SYDNEY GRAMMAR SCHOOL

TRIAL EXAMINATION 2023

FORM VI CHEMISTRY

STRUCTURE OF PAPER

SECTION I

A: Multiple Choice 20 marks

Allow about 30 minutes for this section.

SECTION II 80 marks

Allow about 2 hours and 30 minutes for this section.

EXAMINATION

DATE: Mon 14 August 8.40am

DURATION: 3 hours + 5 minutes reading time

MARKS: 100

CHECKLIST

Each boy should have the following:

- ☐ 1 Examination Paper (data sheet attached on back)
- ☐ 1 Multiple-Choice Answer Sheet

EXAM INSTRUCTIONS

- Remove the centre staple and hand in all parts of the paper in a neat bundle.
- WRITE YOUR CANDIDATE NUMBER IN THE SPACE PROVIDED AT THE TOP OF EACH PAGE WHERE INDICATED ON PAGE 11, 17, 23 and 27.

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SECTION I: MULTIPLE CHOICE (20 marks)

Attempt ALL Questions
Use the Multiple-Choice Answer Sheet.

1 Which of the following would best enable 2,2,4-trimethylpentane to be distinguished from octane?

(A) Mass spectrometry
(B) Determination of molar mass using gravimetric analysis
(C) Measuring volume of carbon dioxide produced when combusted
(D) Addition of bromine water

2 Separate 20.0 mL solutions of a weak monoprotic acid and a strong monoprotic acid of the same concentration are titrated with NaOH solution. Which of the following will be the same for these two titrations?

(A) Initial pH
(B) pH at the equivalence point
(C) Volume of NaOH required to reach the equivalence point
(D) The conductivity of the initial acid solutions

3 Which of the following reagents would liberate carbon dioxide when mixed with a concentrated aqueous solution of sodium carbonate?

(A) ethanoic acid
(B) ethanamine
(C) ethanamide
(D) ethyl ethanoate

4 Which of the following conditions will maximise the yield of dinitrogen tetraoxide?

$$2\ NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H = -57.2\ kJ\ mol^{-1}$$

(A) Low temperature, low pressure
(B) Low temperature, high pressure
(C) High temperature, low pressure
(D) High temperature, high pressure

5 10 mL of 0.01 mol L^{-1} nitric acid (HNO_3) is diluted with 90 mL of water. What is the pH of the resulting solution?

(A) 1

(B) 2

(C) 3

(D) 4

6 Which of the following hydrocarbons contains an atom with trigonal planar geometry?

(A) propane

(B) propene

(C) propyne

(D) 2-methylpropane

7 Ethene reacts with hydrogen gas in the presence of a Pd-C catalyst. Which of the following statements about this reaction is correct?

(A) Ethanol is produced.

(B) The reaction also produces a byproduct.

(C) The Pd-C is consumed in the reaction.

(D) This is an addition reaction.

8 What is the concentration of OH^- ions (in mol L^{-1}) in an aqueous solution in which $[H^+] = 2.0\times10^{-3}$ mol L^{-1} at 25°C?

(A) 2.0×10^{-3}

(B) 4.0×10^{-6}

(C) 5.0×10^{-12}

(D) 2.0×10^{-17}

9 The name 2-propyl-2-chloro-4,5-dibromopentane does not follow IUPAC conventions. What is the systematic name of this compound?

(A) 4,5-dibromo-2-chloro-2-propylpentane

(B) 2-chloro-4,5-dibromo-2-propylpentane

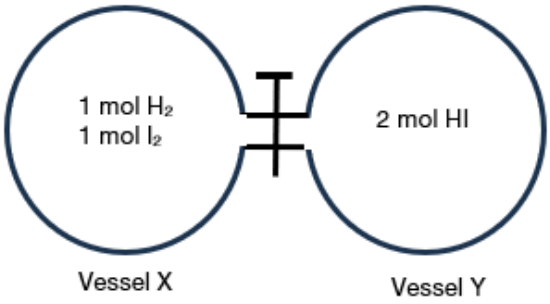
(C) 4-chloro-6,7-dibromo-4-methylheptane

(D) 1,2-dibromo-4-chloro-4-methylheptane

10 Hydrogen and iodine react at 500°C according to the equation:

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

The apparatus shown below is set-up.



The tap between Vessels X and Y is opened and then the system is left at 500°C until no further change occurs. Which of the following statements is true?

(A) X will contain more hydrogen than Y.

(B) X and Y will contain the same amount of HI(g).

(C) X will contain less iodine than Y.

(D) Y will contain more HI(g) than X.

11 An organic compound reacted with concentrated HCl and $ZnCl_2$ to produce 2-chloro-2-methylpentane. What was the name of the original compound?

(A) 2-methylpentan-1-ol

(B) 2-chloropentanal

(C) 2-methylpentan-2-ol

(D) 2-methylpentanal

12 The following equilibrium exists in bromine water:

$$Br_2(aq) + H_2O(l) \rightleftharpoons Br^-(aq) + 2\ H^+(aq) + OBr^-(aq)$$

(red-brown) (colourless) (colourless)

Which of the following solutions could be added to the reaction mixture to cause the red-brown colour of bromine water to fade?

(A) HCl

(B) KBr

(C) $AgNO_3$

(D) NaOBr

13 Which of the following salts has the highest molar solubility?

(A) calcium carbonate

(B) copper(II) carbonate

(C) lead(II) carbonate

(D) silver carbonate

14 A exists in equilibrium with B according to the equation below:

$$A(g) \rightleftharpoons B(g)$$

If 1.0 mole of A was allowed to reach equilibrium, how many moles of B would be formed if K_{eq} is equal to 0.40.

(A) 0.29 mol

(B) 0.40 mol

(C) 0.60 mol

(D) 0.71 mol

15 Propan-2-ol is heated with concentrated sulfuric acid. Compared to propan-2-ol, the product of this reaction:

(A) is more soluble in water.

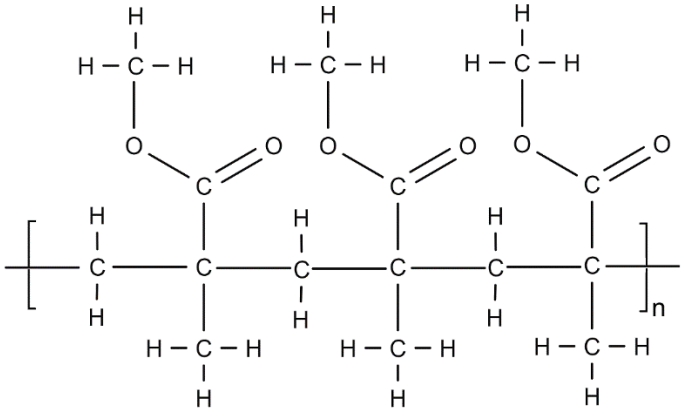
(B) has a higher molar mass.

(C) has fewer signals in ^{13}C NMR.

(D) has a lower boiling point.

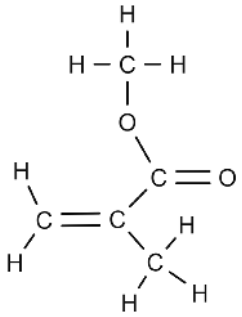
Question 16 and 17 refer to the following information.

A section of a polymer is shown below.

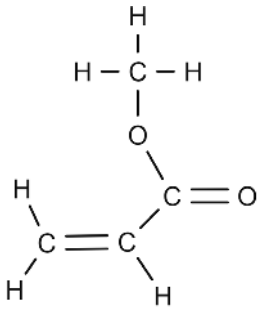


16 Which of the following shows the monomer used to produce the polymer shown above?

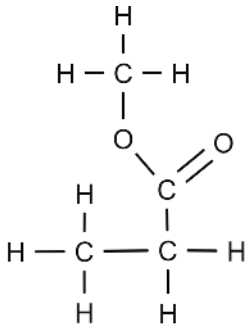
(A)



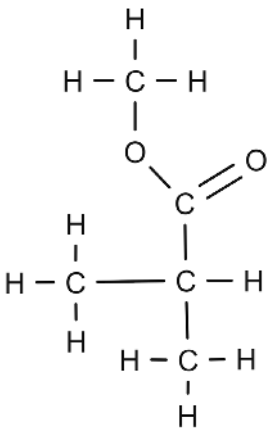
(B)



(C)



(D)



17 If you are comparing this polymer to polyethylene, which of the following would be true?

(A) This polymer is an addition polymer while polyethylene is a condensation polymer.

(B) High-density polyethylene would have weaker intermolecular forces as the chains can pack into a more orderly solid.

(C) Being a polyester, this polymer is used to make clothing while polyethylene is used for car tyres.

(D) Both polymers could be made without the elimination of a small molecule.

18 Ammonia (NH_3) is a weak base in aqueous solution with an ionisation constant K_b.

Which of the following represents the ionisation constant for the reaction:

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

(A) $\dfrac{K_w}{K_a}$

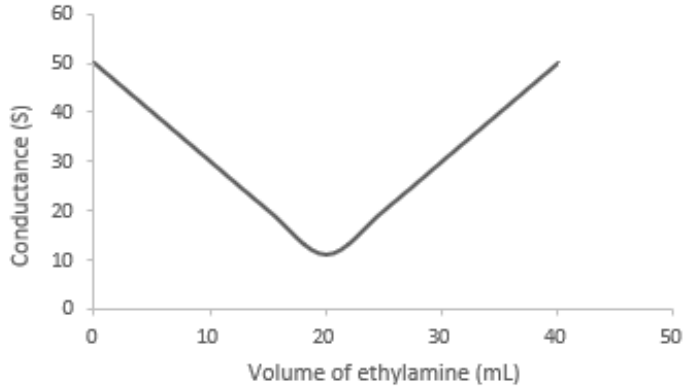
(B) $\dfrac{K_a}{K_w}$

(C) $\dfrac{K_w}{K_b}$

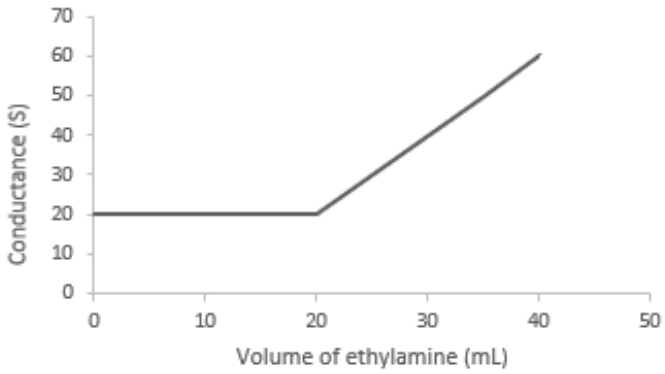
(D) $\dfrac{K_b}{K_w}$

19 Which of the following plots correctly represents the conductometric titration of 0.05 mol L^{-1} H_2SO_4 with 0.1 mol L^{-1} of the weak organic base ethylamine?

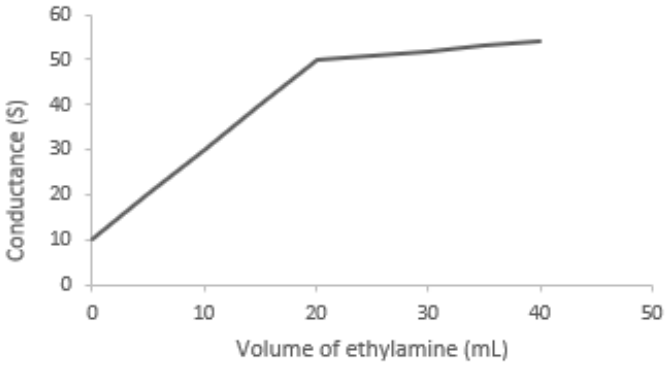
(A)



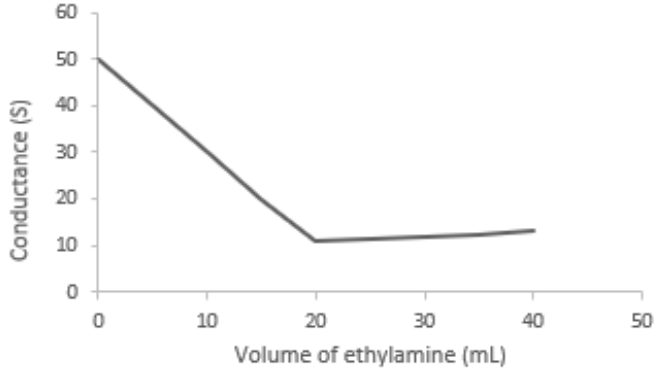
(B)



(C)



(D)



20 Solid calcium chloride is added to 200.0 mL of 0.12 mol L^{-1} potassium sulfate solution at 298 K.

What is the minimum mass of calcium chloride required to produce a precipitate?

