



NSW Education Standards Authority

2019 HIGHER SCHOOL CERTIFICATE EXAMINATION

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A formulae sheet, data sheet and Periodic Table are provided at the back of this paper

Total marks: 100

Section I – 20 marks (pages 2–10)

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

Section II – 80 marks (pages 13–32)

- Attempt Questions 21–34
- Allow about 2 hours and 25 minutes for this section

Section I

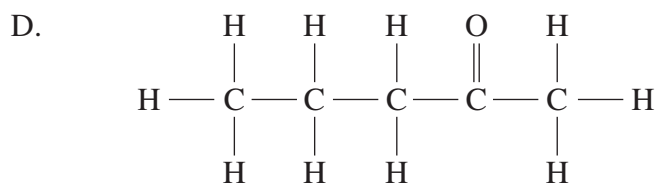
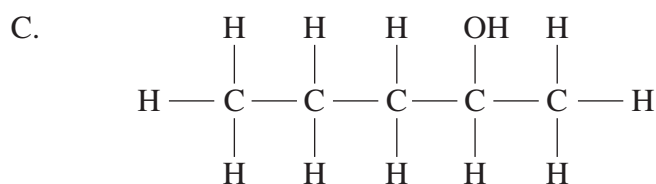
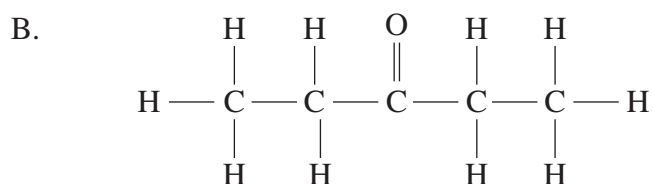
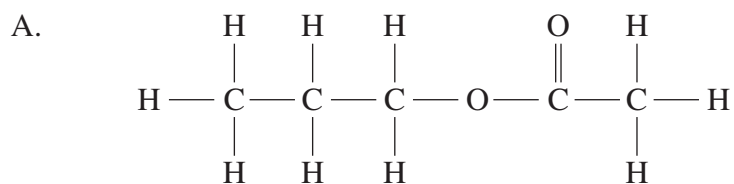
20 marks

Attempt Questions 1–20

Allow about 35 minutes for this section

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

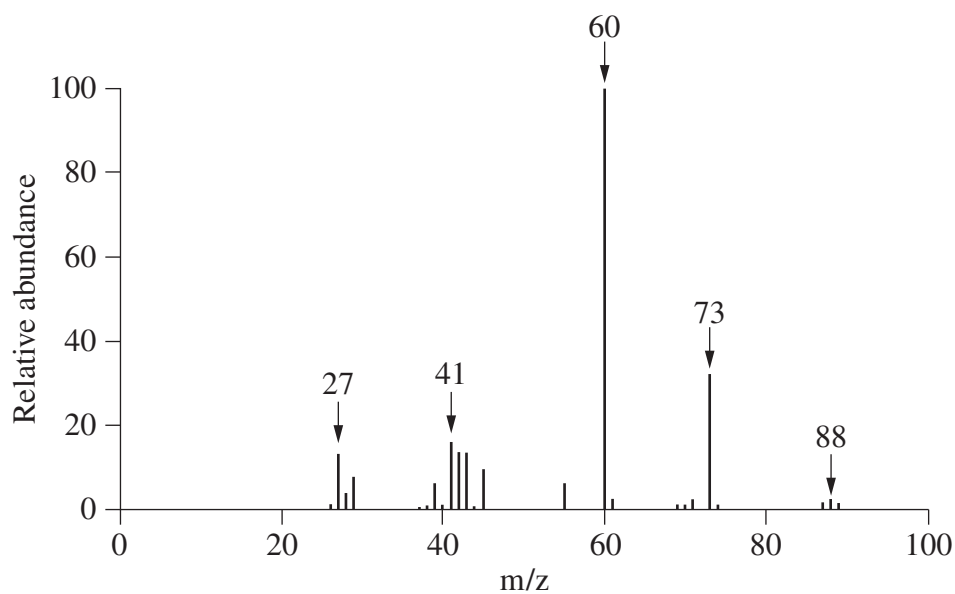
1 Which structural formula represents pentan-2-one?



