Strathfield Girls
High School

Student Number

Chemistry

2022
HIGHER SCHOOL CERTIFICATE
Trial Examination

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- NESA approved calculators may be used
- A formulae sheet, data sheets and Periodic Table are provided at the back of this paper and may be detached
- A Multiple-Choice Answer Sheet is provided at the back of this paper and should be detached

Total marks – 100

Section I – Pages 2–9
20 marks

- Attempt Questions 1–20
- Allow about 30 minutes for this section

Section II – Pages 10–24
80 marks

- Attempt Questions 21–32
- Allow about 2 hours and 30 minutes for this section

This paper MUST NOT be removed from the examination room

Section I
20 marks

Attempt Questions 1–20
Allow about 30 minutes for this section

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

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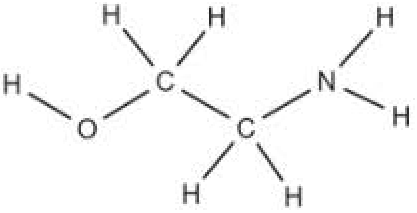
1 Which of the following substances is NOT a Brønsted-Lowry acid?

(A) $H_2PO_4^-$
(B) NH_4^+
(C) H_2O
(D) BF_3

2 Which two compounds would be difficult to distinguish using infrared spectroscopy?

(A) Ethanoic acid and ethanol
(B) Propanal and propanone
(C) Ethane and ethanamine
(D) Propene and propanamide

3 The structure of 2-aminoethanol is shown.



The mass spectrum of 2-aminoethanol contains a peak at *m/z* 31.

What is the most likely source of this peak?

(A) $[CH_2NH_3]$
(B) $[NOH]^+$
(C) $[N_2H_3]^+$
(D) $[CH_2OH]^+$

4 Equal volumes of two 0.01 mol L^{-1} solutions were mixed together.

Which pair of solutions would give the greatest mass of precipitate?

(A) $FeSO_4$ and $Ba(OH)_2$
(B) $FeSO_4$ and $BaCl_2$
(C) $FeSO_4$ and $Ca(OH)_2$
(D) $FeSO_4$ and $CaCl_2$

5 The equation for the auto-ionisation of water is shown.

$$2H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$$

At 60°C, the water ionisation constant, K_w, is 9.55×10^{-14}.

What is the pH of water at 60°C?

(A) 7.14
(B) 7.00
(C) 6.92
(D) 6.51

6 Compound **W** shows two signals in its ^{13}C NMR spectrum.
Treatment of compound **W** with hot concentrated sulfuric acid produces compound **X**.

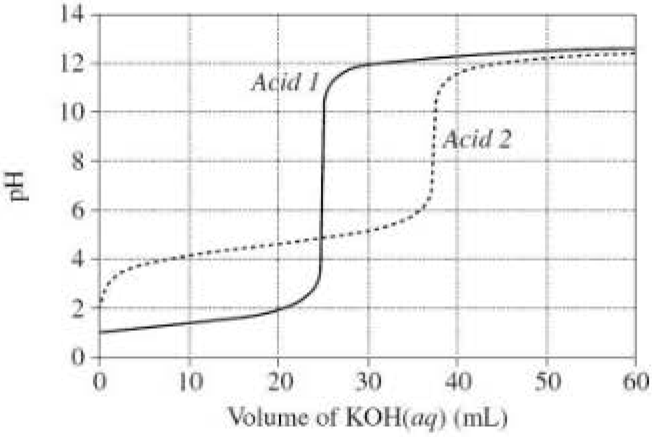
Compound **X** can be mixed with bromine water to produce compound **Y**.

Compound **W** can be reacted with hot acidified potassium permanganate to produce compound **Z**.
Compound **Z** has one signal in its ^1H NMR spectrum.

Which of the following correctly identifies compounds **W**, **X**, **Y** and **Z**?

	Compound W	**Compound X**	**Compound Y**	**Compound Z**
(A)	ethanol	ethene	1,2-dibromoethane	ethanoic acid
(B)	butan-2-ol	but-2-ene	2,3-dibromobutane	butanone
(C)	propan-2-ol	propene	1,2-dibromopropane	propanone
(D)	propan-1-ol	propene	1,2-dibromopropane	propanoic acid

The graph shows changes in pH during the titrations of equal volumes of two acids, *Acid 1* and *Acid 2*.
Use the graph to answer Questions 7 and 8.



7 Which indicator would be most suitable for BOTH titrations?

	Indicator	Colour Change Range (pH)
(A)	alizarin yellow R	10.0-12.0
(B)	phenolphthalein	8.3-10.0
(C)	bromothymol blue	6.0-7.6
(D)	4-nitrophenol	5.4-6.6

8 At which pH would the solution of the *Acid 2* titration be most effective as a buffer?

(A) 4.5
(B) 6
(C) 8.5
(D) 12

9 Which class of organic compound must contain at least two carbon atoms?

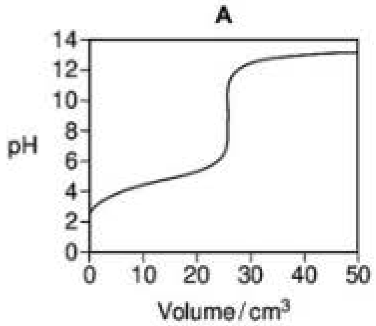
(A) alkane
(B) aldehyde
(C) carboxylic acid
(D) ester

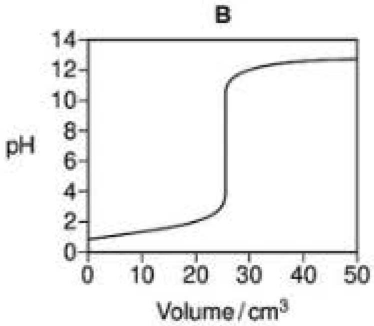
10 The pK_a of hydrofluoric acid (HF) is 3.14. Oxalic acid ($H_2C_2O_4$) has a pK_a of 1.23.

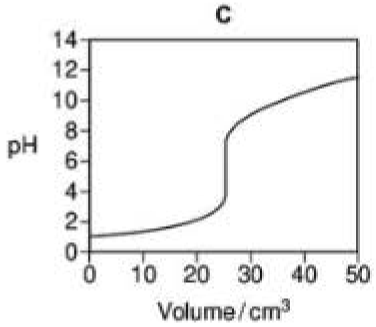
The relative strength of each acid and its conjugate base can be identified as:

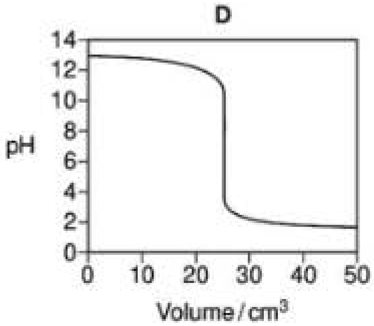
	Stronger Acid	**Stronger Conjugate Base**
(A)	HF	F^-
(B)	HF	$HC_2O_4^-$
(C)	$H_2C_2O_4$	$HC_2O_4^-$
(D)	$H_2C_2O_4$	F^-

11 Which of the following graphs would result from the titration of a *strong* acid with a *weak* base?









(A) Graph A
(B) Graph B
(C) Graph C
(D) Graph D

12 Equal volumes of a monoprotic *strong* acid and a monoprotic *weak* acid, both with the same concentration, are titrated with the same base solution at 25°C.

Which of the following statements about the volume of base solution required to reach the equivalence point is correct?

(A) The strong acid will require more base solution than the weak acid

(B) The weak acid will require more base solution than the strong acid

(C) Both acid solutions will require the same amount of base solution

(D) The amount of base solution required is determined by the acid's K_a at 25°C

13 Solid magnesium hydroxide is added to 150 mL of water to give a solution of pH 13.7.

What mass of magnesium hydroxide dissolved?

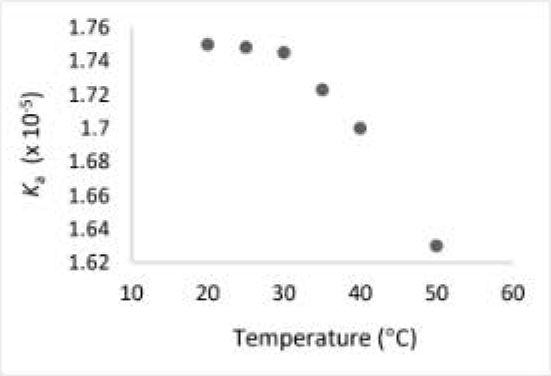
(A) 2.19 g

(B) 3.11 g

(C) 4.38 g

(D) 8.77 g

14 The K_a of ethanoic acid changes with temperature as shown in the graph.



The graph indicates that within the temperature range shown, as the temperature increases the acid becomes:

(A) more ionised

(B) less ionised

(C) more concentrated

(D) less concentrated

15 Which of the following compounds would be suitable for the preparation of a *primary standard* solution for use in an acid-base titration?