(A) 0.0033 g

(B) 0.0091 g

(C) 0.228 g

(D) 6.21 mg

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Question 21 (3 marks)

The table provides thermodynamic data about two bromide salts.

	$\Delta_{sol}H$ (kJ mol^{-1})	$\Delta_{sol}S$ (J K^{-1} mol^{-1})
LiBr	-48.8	21.5
KBr	19.9	89.0

Compare and explain the solubilities of the two bromide salts at 300 K. You should include calculations in your answer.

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Question 22 (7 marks) **Marks**

Sulfur trioxide decomposition reaches equilibrium at 200°C according to the equation:

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

(a) Use Collision Theory to state and explain the effect, if any, of an increase in the overall pressure. **3**

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(b) Identify the effect, if any, on the value of K_{eq}, if the overall pressure of the system is increased. **1**

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(c) A 0.40 mol sample of $SO_3(g)$ is placed in a 2.0 L vessel and allowed to reach equilibrium. Given that $K_{eq} = 1.30 \times 10^{-9}$ at this temperature, calculate the equilibrium concentration of $SO_2(g)$. **3**

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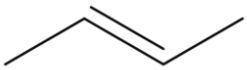
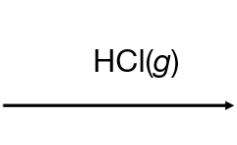
Question 23 (3 marks) **Marks**

Complete the reactions below by drawing the structure of all organic reactant(s) and/or organic product(s).

(a)

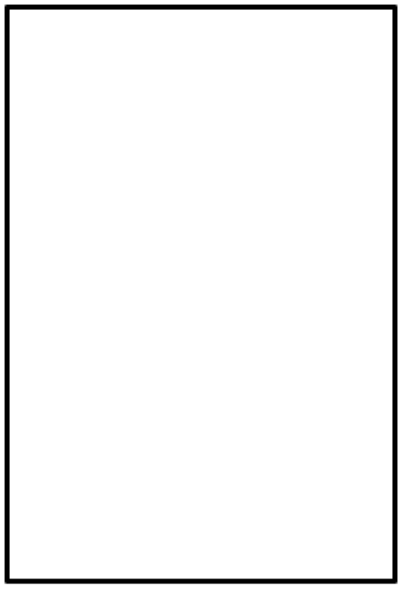


HCl(*g*)



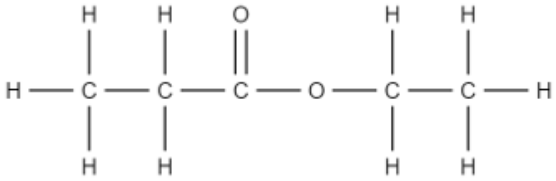
1

(b)



conc H_2SO_4

heat



+ H_2O

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Question 24 (6 marks) **Marks**

Lactic acid $CH_3CH(OH)COOH$ is a weak monoprotic acid. ($pK_a = 3.85$)

(a) Write an equation for the reaction of lactic acid with water. **1**

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(b) Identify a conjugate acid/base pair from this reaction. **1**

Acid: .....

Conjugate base: .....

(c) State the equilibrium constant expression, K_a, for lactic acid. **1**

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(d) Calculate the pH of a 0.20 mol L^{-1} solution of lactic acid. **3**

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Question 25 (3 marks)

You have 0.1 mol L^{-1} solutions of each of $NaNO_3$ and Na_2CO_3. Predict whether these two solutions are acidic, neutral or basic, explaining your reasoning with chemical equation(s), where relevant.

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Question 26 (5 marks) **Marks**

Compound *X* has the molecular formula $C_4H_{10}O$ and is highly soluble in water. It does not react when heated with acidified $KMnO_4$ nor acidified $K_2Cr_2O_7$.

(a) Draw the structure and name compound *X*. **2**

Name:.....

(b) Predict the number of signals that compound *X* will show in ^{13}C NMR. **1**

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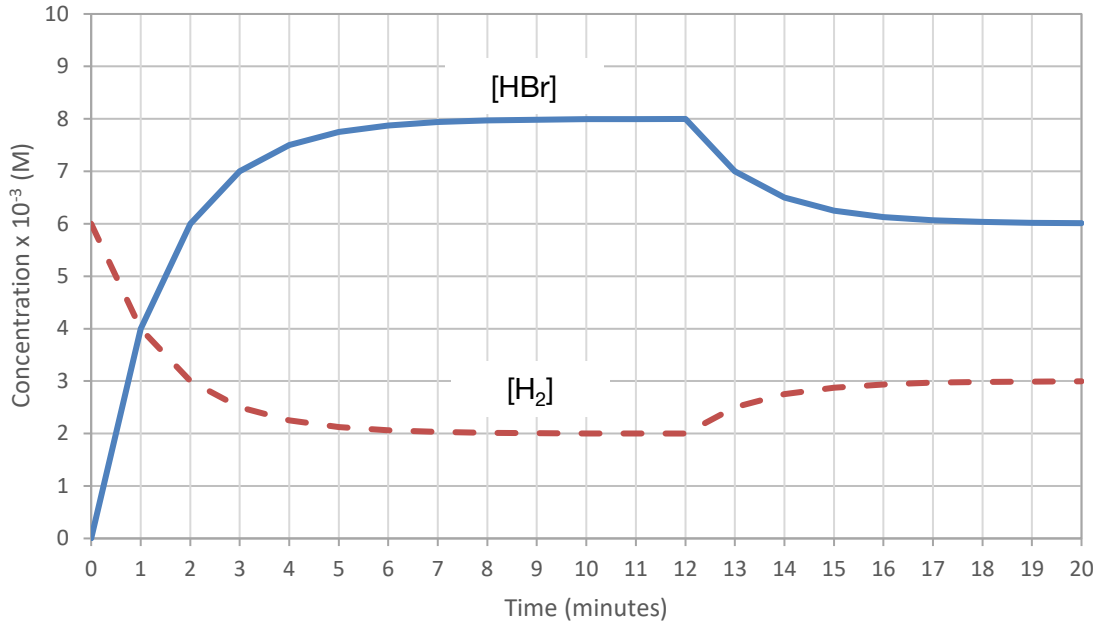
(c) Draw two isomers of compound *X* that contain the same functional group as compound *X*. **2**

Question 27 (7 marks) **Marks**

Equal volumes of hydrogen and bromine are introduced at T = 0 minutes to a sealed vessel and allowed to reach equilibrium at 60˚C.

$$H_2(g) + Br_2(g) \rightleftharpoons 2\ HBr(g) \qquad \Delta H = -103\ kJ\ mol^{-1}$$



(a) Calculate K_{eq} for this reaction at 60˚C. **3**

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Question cont. **Marks**

(b) At 12 minutes, the temperature was changed. Deduce whether the temperature was increased or decreased and explain the change in concentration of $H_2(g)$ and HBr(g) in terms of activation energy of the opposing reactions.

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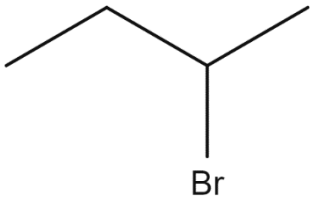
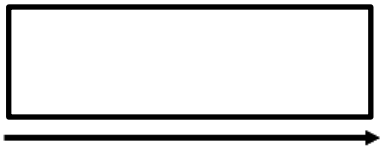
Question 28 (4 marks)

Butan-2-one can be produced from 2-bromobutane in two steps.

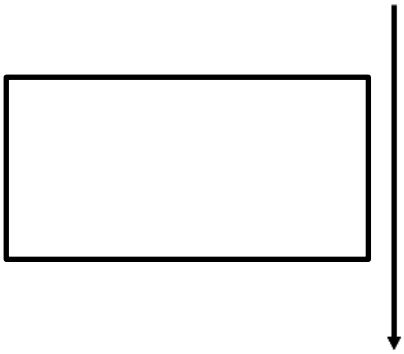
Complete the reaction scheme below to show how 2-bromobutane can be converted to butan-2-one. Include the reaction conditions for each step and diagrams for the intermediate compound and butan-2-one.



2-bromobutane



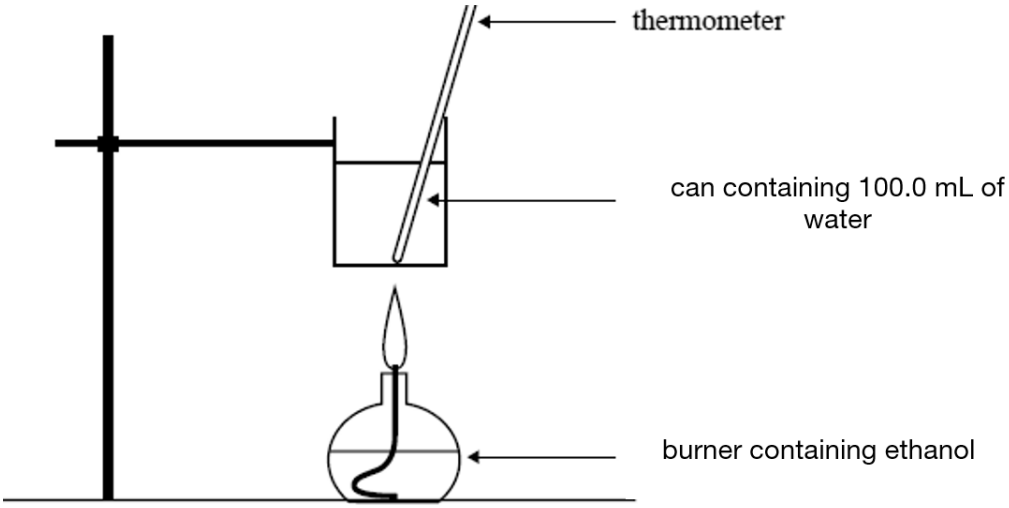
intermediate compound



butan-2-one

Question 29 (5 marks) **Marks**

0.561 g of ethanol undergoes complete combustion using the equipment shown below. The initial temperature of the water was 20.0°C.



(a) Write a balanced chemical equation for the complete combustion of ethanol. **1**

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(b) The enthalpy of combustion of ethanol is -1367 kJ mol^{-1}. Assuming half of the energy released from the burner is transferred into the water, calculate the final temperature of the water. **4**

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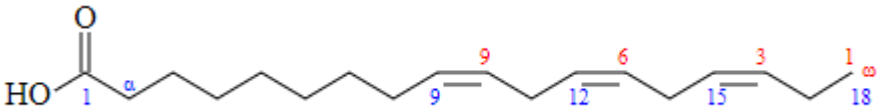
Question 30 (7 marks) **Marks**

Alpha-linolenic acid (ALA) is an omega-3, essential fatty acid. It is found in seeds and oil, and when extracted is a colourless liquid with a density of 0.91 g/mL. Its molar mass is 278.4 g mol^{-1}.

With a formula of $C_{18}H_{30}O_2$, ALA's structure is shown in the diagram below:



(a) On the diagram above, circle the functional groups of this molecule. **1**

(b) Predict whether this molecule would be water-soluble, explaining your reasoning. **2**

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(c) 2 mL of ALA is mixed with 2 mL of bromine water, shaken and then left to stand for a few minutes. Identify and explain **two** observations you would make. You may find a diagram to be helpful. **2**

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Question cont. **Marks**

(d) When used, ALA is often partially hydrogenated, so it is an unhealthy trans-fat that has a single carbon-carbon double bond remaining. Calculate the volume of hydrogen gas at 100 kPa and 25°C required to convert 1.0 g of ALA to its equivalent trans-fat.

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Question 31 (8 marks) **Marks**

This question is about buffers.

(a) State what is meant by the term *buffer* and describe the chemical composition of an acid buffer solution in general terms. **2**

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50.0 mL of 0.10 mol L^{-1} ammonia solution is mixed with 50.0 mL of 0.060 mol L^{-1} hydrochloric acid and the resulting mixture forms a buffer. The K_b of NH_3 is 1.78×10^{-5}.

(b) Describe what would happen if an additional small amount of acid solution was added to this buffer. Use an equation to support your explanation. **2**

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(c) Calculate the pH of the buffer produced when the two solutions were mixed. **4**

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Question 32 (3 marks)

Determine the maximum mass of calcium hydroxide that will dissolve in 230 mL of 0.040 M barium hydroxide solution at 25°C.

