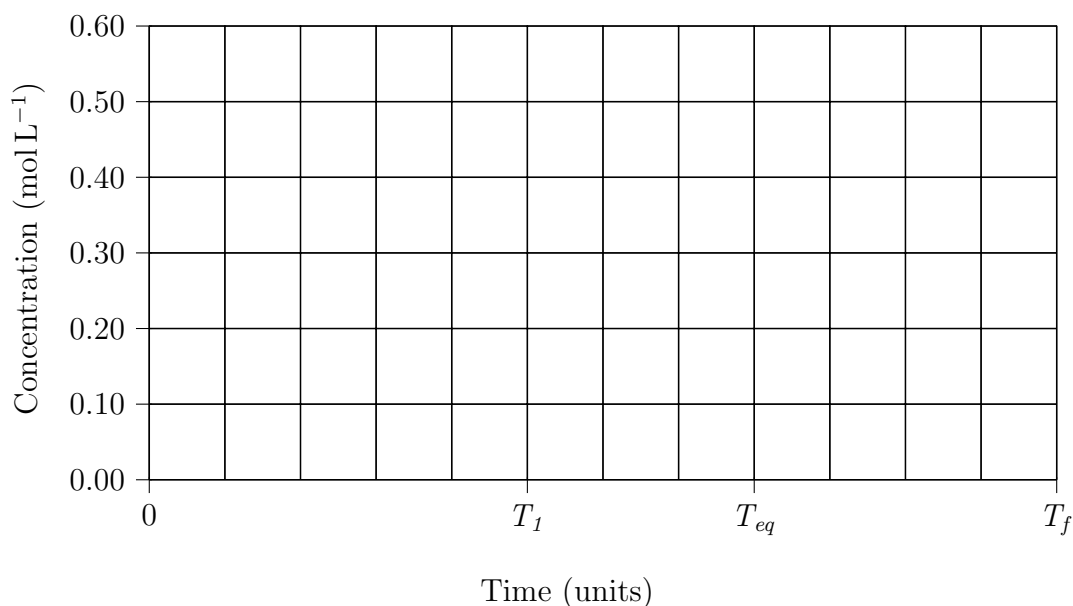
- (b) A reaction vessel initially contained the following concentration of gases at equilibrium. **2**

Gas	Initial equilibrium concentration (mol L^{-1})
N_2O_4	0.15
NO_2	0.25

At time T_1 , the volume of the reaction vessel was halved and the system was then allowed to reach equilibrium at time T_{eq} .

Sketch two curves on the provided graph to show how the concentrations of N_2O_4 and NO_2 gas will vary as a function of time between $t = 0$ and $t = T_f$.

Note that absolute concentration values at T_{eq} are not important.



(c) Explain how the equilibrium position changes after T_1 using collision theory.

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Question 23 (4 marks)

A student carried out an experiment to test the effectiveness of soap in hard water which contains a high content of calcium and magnesium ions.

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The student prepared two beakers, one containing distilled water and the other containing hard water. A fabric soaked in oil was added to both beakers followed by a soap solution. The resultant mixtures were then stirred and the results of the experiment are shown below:

Type of water	Observations
Distilled water	<ul style="list-style-type: none">• Oily stains on fabric were removed
Hard water	<ul style="list-style-type: none">• White precipitate formed in solution• Oily stains remained on the fabric

Account for the results obtained in this experiment with reference to the molecular structure and cleaning action of soap.

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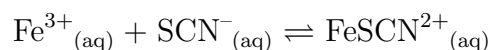
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Question 24 (4 marks)

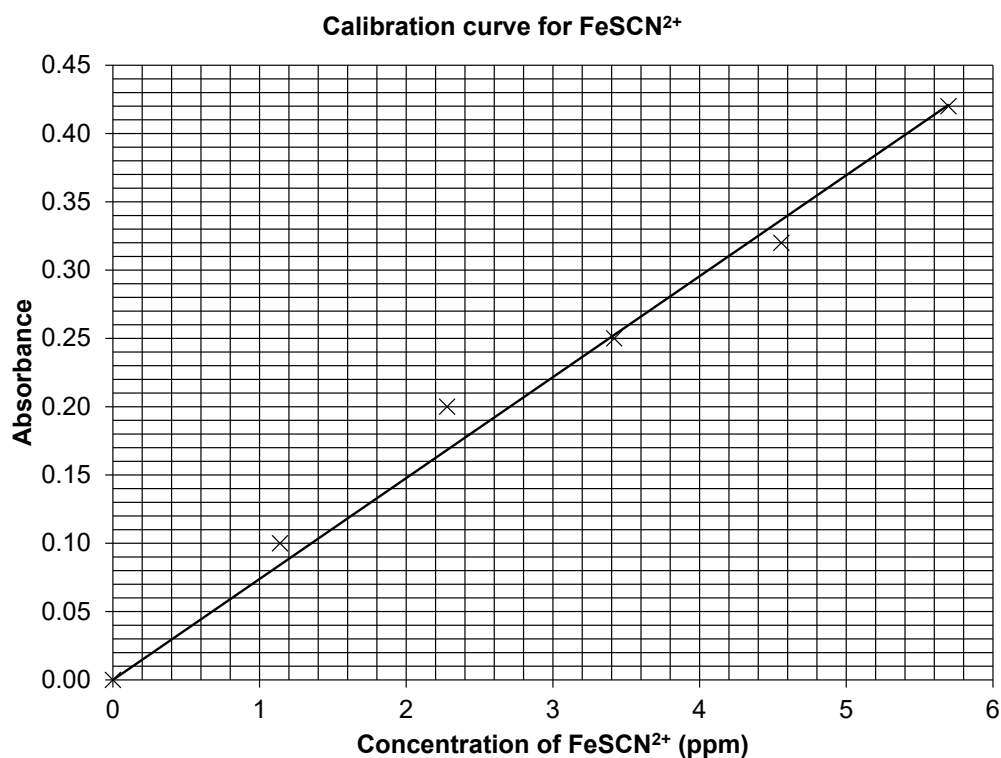
Consider the following equilibrium reaction:

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The following procedure was used to determine the equilibrium constant for this reaction.

- 2.0 mL of $2.5 \times 10^{-3} \text{ mol L}^{-1} \text{ Fe(NO}_3)_3$ and 2.0 mL of $2.5 \times 10^{-3} \text{ mol L}^{-1} \text{ KSCN}$ was mixed in a 10.0 mL volumetric flask and then filled to the mark with distilled water.
- The resultant solution was allowed to reach equilibrium and its absorbance at 480 nm was measured with colourimetry and found to be 0.280.
- A series of standard solutions was used to construct the calibration curve below.



Calculate the equilibrium constant for the reaction.

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Question 25 (10 marks)

Ethanol, propanoic acid and concentrated sulfuric acid were mixed into a flask and then heated under reflux.

(a) Write a chemical equation, using structural formulae, for the reaction that occurs.

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(b) Outline why refluxing is used to carry out this reaction.

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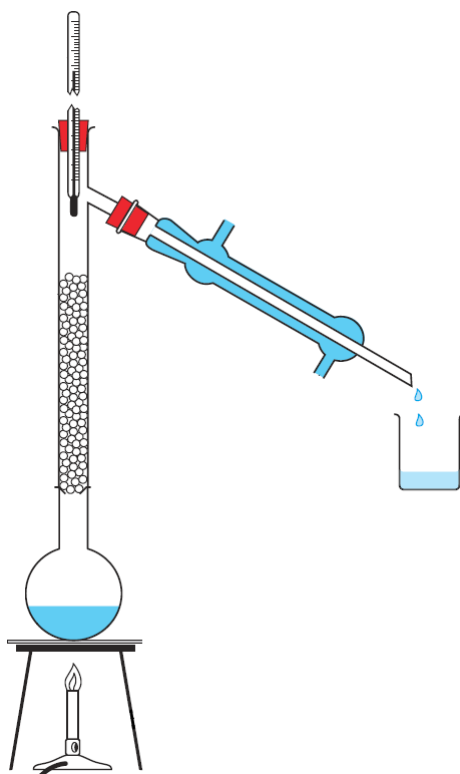
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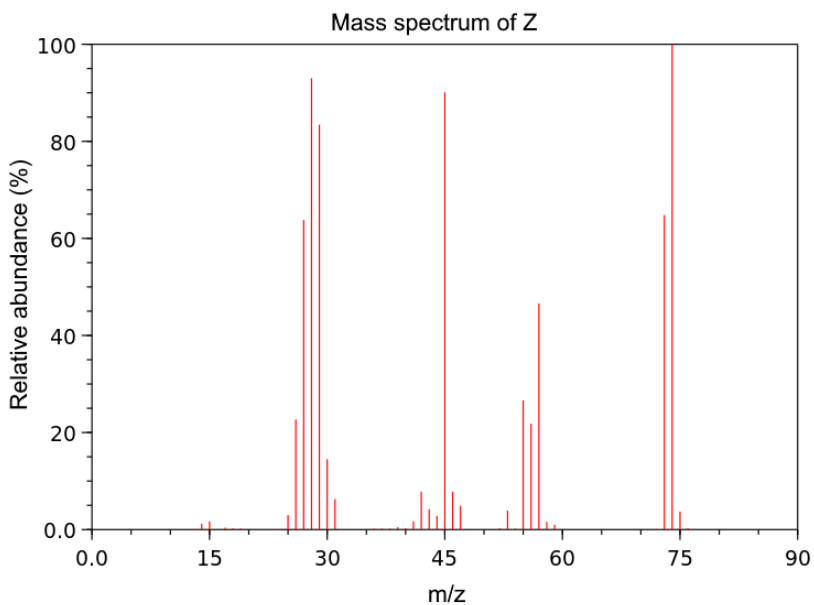
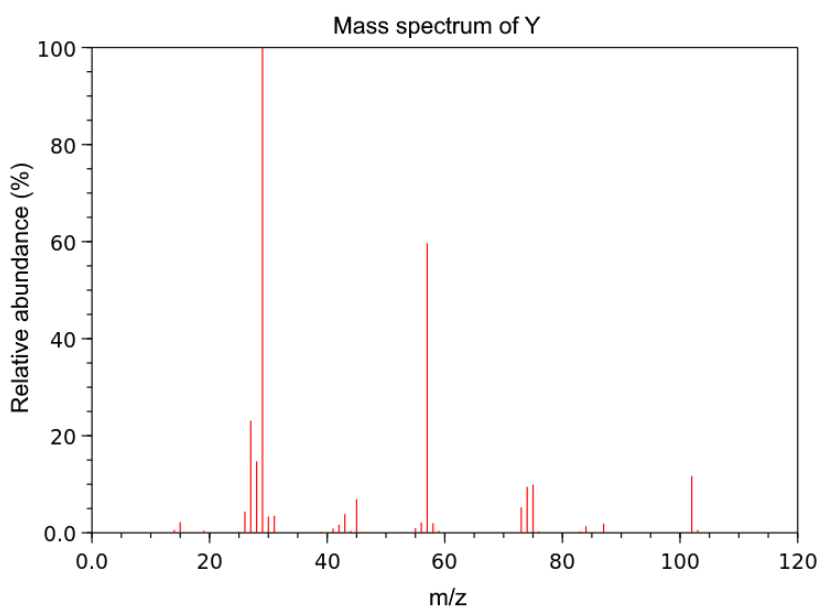
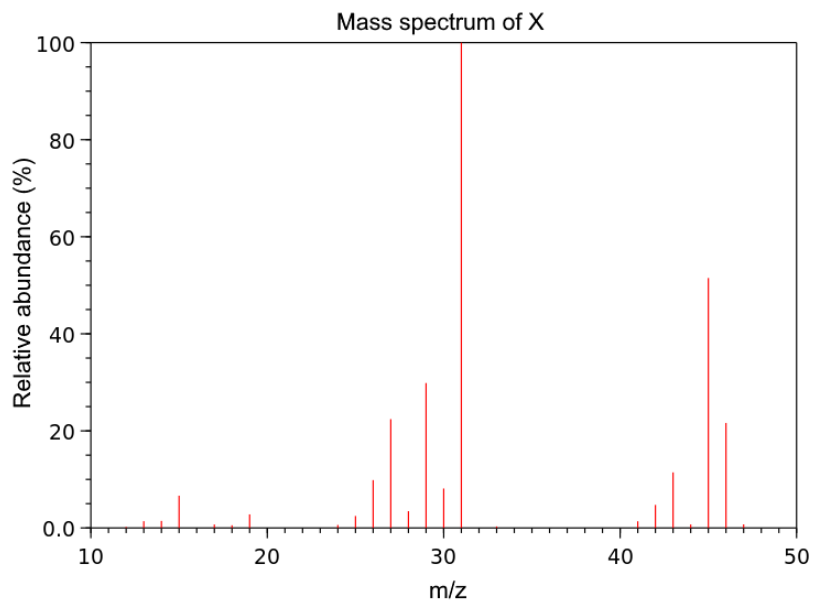
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After the reaction, the reaction mixture was separated using the apparatus shown below.



Three pure organic compounds were collected in separate beakers and were labelled as X, Y and Z in order of collection. Each compound was analysed with mass spectrometry and the resultant mass spectra are shown below.



- (c) What are the identities of compounds X, Y and Z, and which of these has the lowest boiling point as indicated by the order of collection? **1**

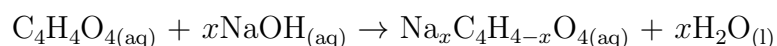
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- (d) Explain the differences in boiling point between compounds X, Y and Z. **5**

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Question 26 (8 marks)

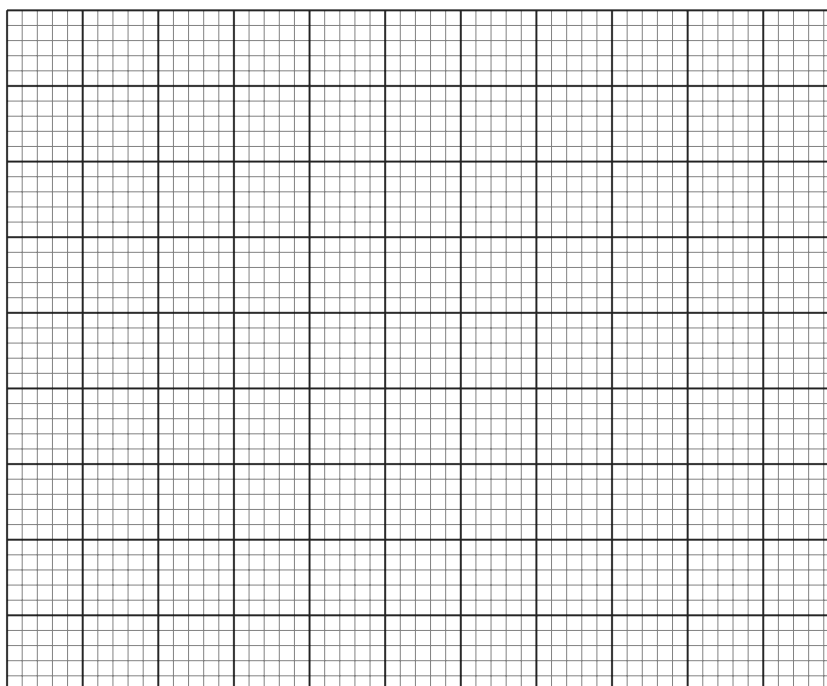
An unknown organic acid with a molecular formula of $\text{C}_4\text{H}_4\text{O}_4$ reacts with sodium hydroxide to form a salt and water according to the following general equation:



To determine the stoichiometric ratio between $\text{C}_4\text{H}_4\text{O}_4$ and sodium hydroxide, ten 10.0 mL samples were prepared by mixing together various volumes of $\text{C}_4\text{H}_4\text{O}_4$ and sodium hydroxide. All of the $\text{C}_4\text{H}_4\text{O}_4$ and sodium hydroxide solutions used had identical concentrations and temperatures. The temperature change of each sample was measured and the results are given below.