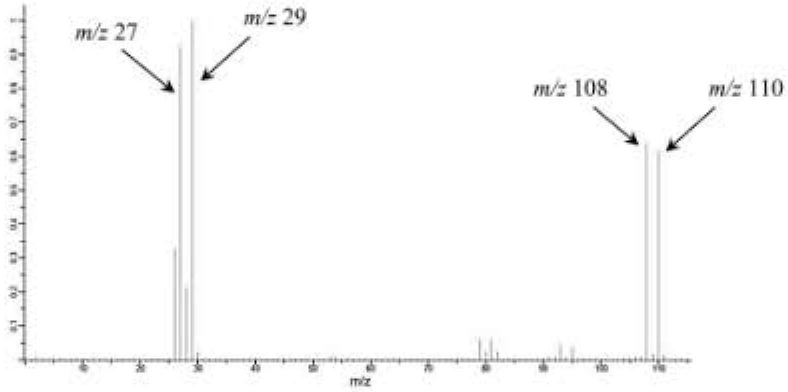
(A) Hydrochloric acid
(B) Sodium hydroxide
(C) Sodium carbonate
(D) Nitric acid

16 Equal volumes of 0.30 mol L^{-1} $AgNO_3$ and 0.20 mol L^{-1} Na_3PO_4 solutions are mixed together and a precipitate is observed.

Which option shows the concentration of all ions remaining in solution?

	[Ag^+] mol L^{-1}	**[NO_3^-] mol L^{-1}**	**[Na^+] mol L^{-1}**	**[PO_4^{3-}] mol L^{-1}**
(A)	0	0.15	0.30	0.05
(B)	0	0.30	0.60	0
(C)	0.15	0.15	0.30	0.10
(D)	0	0.15	0.30	0

17 The *mass spectrum* of an organic compound is shown.



Which compound was analysed?

(A) 3-chlorobutan-1-ol
(B) bromoethane
(C) 1,3-dichloropropene
(D) bromomethanol

18 A chemist used colorimetry to determine the concentration of chromium(VI) ions present in a river used for the discharge of industrial wastewater.

Four water samples were collected from the river. An appropriate ligand compound was added to 50 mL of each water sample and the total volume made up to 100 mL with distilled water.

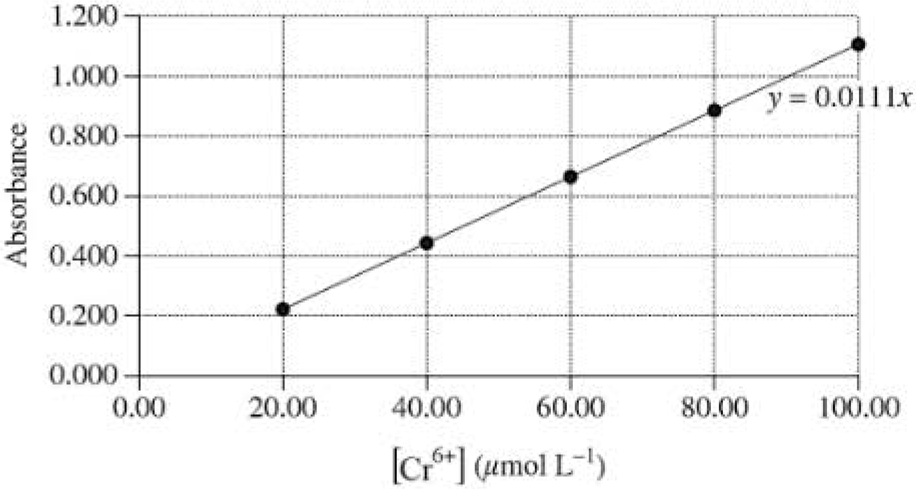
The absorbance of each prepared sample solution was measured. The results are shown in the table.

Sample	**1**	**2**	**3**	**4**
Absorbance	0.7625	0.7715	0.7695	0.7705

The chemist calculated the average absorbance using the results of all four samples.

She then prepared standard solutions of chromium(VI), measured the absorbance of each standard and constructed a calibration curve.

The calibration curve for chromium(VI) is shown.



What is the concentration of chromium(VI) in the river?

(A) 3.6×10^{-3} g L^{-1}

(B) 7.2×10^{-3} g L^{-1}

(C) 8.2×10^{-3} g L^{-1}

(D) 8.8×10^{-3} g L^{-1}

19 A chemist prepares 105 mL of 2.3 mol L^{-1} hydrochloric acid solution and 85 mL of 2.4 mol L^{-1} sodium hydroxide solution. The two solutions were at the same initial temperature before mixing.

The following information about the resulting solution is provided.

Mass of the final solution:	201 g
Temperature of the final solution:	34.0°C
Specific heat capacity of the final solution:	3.99 J g^{-1} $°C^{-1}$
$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$	$\Delta H = -57$ kJ mol^{-1}

Using the above information, the initial temperature of the two solutions would be:

(A) 14.5°C
(B) 16.8°C
(C) 19.5°C
(D) 21.0°C

20 The diagram shows four labelled bottles, each containing 500 mL of an acid.

Which solution contains the strongest acid?

(A) Solution A
(B) Solution B
(C) Solution C
(D) Solution D

Section II
80 marks

Attempt Questions 21–32
Allow about 2 hours and 30 minutes for this section

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.

Extra writing space is provided on pages 25 and 26.
If you use this space, clearly indicate which question you are answering and indicate the use of this extra space with the question on the examination paper.

Question 21 (5 marks)

When ethanamine gas is bubbled into water, an ionisation reaction occurs.

(a) Write a chemical equation for the ionisation of ethanamine in water. **1**

(b) The pK_b of ethanamine is 3.29 at 25°C.
Calculate the pH of a 0.150 mol L^{-1} aqueous solution of ethanamine. **4**

Question 22 (6 marks)

Hydrogen peroxide, a colourless liquid, is commonly used as an aqueous solution in bleach and antiseptic. As hydrogen peroxide decomposes into water and oxygen over a period of time, its concentration in commercial products has to be determined by a suitable titration.

Acidified potassium permanganate is often used in titrations to determine hydrogen peroxide concentration. The titration reaction is:

$$5H_2O_{2(aq)} + 2MnO_4^-{}_{(aq)} + 6H^+{}_{(aq)} \rightarrow 5O_{2(g)} + 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)}$$

To perform the analysis, a chemist titrated 20.0 mL aliquots of the hydrogen peroxide solution against 0.0239 mol L^{-1} acidified potassium permanganate solution. The results are as follows:

Titration Run	Titre (mL)
1	28.85
2	26.90
3	26.80
4	26.65
5	26.90

(a) Given that no other chemical is used in the analysis, how would the equivalence point of each titration be recognised? **2**

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(b) Calculate the concentration of the hydrogen peroxide solution in g L^{-1}. **4**

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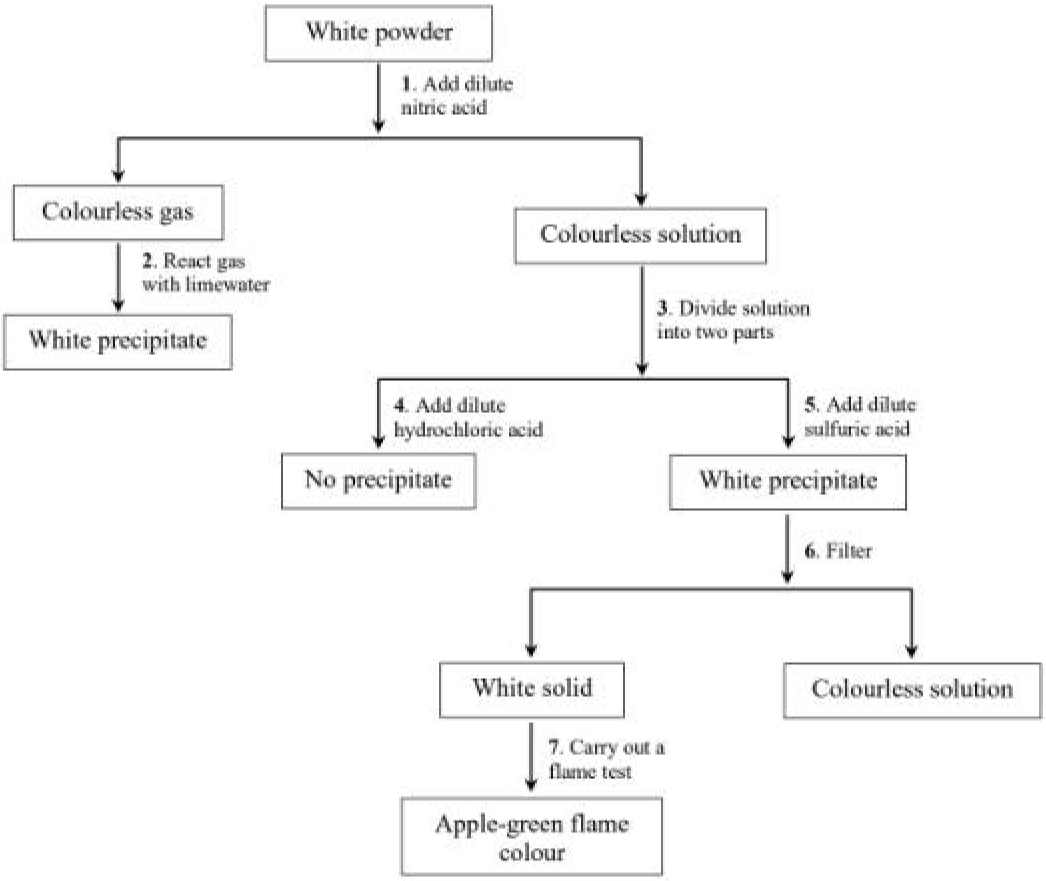
Question 23 (11 marks)

A white powder was known to be a pure *ionic* substance. The diagram below gives the results of various tests used to identify this powder.