2 Which of the following is an Arrhenius base?

- A. Na
- B. NaOH
- C. Na_2CO_3
- D. NaHCO_3

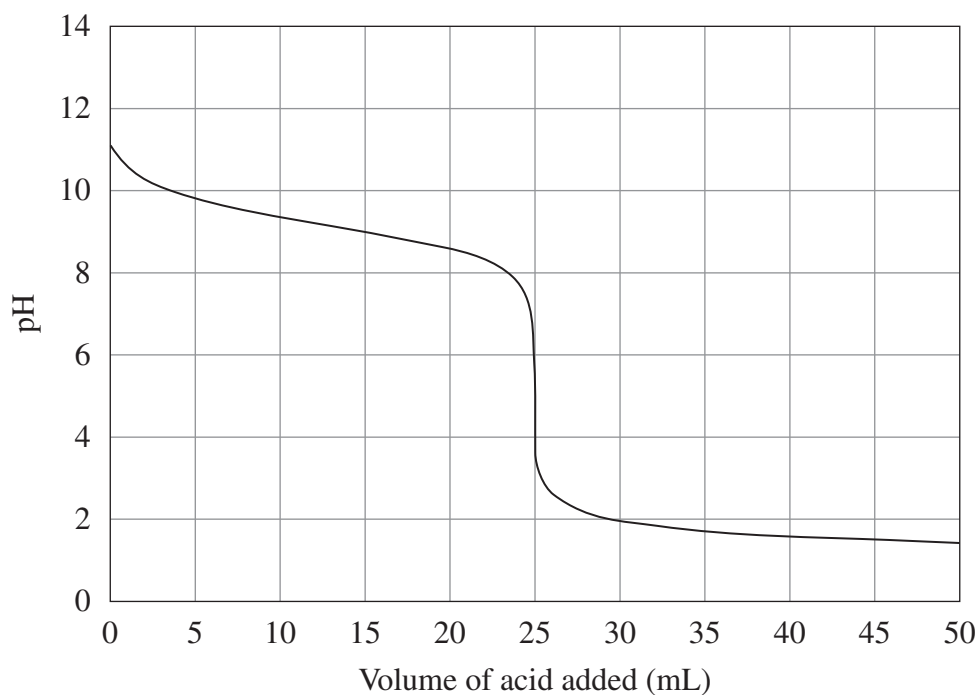
- 3 Which of the following metal carbonates has the highest molar solubility?
- A. Calcium carbonate
 - B. Copper(II) carbonate
 - C. Iron(II) carbonate
 - D. Lead(II) carbonate
- 4 The diagram shows the mass spectrum of an organic compound.



Which compound was analysed?

- A. Butan-1-amine
- B. Butanoic acid
- C. Ethanoic acid
- D. Iron(II) sulfide

The diagram represents the titration curve for a reaction between a particular acid and a particular base. Use the diagram to answer Questions 5 and 6.



5 Which indicator would be best for this titration?

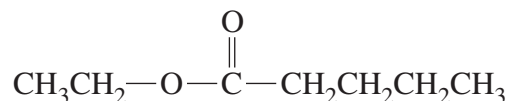
	<i>Indicator</i>	<i>Colour change range (pH)</i>
A.	Martius yellow	2.0 – 3.2
B.	Magdala red	3.0 – 4.0
C.	Isopicramic acid	4.0 – 5.6
D.	Cresol red	7.2 – 8.8