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Question 33 (3 marks)

Deduce whether a precipitate will form when 5.0 mL of 0.010 mol L^{-1} magnesium sulfate solution is added to 10.0 mL of 0.020 mol L^{-1} sodium carbonate solution at 25°C.

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Question 34 (9 marks)

Two organic compounds, *A* and *B*, are isomers with a chemical composition by mass of carbon 54.5%; hydrogen 9.2%; and oxygen 36.3%. *A* is soluble in water, while *B* is a pleasant-smelling liquid.

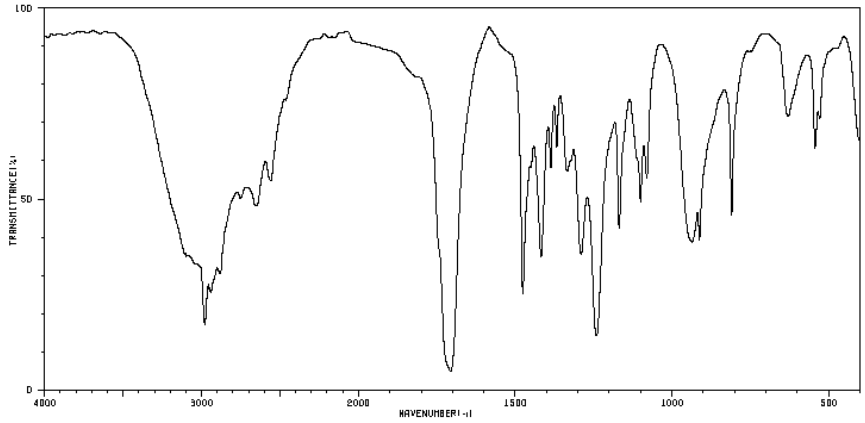
The mass spectrums of both *A* and *B* have the M^+ peak at 88 but are otherwise not helpful in distinguishing between the isomers as they both show peaks at an m/z ratio of 15, 29, 43 and 73.

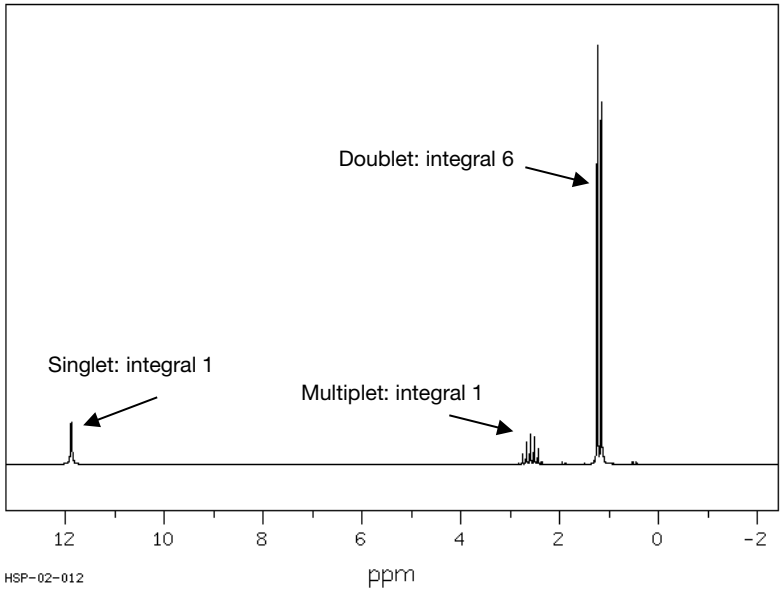
A's carbon-13 NMR has three peaks (one each at 184, 35 and 19 ppm), while *B*'s equivalent has four peaks (171, 60, 21 and 17 ppm).

The IR and proton NMR spectra are shown on the following pages, along with proton NMR shift data.

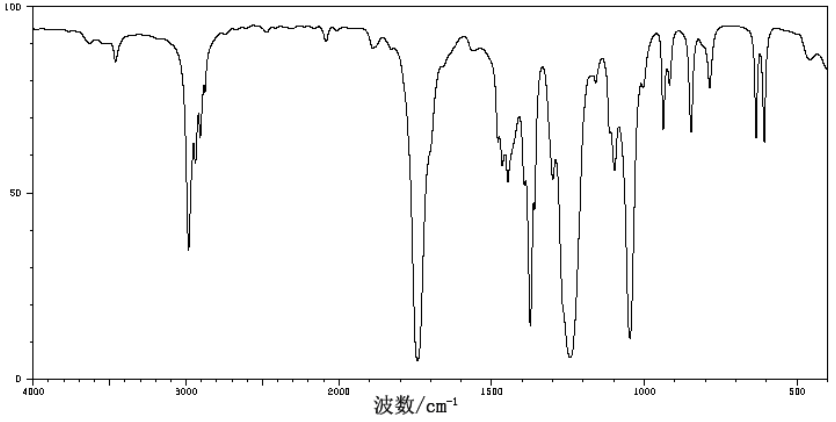
Determine the structure of each of the isomers. Draw and name the isomers in the boxes provided on the following pages. **Justify your choices** based on the information provided, making sure to reference **ALL** spectral types.

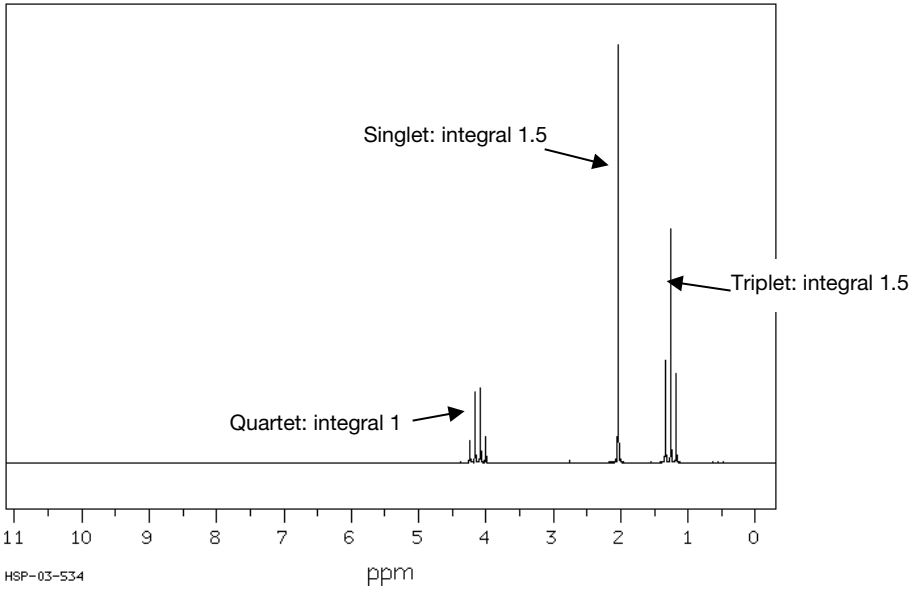
Compound *A*





Compound *B*





^{1}H NMR chemical shift data

Type of proton	δ/ppm
$Si(C\mathbf{H}_3)_4$ (TMS)	0
R–C$\mathbf{H}_3$	0.9–1.0
R–C$\mathbf{H}_2$–R	1.2–1.5
R–C$\mathbf{H}$R$_2$	1.5–2.0
R–C≡C–**H** (alkyne)	2.0–3.1
–CO–C$\mathbf{H}_2$– (aldehydes, ketones or esters)	2.1-2.7
R–C$\mathbf{H}_2$–NH$_2$	2.4–3.0
R–C$\mathbf{H}_2$–X (X = F, Cl, Br, I)	3.0–4.5
–C$\mathbf{H}_2$–O– (alcohols, ethers or esters)	3.3–4.8
R–O**H**	1–6
R–N$\mathbf{H}_2$	1–5
R$_2$C=C**H**R (alkene)	4.5–7.0
R–COON**H**–R (amide)	5–9
Ar-**H** (aromatic)	6.9–9.0
R–C**H**O (aldehyde)	9.4–10.0
R–COO**H**	9.0–13.0

Justification:.....

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Compound *A*: Name .....

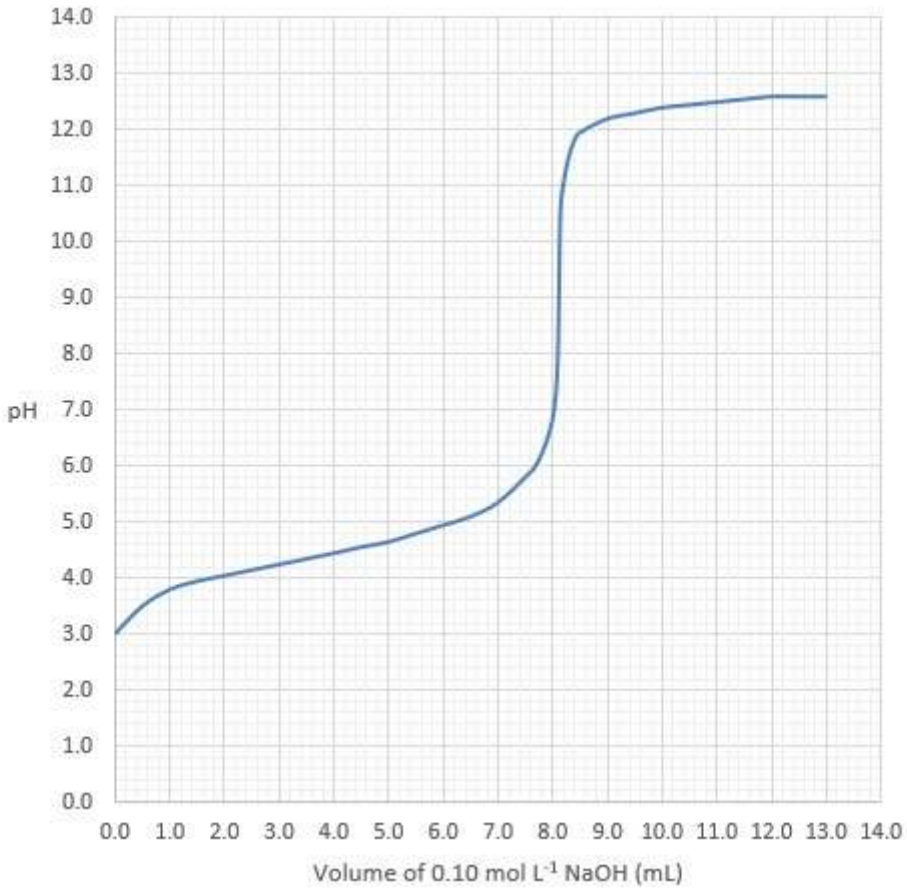
Structure of *A*

Compound *B*: Name .....

Structure of *B*

Question 35 (7 marks) **Marks**

The following graph shows how the pH changes during the titration of 25.00 mL of a solution of a weak monoprotic acid (HA) with NaOH.



(a) Using the graph, identify the pH at the equivalence point.

1

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(b) Bromocresol purple is an indicator that changes from yellow to violet over the range 5.2 – 6.6. If bromocresol purple was used to detect the end point of this titration, what effect, if any, would this have on the calculated concentration of HA compared to its actual concentration?

1

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Question cont. **Marks**

(c) Calculate the pK_a value of the HA acid. Give your answer to 2 decimal places.

5

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END OF EXAMINATION

2019 | HIGHER SCHOOL CERTIFICATE EXAMINATION

Chemistry

FORMULAE SHEET

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

$$q = mC\Delta T \qquad \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \qquad \text{pH} = -\log_{10}[\text{H}^+]$$

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

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

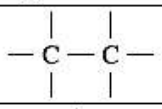
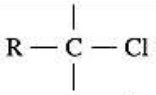
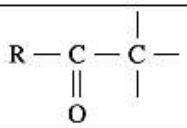
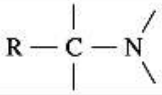
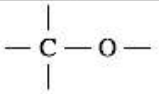
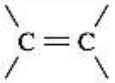
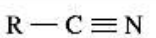
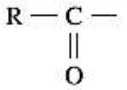
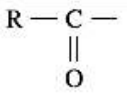
Compound	K_{sp}	*Compound*	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	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}

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

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
		5–40
		10–70
		20–50
		25–60
	alcohols, ethers or esters	50–90
		90–150
		110–125
		110–160
	esters or acids	160–185
	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

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.

SYDNEY GRAMMAR SCHOOL

				C	R	1	B

CANDIDATE NUMBER

2023
TRIAL HIGHER SCHOOL CERTIFICATE EXAMINATION

Chemistry

Section I - Multiple Choice

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

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

A ○ B ● C ○ D ○

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

A ● B ⊗ C ○ D ○

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

correct

A ⊗ B ⊗ C ○ D ○

Start Here →

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

SECTION I: MULTIPLE CHOICE (20 marks)

Attempt ALL Questions
Use the Multiple-Choice Answer Sheet.