(a) Identify an *anion* that could be in the white powder. Justify your choice by explaining the evidence from relevant test results. **3**

Question 23 continues on page 13

(b) Identify a *cation* that could be in the white powder. Justify your choice by explaining the evidence from all relevant test results. **4**

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(c) Explain why it would be poor technique to use sodium sulfate in **step 5** instead of sulfuric acid. **2**

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(d) Assuming an excess of each indicated reagent is added at the various steps, identify all ions that could be present in the colourless solution obtained from **step 6**. Justify your answer. **2**

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End of Question 23

Question 24 (7 marks)

A chemist prepares a *buffer* solution with propanoic acid and sodium propanoate.

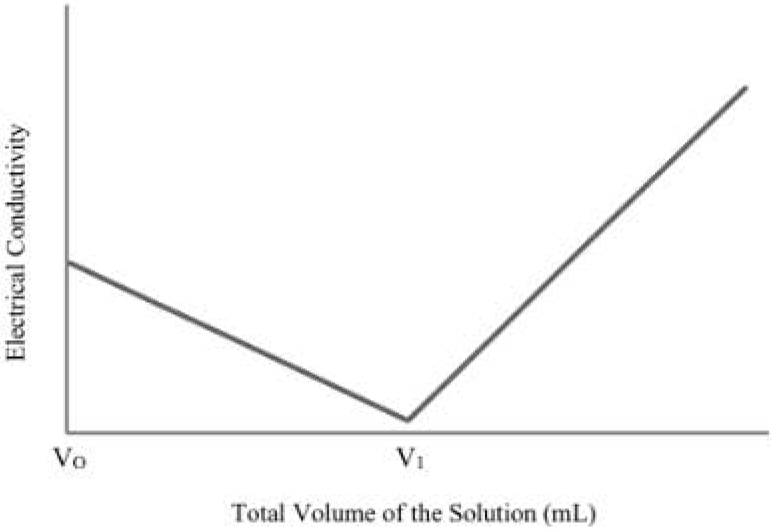
(a) Write a chemical equation to represent this buffer system as an equilibrium in aqueous solution. **1**

(b) Explain why this combination of chemicals will be an effective buffer. Refer to the equation written in part (a) to support your answer. **4**

(c) Which TWO factors are important when *selecting* the weak acid and its conjugate base and *preparing* the buffer solution for a required pH? Justify your answer with reasons. **2**

Question 25 (9 marks)

The graph shows the electrical conductivity of the resulting solution formed when 80 mL of 0.10 mol L^{-1} $BaCl_2$ is slowly added to 400 mL of 0.01 mol L^{-1} Ag_2SO_4.



(a) Write a net *ionic* equation for the chemical reaction that occurred when the $BaCl_2$ solution is added to the Ag_2SO_4 solution. **2**

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(b) Explain why the solution conducts electricity at volume V_O but not significantly at volume V_1. **3**

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Question 25 continues on page 16

Question 25 (continued)

(c) Determine the volume of $BaCl_2$ solution that has been added between volumes V_O and V_1. Justify your answer through calculations. **2**

(d) Explain why the electrical conductivity increases after volume V_1. **2**

Question 26 (4 marks)

160 mL of 0.259 mol L^{-1} sulfuric acid is added to 185 mL of 0.695 mol L^{-1} potassium hydroxide.

Calculate the pH of the resulting solution. **4**

Question 27 (6 marks)

A chemist investigated the acid-base properties of three salts. She dissolved equal masses of sodium bicarbonate, ammonium ethanoate and potassium hydrogen sulfate in 20 mL volumes of distilled water. She measured the pH with a data logger and pH probe.

(a) Complete the table to identify the acid-base property of the salt solutions measured. **1**

Name	**Chemical Formula**	**Acidic, Basic or Neutral?**
Sodium bicarbonate	$NaHCO_3$	
Ammonium ethanoate	NH_4CH_3COO	
Potassium hydrogen sulfate	$KHSO_4$	

(b) Explain the acid-base property of each salt, using chemical equations to support your answer. **4**

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(c) Apart from failing to repeat the experiment, identify the major flaw in the chemist's method that could impact on the validity of her investigation. **1**

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Question 28 (7 marks)

Cobalt and a ligand X react to form a coloured complex as shown in the general equation:

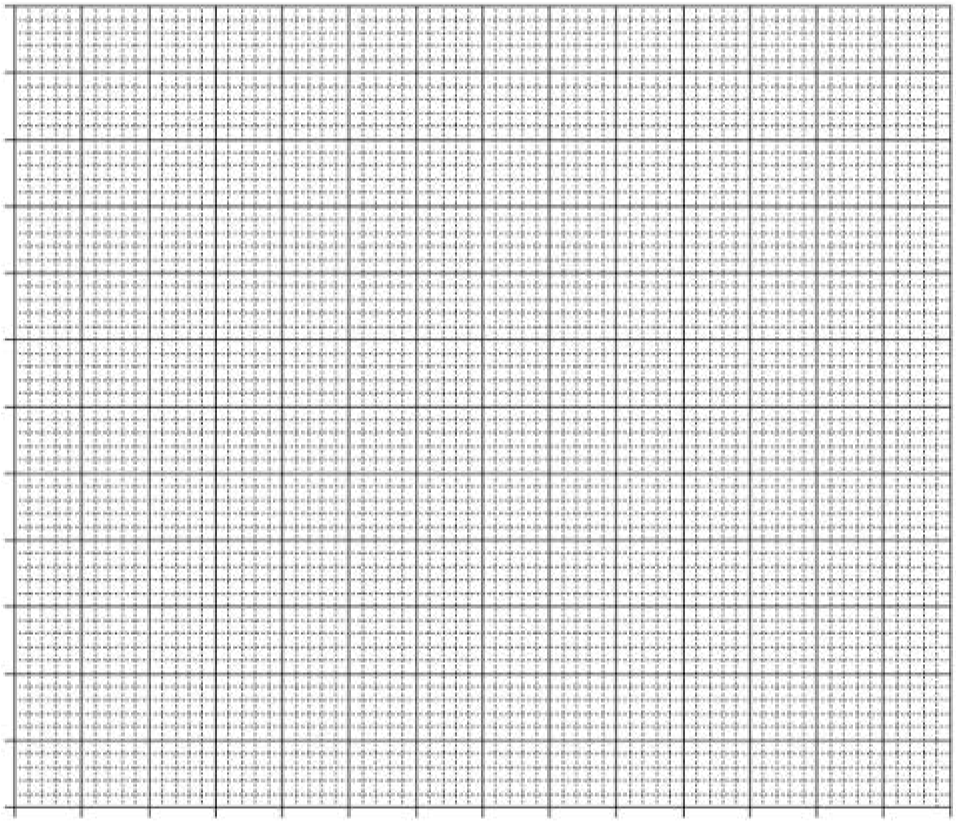
$$a\,\mathrm{Co}^{3+} + b\,\mathrm{X} \rightleftharpoons [\mathrm{Co}_a\mathrm{X}_b]^{3a+}$$

where a and b are numbers representing the ratio in which Co^{3+} and X combine.

To determine the stoichiometric ratio for this reaction, Co^{3+} and X solutions of equal concentration were mixed together in different ratios to make ten 70.0 mL samples. The intensity of colour in each sample was measured using a spectrophotometer. The results are shown in the table below.

	Samples									
Volume of Co^{3+} solution (mL)	0.00	3.00	6.00	9.00	14.0	22.0	35.0	48.0	61.0	70.0
Volume of X solution (mL)	70.0	67.0	64.0	61.0	56.0	48.0	35.0	22.0	9.00	0.00
Absorbance at 430 nm	0.00	0.34	0.66	1.02	1.07	0.92	0.67	0.42	0.17	0.00

(a) Construct a graph of absorbance against the volume of Co^{3+} solution from 0.00 mL to 70.0 mL. Plot the data by drawing TWO lines of best fit. **4**



Question 28 continues on page 19

Question 28 (continued)

(b) Use the graph to determine the highest absorbance that would be obtained for a 70 mL sample, assuming unlimited combinations of the two solutions are measured. **1**

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(c) The reaction to form the coloured complex proceeds according to the general equation:

$$a\,\mathrm{Co}^{3+} + b\,\mathrm{X} \rightleftharpoons [\mathrm{Co}_a\mathrm{X}_b]^{3a+}$$

Determine the values for *a* and *b*. Justify your answer with reference to the graph in part (a). **2**

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Question 29 (6 marks)

A chemist dissolved the calcium carbonate in a section of blocked pipe by soaking the section in 100.0 mL of 0.250 mol L^{-1} hydrochloric acid. After the calcium carbonate had dissolved, the excess hydrochloric acid was titrated with 0.100 mol L^{-1} sodium hydroxide, requiring 39.3 mL.