6 Which of the following equations best represents the reaction described by the titration curve?

- A. $\text{NH}_3(aq) + \text{HCl}(aq) \rightarrow \text{NH}_4\text{Cl}(aq)$
- B. $\text{NaOH}(aq) + \text{HCl}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l)$
- C. $\text{NH}_3(aq) + \text{CH}_3\text{COOH}(aq) \rightarrow \text{CH}_3\text{COONH}_4(aq)$
- D. $\text{NaOH}(aq) + \text{CH}_3\text{COOH}(aq) \rightarrow \text{CH}_3\text{COONa}(aq) + \text{H}_2\text{O}(l)$

- 7 How does the addition of a catalyst affect a reversible reaction?
- A. It increases the activation energy of the forward reaction only.
 - B. It decreases the activation energy of the forward reaction only.
 - C. It increases the activation energy of both the forward and reverse reactions.
 - D. It decreases the activation energy of both the forward and reverse reactions.

- 8 The structure of an organic compound is shown.



Which row of the table correctly gives the name of the compound and one of the reactants used to produce it in a one-step reaction?

	<i>Name</i>	<i>Reactant</i>
A.	Ethyl pentanoate	Ethanol
B.	Ethyl pentanoate	Pentan-1-ol
C.	Pent-1-yl ethanoate	Ethanol
D.	Pent-1-yl ethanoate	Pentan-1-ol

- 9 All of the following compounds have similar molar masses.

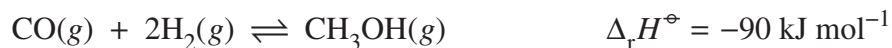
Which has the highest boiling point?

- A. Butane
 - B. Ethanoic acid
 - C. Propan-1-ol
 - D. Propanone
- 10 Which class of organic compound must contain at least three carbon atoms?
- A. Aldehydes
 - B. Alkenes
 - C. Carboxylic acids
 - D. Ketones

- 11** A saturated solution of barium carbonate was stored in a flask. Solid barium carbonate containing radioactive carbon-14 was added to the solution. The mixture was allowed to stand for several days and was then filtered.

Radioactivity could reasonably be expected to be found in

- A. the filtrate only.
 - B. the residue only.
 - C. both residue and filtrate.
 - D. neither residue nor filtrate.
- 12** Methanol can be produced from the reaction of carbon monoxide and hydrogen, according to the following equation:



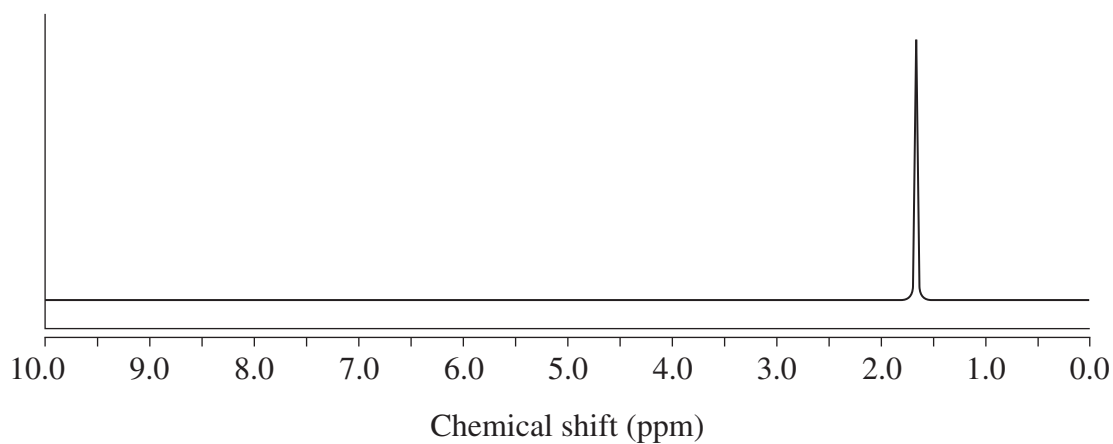
Which set of conditions will produce the maximum yield of methanol?