1 Which of the following would best enable 2,2,4-trimethylpentane to be distinguished from octane?

(A) Mass spectrometry
(B) Determination of molar mass using gravimetric analysis
(C) Measuring volume of carbon dioxide produced when combusted
(D) Addition of bromine water

2 Separate 20.0 mL solutions of a weak monoprotic acid and a strong monoprotic acid of the same concentration are titrated with NaOH solution. Which of the following will be the same for these two titrations?

(A) Initial pH
(B) pH at the equivalence point
(C) Volume of NaOH required to reach the equivalence point
(D) The conductivity of the initial acid solutions

3 Which of the following reagents would liberate carbon dioxide when mixed with a concentrated aqueous solution of sodium carbonate?

(A) ethanoic acid
(B) ethanamine
(C) ethanamide
(D) ethyl ethanoate

4 Which of the following conditions will maximise the yield of dinitrogen tetraoxide?

$$2\ NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H = -57.2\ kJ\ mol^{-1}$$

(A) Low temperature, low pressure
(B) Low temperature, high pressure
(C) High temperature, low pressure
(D) High temperature, high pressure

5 10 mL of 0.01 mol L^{-1} nitric acid (HNO_3) is diluted with 90 mL of water. What is the pH of the resulting solution?

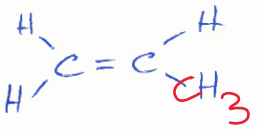
2

$10 \rightarrow 100$ pH +1

(A) 1
(B) 2
(C) 3
(D) 4

6 Which of the following hydrocarbons contains an atom with trigonal planar geometry?

(A) propane
(B) propene
(C) propyne
(D) 2-methylpropane



7 Ethene reacts with hydrogen gas in the presence of a Pd-C catalyst. Which of the following statements about this reaction is correct?

(A) Ethanol is produced. × ethane produced
(B) The reaction also produces a byproduct.
(C) The Pd-C is consumed in the reaction. × catalyst
(D) This is an addition reaction.

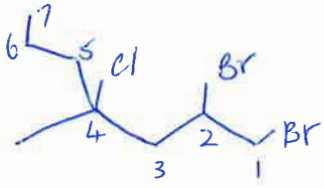
8 What is the concentration of OH^- ions (in mol L^{-1}) in an aqueous solution in which $[H^+] = 2.0\times10^{-3}$ mol L^{-1} at 25°C?

(A) 2.0×10^{-3}
(B) 4.0×10^{-6}
(C) 5.0×10^{-12}
(D) 2.0×10^{-17}

$[H^+][OH^-] = 1\times10^{-14}$

$[OH^-] = \frac{1\times10^{-14}}{2\times10^{-3}}$

9 The name 2-propyl-2-chloro-4,5-dibromopentane does not follow IUPAC conventions. What is the systematic name of this compound?



(A) 4,5-dibromo-2-chloro-2-propylpentane

(B) 2-chloro-4,5-dibromo-2-propylpentane

(C) 4-chloro-6,7-dibromo-4-methylheptane

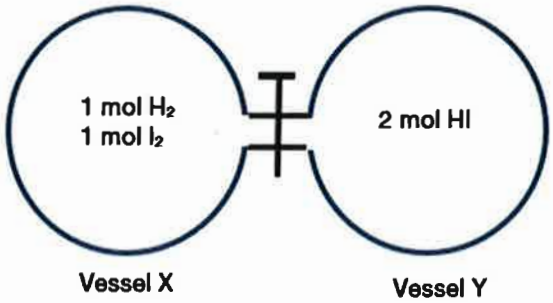
(D) 1,2-dibromo-4-chloro-4-methylheptane

10 Hydrogen and iodine react at 500°C according to the equation:

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

The apparatus shown below is set-up.

- no shift
- diffusion only



The tap between Vessels X and Y is opened and then the system is left at 500°C until no further change occurs. Which of the following statements is true?

(A) X will contain more hydrogen than Y.

(B) X and Y will contain the same amount of HI(g).

(C) X will contain less iodine than Y.

(D) Y will contain more HI(g) than X.

11 An organic compound reacted with concentrated HCl and $ZnCl_2$ to produce 2-chloro-2-methylpentane. What was the name of the original compound?

(A) 2-methylpentan-1-ol

(B) 2-chloropentanal

(C) 2-methylpentan-2-ol

(D) 2-methylpentanal

- OH substituted with Cl.

12 The following equilibrium exists in bromine water:

$$Br_2(aq) + H_2O(l) \rightleftharpoons Br^-(aq) + 2\ H^+(aq) + OBr^-(aq)$$

(red-brown) (colourless) (colourless)

Which of the following solutions could be added to the reaction mixture to cause the red-brown colour of bromine water to fade?

(A) HCl

(B) KBr

(C) $AgNO_3$

(D) NaOBr

$AgBr(s)$ ppt causing $Br^-\downarrow$, so reaction $\rightarrow$

13 Which of the following salts has the highest molar solubility?

(A) calcium carbonate $\sqrt{3.36\times10^{-9}} = 5.8\times10^{-5}$ M.

(B) copper(II) carbonate $\sqrt{1.4\times10^{-10}}$

(C) lead(II) carbonate $\sqrt{9.4\times10^{-14}}$ } smaller

(D) silver carbonate $\sqrt[3]{\frac{8.46\times10^{-12}}{4}} = 1.3\times10^{-4}$ M

14 A exists in equilibrium with B according to the equation below:

$$A(g) \rightleftharpoons B(g)$$

If 1.0 mole of A was allowed to reach equilibrium, how many moles of B would be formed if K_{eq} is equal to 0.40.

(A) 0.29 mol

(B) 0.40 mol

(C) 0.60 mol

(D) 0.71 mol

	[A]	[B]
I	1	0
C	$-x$	$+x$
E	$1-x$	x

$$K_{eq} = \frac{[B]}{[A]} = \frac{x}{1-x} = 0.4$$

$$x = 0.4 - 0.4x$$

$$x = \frac{0.4}{1.4} = 0.29$$

15 Propan-2-ol is heated with concentrated sulfuric acid. Compared to propan-2-ol, the product of this reaction:

(A) is more soluble in water.

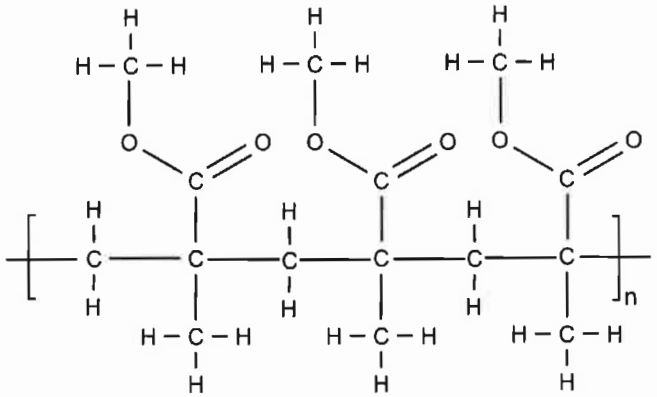
(B) has a higher molar mass.

(C) has fewer signals in ^{13}C NMR.

(D) has a lower boiling point.

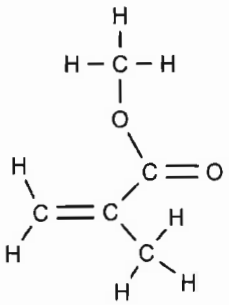
Question 16 and 17 refer to the following information.

A section of a polymer is shown below.

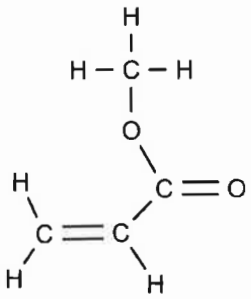


16 Which of the following shows the monomer used to produce the polymer shown above?

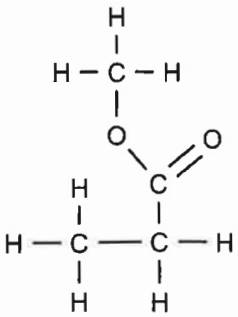
(A)



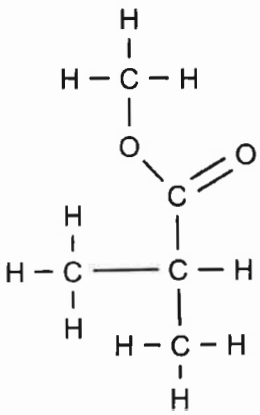
(B)



(C)



(D)



17 If you are comparing this polymer to polyethylene, which of the following would be true?

(A) This polymer is an addition polymer while polyethylene is a condensation polymer.

(B) High-density polyethylene would have weaker intermolecular forces as the chains can pack into a more orderly solid.

(C) Being a polyester, this polymer is used to make clothing while polyethylene is used for car tyres.

(D) Both polymers could be made without the elimination of a small molecule.

18 Ammonia (NH_3) is a weak base in aqueous solution with an ionisation constant K_b. Which of the following represents the ionisation constant for the reaction:

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

(A) $\frac{K_w}{K_a}$

(B) $\frac{K_a}{K_w}$

(C) $\frac{K_w}{K_b}$

(D) $\frac{K_b}{K_w}$

$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$

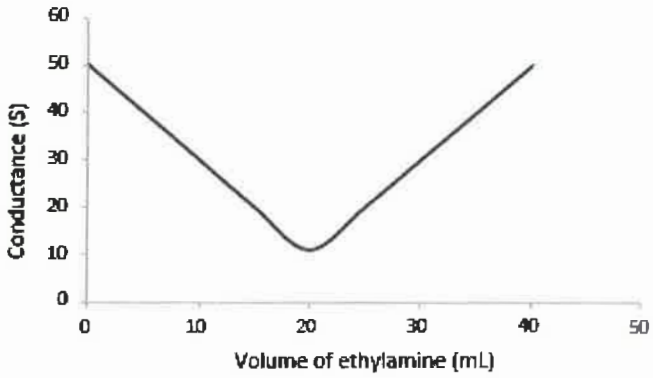
$K_W = [H_3O^+][OH^-]$

$K = \frac{[H_3O^+][NH_3]}{[NH_4^+]}$

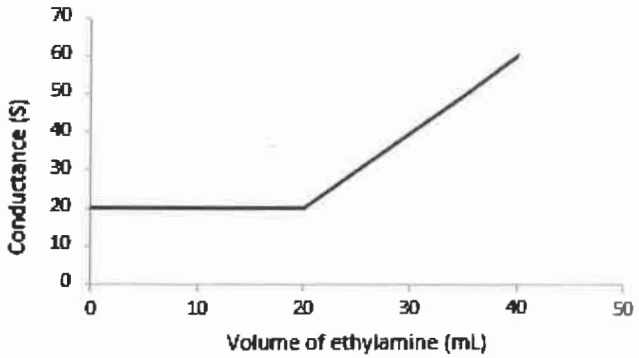
$K = \frac{1}{K_b} \times K_W$

19 Which of the following plots correctly represents the conductometric titration of 0.05 mol L^{-1} H_2SO_4 with 0.1 mol L^{-1} of the weak organic base ethylamine?

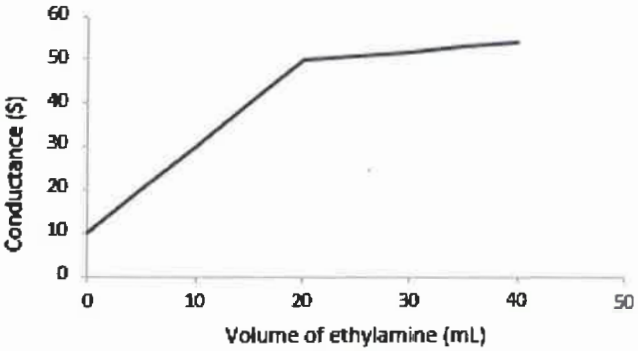
(A)



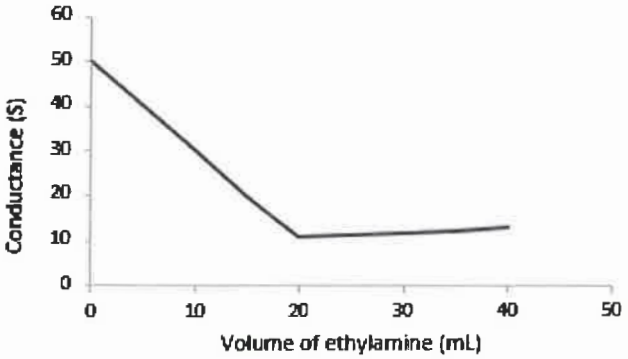
(B)



(C)



(D)



20 Solid calcium chloride is added to 200.0 mL of 0.12 mol L^{-1} potassium sulfate solution at 298 K.

What is the minimum mass of calcium chloride required to produce a precipitate?