(a) Write a chemical equation for the reaction between calcium carbonate and hydrochloric acid. **1**

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(b) Determine the mass of calcium carbonate that was in the blocked pipe. **5**

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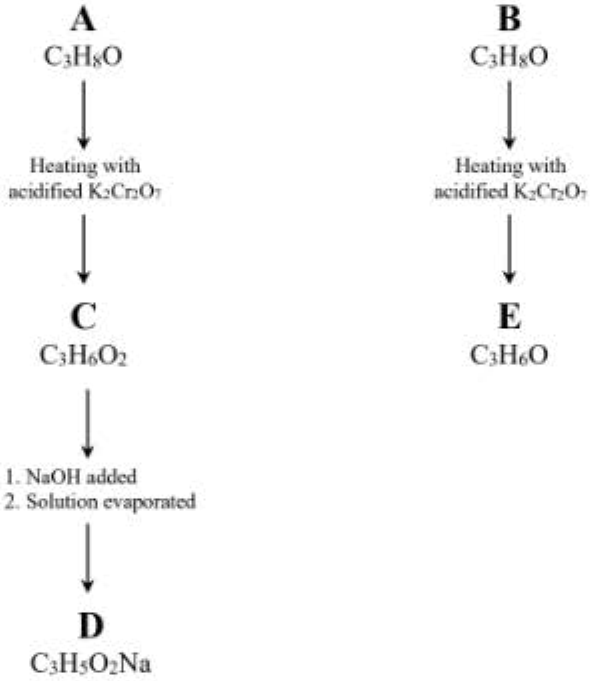
Question 30 (8 marks)

Two different compounds, **A** and **B**, are *isomers* with the molecular formula C_3H_8O.

Compound A and **compound B** undergo a series of reactions as shown below.



(a) Draw structural formulae for **compound C** and **compound E** in the space below. **3**

Compound C

Compound E

(b) Identify **compound A** and **compound B** by providing their systematic (IUPAC) names. **2**

Compound A: ....

Compound B: ....

Question 30 continues on page 21

(c) Pure samples of **compound B** and **compound C** are heated to reflux with a small volume of concentrated sulfuric acid.

Draw the structural formula of the organic compound that would be produced from this reaction. **2**

(d) Identify the name of the synthesis reaction described in part (c). **1**

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End of Question 30

Please turn over

Question 31 (6 marks)

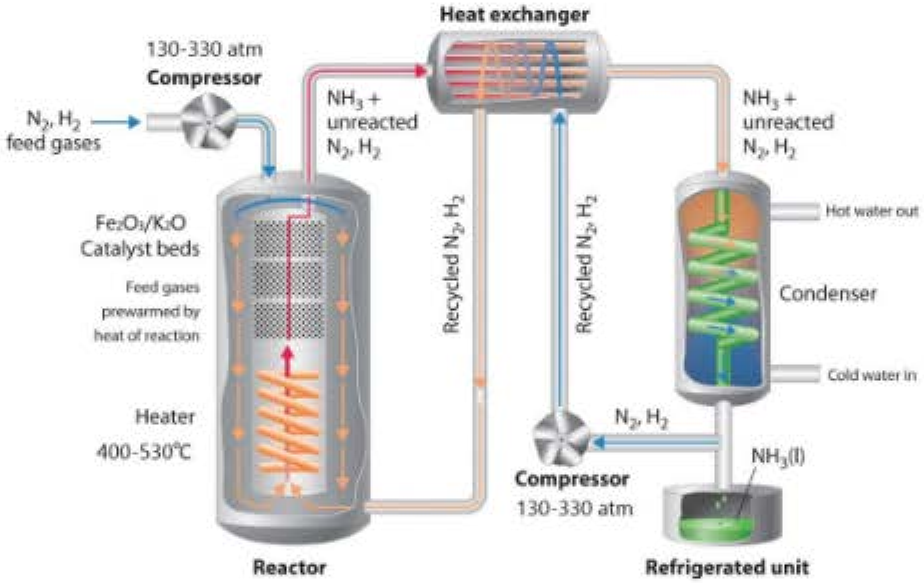
The acid dissociation constant (K_a) of a weak acid remains constant at a set temperature, regardless of the acid's concentration, yet the *degree of ionisation (%)* changes at different acid concentrations.

The K_a of ethanoic acid is 1.75×10^{-5} at 25°C.

Use calculations to show that the addition of 50 mL of water to a 50 mL sample of 0.100 mol L^{-1} ethanoic acid solution results in a *larger* degree of ionisation (%) for the diluted acid at 25°C. **6**

Question 32 (5 marks)

The diagram shows the industrial process used for the production of ammonia from nitrogen and hydrogen gases.



Explain FOUR factors that may have been considered in the design of this industrial process to ensure optimal production. Make specific reference to the diagram in your response. **5**

Question 32 continues on page 24

Question 32 (continued)

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End of paper

Student Number: ________________________________

Section II extra writing space. Clearly indicate which question you are answering.
Please note the use of this extra space with the question in the examination paper.

Student Number: ______________________________

Section II extra writing space. Clearly indicate which question you are answering.
Please note the use of this extra space with the question in the examination paper.

2021 HIGHER SCHOOL CERTIFICATE EXAMINATION

Chemistry

FORMULAE SHEET

$$n = \frac{m}{MM} \qquad c = \frac{n}{V} \qquad PV = nRT$$

$$q = mc\Delta T \qquad \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \qquad \mathrm{pH} = -\log_{10}\left[\mathrm{H}^+\right]$$

$$pK_a = -\log_{10}\left[K_a\right] \qquad A = \varepsilon lc = \log_{10}\frac{I_o}{I}$$

Avogadro constant, N_A	6.022×10^{23} mol^{-1}
Volume of 1 mole ideal gas: at 100 kPa and at 0°C (273.15 K)	22.71 L
at 25°C (298.15 K)	24.79 L
Gas constant	8.314 J mol^{-1} K^{-1}
Ionisation constant for water at 25°C (298.15 K), K_w	1.0×10^{-14}
Specific heat capacity of water	4.18×10^3 J kg^{-1} K^{-1}

DATA SHEET

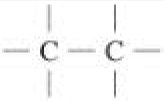
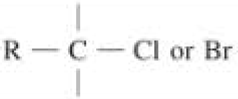
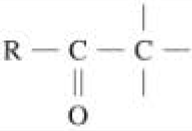
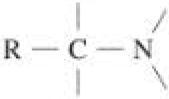
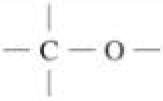
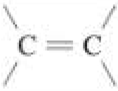
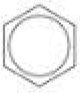
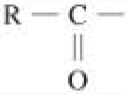
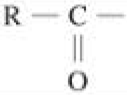
Solubility constants at 25°C

Compound	K_{sp}	*Compound*	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	Lead(II) hydroxide	1.43×10^{-15}
Calcium hydroxide	5.02×10^{-6}	Lead(II) phosphate	8.0×10^{-43}
Calcium phosphate	2.07×10^{-29}	Lead(II) sulfate	2.53×10^{-8}
Calcium sulfate	4.93×10^{-5}	Magnesium carbonate	6.82×10^{-6}
Copper(II) carbonate	1.4×10^{-10}	Magnesium hydroxide	5.61×10^{-12}
Copper(II) hydroxide	2.2×10^{-20}	Magnesium phosphate	1.04×10^{-24}
Copper(II) phosphate	1.40×10^{-37}	Silver bromide	5.35×10^{-13}
Iron(II) carbonate	3.13×10^{-11}	Silver chloride	1.77×10^{-10}
Iron(II) hydroxide	4.87×10^{-17}	Silver carbonate	8.46×10^{-12}
Iron(III) hydroxide	2.79×10^{-39}	Silver hydroxide	2.0×10^{-8}
Iron(III) phosphate	9.91×10^{-16}	Silver iodide	8.52×10^{-17}
		Silver phosphate	8.89×10^{-17}
		Silver sulfate	1.20×10^{-5}

Infrared absorption data

Bond	Wavenumber/cm^{-1}
N—H (amines)	3300–3500
O—H (alcohols)	3230–3550 (broad)
C—H	2850–3300
O—H (acids)	2500–3000 (very broad)
C≡N	2220–2260
C═O	1680–1750
C═C	1620–1680
C—O	1000–1300
C—C	750–1100

^{13}C NMR chemical shift data

Type of carbon		δ/ppm
 $-\overset{\vert}{\underset{\vert}{C}}-\overset{\vert}{\underset{\vert}{C}}-$		5–40
 $R-\overset{\vert}{\underset{\vert}{C}}-Cl$ or Br		10–70
 $R-\underset{O}{\underset{\Vert}{C}}-\overset{\vert}{\underset{\vert}{C}}-$		20–50
 $R-\overset{\vert}{\underset{\vert}{C}}-N\langle$		25–60
 $-\overset{\vert}{\underset{\vert}{C}}-O-$	alcohols, ethers or esters	50–90
 $\rangle C=C\langle$		90–150
$R-C\equiv N$		110–125
		110–160
 $R-\underset{O}{\underset{\Vert}{C}}-$	esters or acids	160–185
 $R-\underset{O}{\underset{\Vert}{C}}-$	aldehydes or ketones	190–220

UV absorption

(This is not a definitive list and is approximate.)