Sample	1	2	3	4	5	6	7	8	9	10
Volume of NaOH (mL)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Volume of $\text{C}_4\text{H}_4\text{O}_4$ (mL)	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0
Temperature increase ($^{\circ}\text{C}$)	0.00	0.56	1.14	1.70	1.80	2.85	3.40	3.42	2.28	1.13

- (a) Construct an appropriate graph of the data and hence determine the value of x to the nearest integer. 4



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- (b) When a few drops of bromine water is added to the unknown organic acid, the bromine water is decolourised. **1**

Draw a possible structural formula for the unknown organic acid that is consistent with all the information provided.

- (c) The enthalpy change per mole of water formed in the neutralisation reaction is -56 kJ mol^{-1} . **3**

If 15% of the heat released by the reaction was lost to the surroundings, calculate the concentration of the sodium hydroxide solution before it was mixed with the organic acid.

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Question 27 (9 marks)

A student transferred 25.00 mL of a benzoic acid solution into a beaker and titrated it against a $0.1389 \text{ mol L}^{-1}$ sodium hydroxide solution. As the titrant was being delivered, changes in pH were monitored using a pH meter immersed in the beaker solution and attached to a data logger. In total, 40.00 mL of sodium hydroxide was added before the recording was stopped (**This does NOT represent the equivalence point**). The benzoic acid solution was found to have a pH of 2.60 and a concentration of $0.1000 \text{ mol L}^{-1}$.

- (a) Given that benzoic acid is a weak monoprotic acid with a molecular formula of $\text{C}_6\text{H}_5\text{COOH}$, show that the amount of salt produced at the equivalence point is $2.500 \times 10^{-3} \text{ mol}$. 1

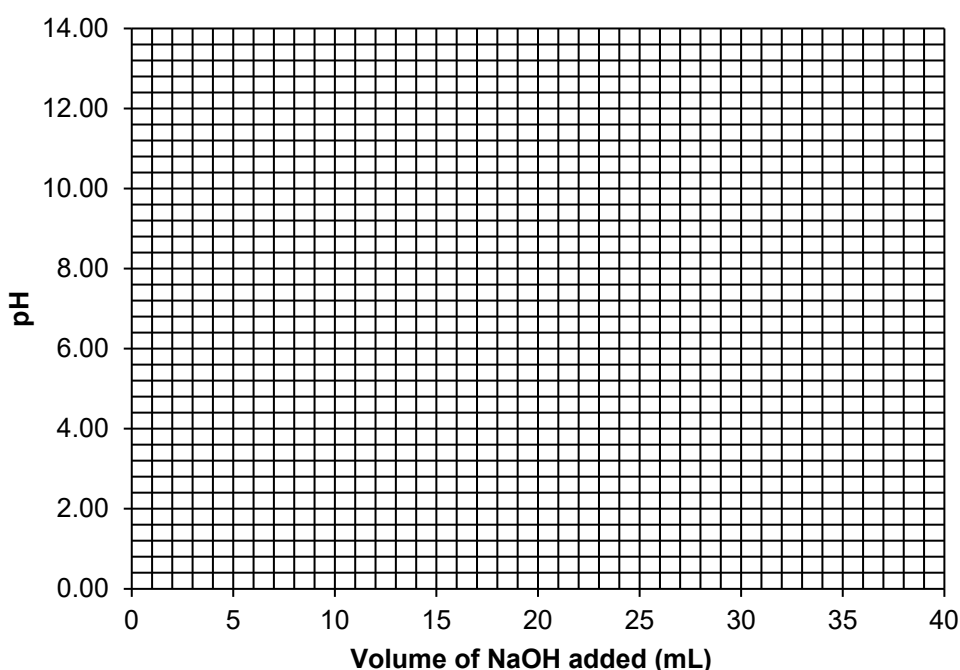
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- (b) The half-equivalence point of a titration occurs when the volume of titrant that has been added is half of what is required to reach the equivalence point. It can be shown that the pH at the half-equivalence point on the titration curve is equal to the $\text{p}K_{\text{a}}$ of the weak acid being titrated. Note that you are NOT required to prove this. 8

Using all of the information provided and relevant calculations, draw a titration curve for this titration on the axes below. In particular, you should clearly mark:

- The initial pH
- The pH and volume of sodium hydroxide added at the half-equivalence point
- The pH and volume of sodium hydroxide added at the equivalence point
- The final pH when 40.00 mL of sodium hydroxide has been added

You may assume that the hydrolysis of the salt produced in part (a) is negligible at the end when 40.00 mL of sodium hydroxide has been added.



Question 28 (6 marks)

The following thermodynamic data applies to the dissolution of solid potassium hydroxide in water at 25°C.

6

$$\Delta_{\text{sol}}H^{\ominus} = -57 \text{ kJ mol}^{-1}$$

$$\Delta_{\text{sol}}S^{\ominus} = +11 \text{ J mol}^{-1} \text{ K}^{-1}$$

With reference to this data and the resultant $\Delta_{\text{sol}}G^{\ominus}$, describe and analyse the changes in structure and bonding that occur when potassium hydroxide is dissolved in water at 25°C. Include a relevant diagram in your answer.

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A chemist conducted an experiment where they measured the pH of a sample of perchloric acid (HClO_4) and hypochlorous acid (HClO). A salt was then dissolved into each acid. The results are summarised in the table below.

Acid	Perchloric acid	Hypochlorous acid
Concentration of acid (mol L ⁻¹)	0.10	0.10
Initial pH	1.00	4.27
Salt dissolved	Sodium perchlorate (NaClO ₄)	Sodium hypochlorite (NaClO)

- 5

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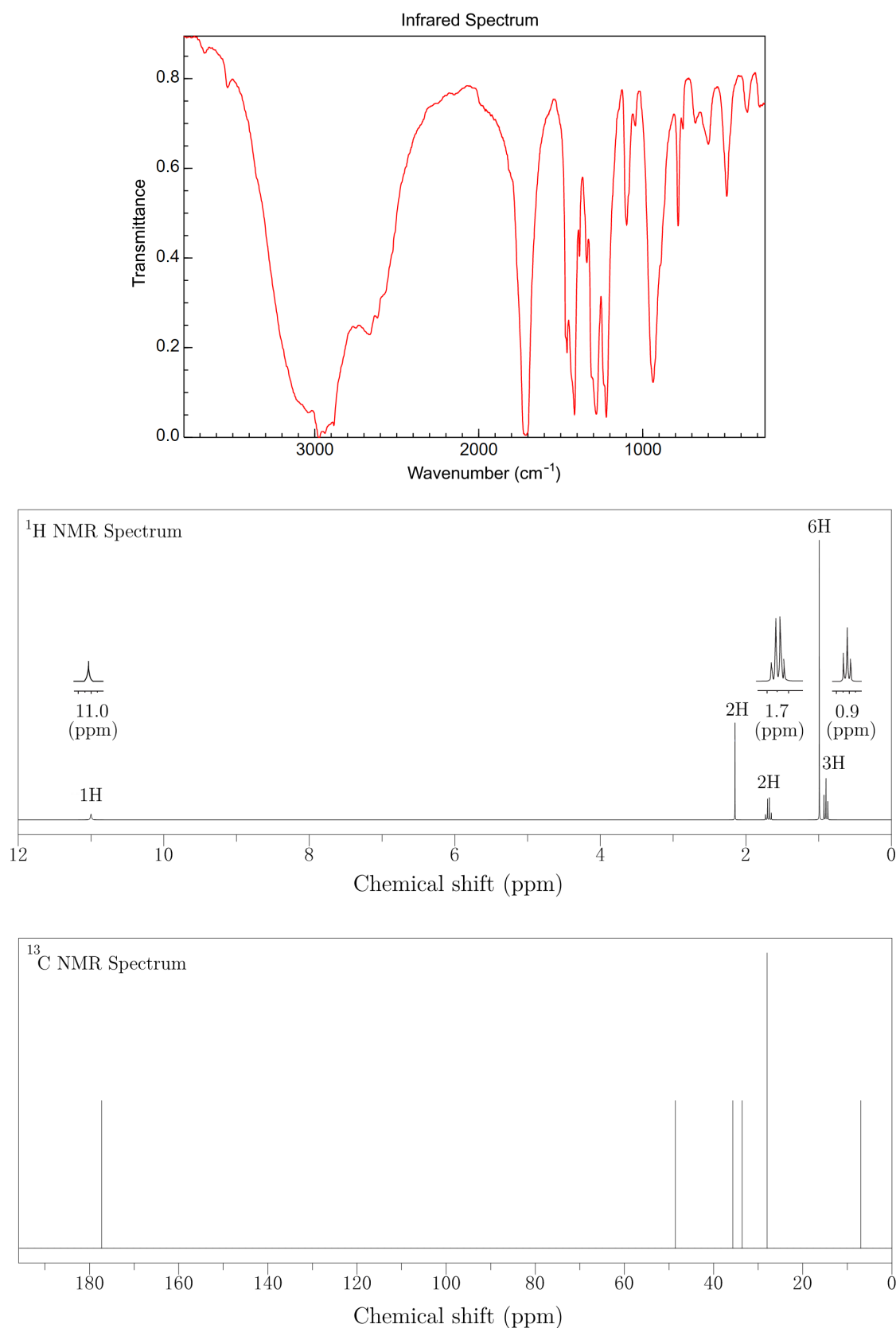
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Question 30 (7 marks)

An unknown organic compound with a molecular formula of $C_7H_{14}O_2$ was analysed with infrared (IR) spectroscopy and nuclear magnetic resonance (NMR) spectroscopy. The following spectra were obtained from these techniques.

7



Analyse the spectra above to determine the structural formula of the organic compound.

Note: 1H NMR chemical shift data has been included on your data sheet.

Question 31 (5 marks)

A beaker is known to contain ONE of the following 0.10 mol L^{-1} solutions:

5

- Sodium sulfate
- Copper(II) nitrate
- Sodium hydroxide
- Silver nitrate
- Sodium carbonate

Describe a series of tests that could be used to confirm the identity of the solution in the beaker. Include any expected observations and relevant net ionic equations in your answer.

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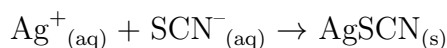
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Question 32 (5 marks)

The following procedure was used to determine the phosphate content of a particular brand of plant food.

- A 4.258 g sample of the plant food was mixed with 50.0 mL of 0.126 mol L^{-1} silver nitrate solution. All of the phosphate ions were precipitated out, leaving an excess of silver ions.
- The precipitate formed was filtered off and the filtrate was diluted to 250.0 mL with distilled water in a volumetric flask.
- Four 50.0 mL aliquots of the resulting solution were transferred to separate conical flasks and, in each case, the excess silver ions was titrated against a $0.0625 \text{ mol L}^{-1}$ potassium thiocyanate (KSCN) solution according to the following equation:



- The results are given in the table below:

Titration	Titre volume (mL)
1	11.90
2	11.60
3	11.70
4	11.65

- (a) Calculate the moles of silver ions that remained unreacted following the reaction with the phosphate ions. **2**

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- (b) Calculate the concentration of phosphate ions in the plant food sample in mg/g. **3**

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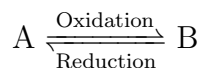
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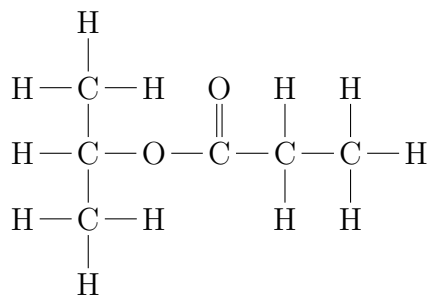
Question 33 (5 marks)

Oxidation and reduction reactions occur as opposing reactions as shown below.

5

In organic chemistry, a strong reductant that is commonly used to carry out reduction reactions is sodium borohydride (NaBH_4).

Using the information above and any other relevant reactions, construct a flowchart to show a reaction pathway that can be used to synthesise the compound below using propanal as the ONLY starting organic reagent.



All reagents used must be clearly shown and the structural formula of all intermediates must be drawn.

End of paper

Section II extra writing space

If you use this space, clearly indicate which question you are answering.

[illegible]



2021

**HIGHER SCHOOL CERTIFICATE
TRIAL EXAMINATION
SOLUTIONS**

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using blue or black pen
Black pen is preferred
- Draw diagrams using pencil
- Board-approved calculators may be used
- A data sheet and a Periodic Table are provided at the back of this paper
- Write your name and class at the top of this page

Total marks – 100

Section I Pages 2 – 10

20 marks

- Attempt Questions 1 – 20
- Allow about 35 minutes for this part

Section II Pages 11 – 29

80 marks

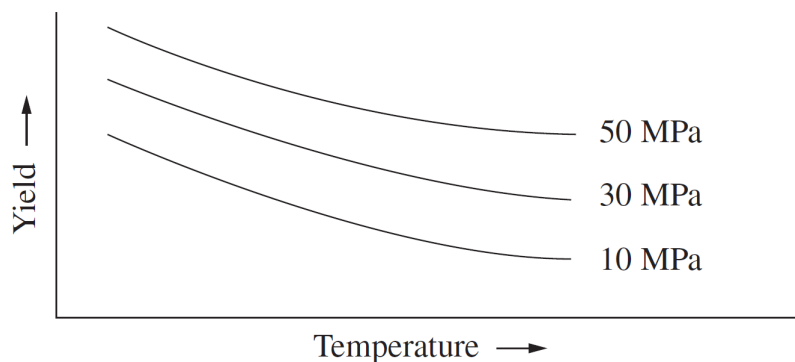
- Attempt Questions 21 – 33
- Allow about 2 hours and 25 minutes for this section

Section I: Multiple Choice Questions (20 marks)
Attempt Questions 1 – 20
Allow about 35 minutes for this section

Use the multiple choice answer sheet for Questions 1 – 20.