(A) 0.0033 g

(B) 0.0091 g

(C) 0.228 g

(D) 6.21 mg

$K_{sp} = [Ca^{2+}][SO_4^{2-}] = 4.93 \times 10^{-5}$

$[Ca^{2+}] = \frac{4.93 \times 10^{-5}}{0.12} = 4.11 \times 10^{-4}\ M$

$n(Ca^{2+}) = 4.11 \times 10^{-4} \times 0.2$

$= 8.21 \times 10^{-4}\ mol$

$m(CaCl_2) = 8.21 \times 10^{-4} \times (40.01 + 2 \times 35.45)$

$= 9.11 \times 10^{-2}\ g$

CRIB - CXS

CANDIDATE NUMBER

Question 21 (3 marks)

The table provides thermodynamic data about two bromide salts.

	$\Delta_{sol}H$ (kJ mol^{-1})	$\Delta_{sol}S$ (J K^{-1} mol^{-1})
LiBr	-48.8	21.5
KBr	19.9	89.0

Compare and explain the solubilities of the two bromide salts at 300 K. You should include calculations in your answer.

1. LiBr $\Delta G = -48.8 - (300 \times \frac{21.5}{1000}) = -55.25$ kJ mol^{-1}
   KBr $\Delta G = 19.9 - (300 \times \frac{89}{1000}) = -6.8$ kJ mol^{-1}] ①
   * 1 mark for both calculations correct
2. As both ΔG values are negative, both reactions are spontaneous and both salts will dissolve to some extent — ①
3. Comparison: Since the ΔG value for LiBr is of a higher magnitude it will dissolve more and therefore it has a greater solubility — ①

Question 22 (7 marks) **Marks**

Sulfur trioxide decomposition reaches equilibrium at 200°C according to the equation:

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

(a) Use Collision Theory to state and explain the effect, if any, of an increase in the overall pressure. **3**

1. Increasing pressure, increases the number of successful collisions between both reactant and product molecules ①
2. However, as there are more moles of product relative to reactant (3:2 mole ratio) ①
3. The reverse reaction is favoured ①

(b) Identify the effect, if any, on the value of K_{eq}, if the overall pressure of the system is increased. **1**

Value of K_{eq} is unaffected

(c) A 0.40 mol sample of $SO_3(g)$ is placed in a 2.0 L vessel and allowed to reach equilibrium. Given that $K_{eq} = 1.30 \times 10^{-9}$ at this temperature, calculate the equilibrium concentration of $SO_2(g)$. **3**

	$2SO_3$	$\rightleftharpoons$	$2SO_2$	+	O_2
[I]	$\frac{0.4}{2.0} = 0.2$		0		0
[C]	$-2x$		$+2x$		$+x$
[E]	$0.2 - 2x$		$2x$		x

$$K_{eq} = 1.30 \times 10^{-9} = \frac{x(2x)^2}{(0.2-2x)^2}$$

$$= \frac{4x^3}{0.04 - 8x + 4x^2}$$

* Assumption: $x \ll 0.2 \therefore \frac{4x^3}{0.2^2} = 1.30 \times 10^{-9}$

$$x^3 = \frac{0.04 \times 1.30 \times 10^{-9}}{4}$$

$$x = 2.35 \times 10^{-3}$$

$$[SO_3] = 2x = 4.7 \times 10^{-4}\ M$$

3 marks for correct answer with working

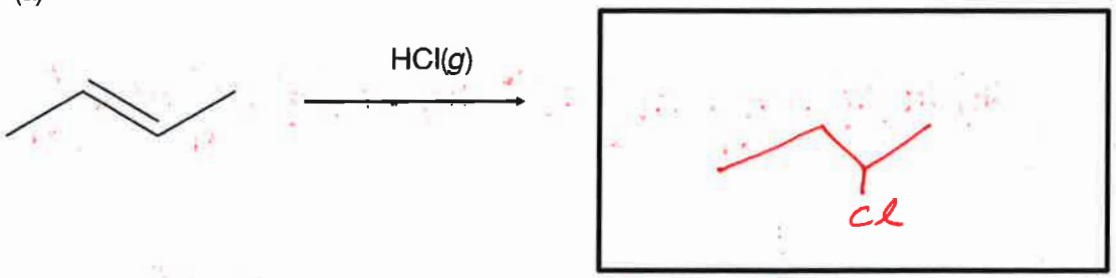
2 Marks for one error

1 mark for one significant step in calculation

Question 23 (3 marks) **Marks**

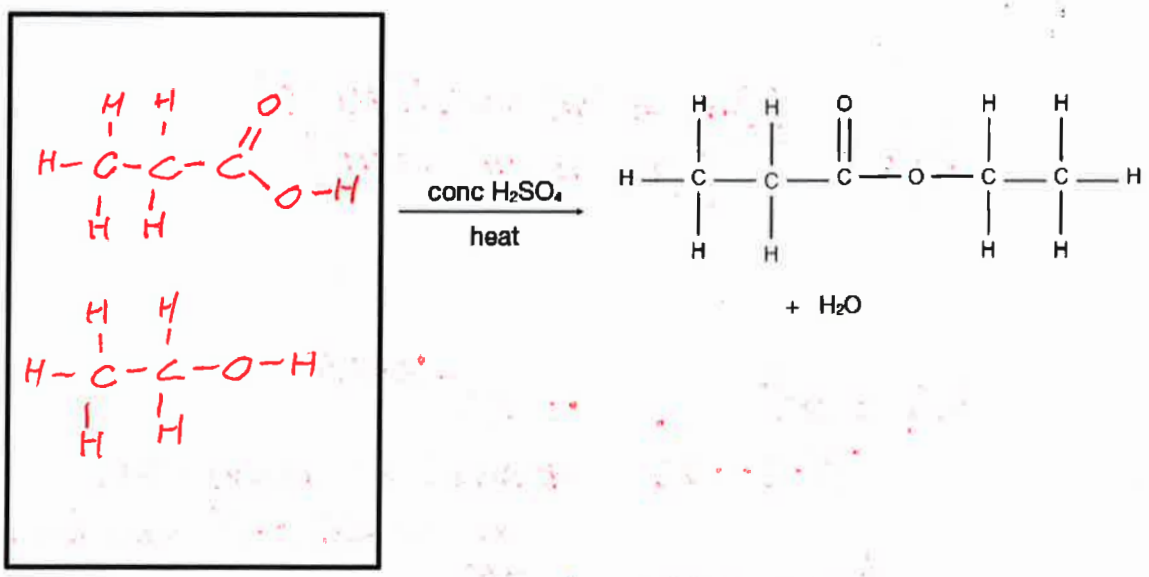
Complete the reactions below by drawing the structure of all organic reactant(s) and/or organic product(s).

(a)



1

(b)



2

Question 24 (6 marks) **Marks**

Lactic acid $CH_3CH(OH)COOH$ is a weak monoprotic acid. ($pK_a = 3.85$)

(a) Write an equation for the reaction of lactic acid with water. **1**

$CH_3CH(OH)COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3CH(OH)COO^-_{(aq)} + H_3O^+_{(aq)}$

(b) Identify a conjugate acid/base pair from this reaction. **1**

Acid: $CH_3CH(OH)COOH$ or H_3O^+

Conjugate base: $CH_3CH(OH)COO^-$ H_2O

(c) State the equilibrium constant expression, K_a, for lactic acid. **1**

$$K_a = \frac{[CH_3CH(OH)COO^-][H_3O^+]}{[CH_3CH(OH)COOH]}$$

(d) Calculate the pH of a 0.20 mol L^{-1} solution of lactic acid. **3**

$$K_a = \frac{x^2}{0.2 - x} = 10^{-3.85}$$

* small x assumption as $x \ll 0.2$ can be ignored

$x^2 = 2.825 \times 10^{-5}$

$x = 5.315 \times 10^{-3}$

$pH = -\log(5.315 \times 10^{-3})$

$= 2.27$

3 marks for correct answer with sufficient working

2 marks for correct working with one error

1 mark for one significant piece of working

Question 25 (3 marks)

You have 0.1 mol L^{-1} solutions of each of $NaNO_3$ and Na_2CO_3. Predict whether these two solutions are acidic, neutral or basic, explaining your reasoning with chemical equation(s), where relevant.

1. $NaNO_3$ is neutral as both Na^+ and NO_3^- are weak conjugates from strong bases and acids and are therefore inert.

1 mark for correct identification as neutral salt with explanation.

2. Na_2CO_3 is basic as Na^+ ions are inert but CO_3^{2-} ions are strong conjugates from a weak acid and will therefore hydrolyse

1 mark for correctly identifying salt as basic with explanation.

3. 1 mark for giving the equation to show why CO_3^{2-} is basic.

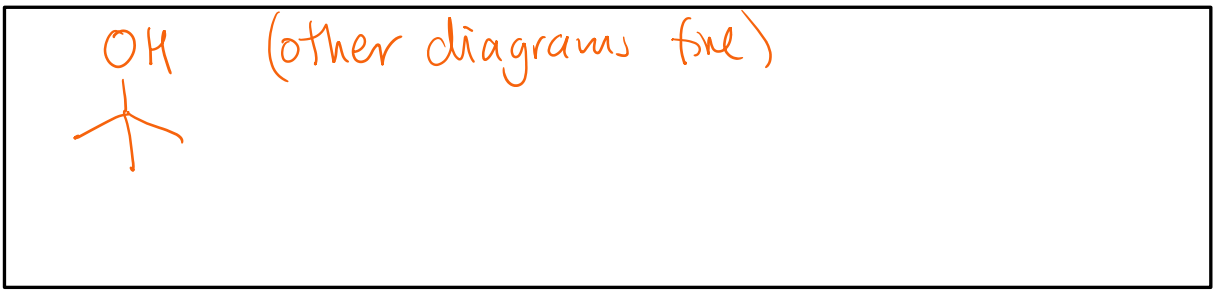
$$CO_3^{2-}_{aq} + H_2O_{\ell} \rightleftharpoons HCO_3^-_{aq} + OH^-_{aq}$$

Question 26 (5 marks) **Marks**

Compound *X* has the molecular formula $C_4H_{10}O$ and is highly soluble in water. It does not react when heated with acidified $KMnO_4$ nor acidified $K_2Cr_2O_7$.

(a) Draw the structure and name compound *X*.

2



(other diagrams fine)

Name: 2-methylpropan-2-ol (or correct for structure)

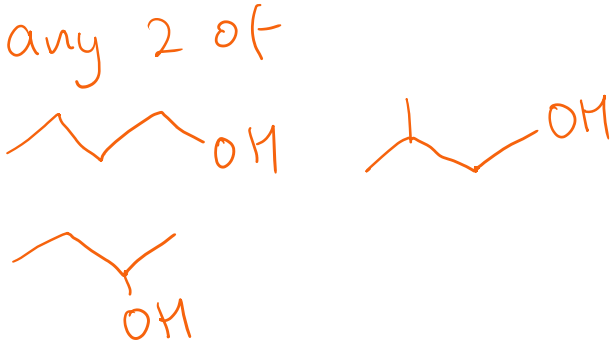
(b) Predict the number of signals that compound *X* will show in ^{13}C NMR.

1

2 (if structure wrong, had to match (a))

(c) Draw two isomers of compound *X* that contain the same functional group as compound *X*.