Chromophore	λ_{max} (nm)
C—H	122
C—C	135
C═C	162

Chromophore	λ_{max} (nm)
C≡C	173 178 196 222
C—Cl	173
C—Br	208

Some standard potentials

$K^+ + e^-$	$\rightleftharpoons$	$K(s)$	–2.94 V
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	$Ba(s)$	–2.91 V
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	$Ca(s)$	–2.87 V
$Na^+ + e^-$	$\rightleftharpoons$	$Na(s)$	–2.71 V
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	$Mg(s)$	–2.36 V
$Al^{3+} + 3e^-$	$\rightleftharpoons$	$Al(s)$	–1.68 V
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	$Mn(s)$	–1.18 V
$H_2O + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g) + OH^-$	–0.83 V
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	$Zn(s)$	–0.76 V
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	$Fe(s)$	–0.44 V
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	$Ni(s)$	–0.24 V
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	$Sn(s)$	–0.14 V
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	$Pb(s)$	–0.13 V
$H^+ + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g)$	0.00 V
$SO_4{}^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2(aq) + 2H_2O$	0.16 V
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	$Cu(s)$	0.34 V
$\frac{1}{2}O_2(g) + H_2O + 2e^-$	$\rightleftharpoons$	$2OH^-$	0.40 V
$Cu^+ + e^-$	$\rightleftharpoons$	$Cu(s)$	0.52 V
$\frac{1}{2}I_2(s) + e^-$	$\rightleftharpoons$	I^-	0.54 V
$\frac{1}{2}I_2(aq) + e^-$	$\rightleftharpoons$	I^-	0.62 V
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	0.77 V
$Ag^+ + e^-$	$\rightleftharpoons$	$Ag(s)$	0.80 V
$\frac{1}{2}Br_2(l) + e^-$	$\rightleftharpoons$	Br^-	1.08 V
$\frac{1}{2}Br_2(aq) + e^-$	$\rightleftharpoons$	Br^-	1.10 V
$\frac{1}{2}O_2(g) + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O	1.23 V
$\frac{1}{2}Cl_2(g) + e^-$	$\rightleftharpoons$	Cl^-	1.36 V
$\frac{1}{2}Cr_2O_7{}^{2-} + 7H^+ + 3e^-$	$\rightleftharpoons$	$Cr^{3+} + \frac{7}{2}H_2O$	1.36 V
$\frac{1}{2}Cl_2(aq) + e^-$	$\rightleftharpoons$	Cl^-	1.40 V
$MnO_4{}^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	1.51 V
$\frac{1}{2}F_2(g) + e^-$	$\rightleftharpoons$	F^-	2.89 V

Aylward and Findlay, *SI Chemical Data* (5th Edition) is the principal source of data for the standard potentials. Some data may have been modified for examination purposes.

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number	79
Symbol	Au
Standard Atomic Weight	197.0
Name	Gold

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.64 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.61 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.96 Molybdenum	43 Tc Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57–71 Lanthanoids	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.9 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89–103 Actinoids	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

Lanthanoids

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.1 Ytterbium	71 Lu 175.0 Lutetium

Actinoids

89 Ac Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Standard atomic weights are abridged to four significant figures.

Elements with no reported values in the table have no stable nuclides.

Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (November 2016 version).

The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.

Strathfield Girls High School

Student Number

HSC Chemistry Trial Examination 2022

Multiple-Choice Answer Sheet

Select the alternative A, B, C or D that best answers the question and indicate your choice with a cross (X) in the appropriate space on the grid below.

	A	B	C	D
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

	A	B	C	D
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

HSC Chemistry Trial Examination 2022
Marking Guidelines and Sample Answers

SECTION I (20 marks)

Multiple Choice Q1-20

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

SECTION II (80 marks)

Q21 (5 marks)

(a)

Criteria	Marks
• Provides an equation to show the ionisation of ethanamine in aqueous solution • Includes an equilibrium arrow and states of matter for all molecular species (both reactants)	1

Sample answer: $CH_3CH_2NH_{2(aq)} + H_2O_{(l)} \rightleftharpoons CH_3CH_2NH_3{}^{+}{}_{(aq)} + OH^{-}{}_{(aq)}$ $CH_3CH_2NH_2$ state may be (g) or (aq)

(b)

Criteria	Marks
• Uses the pK_b to calculate the K_b of ethanamine • Uses an ICE chart to indicate equilibrium concentrations • Uses the K_b expression to calculate the concentration of OH^- ions • Clearly states and applies the assumption ($0.15 - x \cong 0.15$) or uses a quadratic equation • Calculates the pOH of the solution • Calculates the pH of the solution • All working and calculations are shown	4
Provides any FOUR of the following criteria with most working shown: • Uses the pK_b to calculate the K_b of ethanamine • Uses an ICE chart to indicate equilibrium concentrations • Uses the K_b expression to calculate the concentration of OH^- ions • Calculates the pOH of the solution • Calculates the pH of the solution	3
• Provides any TWO of the above criteria (or equivalent) with some working shown	2
• Provides any ONE correct and relevant calculation	1

Sample answer:

K_b of ethanamine $= 10^{-pK_b} = 10^{-3.29} = 5.1286 \times 10^{-4}$

$K_b = [CH_3CH_2NH_3{}^{+}][OH^{-}]/[CH_3CH_2NH_2] = 5.1286 \times 10^{-4}$

	$[CH_3CH_2NH_2]$	$[CH_3CH_2NH_3^+]$	$[OH^-]$
I	0.15	0	0
C	– X	+ X	+ X
E	0.15 – X	X	X

As K_b is very small, we can assume: $0.15 - X \cong 0.15$

$K_b = [CH_3CH_2NH_3^+][OH^-]/[CH_3CH_2NH_2] = X^2/0.15 = 5.1286 \times 10^{-4}$

$X = \sqrt{(5.1286 \times 10^{-4} \times 0.15)} = \sqrt{(7.6929 \times 10^{-5})} = 8.77 \times 10^{-3}$ $\therefore [OH^-] = 8.77 \times 10^{-3}$ M

pOH = $-\log(8.77 \times 10^{-3}) = 2.057$ pH = 14 – pOH = 14 – 2.057 = 11.9

Q22 (6 marks)

(a)

Criteria	**Marks**
• Identifies that the equivalence point is indicated by a persistent purple colour • Explains that this is due to the excess of MnO_4^- ions as all the H_2O_2 is reacted	2
• Identifies that the reaction mixture will turn purple	1

Sample answer: The equivalence point would be recognised by a persistent purple colour as the MnO_4^- titrant is added. This is caused by the first excess of MnO_4^- ions that occurs when all the H_2O_2 has reacted.

(b)

Criteria	**Marks**
• Calculates the average titre of acidified MnO_4^- solution (only titres within 0.1 mL) • Calculates the moles of MnO_4^- ions used in the titration • Applies the reaction mole ratio to calculate the moles of H_2O_2 reacted (in 20 mL aliquot) • Calculates the molar mass of H_2O_2 • Calculates the concentration of H_2O_2 in mol/L OR the mass of H_2O_2 in 20 mL aliquot • Calculates the concentration of H_2O_2 in g/L • All working and calculations are shown	4
Provides any FOUR of the following criteria with most working shown: • Calculates the average titre of acidified MnO_4^- solution (only titres within 0.1 mL) • Calculates the moles of MnO_4^- ions used in the titration • Applies the reaction mole ratio to calculate the moles of H_2O_2 reacted (in 20 mL aliquot) • Calculates the concentration of H_2O_2 in mol/L OR the mass of H_2O_2 (using molar mass) • Calculates the concentration of H_2O_2 in g/L (using molar mass)	3
• Provides any THREE of the above criteria (or equivalent)	2
• Provides any ONE correct and relevant calculation	1

Sample answer:

Average titre of MnO_4^- solution = (26.90 + 26.80 + 26.90) mL ÷ 3 = 26.867 mL (titres within 0.1 mL)

Mol MnO_4^- = 0.0239 mol/L x 0.026867 L = 6.4212×10^{-4} mol

Reaction mol ratio MnO_4^- : H_2O_2 = 2 : 5 = 1 : 5/2 (i.e. ratio 2 : 5 = 2/2 : 5/2 = 1 : 5/2)

$\therefore$ mol H_2O_2 reacted = (5/2) x 6.4212×10^{-4} mol = 1.6053×10^{-3} mol