1.	<input type="checkbox"/>	<input type="radio"/> B	<input type="radio"/> C	<input type="radio"/> D
2.	<input type="radio"/> A	<input type="checkbox"/>	<input type="radio"/> C	<input type="radio"/> D
3.	<input type="radio"/> A	<input type="radio"/> B	<input type="radio"/> C	<input type="checkbox"/>
4.	<input type="checkbox"/>	<input type="radio"/> B	<input type="radio"/> C	<input type="radio"/> D
5.	<input type="radio"/> A	<input type="radio"/> B	<input type="checkbox"/>	<input type="radio"/> D
6.	<input type="radio"/> A	<input type="radio"/> B	<input type="checkbox"/>	<input type="radio"/> D
7.	<input type="checkbox"/>	<input type="radio"/> B	<input type="radio"/> C	<input type="radio"/> D
8.	<input type="radio"/> A	<input type="radio"/> B	<input type="radio"/> C	<input type="checkbox"/>
9.	<input type="radio"/> A	<input type="radio"/> B	<input type="checkbox"/>	<input type="radio"/> D
10.	<input type="radio"/> A	<input type="radio"/> B	<input type="checkbox"/>	<input type="radio"/> D
11.	<input type="radio"/> A	<input type="radio"/> B	<input type="radio"/> C	<input type="checkbox"/>
12.	<input type="radio"/> A	<input type="checkbox"/>	<input type="radio"/> C	<input type="radio"/> D
13.	<input type="radio"/> A	<input type="radio"/> B	<input type="radio"/> C	<input type="checkbox"/>
14.	<input type="radio"/> A	<input type="radio"/> B	<input type="checkbox"/>	<input type="radio"/> D
15.	<input type="checkbox"/>	<input type="radio"/> B	<input type="radio"/> C	<input type="radio"/> D
16.	<input type="radio"/> A	<input type="checkbox"/>	<input type="radio"/> C	<input type="radio"/> D
17.	<input type="radio"/> A	<input type="radio"/> B	<input type="checkbox"/>	<input type="radio"/> D
18.	<input type="radio"/> A	<input type="checkbox"/>	<input type="radio"/> C	<input type="radio"/> D
19.	<input type="radio"/> A	<input type="checkbox"/>	<input type="radio"/> C	<input type="radio"/> D
20.	<input type="radio"/> A	<input type="radio"/> B	<input type="radio"/> C	<input type="checkbox"/>

1. Compounds X, Y and Z are in equilibrium. The graph below shows how the equilibrium yield of compound Z changes with variations in temperature and pressure.



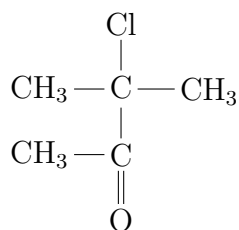
Which equation is consistent with this graph?

- (A) $X_{(g)} + 3 Y_{(g)} \rightleftharpoons 2 Z_{(g)} \quad \Delta H < 0$
- (B) $X_{(g)} + 3 Y_{(g)} \rightleftharpoons 2 Z_{(g)} \quad \Delta H > 0$
- (C) $2 X_{(g)} \rightleftharpoons 2 Y_{(g)} + Z_{(g)} \quad \Delta H < 0$
- (D) $2 X_{(g)} \rightleftharpoons 2 Y_{(g)} + Z_{(g)} \quad \Delta H > 0$
2. Which of the following is a conjugate acid/base pair that contains an amphoteric species?
- (A) HCl/Cl^-
- (B) $\text{HPO}_4^{2-}/\text{PO}_4^{3-}$
- (C) $\text{H}_2\text{CO}_3/\text{CO}_3^{2-}$
- (D) $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$
3. Which of the following compounds are a pair of functional group isomers?
- (A) Hex-1-ene and cyclohexene
- (B) Butan-1-ol and 2-methylpropan-2-ol
- (C) Pentane and 2-methylbutane
- (D) Pentanal and pentan-2-one
4. A sample of solid magnesium hydroxide was added to a sodium hydroxide solution with a pH of 12.00 and only some of the magnesium hydroxide dissolved.

What is the equilibrium concentration of magnesium ions in the resultant solution?

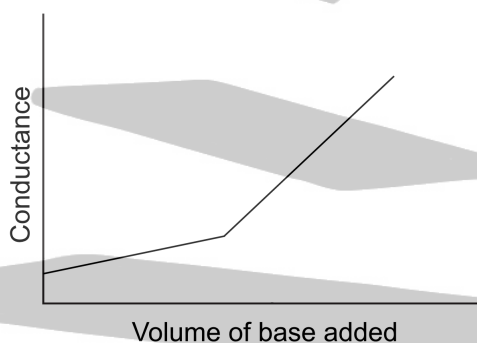
- (A) $5.6 \times 10^{-8} \text{ mol L}^{-1}$
- (B) $5.6 \times 10^{-9} \text{ mol L}^{-1}$
- (C) $5.6 \times 10^{-10} \text{ mol L}^{-1}$
- (D) $5.6 \times 10^{-11} \text{ mol L}^{-1}$

5. Consider the following compound:



What is the systematic name of this compound?

- (A) 2-chloro-2-methylbutanal
(B) 2-chloro-2,2-dimethylpropanal
(C) 3-chloro-3-methylbutan-2-one
(D) 3-chloro-3,3-dimethylpropan-2-one
6. A conductometric acid-base titration was carried out and the following conductivity curve was obtained.



Which row of the following table contains an indicator that would be suitable for this titration?

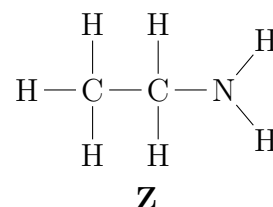
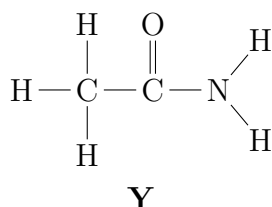
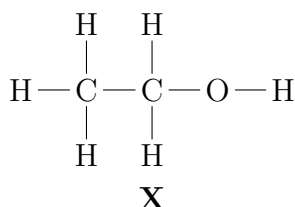
	Indicator	pH range
(A)	Crystal violet	0.0 – 2.0
(B)	Methyl red	4.4 – 6.2
(C)	Cresolphthalein	8.2 – 9.8
(D)	Indigo carmine	11.4 – 13.0

7. A 50.0 mL sample of contaminated water was analysed for its lead ion content. Excess sodium chloride was added to this sample and the lead(II) chloride precipitate that formed was filtered, dried and weighed. It had a mass of 0.110 g.

What is the concentration of lead ions in the water sample?

- (A) 1640 ppm
(B) 1880 ppm
(C) 2120 ppm
(D) 2360 ppm

8. Consider the following compounds which have been labelled as **X**, **Y** and **Z**:



Which of the following arranges these compounds in order of increasing boiling point?

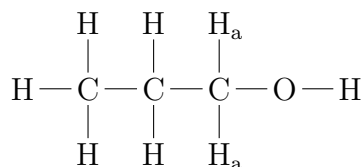
- (A) **X** < **Y** < **Z**
 (B) **X** < **Z** < **Y**
 (C) **Y** < **X** < **Z**
 (D) **Z** < **X** < **Y**
9. A sodium hydroxide solution was prepared by weighing out 1.00 g of solid sodium hydroxide and dissolving it in sufficient distilled water to make a 250.0 mL solution. A hydrochloric acid solution was then titrated with the sodium hydroxide solution using an appropriate indicator. The titration was repeated three more times and the results are shown below.

Titration	Volume of NaOH added (mL)
1	15.20
2	15.15
3	15.10
4	15.10

Which row of the following table best describes the results of this experiment?

	Reliability	Accuracy	Calculated HCl concentration
(A)	Unreliable	Accurate	Correct
(B)	Reliable	Inaccurate	Underestimated
(C)	Reliable	Inaccurate	Overestimated
(D)	Reliable	Accurate	Correct

10. Consider the following compound where one of the ^1H environments has been labelled as H_a :



What would be the splitting pattern of the signal produced by the H_a environment on a ^1H nuclear magnetic resonance (NMR) spectrum under standard conditions?

- (A) Singlet
 (B) Doublet
 (C) Triplet
 (D) Quartet

11. A 40.0 mL solution of 0.20 mol L^{-1} barium nitrate is mixed with 40.0 mL of 0.20 mol L^{-1} sodium hydroxide solution at 25°C .

Which row of the following table correctly predicts if barium hydroxide will form as a precipitate and the reason for this?

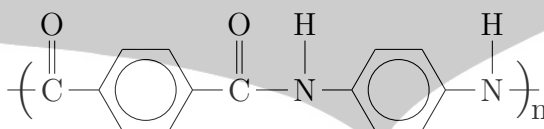
	Will a precipitate form?	Reason
(A)	No	$Q_{\text{sp}} < K_{\text{sp}}$
(B)	No	$Q_{\text{sp}} > K_{\text{sp}}$
(C)	Yes	$Q_{\text{sp}} < K_{\text{sp}}$
(D)	Yes	$Q_{\text{sp}} > K_{\text{sp}}$

12. The table below shows the heat of combustion of three different alcohols in kJ g^{-1} .

Alcohol	Heat of combustion (kJ g^{-1})
Methanol	22.7
Ethanol	29.7
Propan-1-ol	33.6

What is the most likely molar heat of combustion of butan-1-ol?

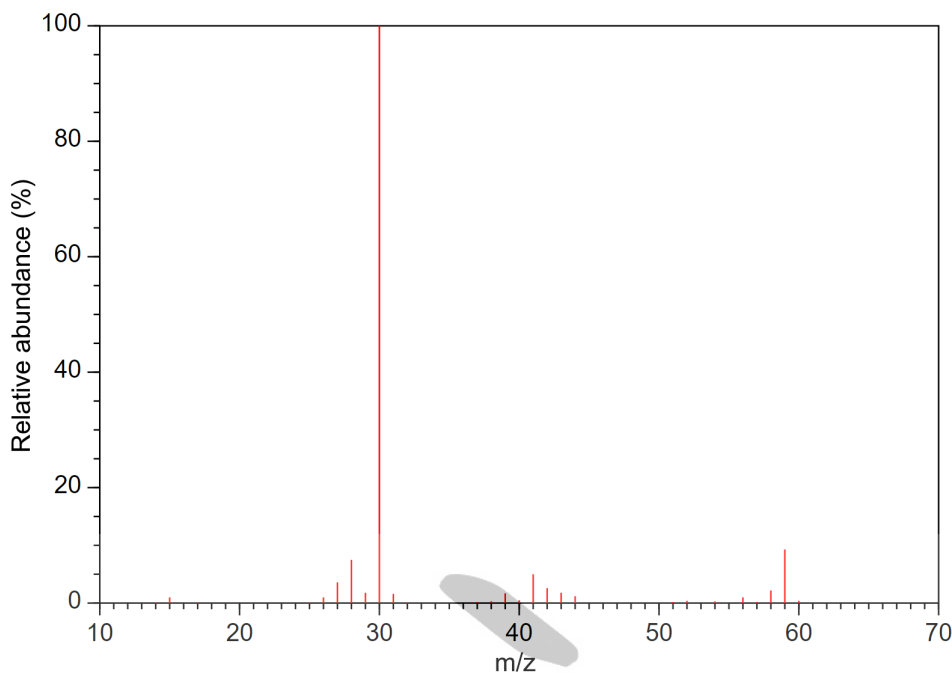
- (A) 2019 kJ mol^{-1}
 (B) 2671 kJ mol^{-1}
 (C) 5286 kJ mol^{-1}
 (D) 36.0 kJ g^{-1}
13. The polymer below can be produced from a reaction between two different monomers.



Which of the following is one of the monomers used to produce the above polymer?

- (A) $\text{H}_2\text{N}-\text{C}_6\text{H}_4-\text{COOH}$
 (B) $\text{HO}-\text{C}_6\text{H}_4-\text{COOH}$
 (C) $\text{H}_2\text{N}-\text{C}_6\text{H}_4-\text{CONH}_2$
 (D) $\text{H}_2\text{N}-\text{C}_6\text{H}_4-\text{NH}_2$

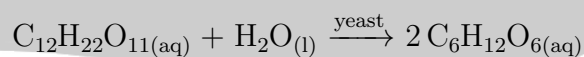
14. The mass spectrum of propan-1-amine is shown below.



Which species is most likely responsible for the base peak on this mass spectrum?

- (A) C_2H_5^+
- (B) C_2H_6^+
- (C) CH_2NH_2^+
- (D) $\text{C}_3\text{H}_7\text{NH}_2^+$

15. A solution of sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) was allowed to undergo fermentation in a conical flask that was stoppered with cotton wool. During this process, yeast enzymes first hydrolyse sucrose into simple carbohydrates according to the following equation:



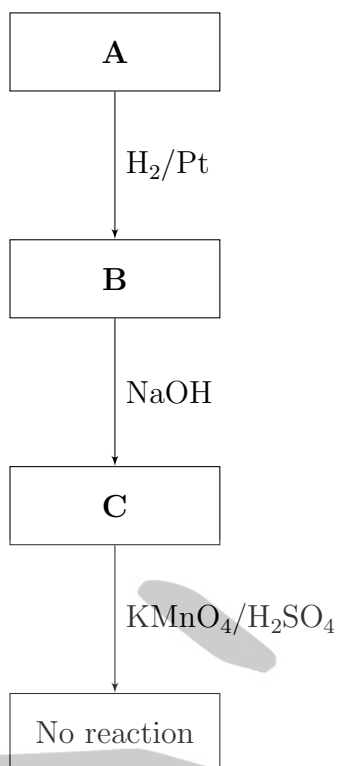
The simple carbohydrates produced are then converted into ethanol and carbon dioxide.

The initial mass of the conical flask with its contents was 365.8 g and after several days, the final mass was found to be 354.3 g.

What is the theoretical mass of sucrose that got consumed during this time period?

- (A) 22.4 g
- (B) 33.6 g
- (C) 44.8 g
- (D) 56.0 g

16. Consider the following series of reactions where **A**, **B** and **C** are different organic compounds.



Based on the above information, a possible identity for compound **A** is:

- (A) 4-bromo-3-methylbut-1-ene
 - (B) 3-bromo-3-methylbut-1-ene
 - (C) 2-bromo-3-methylbut-1-ene
 - (D) 1-bromo-3-methylbut-1-ene
17. A laboratory contains solutions of hydrochloric acid and acetic acid, both at equal volumes with the same pH of 2.00. A chemist made the following statements regarding these solutions:
- (i) Both solutions have the same hydronium ion concentration
 - (ii) A 10-fold dilution of both acids would cause both their pH values to increase by 1 unit
 - (iii) The hydrochloric acid solution would require a smaller volume of 0.10 mol L⁻¹ sodium hydroxide solution to be completely neutralised than the acetic acid solution

Which of the above statement(s) are correct?

- (A) (i) only
- (B) (i) and (ii) only
- (C) (i) and (iii) only
- (D) (i), (ii) and (iii)

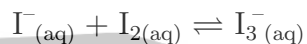
18. The table shows some properties of two organic compounds, X and Y.

Compound	Solubility in water	Litmus paper test
X	Partially soluble	Blue litmus turns red
Y	Soluble	Red litmus turns blue

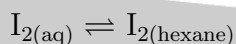
Which row of the following table best identifies compounds X and Y?