2



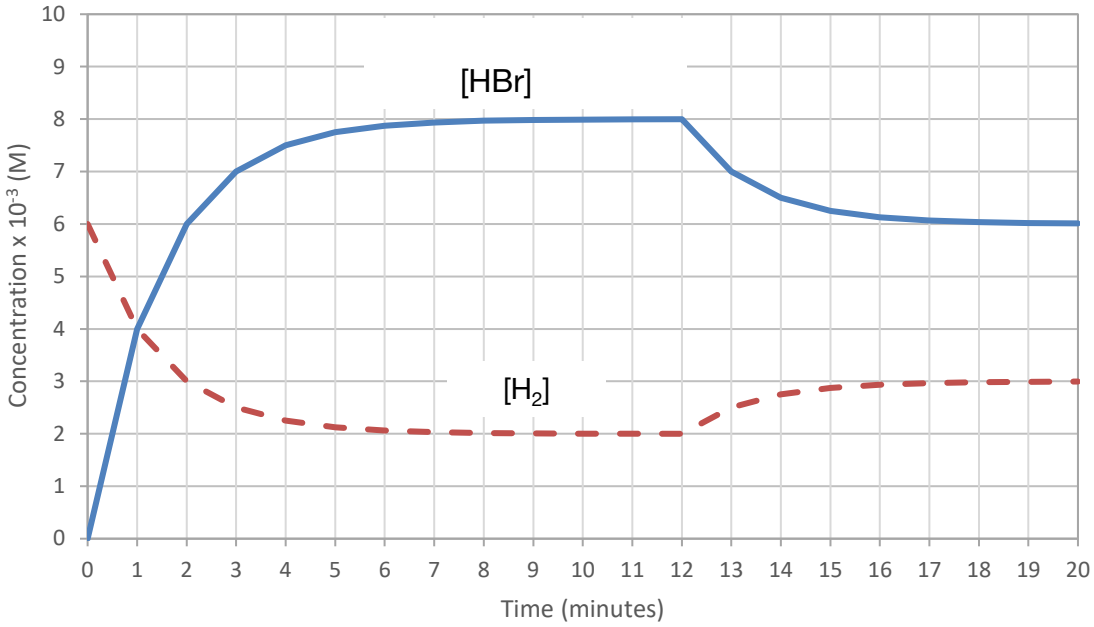
(had to match functional group in (a))

Note: bond had to clearly go to oxygen atom of hydroxyl. Max 1 mark lost in this section, Q28 included.

Question 27 (7 marks) **Marks**

Equal volumes of hydrogen and bromine are introduced at T = 0 minutes to a sealed vessel and allowed to reach equilibrium at 60°C.

$H_2(g) + Br_2(g) \rightleftharpoons 2\ HBr(g)$ $\Delta H = -103\ kJ\ mol^{-1}$



(a) Calculate K_{eq} for this reaction at 60°C. **3**

$K_{eq} = \frac{[HBr]^2}{[H_2][Br_2]}$

$= \frac{(8 \times 10^{-3})^2}{(2 \times 10^{-3})(2 \times 10^{-3})}$

$= 16$

① equil expression

① correct substitution including $\times 10^{-3}$

① correct answer

Question cont.

Marks

(b) At 12 minutes, the temperature was changed. Deduce whether the temperature was increased or decreased and explain the change in concentration of $H_2(g)$ and HBr(g) in terms of activation energy of the opposing reactions.

4

marked holistically, but generally needed
- statement that T was increased
- successful collision requires $KE > E_A$
- comparison of E_A for exo & endo directions
- understanding that both rates increase but endo increases more
- answering Q in terms of $\uparrow [H_2]$ & $\downarrow [HBr]$

note: * you shouldn't refer to "the reaction". There is a forward & a reverse reaction, please be specific
* There is no "endothermic side", there is an endothermic direction
* reactants / products do not have ΔH, a reaction has a ΔH value
* you can refer to LCP, but it is not an explanation

Sample answer Q27(b)

As $[H_2]$ increases and [HBr] decreases, the equilibrium has shifted to the reactants side. The forward reaction is exothermic ($\Delta H<0$) so the reverse reaction is endothermic. As the endothermic reaction has been favoured, the temperature must have been increased.

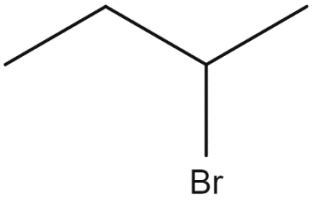
The endothermic direction has a higher activation energy than the exothermic direction, so a T increase means that the proportion of particles with kinetic energy > activation energy increases more for the endothermic reaction than the exothermic. Both reactions have an increase in successful collisions, but the increase is more significant for the reverse reaction than for the forward reaction, so the rate of the reverse reaction increases more.

This ultimately results in a new equilibrium position with higher $[H_2]$ and lower [HBr].

Question 28 (4 marks)

Butan-2-one can be produced from 2-bromobutane in two steps.

Complete the reaction scheme below to show how 2-bromobutane can be converted to butan-2-one. Include the reaction conditions for each step and diagrams for the intermediate compound and butan-2-one.

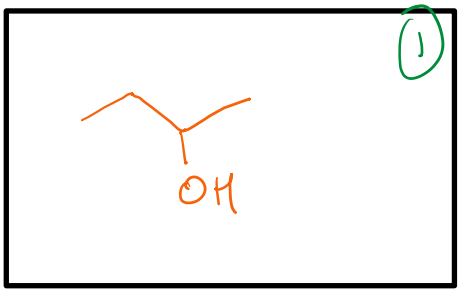


2-bromobutane

KOH (aq)

(or dilute KOH)

(1)



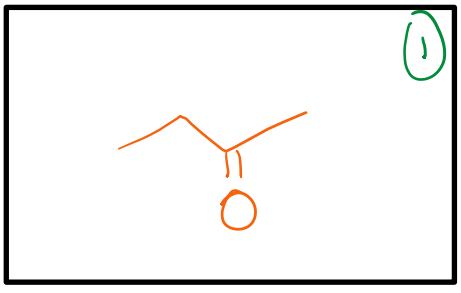
(1)

intermediate compound

acidified $K_2Cr_2O_7$

(PCC & acidified $KMnO_4$ OK)

(1)



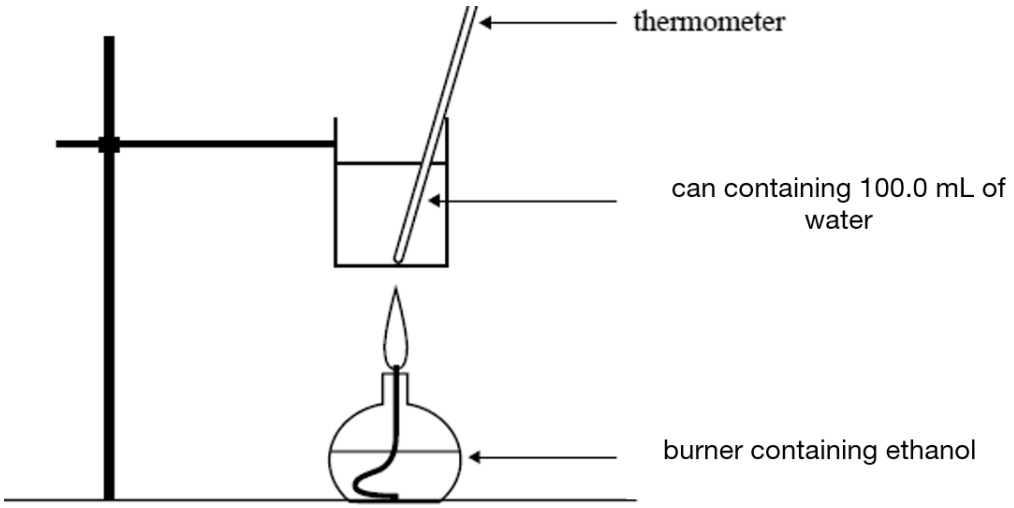
(1)

butan-2-one

Note: bond had to clearly go to oxygen atom of hydroxyl. Max 1 mark lost in this section, Q26 included.

Question 29 (5 marks) **Marks**

0.561 g of ethanol undergoes complete combustion using the equipment shown below. The initial temperature of the water was 20.0°C.



(a) Write a balanced chemical equation for the complete combustion of ethanol. **1**

$C_2H_5OH_{(l)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 3H_2O_{(l)}$

(states were not marked, so many boys got lucky!)

(b) The enthalpy of combustion of ethanol is -1367 kJ mol^{-1}. Assuming half of the energy released from the burner is transferred into the water, calculate the final temperature of the water. **4**

$\Delta H = \frac{-q}{n}$ $n(\text{ethanol}) = \frac{0.561}{46.068} = 0.01218$ mol

$-q = 1367 \times 0.01218 \times \frac{1}{2} = 8.323$ kJ $= 8323$ J

$\Delta T = \frac{q}{mC} = \frac{8323\text{ J}}{4.18\text{ J g}^{-1}\text{ K}^{-1} \times 100} = 19.91$ K $= 19.91\ ^\circ$C (ΔT)

$\therefore T_{final} = 20.0 + 19.9$

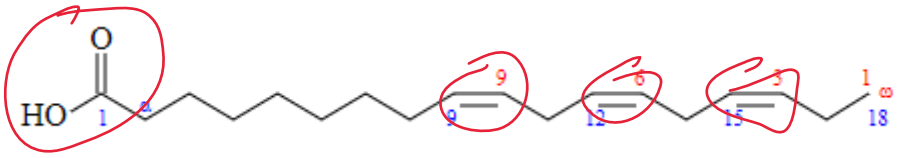
$= 39.9\ ^\circ$C (3 s.f.) -1 per mistake

common mistakes included
- forgetting only ½ energy went into water
- using moles of water instead of ethanol
- forgetting J / kJ conversion

Question 30 (7 marks) **Marks**

Alpha-linolenic acid (ALA) is an omega-3, essential fatty acid. It is found in seeds and oil, and when extracted is a colourless liquid with a density of 0.91 g/mL. Its molar mass is 278.4 g mol^{-1}.

With a formula of $C_{18}H_{30}O_2$, ALA's structure is shown in the diagram below:



(a) **On the diagram above, circle the functional groups of this molecule.** **1**

Marking criteria	Marks
Circles alkanoic acid/carboxyl group (-COOH) **AND** alkene groups (C=C) **only**	1

Markers Note:

- *Students should circle **all** the alkene groups. (Circling just one example of this functional group was accepted)*
- *The carbonyl and hydroxy groups should not have been circled separately.*
- *C-C single bonds are not a functional group.*

(b) **Predict whether this molecule would be water-soluble, explaining your reasoning.** **2**

Marking criteria	Marks
Correct prediction of solubility with a **thorough** explanation of insolubility with reference to: - dispersion forces and hydrogen bonding - polarity of water - non-polar fatty acid (dominance of non-polar tail in fatty acid) OR Correct prediction of solubility with a **thorough** explanation of insolubility with reference to: - enthalpic considerations - entropic considerations	2
Correct prediction of solubility and a sound explanation that lacks depth and detail.	1

Sample answer:
This molecule will not be soluble in water since this large molecule is dominated by a long non-polar hydrocarbon tail. This hydrophobic (non-polar) tail exhibits dispersion forces that are not strong enough to overcome the strong hydrogen bonds that exist between the polar water molecules and hence will not dissolve. Even though the fatty acid has a polar acid functional group that could form some hydrogen bonding with the water molecules, this interaction will be outweighed by the dispersion forces that exist between the long non-polar tails of the fatty acid, that form the majority of the molecule.

(c) **2 mL of ALA is mixed with 2 mL of bromine water, shaken and then left to stand for a few minutes. Identify and explain two observations you would make. You may find a diagram to be helpful.**

2

Marking criteria	Marks
Identifies and explains TWO observations	2
Identifies and explains ONE observation. OR Identifies TWO observations	1

Sample answer:

- *The orange-brown bromine water is decolourised due to the addition reaction of bromine water across the C=C double bonds in the ALA forming a colourless product.*
- *The non-polar ALA will separate and float on top of the aqueous layer since ALA is less dense than water and insoluble in water.*

Markers note:
*It was not enough for an explanation to simply say the bromine water would decolourise due to **presence** of C=C. Students needed to explain how the reaction occurs.*
Note: Clear is not a colour (i.e., bromine water goes clear did not score marks for observation as the bromine water was clear to start with (i.e., clear brown/orange at star)t, also it is not the ALA that goes colourless as this was colourless at the start.

(d) **When used, ALA is often partially hydrogenated, so it is an unhealthy trans-fat that has a single carbon-carbon double bond remaining. Calculate the volume of hydrogen gas at** 100 kPa and 25°C **required to convert 1.0 g of ALA to its equivalent trans-fat.**

2

Marking criteria	Marks
Correct answer	2
One step correct	1

Sample answer:
$2H_2$ needed to convert 2 C = C in ALA
n_{ALA} = m/MM= 1/278.4 = 3.59 x 10^{-3} mol
n_{H2} = 2 x n_{ALA} = 7.18 x 10^{-3}mol H_2 needed.
At 25 °C and 100KPa, v_{H2} = n x 24.79 = 0.178L = 0.18 L (2 sf)

Markers note:
Responses need to show working clearly and use some words to show what they are calculating.
Many responses failed to recognise that 2 moles of H_2 were needed in the reaction.