Molar mass H_2O_2 = (2 x 1.008 g/mol) + (2 x 16.0 g/mol) = 34.016 g/mol

Concentration H_2O_2 = n/V = 1.6053×10^{-3} mol / 0.020 L = 0.0803 mol/L **OR**

Mass H_2O_2 in 20 mL aliquot = n x MM = 1.6053×10^{-3} mol x 34.016 g/mol = 0.0546 g

Concentration H_2O_2 in g/L = mol/L x g/mol = 0.0803 mol/L x 34.016 g/mol = 2.73 g/L **OR**
Concentration H_2O_2 in g/L = mass ÷ volume = 0.0546 g / 0.020 L = 2.73 g/L

Q23 (11 marks)

(a)

Criteria	Marks
• Identifies the anion as carbonate • Identifies the white precipitate product of **step 2** as $CaCO_3$ • Reasons that the colourless gas must be CO_2 • Explains that CO_2 gas is produced from the reaction of a carbonate with HNO_3 in **step 1**	3
• Identifies the anion as carbonate • Provides some correct reasoning from ONE step (identifies $CaCO_3$ precipitate or CO_2 gas)	2
• Identifies the anion as carbonate OR identifies $CaCO_3$ precipitate or CO_2 gas	1

Sample answer: The anion in the white powder is carbonate. In step 2, a white precipitate is produced when the gas is bubbled through limewater. This precipitate would be $CaCO_3$ and indicates a positive test for CO_2 gas. As the white powder produces CO_2 when reacted with HNO_3 (step 1), the pure white powder must contain carbonate ions.

(b)

Criteria	Marks
• Identifies the cation as barium and supports this choice with the flame test result • Explains that insoluble $BaSO_4$ was produced when H_2SO_4 was added in **step 5** • Explains that $BaCl_2$ is soluble so the addition of HCl produced no precipitate in **step 4** • All reasoning provided for the three tests is valid and correct	4
• Identifies the cation as barium **AND** *Any TWO of the following criteria:* • Supports the choice of barium with the flame test result • States that barium produces a precipitate with H_2SO_4 in **step 5** • States that barium produces no precipitate with HCl in **step 4**	3
• Identifies the cation as barium AND provides ONE reason from the above criteria **OR** *Suggests an alternative cation that is consistent with:* • An insoluble sulfate being produced when H_2SO_4 was added in **step 5** • A soluble chloride resulting from the addition of HCl in **step 4**	2
• Any information relating to the question criteria	1

Sample answer: The cation in the white powder is barium. The apple green flame in the flame test is unique to barium. Further evidence is provided by the tests in steps 4 & 5. When dilute HCl was added in step 4, there was no precipitate, as the combination of barium ions with chloride is soluble. When dilute H_2SO_4 was added in step 5, a white precipitate of $BaSO_4$ was formed.

(c)

Criteria	Marks
• Identifies that using Na_2SO_4 would contaminate the unknown cation with Na^+ ions • Explains that the flame test may give a mixed result if Na^+ ions are also present	2
• Identifies that Na^+ ions may affect the flame test result **OR** • Identifies that contamination with a cation may affect subsequent tests	1

Sample answer: Using Na_2SO_4 in step 5 would contaminate the mixture with Na^+ ions. These ions may be carried through with the filtered solid in step 6, giving a mixed result in the flame test.

(d)

Criteria	Marks
• Identifies all ions that could be present in the colourless solution • Provides adequate reasoning to justify the ion mixture present • Relates to the acidic properties of nitric acid, sulfuric acid and the HSO_4^- ion	2
• Identifies some ions that could be present in the colourless solution **OR** • Identifies ONE ion with some justification (based on solubility or ionisation)	1

Sample answer: The ions that could be present in the colourless mixture obtained from step 6 are NO_3^-, H_3O^+, HSO_4^- and SO_4^{2-}. These ions are present due to the addition of nitric acid at step 1 and sulfuric acid at step 6. Both nitric acid and sulfuric acid are strong acids, producing H_3O^+ ions in aqueous solution. The HSO_4^- ion is present as it is a weak acid, with only some of these ions producing SO_4^{2-}.

Q24 (7 marks)

(a)

Criteria	Marks
• Writes a balanced chemical equation to represent the buffer equilibrium system	1

Sample answer: $C_2H_5COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons C_2H_5COO^-_{(aq)} + H_3O^+_{(aq)}$ (States of matter not required for the mark)

(b)

Criteria	Marks
• States the role of a buffer is to prevent large changes in pH (or H_3O^+ concentration) • Explains how the buffer components absorb H_3O^+ and re-establish equilibrium • Explains how the buffer components neutralise base and re-establish equilibrium • Refers to the equilibrium equation in part (a) to explain how the buffer works (directions)	4
• Provides any THREE of the above criteria to describe the action of a buffer • Demonstrates a good understanding of how a buffer works	3
• Provides any TWO of the above criteria to outline the action of a buffer • Demonstrates a basic understanding of how a buffer works	2
• Identifies some features of a buffer system (any relevant information)	1

Sample answer: A buffer regulates pH by maintaining the concentration of H_3O^+ ions through an equilibrium reaction where the weak acid and its conjugate base work to neutralise any excess acid and base. In the equilibrium reaction shown in part (a), if a strong acid is added, there will be an excess of hydronium ions. This will cause the reverse reaction in the equation will be favoured. The propanoate ion will react with hydronium ions to give propanoic acid and water. If a strong base is added, the hydronium ions will immediately neutralise the added base to give water. This will cause the forward reaction to be favoured to regenerate the hydronium ions consumed. Through these processes, the pH of the buffer remains at the approximately the same level despite the addition of strong acid or base.

(c)

Criteria	Marks
• The weak acid should be selected on its pK_a (or K_a) as this determines the resulting pH • Prepare a buffer with equal concentrations of the weak acid and its conjugate base to ensure maximum buffering capacity	2
• Provides ONE factor that is important for the preparation of buffer solution	1

Sample answer: To prepare a buffer to a certain pH, the choice of weak acid is important as the pK_a of a weak acid will determine how well it ionises in solution and, consequently, the resulting pH. To ensure maximum buffering capacity, the buffer solution should have equal concentrations of the weak acid and its conjugate base.

Q25 (9 marks)

(a)

Criteria	Marks
• Writes a balanced *ionic* equation for the formation of AgCl and $BaSO_4$ precipitates • Includes states of matter for the two precipitates	2
Provides any ONE of the following (with states for precipitates): • A balanced ionic equation for the precipitation of AgCl or $BaSO_4$ • A balanced chemical equation for the formation of AgCl and $BaSO_4$ precipitates (not ionic) • A substantially correct ionic equation for the formation of AgCl and $BaSO_4$ (one error only)	1

Sample answer: $Ba^{2+}{}_{(aq)} + 2Cl^-{}_{(aq)} + 2Ag^+{}_{(aq)} + SO_4{}^{2-}{}_{(aq)} \rightarrow BaSO_{4(s)} + 2AgCl_{(s)}$

(b)

Criteria	Marks
• Identifies the presence of Ag^+ and $SO_4{}^{2-}$ ions in solution at volume V_o • Relates the high conductivity at volume V_o to the presence of ions in solution • Identifies the formation of AgCl and $BaSO_4$ precipitates as $BaCl_2$ is added • States that all ions are in precipitates to explain the minimum conductivity at volume V_1	3
Any THREE of the following criteria (or equivalent combination): • Identifies the ions present at volume V_o • Relates conductivity to the presence of ions in solution • Identifies that precipitation occurs as $BaCl_2$ is added • Relates to precipitation of ions to explain the minimum conductivity at volume V_1	2

• Identifies components at V_o or V_1 **OR** • Provides some relevant information or reasoning for the high/low conductivity at V_o or V_1	1

Sample answer: At **volume V_o**, there are Ag^+ and SO_4^{2-} ions in solution which conduct a current well, resulting in high conductivity. As $BaCl_2$ solution is added, precipitates of $BaSO_4$ and AgCl begin to form, removing ions from solution. At **volume V_1**, all of the Ag^+ and SO_4^{2-} ions have formed precipitates with the Ba^{2+} and Cl^- ions, leaving virtually no ions in solution, thereby reducing the conductivity to a minimum.

(c)

Criteria	Marks
• Calculates the moles of Ag_2SO_4 present at volume V_o • Applies the 1:1 reaction mole ratio (Ag_2SO_4 : $BaCl_2$) to determine the moles of $BaCl_2$ at V_1 • Calculates the volume of $BaCl_2$ solution added between V_o and V_1 • All required working is shown	2
• Provides ONE correct and relevant calculation OR states the volume of $BaCl_2$ used	1

Sample answer:

Mol Ag_2SO_4 in solution initially = c x V = 0.01 mol L^{-1} x 0.4 L = 0.004 mol

Mole ratio Ag_2SO_4 **:** $BaCl_2$ is 1**:**1 $\therefore$ Mol $BaCl_2$ added at volume V_1 = mol Ag_2SO_4 present = 0.004 mol

Volume $BaCl_2$ added: V = n / c = 0.004 mol / 0.1 mol L^{-1} = 0.04 L $BaCl_2$

(d)

Criteria	Marks
• Identifies the increasing excess of Ba^{2+} and Cl^- ions (excess $BaCl_2$) in solution after V_1 • Relates the increasing conductivity to a property of the ions in solution	2
• Identifies the excess of Ba^{2+} and/or Cl^- ions (excess $BaCl_2$) in solution after V_1 **OR** • Identifies a property of Ba^{2+} and Cl^- ions in solution that increases conductivity	1

Sample answer: After volume V_1, there is an increasing excess of Ba^{2+} and Cl^- ions in solution. As these ions are freely moving, the level of conductivity also increases.