	X	Y
(A)	HCOOH	C ₆ H ₁₃ NH ₂
(B)	C ₅ H ₁₁ COOH	CH ₃ NH ₂
(C)	CH ₃ NH ₂	C ₅ H ₁₁ COOH
(D)	C ₆ H ₁₃ NH ₂	HCOOH

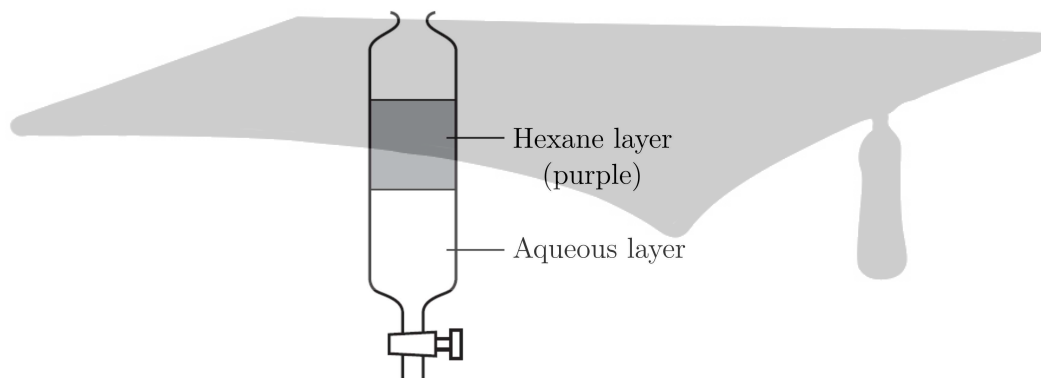
19. In aqueous solution, iodide ions (I⁻) can react with iodine (I₂) to form triiodide ions (I₃⁻) and an equilibrium is established.



When hexane is added to this system, two separate layers form and some iodine dissolves into the hexane layer which becomes purple due to the dissolved iodine. The following distribution equilibrium is then established:



The diagram below shows the appearance of the equilibrium mixture.



Which row of the following table shows the most likely colour changes that would occur in the hexane layer when potassium iodide and silver nitrate are added to the aqueous layer?

	KI added	AgNO ₃ added
(A)	Purple colour fades	Purple colour fades
(B)	Purple colour fades	Purple colour intensifies
(C)	Purple colour intensifies	Purple colour fades
(D)	Purple colour intensifies	Purple colour intensifies

20. A 25.0 mL solution of 0.15 mol L^{-1} nitric acid was mixed with a 20.0 mL solution of 0.10 mol L^{-1} barium hydroxide.

What is the pH of the resultant solution?

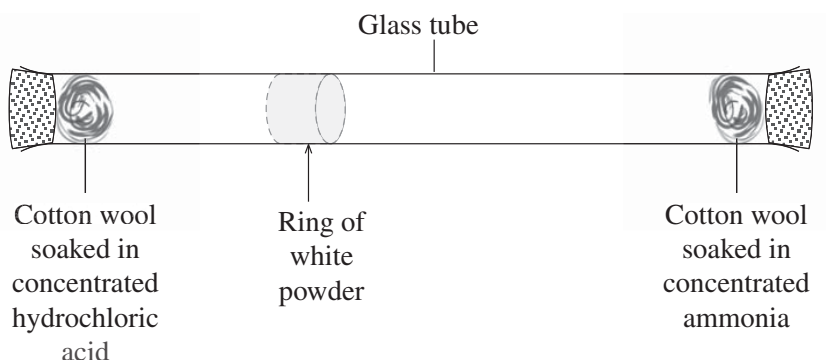
- (A) 7.70
- (B) 9.06
- (C) 10.40
- (D) 11.74



Section II: Short Answer Questions (80 marks)

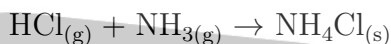
Question 21 (4 marks)

A chemist placed two pieces of cotton wool at opposite ends of a sealed horizontal glass tube. One piece of cotton wool was soaked in concentrated ammonia solution, and the other was soaked in concentrated hydrochloric acid solution. Over time, a ring of white powder is formed inside the tube. This is shown in the schematic diagram below.



- (a) Explain why this reaction is well accounted for by the Brønsted-Lowry theory of acids and bases, but not by the Arrhenius theory. Include a relevant chemical equation in your answer. 3

Brønsted/Lowry defined acids as proton donors and bases as proton acceptors. In this case, Brønsted/Lowry would view this as a classic acid-base reaction since HCl acts as an acid by transferring a proton to NH_3 which acts as a base.



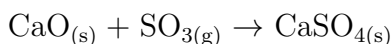
Arrhenius defined acids as substances that ionised to produce H^+ ions and bases as substances that produced OH^- ions in aqueous solution. Arrhenius would not have classified this as an acid-base reaction, as there is no aqueous solvent and no ionisation of the acid has occurred.

2 marks – Explains how the process would be viewed differently by both theories

1 mark – Provides a relevant chemical equation

- (b) Describe ONE limitation of the Brønsted-Lowry theory of acids and bases. 1

The Brønsted-Lowry theory cannot account for reactions involving acidic non-metal oxides and basic metal oxides, since there is no proton transfer occurring.



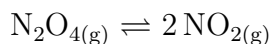
1 mark – Describes ONE limitation of the Brønsted-Lowry theory

Answers may also include:

- The Brønsted-Lowry theory cannot account for the acidic nature of substances such as AlCl_3 or BF_3 which do not contain any hydrogen and cannot donate a proton.

Question 22 (7 marks)

N_2O_4 is a colourless gas that can dissociate into brown NO_2 gas according to this equation:



- (a) When an equilibrium mixture of N_2O_4 and NO_2 is placed into an ice bath, the brown colour of the mixture fades. 2

Explain whether the decomposition of N_2O_4 into NO_2 is endothermic or exothermic.

At lower temperatures, Le Chatelier's principle predicts the equilibrium will favour the heat releasing exothermic reaction to increase the temperature. When the mixture was placed into an ice bath, the brown colour fades, indicating that the reverse reaction is favoured at lower temperatures. Therefore, the reverse reaction must be exothermic and so the forward reaction (the decomposition of N_2O_4) must be endothermic.

1 mark – Identifies that the decomposition of N_2O_4 is endothermic

1 mark – Explains why the decomposition of N_2O_4 is endothermic with reference to the observation and Le Chatelier's principle

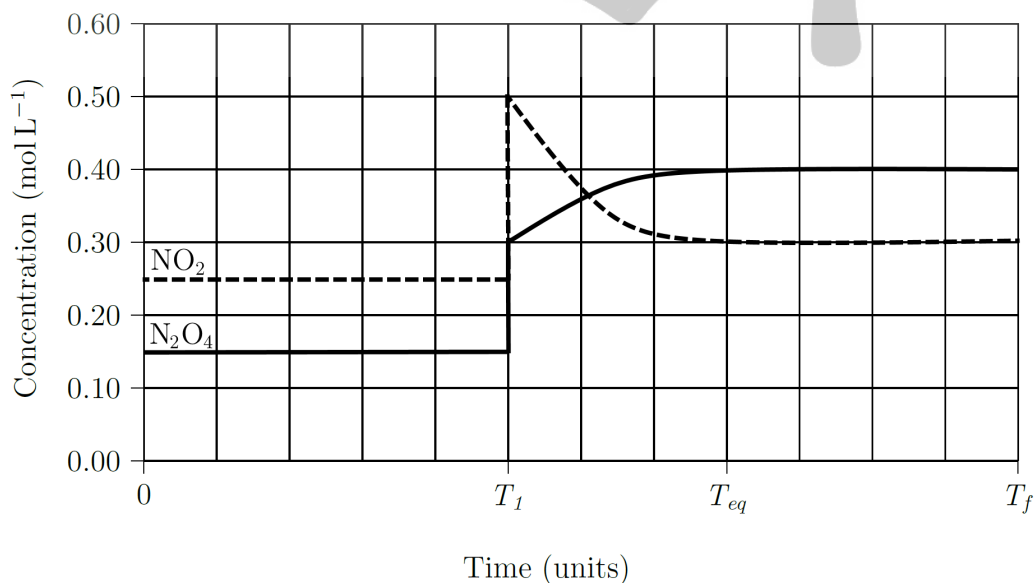
- (b) A reaction vessel initially contained the following concentration of gases at equilibrium. 2

Gas	Initial equilibrium concentration (mol L^{-1})
N_2O_4	0.15
NO_2	0.25

At time T_1 , the volume of the reaction vessel was halved and the system was then allowed to reach equilibrium at time T_{eq} .

Sketch two curves on the provided graph to show how the concentrations of N_2O_4 and NO_2 gas will vary as a function of time between $t = 0$ and $t = T_f$.

Note that absolute concentration values at T_{eq} are not important.



- 1 mark – Indicates a gradual increase in $[\text{N}_2\text{O}_4]$ and a gradual decrease in $[\text{NO}_2]$ after T_1
- 1 mark – Indicates constant concentrations at equilibrium and an instant increase in the concentration of both gases (doubled) at T_1 , and also conserves the stoichiometric ratio

(c) Explain how the equilibrium position changes after T_1 using collision theory.

3

When the volume is reduced, the collision theory predicts that the rates of both the forward and reverse reactions will increase since there will be more successful collisions between gas particles that are packed more closely together. However, the rate of the reverse reaction, which involves more moles of gas, will increase to a greater extent. As such, the reverse reaction rate will be higher than the forward reaction rate, causing the equilibrium to shift left due to the net reverse reaction that occurs.

- 1 mark – Identifies that the equilibrium position will shift left (favour the reactants)
- 1 mark – Explains that the forward and reverse reaction rates both increase with reference to collision theory
- 1 mark – Explains the equilibrium position shifting left with reference to the relative rates of the forward and reverse reactions

Question 23 (4 marks)

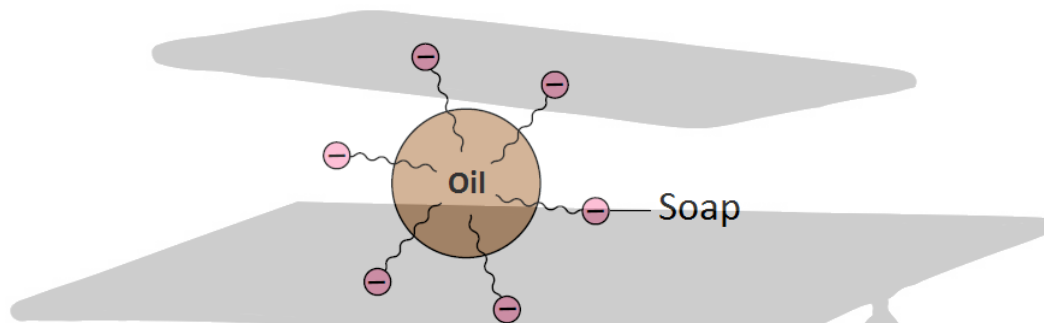
A student carried out an experiment to test the effectiveness of soap in hard water which contains a high content of calcium and magnesium ions. 4

The student prepared two beakers, one containing distilled water and the other containing hard water. A fabric soaked in oil was added to both beakers followed by a soap solution. The resultant mixtures were then stirred and the results of the experiment are shown below:

Type of water	Observations
Distilled water	<ul style="list-style-type: none">• Oily stains on fabric were removed
Hard water	<ul style="list-style-type: none">• White precipitate formed in solution• Oily stains remained on the fabric

Account for the results obtained in this experiment with reference to the molecular structure and cleaning action of soap.

Soap contains a long non-polar hydrocarbon tail and a negatively charged carboxylate polar head. When soap is added to the oily fabric in distilled water, the hydrophobic tail is embedded in the oil via dispersion forces, while the hydrophilic head interacts with water through ion-dipole forces. With agitation, the oil particles are lifted off the fabric and micelles are formed.



The micelles are stabilised due to repulsions between the negative polar heads so the oil particles cannot coalesce. This forms a stable emulsion of water and oil that can be washed away, leaving the fabric clean.

In hard water, Ca^{2+} and Mg^{2+} ions can react with soap anions to form a white precipitate known as 'scum'. This disrupts the cleaning efficacy of soap resulting in the oily stains remaining on the fabric.

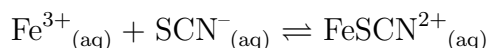
1 mark – Describes the molecular structure of soap

2 marks – Accounts for the removal of the oily stains from the fabric in distilled water with reference to intermolecular forces and micelle formation

1 mark – Accounts for the formation of the white precipitate and the oily stains remaining on the fabric in hard water

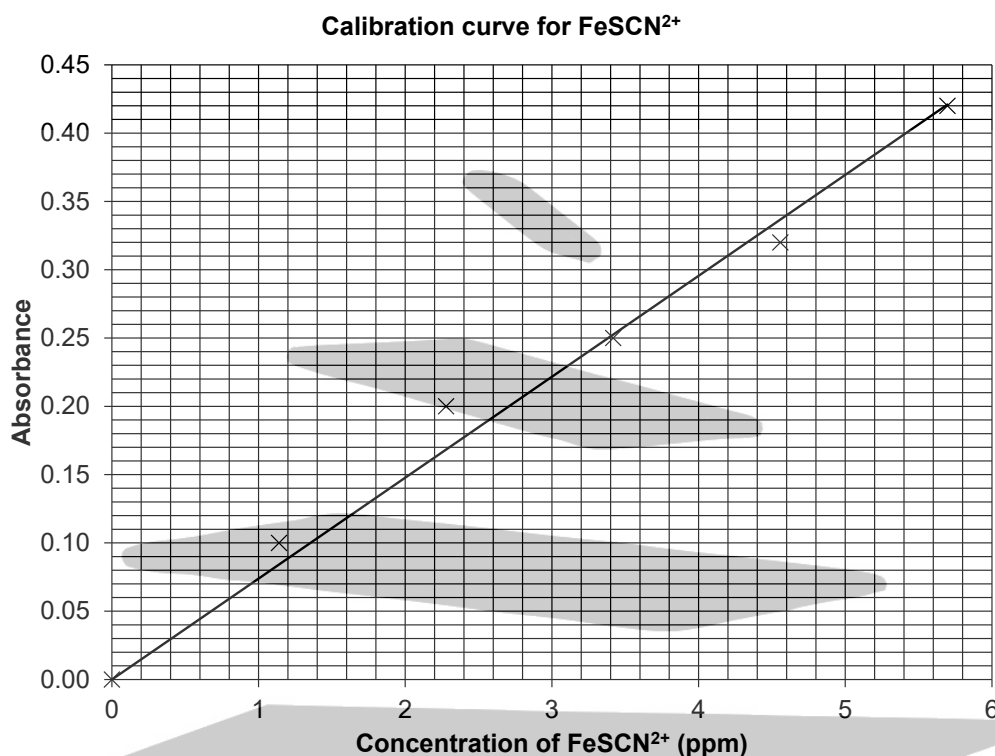
Question 24 (4 marks)

Consider the following equilibrium reaction:



The following procedure was used to determine the equilibrium constant for this reaction.

- 2.0 mL of $2.5 \times 10^{-3} \text{ mol L}^{-1} \text{ Fe(NO}_3)_3$ and 2.0 mL of $2.5 \times 10^{-3} \text{ mol L}^{-1} \text{ KSCN}$ was mixed in a 10.0 mL volumetric flask and then filled to the mark with distilled water.
- The resultant solution was allowed to reach equilibrium and its absorbance at 480 nm was measured with colourimetry and found to be 0.280.
- A series of standard solutions was used to construct the calibration curve below.