Question 31 (8 marks) **Marks**

This question is about buffers.

(a) State what is meant by the term *buffer* and describe the chemical composition of an acid buffer solution in general terms. **2**

Marking criteria	Marks
• Describes a buffer system as helping to maintain pH/resist changes to pH • Correctly describes the chemical composition and equimolar concentrations of an acid buffer	2
One of the above	1

Sample answer:
A buffer resists changes in pH when acid or base is added to a system.
*An acid buffer is composed of a **50:50 ratio** (or equimolar or approx. equal amounts) of a **WEAK** acid with its conjugate base e.g., CH_3COOH/CH_3COONa*

Markers note:
Responses for the composition of the buffer often lacked detail such as:
- the equivalent amounts of weak acid : conjugate base
- recognising that the acid used needed to be weak.
Some responses did not address the question re the composition of an acid buffer and students generically wrote the components of all buffers . eg weak acid/base with conjugate base/acid.

50.0 mL of 0.10 mol L^{-1} ammonia solution is mixed with 50.0 mL of 0.060 mol L^{-1} hydrochloric acid and the resulting mixture forms a buffer. The K_b of NH_3 is 1.78 x 10^{-5}.

(b) Describe what would happen if an additional small amount of acid solution was added to this buffer. Use an equation to support your explanation.

Marking criteria	Marks
Thorough description involving shift of equilibrium to counteract change with a correct equation showing equilibrium arrows	2
Sound description relating to a suitable equation OR a correct equilibrium equation.	1

Sample answer:
The buffer system formed is $NH_{3\,(aq)} + H_2O_{(l)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$
If H_3O^+ added to this buffer system, it would remove OH^- from the equilibrium system due to the reaction of $H_3O^+ + OH^- \rightarrow 2H_2O$.
The equilibrium shifts to the RHS (LCP), therefore resisting change to pH, since H_3O^+ has been removed and pH = - log $[H_3O^+]$. The buffer reestablishes equilibrium, and pH is minimally affected.

OR

The buffer system formed is $NH_3\,(aq) + H_3O^+(aq) \rightleftharpoons NH_4^+(aq) + H_2O(l)$

If H_3O^+ added to this buffer system, the equilibrium shifts to the RHS (LCP), therefore resisting change to pH, since H_3O^+ has been removed and pH = - log $[H_3O^+]$. The buffer reestablishes equilibrium, and pH is minimally affected.

Markers note:
Many responses did not demonstrate a thorough understanding of buffers.
Responses for the buffer needed an equilibrium arrow and a description of the shift in equilibrium when an acid added to the system.

(c) Calculate the pH of the buffer produced when the two solutions were mixed.

4

Marking criteria	Marks
Correct answer with all working	4
One error in calculation but all correct steps.	3
Two correct steps	2
Any correct step eg calculating moles ammonia **and** HCl, identifying limiting reagent, calculating *$[NH_3]$, $[NH_4^+]$,* expression for K_b, pOH or pH calculation	1

Sample answer:

$n(NH_3) = 0.10 \times 0.05 = 0.005$ mol

$n(HCl) = 0.060 \times 0.05 = 0.003$ mol

HCl is limiting.

Therefore, in buffer $n(NH_3) = 0.002$ (0.005 – 0.003) and $n(NH_4^+) = n(HCl) = 0.003$
This is in 100 mL, therefore:
$[NH_3] = 0.002/.1 = 0.02M$,
$[NH_4^+] = 0.003/.1 = 0.03M$

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

	NH_3	H_2O	NH_4^+	OH-
I	*0.020*		*0.030*	*0*
C	*- x*		*+ x*	*+ x*
E	*0.020 - x*		*0.030 + x*	*x*

K_b $NH_3 = 1.78 \times 10^{-5}$
(x is negligible compared to concentrations of 0.02 M and 0.03 M)
$1.78 \times 10^{-5} = [NH_4^+][OH^-]/[NH_3] = 0.030\ x/0.020$
$x = [OH^-] = (1.78 \times 10^{-5} \times 0.020)/0.030 = 1.186666 \times 10^{-5}$ M
pOH = - log $[OH^-]$ = 4.926
pH = 14 – pOH = 9.07

Markers note:

If solve with H-H:
$pH = pK_a + \log [A^-]/[HA]$
$pK_a = 14 - pK_b = 14 - (-\log 1.78 \times 10^{-5}) = 9.25$

(Or find via $K_a = K_w/K_b = 1 \times 10^{-14}/1.78 \times 10^{-5} = 5.61798 \times 10^{-10}$, $pKa = -\log 5.61798 \times 10^{-10}$)

In buffer $n(NH_3) = 0.002$ (0.005 – 0.003) and $n(NH_4^+) = 0.003$
$[NH_3] = 0.002/.1 = 0.02M$, $[NH_4^+] = 0.003/.1 = 0.03M$

$pH = pK_a + \log [A^-]/[HA]$
$pH = 9.25 + \log (0.02/0.03) = 9.07$

OR

$pOH = pK_b + \log [NH_4^+]/[NH_3]$
$= -\log 1.78 \times 10^{-5} + \log (0.03/0.02) = 4.9256\ldots$
$pH = 14 - 4.9256\ldots = 9.07$

Question 32 (3 marks)

Determine the maximum mass of calcium hydroxide that will dissolve in 230 mL of 0.040 M barium hydroxide solution at 25°C.

Marking criteria	Marks
Correct answer with calculations	3
One error in calculation	2
One correct step. eg correct $[OH^-]$, correct molar mass of $Ca(OH)_2$	1

Sample answer:
K_{sp} of $Ca(OH)_2 = 5.02 \times 10^{-6}$
$K_{sp} = [Ca^{2+}][OH^-]^2$

$[Ba(OH)_2] = 0.04$ M, therefore $[OH^-] = 0.08$M (hydroxide ion will have negligible change in concentration with dissolution of calcium hydroxide)

$K_{sp} = [Ca^{2+}][OH^-]^2$
$5.02 \times 10^{-6} = x \cdot 0.08^2$
$x = 7.843 \times 10^{-4}$ mol L^{-1}
$n_{Ca2+} = c \times v = 7.843 \times 10^{-4} \times 0.230 = 1.804 \times 10^{-4}$ mol L^{-1}
$n_{Ca2+} = n_{Ca(OH)2}$
mass calcium hydroxide = n x MM = $1.804 \times 10^{-4} \times 74.096 = 0.0134$ g

Markers note:

- *Students are advised to show their working and logic clearly. Using some words to show what is being calculated is strongly advised! (A bunch of numbers on a page is not very helpful.)*

Question 33 (3 marks)

Deduce whether a precipitate will form when 5.0 mL of 0.010 mol L^{-1} magnesium sulfate solution is added to 10.0 mL of 0.020 mol L^{-1} sodium carbonate solution at 25°C.

Marking criteria	Marks
Correct • calculations for $[Mg^{2+}]$ and $[CO_3^{2-}]$, • calculation for Q_{sp} • relationship between Q_{sp} and K_{sp} and deduction of ppt forming	3
One minor error in above but must show calculation of Qsp	2
One correct step.	1

Sample answer:

$[Mg^{2+}] = (0.01 \times 0.005)/0.015 = 3.33 \times 10^{-3}$ mol L^{-1}

$[CO_3^{2-}] = Vc = (0.020 \times 0.01)/0.015 = 1.33 \times 10^{-2}$ mol L^{-1}

$Q_{sp} = [Mg^{2+}] \times [CO_3^{2-}] = 4.44 \times 10^{-5}$

K_{sp} ($MgCO_3$)= 6.82×10^{-6}

$Q_{sp} > K_{sp}$, therefore a precipitate will form.

Markers note:

- *Students are advised to show their working clearly.*
- *Some responses showed calculations for a limiting reagent. i.e., Students identified that number of moles of* Mg^{2+} *was limiting reagent and tried calculating Qsp using* $[Mg^{2+}] = [CO_3^{2-}] = 3.33 \times 10^{-3}$ *mol* L^{-1}*. If correct steps, Qsp =* 1.11×10^{-5} *and Qsp >* 6.82×10^{-6}*, therefore a ppt forms, followed this answer, students could score a maximum of 2 marks.*

Question 34 (9 marks)

Two organic compounds, *A* and *B*, are isomers with a chemical composition by mass of carbon 54.5%; hydrogen 9.2%; and oxygen 36.3%. *A* is soluble in water, while *B* is a pleasant-smelling liquid.

The mass spectrums of both *A* and *B* have the M^+ peak at 88 but are otherwise not helpful in distinguishing between the isomers as they both show peaks at an m/z ratio of 15, 29, 43 and 73.

A's carbon-13 NMR has three peaks (one each at 184, 35 and 19 ppm), while *B*'s equivalent has four peaks (171, 60, 21 and 17 ppm).

The IR and proton NMR spectra are shown on the following pages, along with proton NMR shift data.

Determine the structure of each of the isomers. Draw and name the isomers in the boxes provided on the following pages. **Justify your choices** based on the information provided, making sure to reference **ALL** spectral types.

Marked holistically

Marks	Criteria
9	• Draws and names Compound A as 2-methylpropanic acid • Draws and names Compound B as ethyl ethanoate • Clear, logical justification with detailed reference to all four spectra and other supplied information • Eliminates all possible alternatives
8	Missing one item from 9 – often incorrect name OR alternative elimination
7	Missing two items from 9
5-6	Correctly identified compounds but gives limited justification
3-4	Gives a list of features with limited justification AND correctly identifies at least one of the compounds
1-2	Any **new** information of relevance

Marking notes:

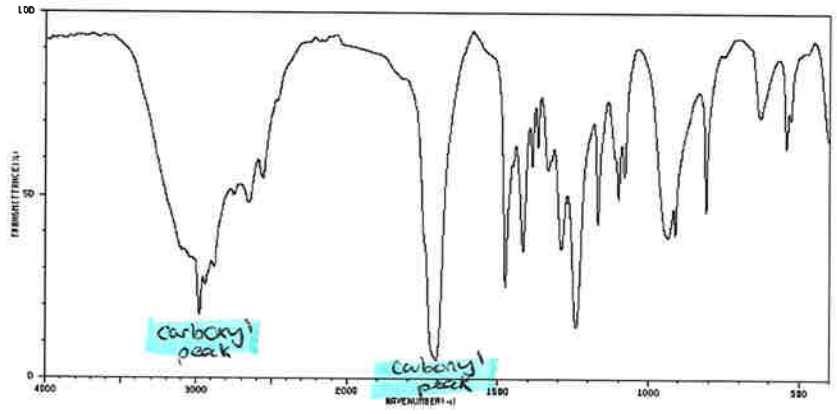
MP = methyl propanoate; EE = ethyl ethanoate

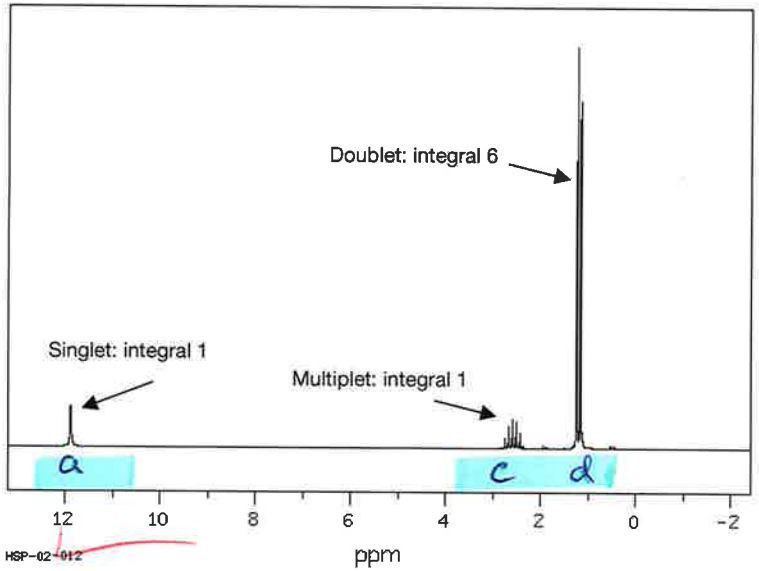
Identification of peaks on graphs were also marked when justification was insufficient in written response.