Q26 (4 marks)

Criteria	Marks
• Calculates the moles of H^+ available to react with the base • Calculates the moles of OH^- available to react with the acid • Calculates the excess moles of OH^- ions • Calculates the concentration of OH^- ions • Calculates the pOH of the resulting solution • Calculates the pH of the resulting solution	4
• Provides any FOUR of the above criteria	3
• Provides any TWO of the above criteria	2
• Provides any ONE correct and relevant calculation	1

Sample answer:

Mol H^+ = 0.259 mol L^{-1} x 0.160 L x 2 = 0.08288 mol

Mol OH^- = 0.695 mol L^{-1} x 0.185 L = 0.1286 mol

Mol excess OH^- = (0.1286 – 0.08288) mol = 0.04572 mol

Concentration OH^- = n / v = 0.04572 mol / (0.160 + 0.185) L = 0.1325 mol L^{-1}

pOH of solution = –log [OH^-] = –log 0.1325 = 0.8778

pH of solution = 14 – pOH = 14 – 0.8778 = 13.1

Q27 (6 marks)

(a)

Criteria	Marks
• Identifies the acid-base property of all three salts	1

Sample answer: $NaHCO_3$ is basic; NH_4CH_3COO is neutral; $KHSO_4$ is acidic.

(b)

Criteria	Marks
• Provides <u>equations</u> for the partial hydrolysis* of relevant ions in EACH salt to show effects • Explains the acid-base property of EACH salt by relating to the H_3O^+ or OH^- produced	4
Demonstrates a good understanding of acidic/basic effects through the following (or equivalent): • Provides equations for the partial hydrolysis* of TWO relevant ions to show the effects • Relates to the acid-base properties of the ions in aqueous solution **OR** • Describes the hydrolysis* reactions of TWO relevant ions (e.g. two flawed equations) • Explains the acid-base properties in aqueous solution by relating to H_3O^+ or OH^- produced	3
Demonstrates a basic understanding of acidic/basic effects through the following (or equivalent): • Provides an equation for the partial hydrolysis* of ONE relevant ion to show an effect **OR** • Describes the hydrolysis* reaction of ONE relevant ion (e.g. one flawed equation) • Relates to the acid-base property of the ion **OR** • Describes, in general terms, the acidic or basic effects (relating to H_3O^+ or OH^-) of TWO salts without identifying the ions responsible for these effects	2
• Any information relevant to the criteria	1

Hydrolysis** *means the equation* ***involves water *as a reactant and* ***produces H_3O^+ or OH^-***

Sample answer:

The acid-base property of each salt is caused by hydrolysis reactions of ions in aqueous solution.

The **bicarbonate ion** in $NaHCO_3$ is protonated by water in aqueous solution, as shown by the equation: $HCO_3^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)} + OH^-{}_{(aq)}$. As the reaction produces a **small amount of OH^-**, this results in a **basic pH**.

The **ammonium ion** in NH_4CH_3COO releases a hydrogen ion in aqueous solution, as shown by the equation: $NH_4^+{}_{(aq)} + H_2O_{(l)} \rightleftharpoons NH_{3(aq)} + H_3O^+{}_{(aq)}$. The **ethanoate ion** is protonated by water in aqueous solution, as shown by the equation: $CH_3COO^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COOH_{(aq)} + OH^-{}_{(aq)}$. As **both H_3O^+ and OH^- ions** are produced in approximately equivalent amounts, this results in a **neutral pH**.

The **hydrogen sulfate ion** in $KHSO_4$ releases a hydrogen ion in aqueous solution, as shown by the equation: $HSO_4^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons SO_4^{2-}{}_{(aq)} + H_3O^+{}_{(aq)}$. The formation of a **small amount of H_3O^+** results in an **acidic pH**.

Note: States of matter were not required in equations. Marks are not awarded for **incorrect acid/base effects** regardless of information shown in (a). The equations must show what **can occur in water**. Contradictory information (presenting both effects) was not awarded marks. Only the ammonium ethanoate salt was neutral (both effects are relevant).

(c)

Criteria	Marks
• Identifies that the chemist did not prepare the salt solutions at the same concentrations	1

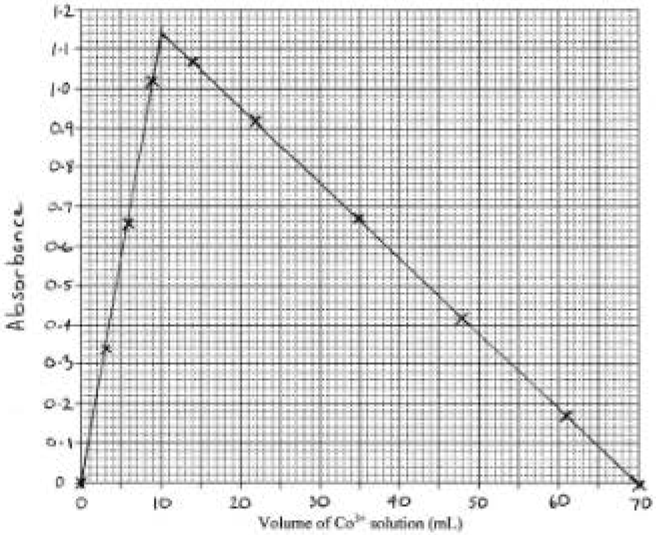
Sample answer: Equal masses of the compounds will not provide equal moles (salts have different molar masses). The salt solutions were prepared at different concentrations which means they were not fairly compared when measuring the pH of each solution.

Q28 (7 marks)

(a)

Criteria	Marks
• Labels the Y axis correctly (absorbance has no units) • Draws consistent numerical scales • Correctly plots all data points • Draws **two intersecting straight lines of best fit** from the X-axis through the data points	4
Any THREE of the following criteria: • Labels the Y axis correctly (absorbance has no units) • Draws consistent numerical scales • Correctly plots all data points • Draws two straight lines of best fit from the X-axis through the data points	3
Any TWO of the following criteria: • Labels the Y axis correctly (absorbance has no units) • Draws consistent numerical scales • Correctly plots all data points • Draws two straight lines of best fit from the X-axis through the data points	2
• Provides a numerical scale relevant to the graph (or any combination of numeracy skills)	1

Sample answer:



(b)

Criteria	Marks
• Provides an estimate of maximum absorbance based on the graph	1

Sample answer: An absorbance of 1.14 (figure shown by the graph at the intersection of the two lines).

(c)

Criteria	Marks
• Identifies the volumes of solutions required to give maximum absorbance • Relates the volumes of the reacting solutions to a reaction ratio • Identifies the correct whole number values for *a* and *b* (empirical ratio from the data)	2
• Any ONE of the above criteria or equivalent information	1

Sample answer: Maximum complexation occurs at the absorbance of 1.14. As shown by the graph, the two lines of best fit intersect at a peak where 10 mL of Co^{3+} is mixed with 60 mL of ligand X solution. As these two solutions are of equal concentration, this represents a volume ratio of 10:60 and an empirical reaction ratio of 1:6 for Co^{3+}:X. Therefore, the values for *a* and *b* are *a* = 1 and *b* = 6.