Calculate the equilibrium constant for the reaction.

Interpolating from the calibration curve, when $A = 0.280$, $[\text{FeSCN}^{2+}]_{\text{eq}} = 3.8 \text{ ppm}$

$$\begin{aligned}
 [\text{FeSCN}^{2+}]_{\text{eq}} &= 3.8 \text{ mg L}^{-1} \\
 &= 3.8 \times 10^{-3} \text{ g L}^{-1} \\
 &= \frac{3.8 \times 10^{-3} \text{ g L}^{-1}}{(55.85 + 32.07 + 12.01 + 14.01) \text{ g mol}^{-1}} \\
 &= 3.3 \times 10^{-5} \text{ mol L}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{Fe}^{3+}) &= 2.5 \times 10^{-3} \text{ mol L}^{-1} \times 2.0 \times 10^{-3} \text{ L} \\
 &= 5.0 \times 10^{-6} \text{ mol} \\
 [\text{Fe}^{3+}]_{\text{i}} &= \frac{5.0 \times 10^{-6} \text{ mol}}{0.010 \text{ L}} \\
 &= 5.0 \times 10^{-4} \text{ mol L}^{-1}
 \end{aligned}$$

Similarly,

$$[\text{SCN}^-]_{\text{i}} = 5.0 \times 10^{-4} \text{ mol L}^{-1}$$

	Fe^{3+}	SCN^-	FeSCN^{2+}
Initial	5.0×10^{-4}	5.0×10^{-4}	0
Change	-3.3×10^{-5}	-3.3×10^{-5}	$+3.3 \times 10^{-5}$
Equilibrium	4.7×10^{-4}	4.7×10^{-4}	3.3×10^{-5}

$$\begin{aligned} K &= \frac{[\text{FeSCN}^{2+}]}{[\text{Fe}^{3+}][\text{SCN}^-]} \\ &= \frac{3.3 \times 10^{-5}}{4.7 \times 10^{-4} \times 4.7 \times 10^{-4}} \\ &= 150 \end{aligned}$$

1 mark – Correctly interpolates the FeSCN^{2+} concentration from the graph AND converts the value to mol L^{-1}

1 mark – Calculates the correct equilibrium concentration of all species

1 mark – Writes a correct expression for K

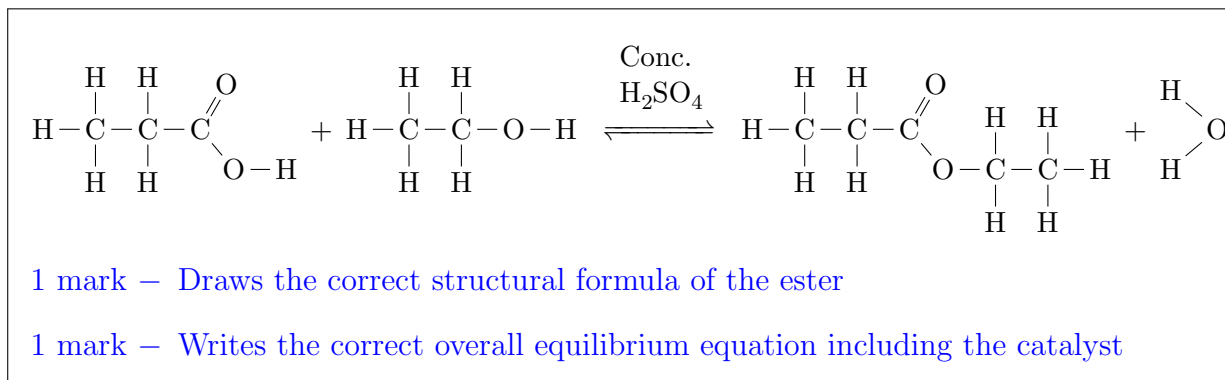
1 mark – Calculates the correct value of K

Question 25 (10 marks)

Ethanol, propanoic acid and concentrated sulfuric acid were mixed into a flask and then heated under reflux.

- (a) Write a chemical equation, using structural formulae, for the reaction that occurs.

2



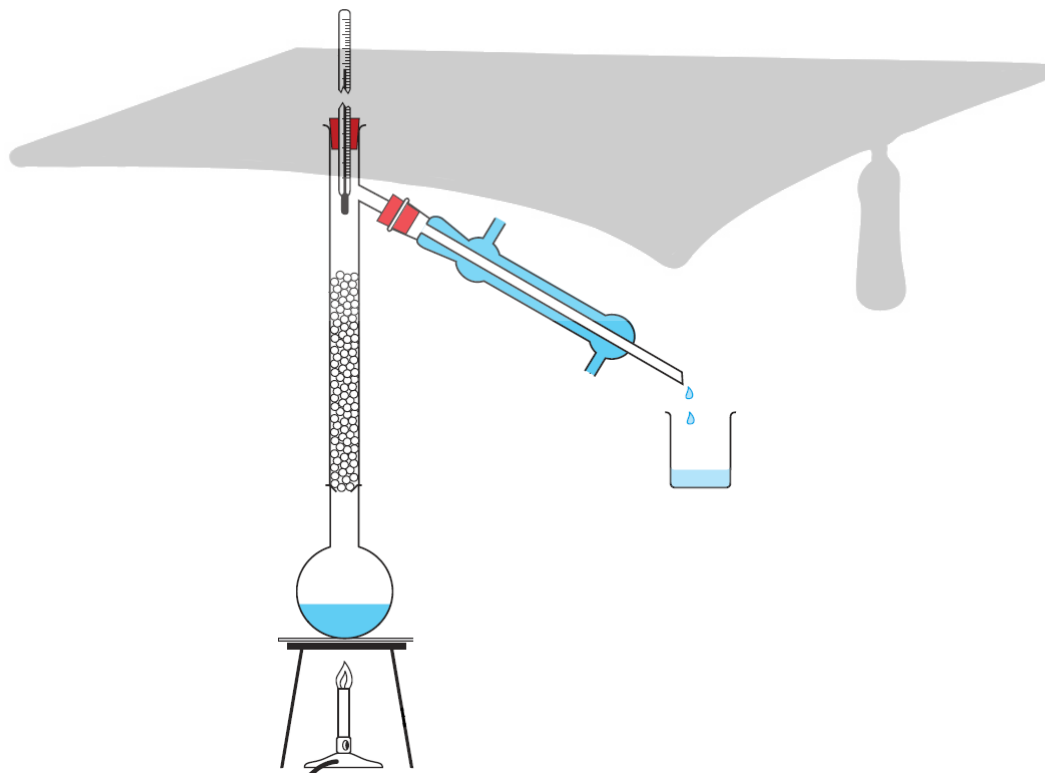
- (b) Outline why refluxing is used to carry out this reaction.

2

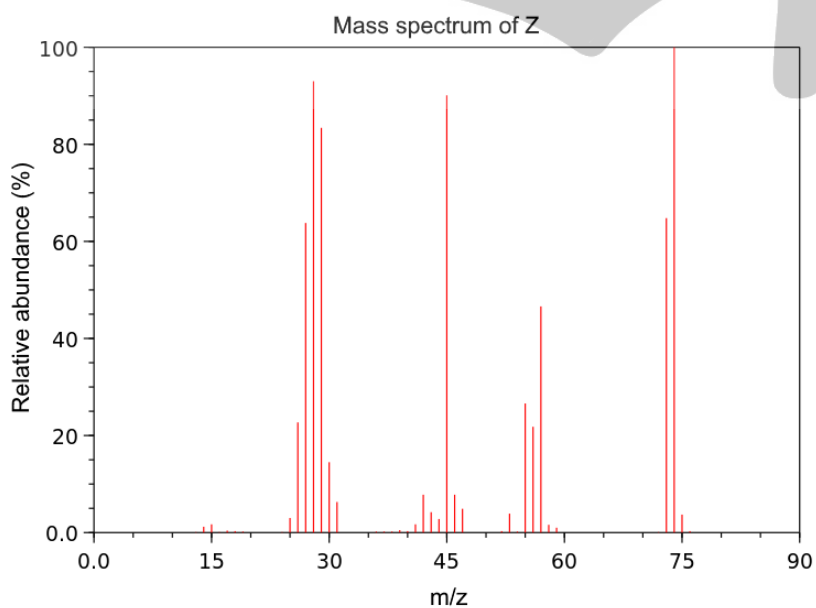
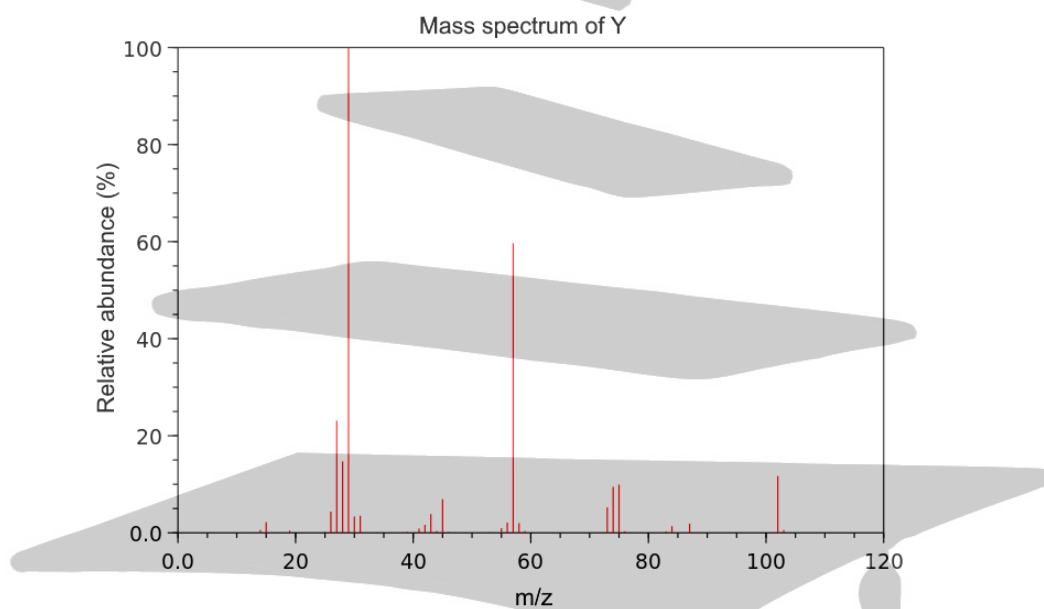
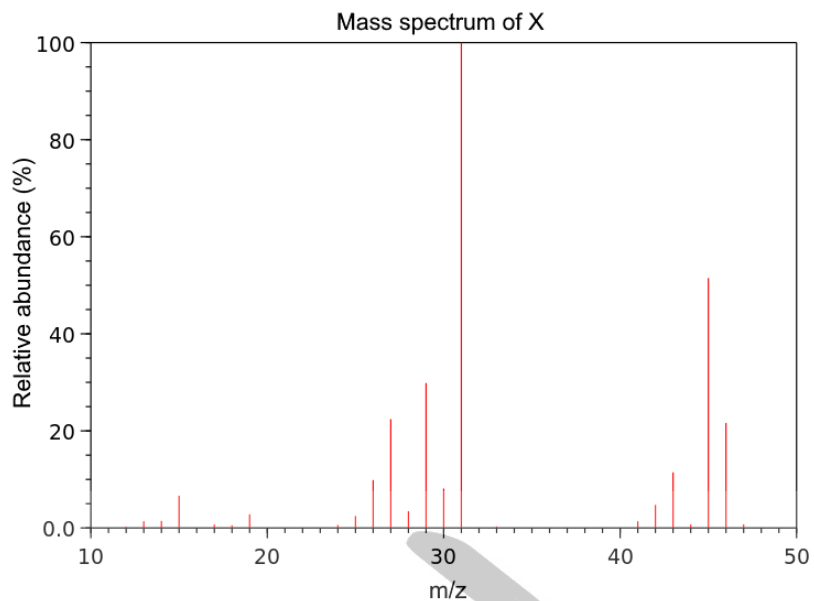
Refluxing is used as it allows the reaction mixture to be heated to increase the reaction rate while preventing the loss of any volatile substances. Any substances that vaporise from the heat enter an attached condenser, condense and trickle back into the reaction vessel. Using a reflux condenser that is open at the top is also much safer than a closed system prone to dangerous gas pressure build-up.

2 marks – Outlines at least TWO reasons for why refluxing is used

After the reaction, the reaction mixture was separated using the apparatus shown below.



Three pure organic compounds were collected in separate beakers and were labelled as X, Y and Z in order of collection. Each compound was analysed with mass spectrometry and the resultant mass spectra are shown below.



- (c) What are the identities of compounds X, Y and Z, and which of these has the lowest boiling point as indicated by the order of collection? 1

X = ethanol, Y = ethyl propanoate, Z = propanoic acid.

Ethanol (X) has the lowest BP.

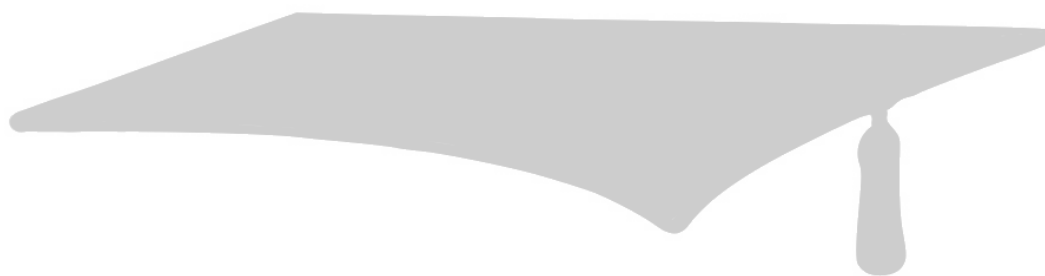
1 mark – Clearly identifies X, Y and Z, and states that ethanol (X) has the lowest BP

- (d) Explain the differences in boiling point between compounds X, Y and Z. 5

Ethanol is a polar molecule that can form strong hydrogen bonds due to its polar hydroxyl (-OH) group. Ethyl propanoate is also polar due to its ester (-COO-) group, but it cannot form hydrogen bonds since it doesn't contain any O-H bonds. Instead, it forms weaker dipole-dipole forces. However, ethyl propanoate has a much larger molar mass (102 g mol^{-1}) than ethanol (46 g mol^{-1}) and thus stronger dispersion forces which compensates for its lack of hydrogen bonding. Larger molecules contain more electrons which results in a higher probability of temporary dipoles forming and stronger dispersion forces. Ultimately, more energy will be required to overcome the total intermolecular forces of ethyl propanoate, giving it a higher BP than ethanol.

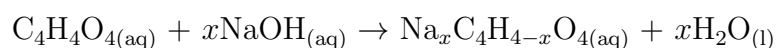
Propanoic acid has the highest BP despite having a lower molar mass (74 g mol^{-1}) than ethyl propanoate and thus weaker dispersion forces. This is because it is a polar molecule that contains a highly polar carboxyl (-COOH) group which allows it to form more extensive hydrogen bonds that are very strong and require significant energy to overcome.