Generally, well done. The following items were NOT marked down BUT:

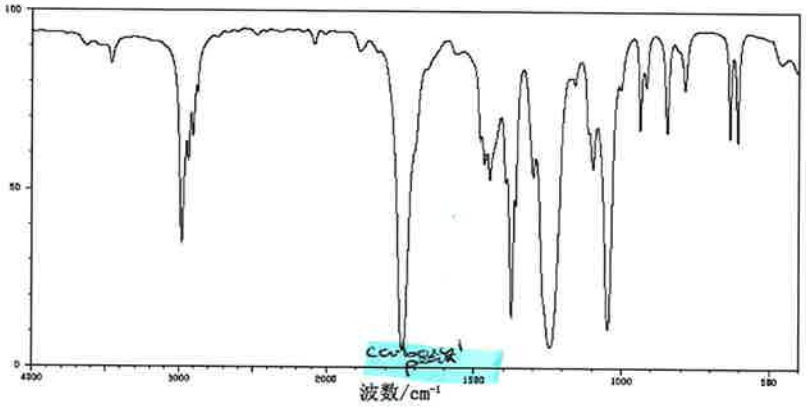
- Good practice to use units (e.g., 184 **ppm**)
- Good practice to refer to datasheet when making claims about peaks
- Good practice to read IR peak as value at the bottom of the peak.

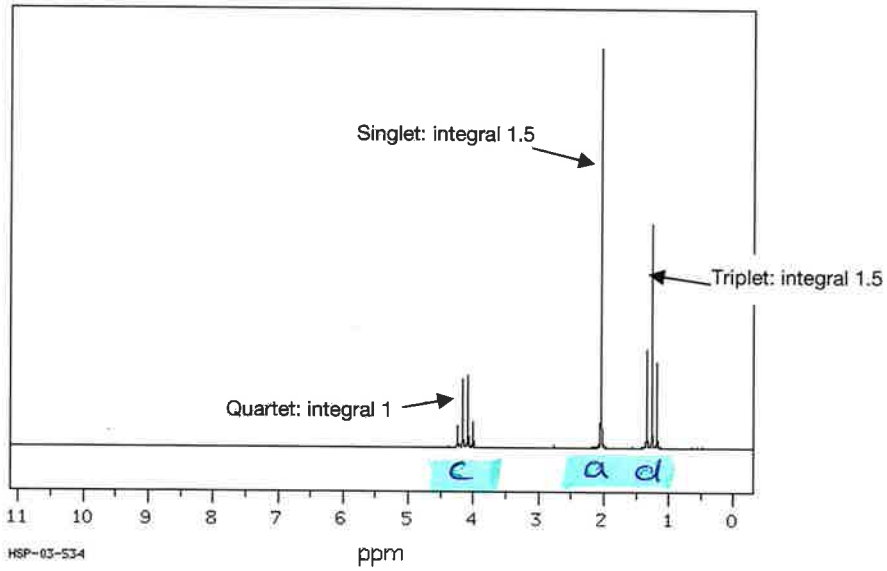
Compound *A*





Compound *B*





Justification:

Mass Spec:

- M^+ peak = 88 is consistent with the molar mass of formula $C_4H_8O_2$ of both compounds
- 15 peak corresponds to common fragment $[CH_3]^+$ of both compounds. 73 peak represents corresponding opposite fragment $\rightarrow$ 88-15 = 73.

Composition information:

- C : H : O = 54.5% : 9.2% : 36.3% = 48 : 8 : 32 distribution of molar mass in the formula $C_4H_8O_2$ of both compounds
- carboxylic acids are highly soluble in water due to their polar carboxylic acid functional group, whose hydroxyl group hydrogen bonds with the water, supporting a carboxylic acid conclusion for A
- esters often smell sweet, and their ~~lack of strong hydrogen bonding => weaker IMF => less~~ lack of strong polar C-O and C=O bonds mean they have higher IMF => higher b.p. and so are often liquids at room temp., supporting an ester conclusion for B.

^{13}C NMR: Please see environment assignments on first page & overleaf.

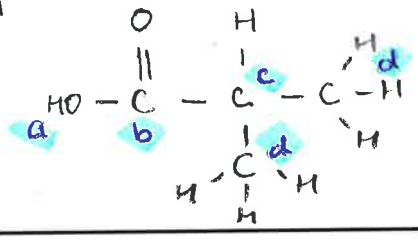
A: - three peaks consistent with three carbon environments
- (b) environment & peak greatly downshifted due to participation in carboxylic acid group, into the 160 - 185 ppm range characteristic of this (by data sheet). Similar reasoning for B's environment and peak (b).

B: - four peaks consistent with four carbon environments
- (c) environment & peak downshifted to range 50 - 90 ppm characteristic of participation in C-O bond (by data sheet)

please see next page for further justification

Compound *A*: Name ..... 2-methylpropanoic acid .....

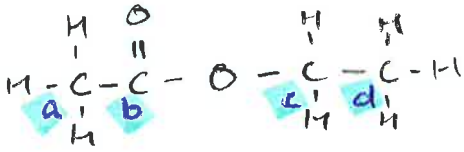
Structure of *A*



Compound *B*: Name ..... ethyl ethanoate .....

9

Structure of *B*



IR spec: Please see annotation on spectroscopy page.

A: – large broad peak around 3000 cm^{-1} overlapping with C-H peaks. This is characteristic of the O-H bond in acids, via data sheet; consistent with a carboxylic acid conclusion for A.

A&B: – both A & B contain a large peak around 1700 cm^{-1} within the characteristic range of a carbonyl bond C=O (1680–1750 cm^{-1}, by data sheet).

– Neither A nor B contain any additional noteworthy peaks outside the fingerprint range aside from C-H peaks.

1H NMR: Please see environment & peak allocation above & on spectroscopy page.

A: – 3 hydrogen peaks and environments

– (a) environment is a singlet of integral 1, consistent with a single hydrogen's participation in a COOH group. Its downshifting to approx 12 ppm is also consistent with participation in COOH group (9.0–13.0 range from given ^{1}H NMR data)

– (c) is a multiplet: likely a messy heptet via the n+1 rule (adjacent to 6 hydrogens). It has integral 1 due to singular hydrogen and is slightly more downshifted than (d) due to proximity to the deshielding COOH group.

– (d) has integral 6, consistent w/ 6 hydrogens in this environment. It is a doublet, consistent with adjacency to 1 hydrogen via n+1 rule.

please see the ^{1}H NMR chemical shift data page for B's ^{1}H NMR justification.

^{1}H NMR chemical shift data

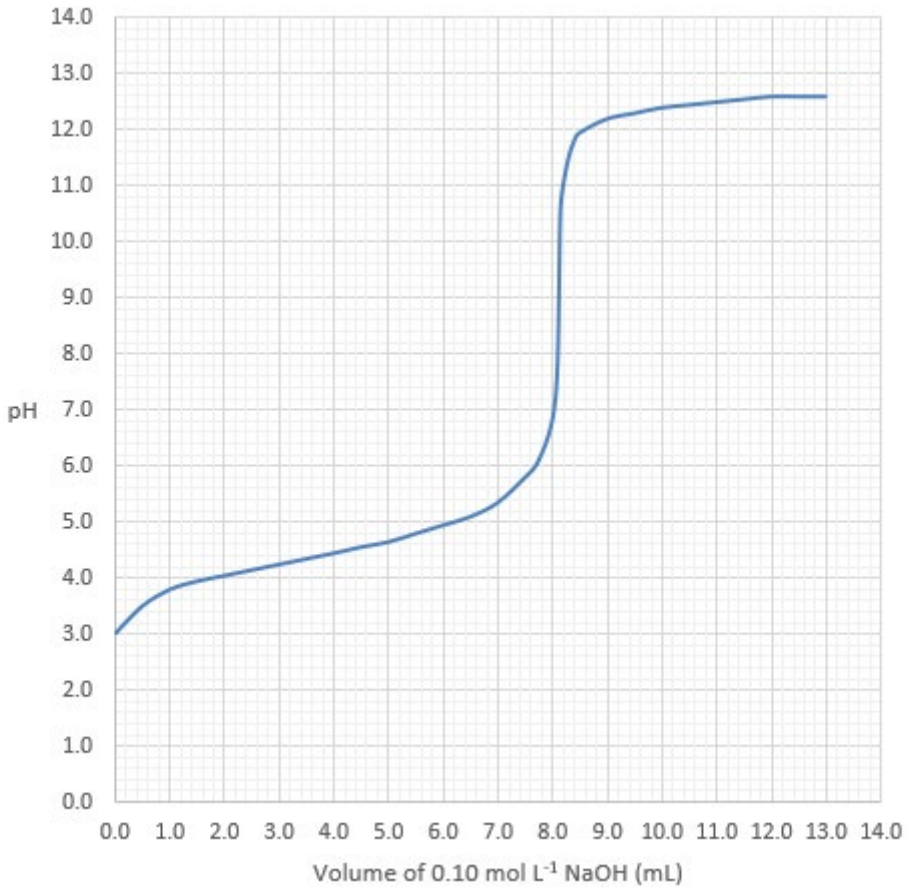
Type of proton	δ/ppm
$Si(CH_3)_4$ (TMS)	0
R–C**H**$_3$	0.9–1.0
R–C**H**$_2$–R	1.2–1.5
R–C**H**R$_2$	1.5–2.0
R–C≡C–**H** (alkyne)	2.0–3.1
–CO–C**H**$_2$– (aldehydes, ketones or esters)	2.1-2.7
R–C**H**$_2$–NH$_2$	2.4–3.0
R–C**H**$_2$–X (X = F, Cl, Br, I)	3.0–4.5
–C**H**$_2$–O– (alcohols, ethers or esters)	3.3–4.8
R–O**H**	1–6
R–N**H**$_2$	1–5
R$_2$C=C**H**R (alkene)	4.5–7.0
R–COON**H**–R (amide)	5–9
Ar-**H** (aromatic)	6.9–9.0
R–C**H**O (aldehyde)	9.4–10.0
R–COO**H**	9.0–13.0

1H NMR of B:

- 3 hydrogen peaks and environments
- integration data of ⓒ:ⓐ:ⓓ = 1 : 1.5 : 1.5 = 2 : 3 : 3 supports the 2:3:3 ratio of #hydrogens in each of these environments.
- ⓐ is a singlet, consistent via the n+1 rule with adjacency to no other hydrogen environments.
- ⓒ downshifted to approx 4ppm, consistent with the 3.3–4.8 ppm range given above for adjacency to C–O bond in the ester B. It is a quartet (multiplicity 4), consistent via the n+1 rule to adjacency to 3 hydrogens in environment ⓓ.
- ⓓ is a triplet, consistent via the n+1 rule with adjacency to 2 hydrogens in environment ⓒ.

Question 35 (7 marks) **Marks**

The following graph shows how the pH changes during the titration of 25.00 mL of a solution of a weak monoprotic acid (HA) with NaOH.



(a) Using the graph, identify the pH at the equivalence point.

1

Paid range 8.4-9.2

(b) Bromocresol purple is an indicator that changes from yellow to violet over the range 5.2 – 6.6. If bromocresol purple was used to detect the end point of this titration, what effect, if any, would this have on the calculated concentration of HA compared to its actual concentration?

1

Less than actual

(Explanation - V decrease from graph; so n(OH) decrease; so n(H^+) decrease; so c(HA) decreases) - not required in answer

(c) Calculate the pK_a value of the HA acid. Give your answer to 2 decimal places.

Marks	Criteria
5	• Reads volume at equivalence points as 8.2 mL • Chooses a suitable point on graph to use in calculations • Takes any equilibrium shift into account in calculation • Calculates pKa as 4.50 to 2 d.p.
4	As above less one point
3	As above less two points
2	Any two correct calculations – with working shown
1	Any relevant information

- Note it was possible to calculate 4.50 but not get full marks if errors or working not shown.
- Many marks were not lost by not showing working.
- Do not round too soon.

Codes used in marking:

Code	Meaning
IPC	inflection point chosen when it is impossible to read graph accurately when pH changing so quickly (usually ended up with a pKa = 5.61)
E	Errors

Sample Answer – but other points can be chosen

From titration curve, V(NaOH at equivalence point) = 8.2 mL

n(NaOH) = n(OH^-) = Vc = 0.0082 x 0.1 = 8.2 x 10^{-4} mol = n(H^+) = n(HA)

Initial [HA] = n/V = 8.2 x 10^{-4} / 0.025 = 3.28 x 10^{-2} M

Initial [H+] = 10^{-pH} = 1 x 10^{-3} M (since curve starts at pH = 3)

	HA	⇌	H^+	+	A^-
I	3.28 x 10^{-2}		0		0
C	-0.001		+0.001		+0.001
E	3.18 x 10^{-2}		0.001		0.001

K_a = [H^+][A^-] / [HA] = $(0.001)^2$ / 3.18 x 10^{-2} = 3.14 x 10^{-5}

p K_a = -log K_a = 4.50