Q29 (6 marks)

(a)

Criteria	Marks
• Provides a balanced chemical equation for the neutralisation reaction	1

Sample answer: $CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$ (States of matter not required for the mark)

(b)

Criteria	Marks
• Calculates the moles of NaOH used to neutralise the excess HCl • Calculates the moles of excess HCl (reaction with NaOH) • Calculates the moles of HCl added to the section of pipe • Calculates the moles of HCl that reacted with $CaCO_3$ in the pipe • Applies the reaction mole ratio to calculate the moles of $CaCO_3$ • Calculates the molar mass $CaCO_3$ • Calculates the mass of $CaCO_3$ that was in the pipe to 3 significant figures	5
Any SIX of the following criteria: • Calculates the moles of NaOH used to neutralise the excess HCl • Calculates the moles of excess HCl (reaction with NaOH) • Calculates the moles of HCl added to the section of pipe • Calculates the moles of HCl that reacted with $CaCO_3$ in the pipe • Applies the reaction mole ratio to calculate the moles of $CaCO_3$ • Calculates the molar mass $CaCO_3$ • Calculates the mass of $CaCO_3$ that was in the pipe	4
• Provides any FIVE of the above criteria	3
• Provides any THREE of the above criteria	2
• Provides any ONE correct and relevant calculation	1

Sample answer: $NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

Moles of NaOH used in titration = 0.100 mol L^{-1} x 0.0393 L = 0.00393 mol

Moles HCl excess = moles NaOH used in titration = 0.00393 mol (1:1 mole ratio)

Moles HCl added to the section of pipe = 0.250 mol L^{-1} x 0.100 L = 0.0250 mol

Moles HCl that reacted with $CaCO_3$ in pipe = (0.0250 – 0.00393) mol = 0.02107 mol

Mole ratio $CaCO_3$: HCl = 1:2 ∴ moles $CaCO_3$ = moles HCl ÷ 2 = 0.02107 mol ÷ 2 = 0.010535 mol

Molar mass $CaCO_3$ = 100.09 g mol^{-1}

Mass $CaCO_3$ = n x MM = 0.010535 mol x 100.09 g mol^{-1} = 1.05 g

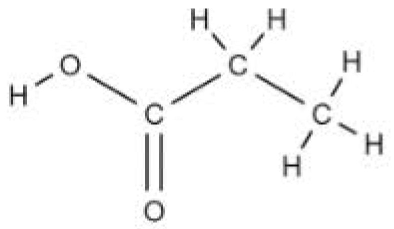
Q30 (8 marks)

(a)

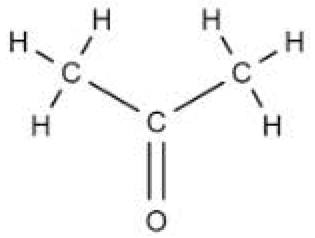
Criteria	Marks
• Provides the structures of compounds C and E • Both compounds are drawn as structural formulae (all bonds are shown)	3
• Provides the structures of compounds C and E in any format **OR** • Provides the structural formula of compound C or E	2
• Provides the structure of compound C or E in any format	1

Sample answer:

Compound C



Compound E



(b)

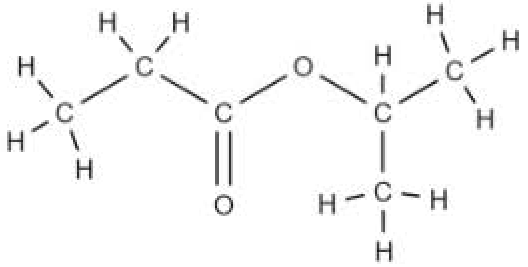
Criteria	Marks
• States the IUPAC names of compounds A and B	2
• States the IUPAC name of compound A or B	1

Sample answer: **Compound A:** propan-1-ol **Compound B:** propan-2-ol

(c)

Criteria	Marks
• Provides the structure of the ester resulting from the reaction of compounds B and C • The structural formula is drawn (all bonds are shown)	2
• Provides a substantially correct structure of the ester produced from the reaction of B and C	1

Sample answer:



(d)

Criteria	Marks
• Identifies the reaction as esterification	1

Sample answer: Esterification

Q31 (6 marks)

Criteria	Marks
• Uses the K_a of ethanoic acid and applies relevant calculations throughout the response • Calculates the [CH_3COO^-] *at equilibrium* for 0.100 M ethanoic acid • Calculates the degree of ionisation (%) for 0.100 M ethanoic acid • Calculates the concentration of diluted ethanoic acid (2x dilution factor) • Calculates the [CH_3COO^-] *at equilibrium* for 0.050 M ethanoic acid • Calculates the degree of ionisation (%) for 0.050 M ethanoic acid	6
• Uses the K_a of ethanoic acid and applies relevant calculations throughout the response **AND** *Provides any FOUR of the following criteria:* • Calculates the [CH_3COO^-] *at equilibrium* for 0.100 M ethanoic acid • Calculates the degree of ionisation (%) for 0.100 M ethanoic acid • Calculates the concentration of diluted ethanoic acid (2x dilution factor) • Calculates the [CH_3COO^-] *at equilibrium* for 0.050 M ethanoic acid • Calculates the degree of ionisation (%) for 0.050 M ethanoic acid	5
• Uses the K_a of ethanoic acid and applies relevant calculations throughout the response **AND** *Provides any THREE of the following criteria:* • Calculates the [CH_3COO^-] *at equilibrium* for 0.100 M ethanoic acid • Calculates the degree of ionisation (%) for 0.100 M ethanoic acid • Calculates the concentration of diluted ethanoic acid (2x dilution factor) • Calculates the [CH_3COO^-] *at equilibrium* for 0.050 M ethanoic acid • Calculates the degree of ionisation (%) for 0.050 M ethanoic acid	4
Provides any THREE of the following criteria: • Uses the K_a of ethanoic acid in relevant calculations • Calculates the [CH_3COO^-] *at equilibrium* for 0.100 M ethanoic acid • Calculates the degree of ionisation (%) for 0.100 M ethanoic acid • Calculates the concentration of diluted ethanoic acid (2 x dilution factor) • Calculates the [CH_3COO^-] *at equilibrium* for 0.050 M ethanoic acid • Calculates the degree of ionisation (%) for 0.050 M ethanoic acid	3
• Provides any TWO of the above criteria (or equivalent information)	2

• Provides any ONE of the above criteria (or equivalent information)	1

Sample answer:

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

$K_a = [CH_3COO^-][H_3O^+]/[CH_3COOH]$

	$[CH_3COOH]$	**$[CH_3COO^-]$**	**$[H_3O^+]$**
I	0.100	0	0
C	– X	+ X	+ X
E	0.100 – X	X	X

Using ICE chart concentrations:

$K_a = X^2/0.100 = 1.75 \times 10^{-5}$

As K_a is very small, we can assume: $0.100 - x \cong 0.100$

$X = \sqrt{(1.75 \times 10^{-5} \times 0.100)} = 1.323 \times 10^{-3}$

$\therefore X = [CH_3COO^-] = \mathbf{1.323 \times 10^{-3}\ mol\ L^{-1}}$

$\therefore$ Degree of ionisation at 0.100 mol L^{-1} = $(1.323 \times 10^{-3}/0.100) \times 100$ = **1.32%**

Ethanoic acid is diluted to 0.050 mol L^{-1} with water (50 mL → 100 mL)

$K_a = X^2/0.050 = 1.75 \times 10^{-5}$ (using ICE chart – same process as used previously)

$X = \sqrt{(1.75 \times 10^{-5} \times 0.050)} = 9.354 \times 10^{-4}$

$\therefore X = [CH_3COO^-] = \mathbf{9.354 \times 10^{-4}\ mol\ L^{-1}}$

$\therefore$ Degree of ionisation at 0.050 mol L^{-1} = $(9.354 \times 10^{-4}/0.050) \times 100$ = **1.87%**

When ethanoic acid is diluted, the degree of ionisation increases.

Q32 (5 marks)

Criteria	Marks
• Describes FOUR chemical design factors that are relevant to features of the industrial process • Explains how EACH factor optimises the production of ammonia • Comprehensively relates the explanation to the diagram as relevant for each factor	5
• Explains THREE chemical design factors that optimise the production of ammonia • Makes specific reference to the diagram as relevant **OR** • Describes FOUR chemical design factors that optimise the production of ammonia • Makes specific reference to the diagram as relevant	4
• Explains TWO chemical design factors that optimise the production of ammonia • Makes some reference to the diagram as relevant **OR** • Describes THREE chemical design factors that optimise the production of ammonia • Makes some reference to the diagram as relevant	3
• Explains ONE chemical design factor that optimises the production of ammonia **OR** • Describes TWO chemical design factors that optimise the production of ammonia **OR** • Identifies FOUR chemical design factors that optimise the production of ammonia	2
• Any information relevant to the above criteria	1

Sample answer:

Four factors that may have been considered in the design of this industrial process include the following:

- **Use of moderately high temperature 400-530°C**. When gases are heated, the molecules gain more kinetic energy. This results in more energetic and successful collisions and, consequently, a faster reaction rate.
- **Use of catalyst beds Fe_2O_3/K_2O**. Catalysts increase the reaction rate by providing an alternative reaction pathway with a lower activation energy. In the presence of the catalyst, more molecules of N_2 and H_2 have the require activation energy, so the conversion of N_2 and H_2 to the NH_3 product is faster.
- **Use of high pressure 130-330 atm**. Increasing the pressure of a gaseous reaction results in more frequent collisions between reactant molecules. This causes the reaction rate to increase as there are a greater proportion of successful collisions at high pressure.
- **Recycling of unused reactants**. Reactions are most efficient when all molecules of the reactants are converted to products. Through the repeated recycling of unused N_2 and H_2 reactant gases in the system, the complete conversion of these reactants to NH_3 product is possible. This ensures that almost 100% atom economy can be achieved. The cost of sourcing more reactants is also minimised.

The use of a moderately high temperature, along with the Fe_2O_3 catalyst and high pressure all serve to increase the reaction rate. If the reaction of N_2 and H_2 to give NH_3 is faster, the industrial process is more efficient and economic (more product in less time), as NH_3 production is optimised. The recycling of reactants until the conversion to product is complete ensures a maximum yield of NH_3 product is achieved