5 marks – Explains the differences in BP between the three compounds in terms of intermolecular forces



Question 26 (8 marks)

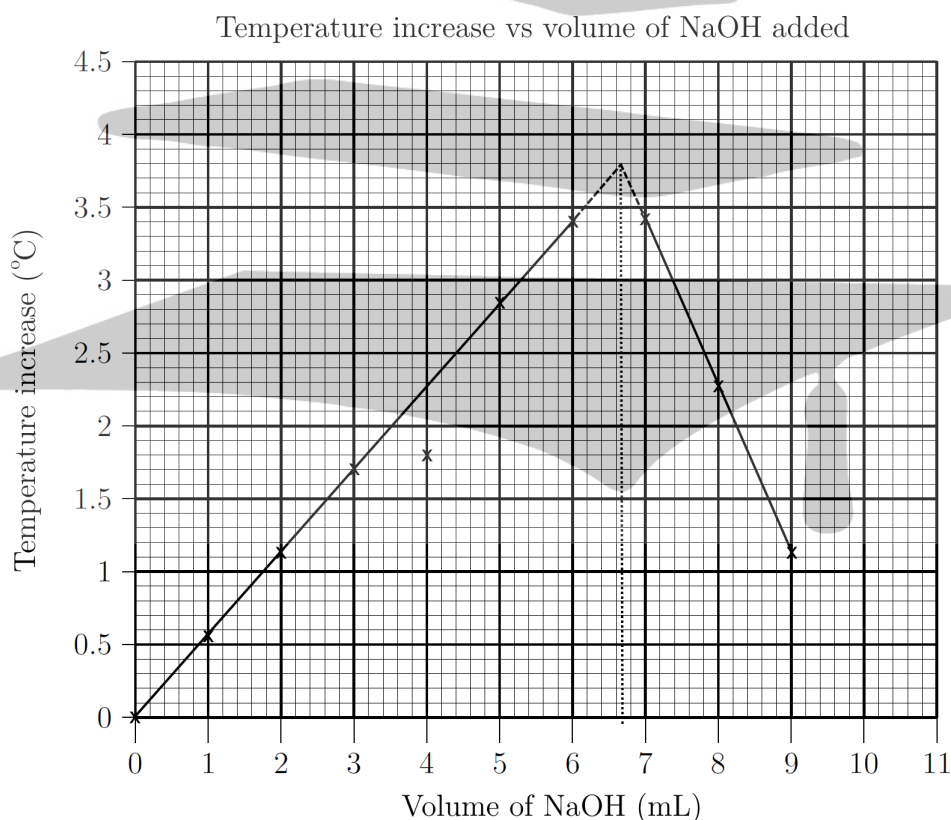
An unknown organic acid with a molecular formula of $\text{C}_4\text{H}_4\text{O}_4$ reacts with sodium hydroxide to form a salt and water according to the following general equation:



To determine the stoichiometric ratio between $\text{C}_4\text{H}_4\text{O}_4$ and sodium hydroxide, ten 10.0 mL samples were prepared by mixing together various volumes of $\text{C}_4\text{H}_4\text{O}_4$ and sodium hydroxide. All of the $\text{C}_4\text{H}_4\text{O}_4$ and sodium hydroxide solutions used had identical concentrations and temperatures. The temperature change of each sample was measured and the results are given below.

Sample	1	2	3	4	5	6	7	8	9	10
Volume of NaOH (mL)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Volume of $\text{C}_4\text{H}_4\text{O}_4$ (mL)	10.0	9.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0
Temperature increase ($^{\circ}\text{C}$)	0.00	0.56	1.14	1.70	1.80	2.85	3.40	3.42	2.28	1.13

- (a) Construct an appropriate graph of the data and hence determine the value of x to the nearest integer. 4



The maximum of the graph indicates when NaOH has stoichiometrically reacted with C₄H₄O₄. This occurs when 6.67 mL of NaOH has been mixed with 3.33 mL of C₄H₄O₄.

$$\begin{aligned}\frac{x}{1} &= \frac{n(\text{NaOH})}{n(\text{C}_4\text{H}_4\text{O}_4)} \\ x &= \frac{cV(\text{NaOH})}{cV(\text{C}_4\text{H}_4\text{O}_4)} \\ &= \frac{V(\text{NaOH})}{V(\text{C}_4\text{H}_4\text{O}_4)} \\ &= \frac{6.67 \text{ mL}}{3.33 \text{ mL}} \\ &= 2\end{aligned}$$

2 marks – Constructs an appropriate graph with volume of NaOH (or C₄H₄O₄) on the *x*-axis and temperature increase on the *y*-axis including units

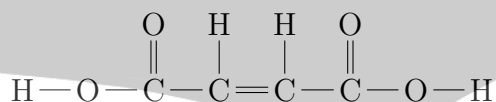
1 mark – Draws TWO lines of best fit for the data (NOT curved) and ignores the outlier

1 mark – Determines the correct value of *x*

- (b) When a few drops of bromine water is added to the unknown organic acid, the bromine water is decolourised. 1

Draw a possible structural formula for the unknown organic acid that is consistent with all the information provided.

The organic acid is a diprotic acid since $x = 2$, so it likely contains two carboxyl (–COOH) groups. It also contains a C=C double bond since it decolourises bromine water. A possible structure would be:



1 mark – Draws a possible structural formula for the organic acid

(c) The enthalpy change per mole of water formed in the neutralisation reaction is -56 kJ mol^{-1} .

3

If 15% of the heat released by the reaction was lost to the surroundings, calculate the concentration of the sodium hydroxide solution before it was mixed with the organic acid.

The concentration of NaOH can be calculated using any of the data points on the line where NaOH is the limiting reagent. Using the maximum point of (6.67, 3.80):

$$\begin{aligned}q_{\text{mixture}} &= mc\Delta T \\&= 10.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times 3.80 \text{ K} \\&= 158.84 \text{ J}\end{aligned}$$

If 15% of the heat released by the reaction was lost to the surroundings, then only 85% of it was absorbed by the mixture.

$$\begin{aligned}q_{\text{mixture}} &= -0.85q_{\text{reaction}} \\q_{\text{reaction}} &= \frac{-q_{\text{mixture}}}{0.85} \\&= \frac{-158.84 \text{ J}}{0.85} \\&= -186.87 \text{ J} \\ \Delta H_{\text{neut}} &= \frac{q_{\text{reaction}}}{n(\text{H}_2\text{O})_{\text{formed}}} \\-56 \times 10^3 \text{ J mol}^{-1} &= \frac{-186.87 \text{ J}}{n(\text{H}_2\text{O})_{\text{formed}}} \\ \Rightarrow n(\text{H}_2\text{O})_{\text{formed}} &= 3.34 \times 10^{-3} \text{ mol} \\ n(\text{NaOH}) &= 3.34 \times 10^{-3} \text{ mol} \\ [\text{NaOH}] &= \frac{3.34 \times 10^{-3} \text{ mol}}{6.67 \times 10^{-3} \text{ L}} \\ &= 0.50 \text{ mol L}^{-1}\end{aligned}$$

3 marks – Calculates the correct concentration of NaOH (may use a different data point and the final answer may vary slightly)

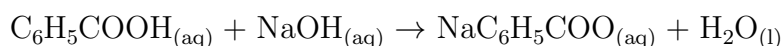
Answers may also include:

$$\begin{aligned}\Delta H_{\text{neut}} &= \frac{q_{\text{reaction}}}{n(\text{H}_2\text{O})_{\text{formed}}} \\&= \frac{-q_{\text{mixture}}}{0.85 \times [\text{NaOH}] \times V} \\&= \frac{-mc\Delta T}{0.85 \times [\text{NaOH}] \times V} \\ \Rightarrow \Delta T &= -\frac{0.85 \times [\text{NaOH}] \times \Delta H_{\text{neut}} V}{mc} \\ \Rightarrow \text{Gradient} &= -\frac{0.85 \times [\text{NaOH}] \times \Delta H_{\text{neut}}}{mc} \\ \frac{(3.80 - 0) \text{ K}}{(6.67 \times 10^{-3} - 0) \text{ L}} &= -\frac{0.85 \times [\text{NaOH}] \times -56 \times 10^3 \text{ J mol}^{-1}}{10.0 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1}} \\ \Rightarrow [\text{NaOH}] &= 0.50 \text{ mol L}^{-1}\end{aligned}$$

Question 27 (9 marks)

A student transferred 25.00 mL of a benzoic acid solution into a beaker and titrated it against a $0.1389 \text{ mol L}^{-1}$ sodium hydroxide solution. As the titrant was being delivered, changes in pH were monitored using a pH meter immersed in the beaker solution and attached to a data logger. In total, 40.00 mL of sodium hydroxide was added before the recording was stopped (**This does NOT represent the equivalence point**). The benzoic acid solution was found to have a pH of 2.60 and a concentration of $0.1000 \text{ mol L}^{-1}$.

- (a) Given that benzoic acid is a weak monoprotic acid with a molecular formula of $\text{C}_6\text{H}_5\text{COOH}$, show that the amount of salt produced at the equivalence point is $2.500 \times 10^{-3} \text{ mol}$. 1



$$\begin{aligned} n(\text{C}_6\text{H}_5\text{COOH}) &= cV \\ &= 0.1000 \text{ mol L}^{-1} \times 0.02500 \text{ L} \\ &= 2.500 \times 10^{-3} \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{NaC}_6\text{H}_5\text{COO}) &= n(\text{C}_6\text{H}_5\text{COOH}) \\ &= 2.500 \times 10^{-3} \text{ mol} \end{aligned}$$

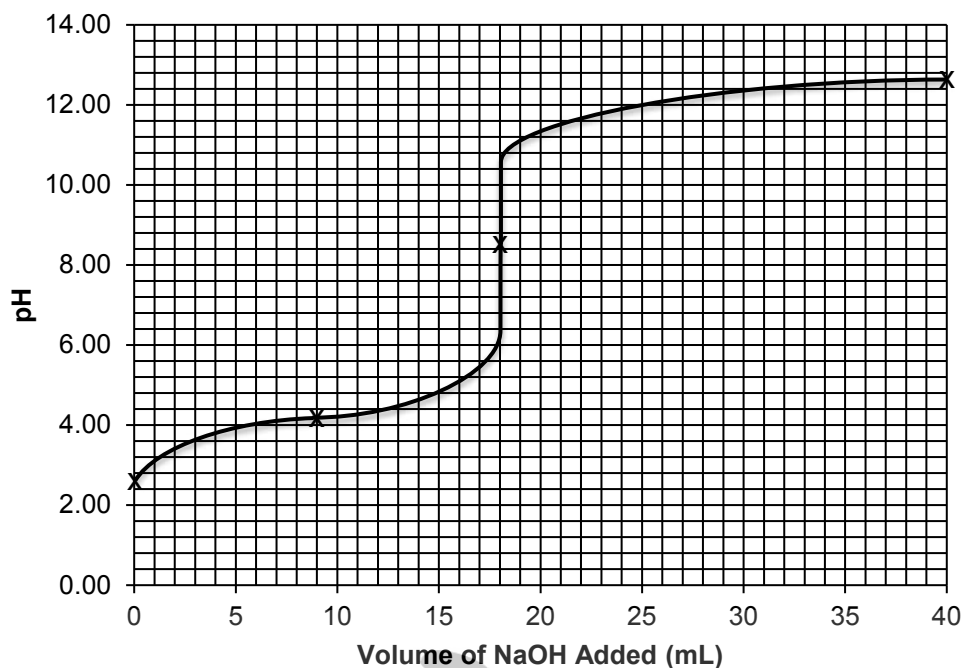
1 mark – Shows that the amount of salt produced is $2.500 \times 10^{-3} \text{ mol}$, including a relevant chemical equation

- (b) The half-equivalence point of a titration occurs when the volume of titrant that has been added is half of what is required to reach the equivalence point. It can be shown that the pH at the half-equivalence point on the titration curve is equal to the $\text{p}K_{\text{a}}$ of the weak acid being titrated. Note that you are NOT required to prove this. 8

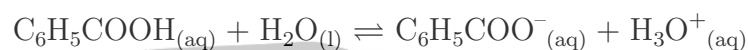
Using all of the information provided and relevant calculations, draw a titration curve for this titration on the axes below. In particular, you should clearly mark:

- The initial pH
- The pH and volume of sodium hydroxide added at the half-equivalence point
- The pH and volume of sodium hydroxide added at the equivalence point
- The final pH when 40.00 mL of sodium hydroxide has been added

You may assume that the hydrolysis of the salt produced in part (a) is negligible at the end when 40.00 mL of sodium hydroxide has been added.



Half-equivalence point



$$[\text{H}_3\text{O}^+]_{\text{eq}} = 10^{-2.60} \text{ mol L}^{-1}$$

	$\text{C}_6\text{H}_5\text{COOH}$	$\text{C}_6\text{H}_5\text{COO}^-$	H_3O^+
Initial	0.1000	0	0
Change	$-10^{-2.60}$	$+10^{-2.60}$	$+10^{-2.60}$
Equilibrium	0.097	$10^{-2.60}$	$10^{-2.60}$

$$K_a = \frac{[\text{C}_6\text{H}_5\text{COO}^-][\text{H}_3\text{O}^+]}{[\text{C}_6\text{H}_5\text{COOH}]}$$

$$= \frac{10^{-2.60} \times 10^{-2.60}}{0.097}$$

$$= 6.5 \times 10^{-5}$$

$$\text{p}K_a = -\log_{10}(6.5 \times 10^{-5})$$

$$= 4.19$$

$$\text{pH}_{\text{half eq pt}} = 4.19$$

$$n(\text{NaOH}) = 2.500 \times 10^{-3} \text{ mol}$$

$$V(\text{NaOH})_{\text{eq pt}} = \frac{2.500 \times 10^{-3} \text{ mol}}{0.1389 \text{ mol L}^{-1}}$$

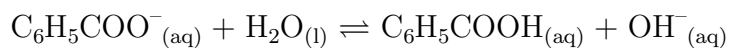
$$= 0.01800 \text{ L}$$

$$= 18.00 \text{ mL}$$

$$V(\text{NaOH})_{\text{half eq pt}} = \frac{1}{2} \times 18.00 \text{ mL}$$

$$= 9.000 \text{ mL}$$

Equivalence point



$$K_{\text{a}}K_{\text{b}} = K_{\text{w}}$$

$$6.5 \times 10^{-5} \times K_{\text{b}} = 1.00 \times 10^{-14}$$

$$K_{\text{b}} = 1.5 \times 10^{-10}$$

The volume of solution at the equivalence point is $(25.00 + 18.00) \text{ mL} = 43.00 \text{ mL}$, so:

$$\begin{aligned} [\text{C}_6\text{H}_5\text{COO}^-]_{\text{eq pt}} &= \frac{2.500 \times 10^{-3} \text{ mol}}{0.04300 \text{ L}} \\ &= 0.05814 \text{ mol L}^{-1} \end{aligned}$$

	$\text{C}_6\text{H}_5\text{COO}^-$	$\text{C}_6\text{H}_5\text{COOH}$	OH^-
Initial	0.05814	0	0
Change	$-x$	$+x$	$+x$
Equilibrium	$0.05814 - x$	x	x

$$\begin{aligned} K_{\text{b}} &= \frac{[\text{C}_6\text{H}_5\text{COO}^-][\text{OH}^-]}{[\text{C}_6\text{H}_5\text{COOH}]} \\ 1.5 \times 10^{-10} &= \frac{x^2}{0.05814 - x} \end{aligned}$$

Assume that $0.05814 - x \doteq 0.05814$ since K_{b} has a small value.

$$\begin{aligned} 1.5 \times 10^{-10} &= \frac{x^2}{0.05814} \\ \Rightarrow x &= 3.0 \times 10^{-6} \text{ mol L}^{-1} \\ [\text{OH}^-] &= 3.0 \times 10^{-6} \text{ mol L}^{-1} \\ \text{pOH} &= -\log_{10}(3.0 \times 10^{-6}) \\ &= 5.52 \\ \text{pH} &= 14.00 - 5.52 \\ &= 8.48 \end{aligned}$$

Checking the assumption,

$$\begin{aligned} K_{\text{b}} &= \frac{(3.0 \times 10^{-6})^2}{0.05814 - 3.0 \times 10^{-6}} \\ &= 1.5 \times 10^{-10} \Rightarrow \text{Valid assumption} \end{aligned}$$

Final pH

At the end, there are $(40.00 - 18.00) \text{ mL} = 22.00 \text{ mL}$ of excess NaOH in the solution.

$$\begin{aligned} n(\text{NaOH})_{\text{excess}} &= 0.1389 \text{ mol L}^{-1} \times 0.02200 \text{ L} \\ &= 3.056 \times 10^{-3} \text{ mol} \end{aligned}$$

Noting that the volume of solution at the end is $(25.00 + 40.00) \text{ mL} = 65.00 \text{ mL}$ and assuming that the hydrolysis of the $\text{C}_6\text{H}_5\text{COO}^-$ ion is negligible,

$$[\text{OH}^-] = \frac{3.056 \times 10^{-3} \text{ mol}}{0.06500 \text{ L}}$$

$$= 0.04701 \text{ mol L}^{-1}$$

$$\text{pOH} = -\log_{10}(0.04701)$$

$$= 1.328$$

$$\text{pH} = 14.00 - 1.328$$

$$= 12.67$$

2 marks – Calculates the correct $\text{p}K_{\text{a}}$ of benzoic acid

1 mark – Calculates the correct volume of NaOH added at the equivalence point and half-equivalence point

1 mark – Calculates the correct K_{b} of the benzoate ion

3 marks – Calculates the correct pH at the equivalence point

1 mark – Calculates the correct final pH

1 mark – Draws a weak acid-strong base titration curve with all the relevant points marked and includes a buffer region

Question 28 (6 marks)

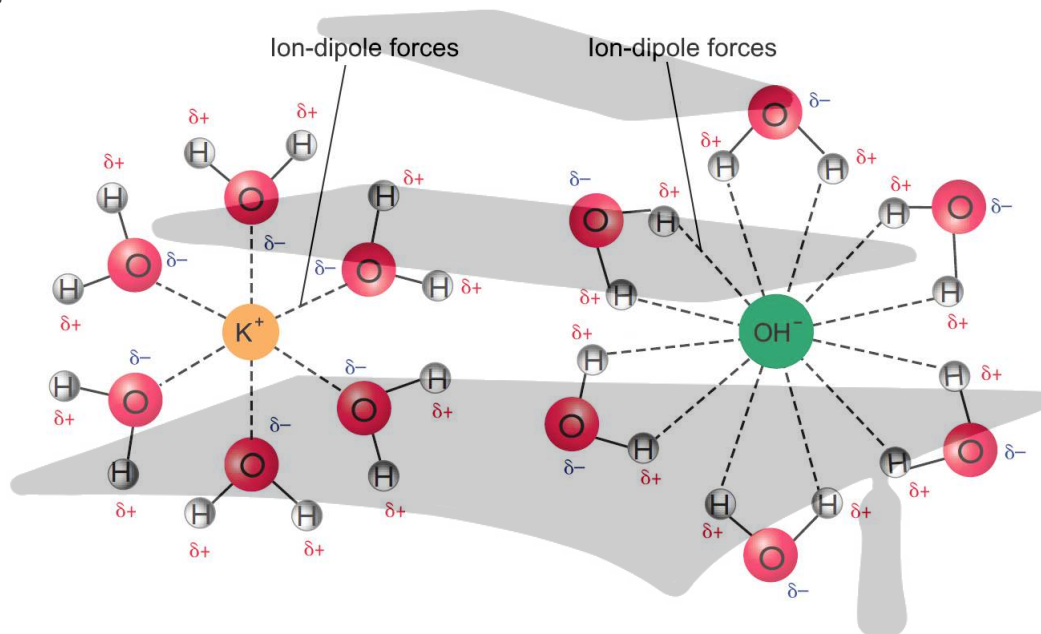
The following thermodynamic data applies to the dissolution of solid potassium hydroxide in water at 25°C. 6

$$\Delta_{\text{sol}}H^{\ominus} = -57 \text{ kJ mol}^{-1}$$

$$\Delta_{\text{sol}}S^{\ominus} = +11 \text{ J mol}^{-1} \text{ K}^{-1}$$

With reference to this data and the resultant $\Delta_{\text{sol}}G^{\ominus}$, describe and analyse the changes in structure and bonding that occur when potassium hydroxide is dissolved in water at 25°C. Include a relevant diagram in your answer.

The dissolution of solid KOH involves two main steps. Step 1 involves breaking the ionic bonds holding the KOH lattice together to allow the ions to dissociate, and this requires an energy input (an endothermic step). Some hydrogen bonds between water molecules will also be broken in this step. The entropy will increase during this step since the orderly ionic lattice has been broken and the ions have been randomly dispersed into the solution, resulting in more disorder. Step 2 involves the formation of ion-dipole forces between water molecules and the dissociated ions, and this releases energy (an exothermic step). The water molecules surround the ions to form hydration spheres where the $\delta^{-}\text{O}$ of water is attracted to the K^{+} ion while the $\delta^{+}\text{H}$ of water is attracted to the OH^{-} ion through ion-dipole forces. The entropy decreases in this step since the water molecules move into a more orderly arrangement.



The dissolution of KOH is exothermic overall ($\Delta_{\text{sol}}H^{\ominus} < 0$), because the energy output in Step 2 is greater than the energy input in Step 1. The entropy also increases ($\Delta_{\text{sol}}S^{\ominus} > 0$) which indicates the breakdown of the ionic lattice in Step 1 results in a greater entropy change than the rearrangement of water in Step 2. Both the enthalpy and entropy changes are thermodynamically favourable which results in a negative $\Delta_{\text{sol}}G^{\ominus}$:

$$\begin{aligned}\Delta_{\text{sol}}G^{\ominus} &= \Delta_{\text{sol}}H^{\ominus} - T\Delta_{\text{sol}}S^{\ominus} \\ &= -57 \text{ kJ mol}^{-1} - (25 + 273.15) \text{ K} \times 0.011 \text{ kJ mol}^{-1} \text{ K}^{-1} \\ &= -60 \text{ kJ mol}^{-1} \\ &< 0\end{aligned}$$

As such, the dissolution of KOH in water will occur spontaneously, so KOH is soluble in water at 25°C.

- 1 mark – Describes the breaking of the ionic bonds and the ionic lattice
- 1 mark – Describes the formation of ion-dipole bonds between water and the ions
- 1 mark – Explains why the enthalpy change is negative with reference to the energy released when ion-dipole forces are formed and the energy absorbed when ionic bonds are broken
- 1 mark – Explains why the entropy change is positive with reference to the changes in structure
- 1 mark – Calculates the correct value of $\Delta_{\text{sol}}G^{\ominus}$ and states that the dissolution of KOH is spontaneous with reference to the sign of $\Delta_{\text{sol}}G^{\ominus}$
- 1 mark – Provides a labelled diagram of the hydration spheres that are formed



Question 29 (6 marks)

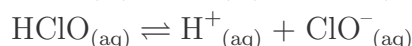
A chemist conducted an experiment where they measured the pH of a sample of perchloric acid (HClO_4) and hypochlorous acid (HClO). A salt was then dissolved into each acid. The results are summarised in the table below.

Acid	Perchloric acid	Hypochlorous acid
Concentration of acid (mol L^{-1})	0.10	0.10
Initial pH	1.00	4.27
Salt dissolved	Sodium perchlorate (NaClO_4)	Sodium hypochlorite (NaClO)

- (a) Account for the pH readings measured in this experiment and explain how the pH of each acid solution will be affected by the dissolution of the salts. Include relevant chemical equations in your answer.

5

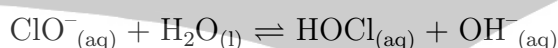
HClO_4 is a strong acid that completely ionises in water to form H^+ ions, whereas HClO is a weak acid that only partially ionises in water to form H^+ ions.



As such, at the same concentration, HClO_4 has a higher $[\text{H}^+]$ (0.10 mol L^{-1}) than HClO ($10^{-4.27} \text{ mol L}^{-1}$) and thus a lower pH since $\text{pH} = -\log_{10}[\text{H}^+]$.

When NaClO_4 is dissolved into HClO_4 , it dissociates into the Na^+ and ClO_4^- ions. The Na^+ ion is a group 1 metal cation that does not react with water to any significant extent. The ClO_4^- ion is the extremely weak conjugate base of a strong acid (HClO_4), so it also has no tendency to react with water. As such, NaClO_4 is a neutral salt and will have no effect on the pH of the HClO_4 solution.

When NaClO is dissolved into HClO , it dissociates into the Na^+ and ClO^- ions. The ClO^- ion is the weak conjugate base of a weak acid (HClO), so it can accept a proton from water:



This hydrolysis reaction produces OH^- ions so NaClO is a basic salt and would cause the pH of the HClO solution to increase.

2 marks – Accounts for why the initial pH of the acids are different with reference to acid strength, degree of ionisation and $[\text{H}^+]$

2 marks – Explains that the pH of the HClO_4 solution will not be affected while the pH of the HClO solution will increase after the salts are dissolved

1 mark – Provides at least TWO relevant chemical equations

Answers may also include:

- The ionisation of HClO_4 is not reversible, so no equilibrium shift can occur when NaClO_4 dissolves and $[\text{ClO}_4^-]$ increases. This results in the pH being unaffected.

- The dissolution of NaClO increases $[\text{ClO}^-]$ so Le Chatelier's principle predicts that the equilibrium for the ionisation of HClO shifts left, causing $[\text{H}^+]$ to decrease and the pH to increase.

(b) Predict which of the resultant mixtures can potentially act as a buffer solution and briefly justify your answer.

1

The HClO/NaClO mixture can act as a buffer since it contains a weak acid and its conjugate base (ideally in similar amounts). The $\text{HClO}_4/\text{NaClO}_4$ mixture cannot act as a buffer since it contains a strong acid and its extremely weak conjugate base.

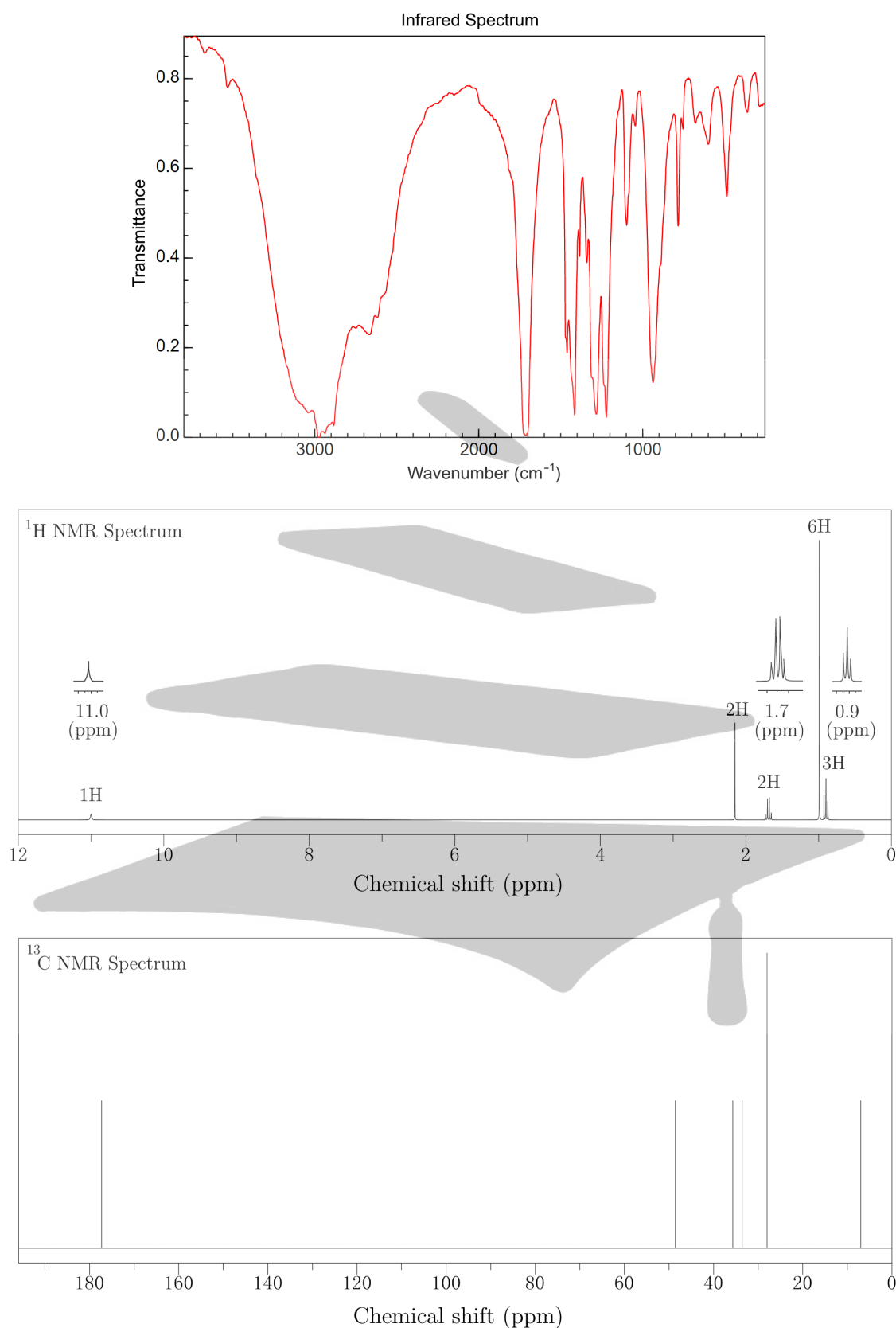
1 mark – Predicts that the HClO/NaClO mixture can act as a buffer and briefly justifies why



Question 30 (7 marks)

An unknown organic compound with a molecular formula of $C_7H_{14}O_2$ was analysed with infrared (IR) spectroscopy and nuclear magnetic resonance (NMR) spectroscopy. The following spectra were obtained from these techniques.

7



Analyse the spectra above to determine the structural formula of the organic compound.

Note: 1H NMR chemical shift data has been included on your data sheet.

IR spectrum

- Very broad absorption at $2500 - 3300\text{ cm}^{-1}$ indicates the presence of a O–H (acid) group.
- Strong absorption at $1680 - 1750\text{ cm}^{-1}$ indicates a C=O group.

\Rightarrow The compound must be a carboxylic acid.

^1H NMR spectrum

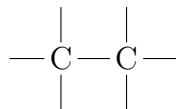
There are 5 signals on the ^1H NMR spectrum, so there are 5 ^1H environments and these are summarised in the table below:

δ (ppm)	Integration	Multiplicity	^1H Neighbours ($n + 1$ rule)	Conclusion
0.9	3H	Triplet (3)	2	A CH_3 – group next to a $-\text{CH}_2-$ group CH_3-CH_2-
1.0	6H	Singlet (1)	0	2 equivalent CH_3 – groups with no H neighbours $\begin{array}{c} \text{CH}_3 \\ \\ -\text{C}- \\ \\ \text{CH}_3 \end{array}$
1.7	2H	Quartet (4)	3	A $-\text{CH}_2-$ group next to a CH_3 – group CH_3-CH_2-
2.2	2H	Singlet (1)	0	A deshielded $-\text{CH}_2-$ group adjacent to a C=O group $\begin{array}{c} \text{O} \\ \\ -\text{CH}_2-\text{C}- \end{array}$
11.0	1H	Singlet (1)	0	A very deshielded H of a carboxyl group $\begin{array}{c} \text{O} \\ \\ -\text{C}-\text{O}-\text{H} \end{array}$

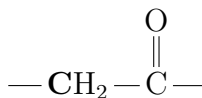
^{13}C NMR spectrum

There are 6 signals on the ^{13}C NMR spectrum, so there are 6 C environments which is less than the 7 C atoms present in the molecule, indicating that there is some symmetry in the structure.

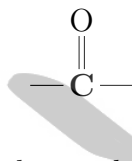
- The signals at 7, 28 34 and 36 ppm represent typical alkyl carbons.



- The signal at 49 ppm indicates a C adjacent to a C=O group.



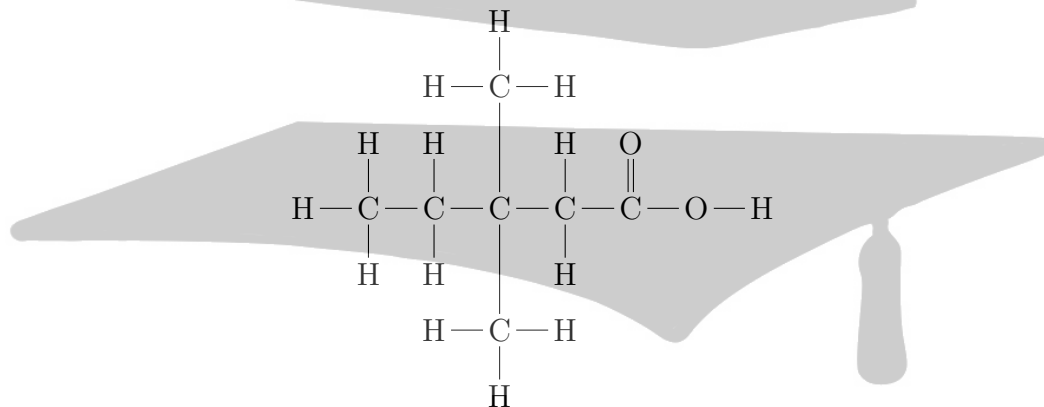
- The signal at 177 ppm indicates a C=O group of a carboxylic acid.



From the information above, the fragments that make up the molecule are:



The structure is therefore:



1 mark – Analyses the IR spectrum and identifies the presence of a O–H (acid) group and a C=O group

4 marks – Analyses the ^1H NMR spectrum to identify the major structural fragments of the organic compound

1 mark – Analyses the ^{13}C NMR spectra to identify the major structural fragments of the organic compound

1 mark – Determines the correct structural formula of the organic compound

Question 31 (5 marks)

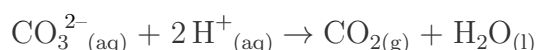
5

A beaker is known to contain ONE of the following 0.10 mol L^{-1} solutions:

- Sodium sulfate
- Copper(II) nitrate
- Sodium hydroxide
- Silver nitrate
- Sodium carbonate

Describe a series of tests that could be used to confirm the identity of the solution in the beaker. Include any expected observations and relevant net ionic equations in your answer.

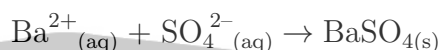
HNO_3 can be added to a sample of the solution and if effervescence of gas (bubbling) is observed, then the solution is Na_2CO_3 .



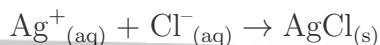
If no bubbling occurs, then the solution is not Na_2CO_3 .

A fresh sample can then be tested with red litmus paper, and if the litmus turns blue, then the solution is NaOH . If the litmus remains red, then the solution is not NaOH .

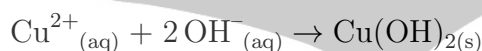
$\text{Ba}(\text{NO}_3)_2$ can then be added to a fresh sample and if a white precipitate forms, then the solution is Na_2SO_4 .



If no precipitate forms, then the solution is either $\text{Cu}(\text{NO}_3)_2$ or AgNO_3 . HCl can be added to a fresh sample and if a white precipitate forms, then the solution is AgNO_3 .



If no precipitate forms, then the solution must be $\text{Cu}(\text{NO}_3)_2$ and this can be confirmed by adding NaOH which should result in the formation of a blue precipitate.



4 marks – Describes appropriate chemical tests that can be used to identify the solution

1 mark – Includes all observations and at least TWO net ionic equations

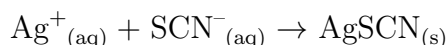
Answers may also include:

- Using a pH meter to measure the pH of the solution; NaOH would have $\text{pH} = 13.00$ while Na_2CO_3 would have $7.00 < \text{pH} < 13.00$.
- Using a flame test (blue green flame colour for $\text{Cu}(\text{NO}_3)_2$, yellow flame colour for Na_2SO_4 , NaOH or Na_2CO_3 , no flame colour for AgNO_3).
- Any other correct precipitation tests.

Question 32 (5 marks)

The following procedure was used to determine the phosphate content of a particular brand of plant food.

- A 4.258 g sample of the plant food was mixed with 50.0 mL of 0.126 mol L^{-1} silver nitrate solution. All of the phosphate ions were precipitated out, leaving an excess of silver ions.
- The precipitate formed was filtered off and the filtrate was diluted to 250.0 mL with distilled water in a volumetric flask.
- Four 50.0 mL aliquots of the resulting solution were transferred to separate conical flasks and, in each case, the excess silver ions was titrated against a $0.0625 \text{ mol L}^{-1}$ potassium thiocyanate (KSCN) solution according to the following equation:



- The results are given in the table below:

Titration	Titre volume (mL)
1	11.90
2	11.60
3	11.70
4	11.65

- (a) Calculate the moles of silver ions that remained unreacted following the reaction with the phosphate ions.

2

Discarding the 1st rough titre,

$$V(\text{KSCN}) = \frac{(11.60 + 11.70 + 11.65) \text{ mL}}{3}$$

$$= 11.65 \text{ mL}$$

$$n(\text{SCN}^-) = 0.0625 \text{ mol L}^{-1} \times 0.01165 \text{ L}$$

$$= 7.28 \times 10^{-4} \text{ mol}$$

$$n(\text{Ag}^+) = 7.28 \times 10^{-4} \text{ mol}$$

These moles of Ag^+ came from a 50.0 mL aliquot, so the concentration of Ag^+ is:

$$[\text{Ag}^+] = \frac{7.28 \times 10^{-4} \text{ mol}}{0.0500 \text{ L}}$$

$$= 0.0146 \text{ mol L}^{-1}$$

Therefore, the moles of leftover Ag^+ in the 250.0 mL diluted filtrate is:

$$n(\text{Ag}^+)_{\text{leftover}} = 0.0146 \text{ mol L}^{-1} \times 0.2500 \text{ L}$$

$$= 3.64 \times 10^{-3} \text{ mol}$$

1 mark – Calculates the correct moles of SCN^-

1 mark – Calculates the correct moles of Ag^+ leftover

Answers may also include:

- The 7.28×10^{-4} moles of Ag^+ came from a 50.0 mL aliquot. Therefore, the moles of leftover Ag^+ in the 250.0 mL diluted filtrate is:

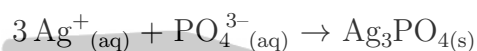
$$\begin{aligned}n(\text{Ag}^+)_{\text{leftover}} &= 5 \times 7.28 \times 10^{-4} \text{ mol} \\ &= 3.64 \times 10^{-3} \text{ mol}\end{aligned}$$

(b) Calculate the concentration of phosphate ions in the plant food sample in mg/g.

3

$$\begin{aligned}n(\text{Ag}^+)_{\text{added}} &= 0.126 \text{ mol L}^{-1} \times 0.0500 \text{ L} \\ &= 6.30 \times 10^{-3} \text{ mol} \\ n(\text{Ag}^+)_{\text{reacted}} &= n(\text{Ag}^+)_{\text{added}} - n(\text{Ag}^+)_{\text{leftover}} \\ &= 6.30 \times 10^{-3} \text{ mol} - 3.64 \times 10^{-3} \text{ mol} \\ &= 2.66 \times 10^{-3} \text{ mol}\end{aligned}$$

The initial reaction is:



$$\begin{aligned}n(\text{PO}_4^{3-}) &= \frac{1}{3} \times 2.66 \times 10^{-3} \text{ mol} \\ &= 8.86 \times 10^{-4} \text{ mol}\end{aligned}$$

$$\begin{aligned}m(\text{PO}_4^{3-}) &= 8.86 \times 10^{-4} \text{ mol} \times (30.97 + 4 \times 16.00) \text{ g mol}^{-1} \\ &= 0.0842 \text{ g} \\ &= 84.2 \text{ mg}\end{aligned}$$

$$\begin{aligned}[\text{PO}_4^{3-}] &= \frac{84.2 \text{ mg}}{4.258 \text{ g}} \\ &= 19.8 \text{ mg/g}\end{aligned}$$

1 mark – Calculates the correct moles of Ag^+ reacted

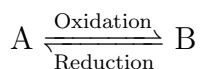
1 mark – Calculates the correct mass of PO_4^{3-}

1 mark – Calculates the correct concentration of PO_4^{3-} in mg/g to 3 significant figures

Question 33 (5 marks)

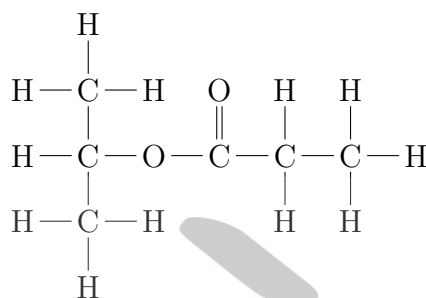
Oxidation and reduction reactions occur as opposing reactions as shown below.

5

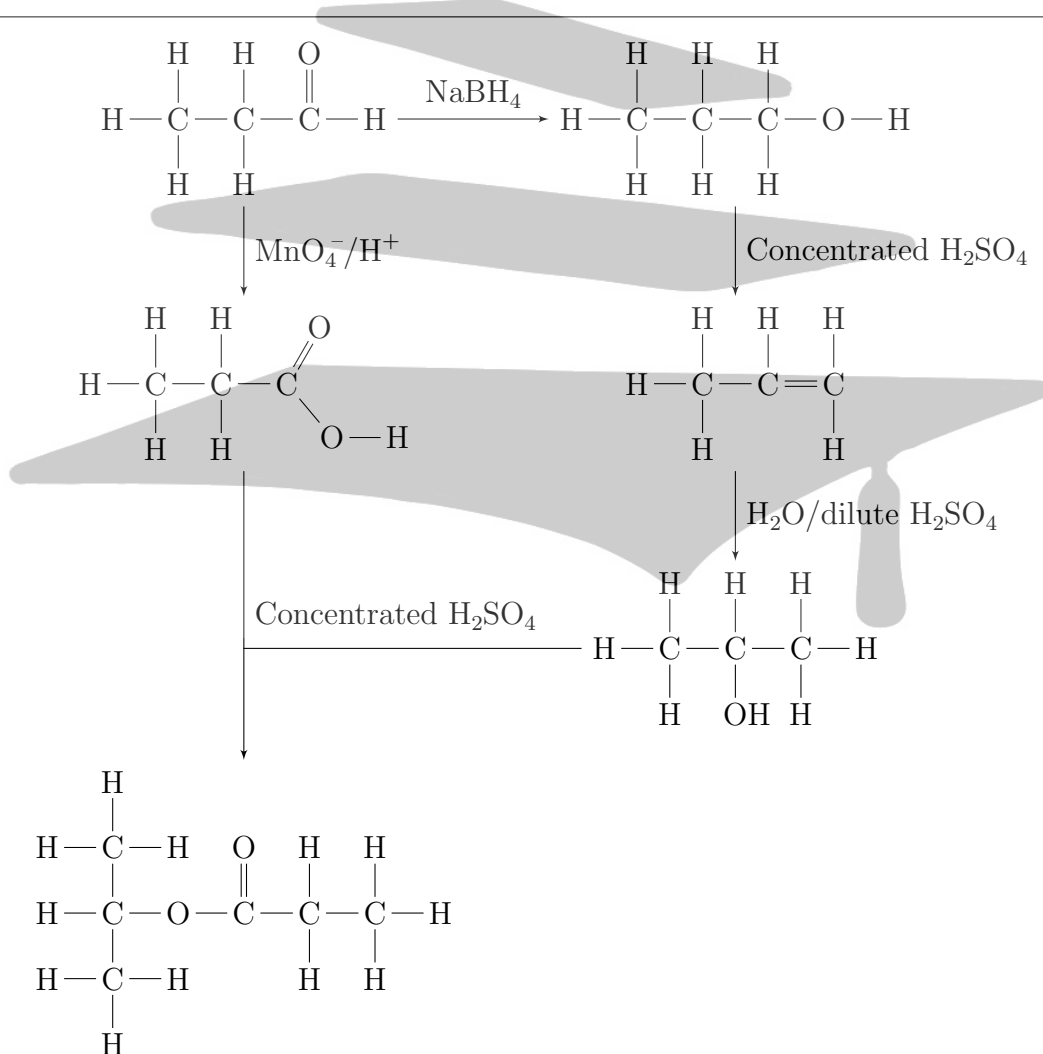


In organic chemistry, a strong reductant that is commonly used to carry out reduction reactions is sodium borohydride (NaBH_4).

Using the information above and any other relevant reactions, construct a flowchart to show a reaction pathway that can be used to synthesise the compound below using propanal as the ONLY starting organic reagent.



All reagents used must be clearly shown and the structural formula of all intermediates must be drawn.



5 marks – Constructs a flowchart showing the five steps above (1 mark each)