- A. Low pressure and low temperature
 - B. Low pressure and high temperature
 - C. High pressure and low temperature
 - D. High pressure and high temperature
- 13** A sample of polydifluoroethylene is determined to have an average molar mass of $4.8 \times 10^4 \text{ g mol}^{-1}$.

Approximately how many carbon atoms are there in an average molecule?

- A. 750
- B. 1500
- C. 2500
- D. 4000

- 14 A molecule, $\text{C}_4\text{H}_9\text{Cl}$, is analysed. The ^1H NMR spectrum of this molecule is shown.

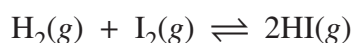


What is the structural formula of this molecule?

- A. $\begin{array}{c} \text{CH}_3 \\ | \\ \text{CH}_3 - \text{C} - \text{Cl} \\ | \\ \text{CH}_3 \end{array}$
- B. $\begin{array}{c} \text{CH}_3 - \text{CH} - \text{CH}_2 - \text{Cl} \\ | \\ \text{CH}_3 \end{array}$
- C. $\begin{array}{c} \text{CH}_3 - \text{CH}_2 - \text{CH} - \text{CH}_3 \\ | \\ \text{Cl} \end{array}$
- D. $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{Cl}$

- 15 What is the concentration of hydroxide ions (in mol L^{-1}) in a solution that has a pH of 8.53?
- A. 3.0×10^{-9}
B. 3.4×10^{-6}
C. 5.5
D. 3.0×10^5

- 16 At equilibrium, a 1.00 L vessel contains 0.0430 mol of H_2 , 0.0620 mol of I_2 , and 0.358 mol of HI. The system is represented by the following equation:



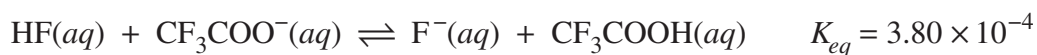
Which of the following is closest to the value of the equilibrium constant, K_{eq} , for this reaction?

- A. 0.0208
B. 48.1
C. 134
D. 269
- 17 A student makes a solution with a final volume of 200 mL by mixing 100 mL of $0.0500 \text{ mol L}^{-1}$ barium nitrate solution with 100 mL of 0.100 mol L^{-1} sodium hydroxide solution.

Which row of the table correctly identifies if a precipitate will form under these conditions and the reason?

	<i>Will a precipitate form?</i>	<i>Reason</i>
A.	Yes	$Q > K_{sp}$
B.	Yes	$Q < K_{sp}$
C.	No	$Q > K_{sp}$
D.	No	$Q < K_{sp}$

- 18 Consider the following equilibrium.



Which row of the table correctly identifies the strongest acid and the strongest base in this system?

	<i>Strongest acid</i>	<i>Strongest base</i>
A.	$\text{CF}_3\text{COOH}(aq)$	$\text{F}^-(aq)$
B.	$\text{CF}_3\text{COOH}(aq)$	$\text{CF}_3\text{COO}^-(aq)$
C.	$\text{HF}(aq)$	$\text{F}^-(aq)$
D.	$\text{HF}(aq)$	$\text{CF}_3\text{COO}^-(aq)$

- 19 Compound X shows three signals in its ^{13}C NMR spectrum.

Treatment of X with hot acidified potassium permanganate produces a compound Y. Compound Y turns blue litmus red.

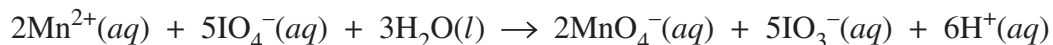
Compound X produces compound Z upon reaction with hot concentrated sulfuric acid.

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

	<i>Compound X</i>	<i>Compound Y</i>	<i>Compound Z</i>
A.	butan-1-ol	butanoic acid	but-1-ene
B.	butan-2-ol	butanone	but-2-ene
C.	methyl ethanoate	methanoic acid	ethene
D.	2-methylpropan-1-ol	2-methylpropanoic acid	2-methylprop-1-ene

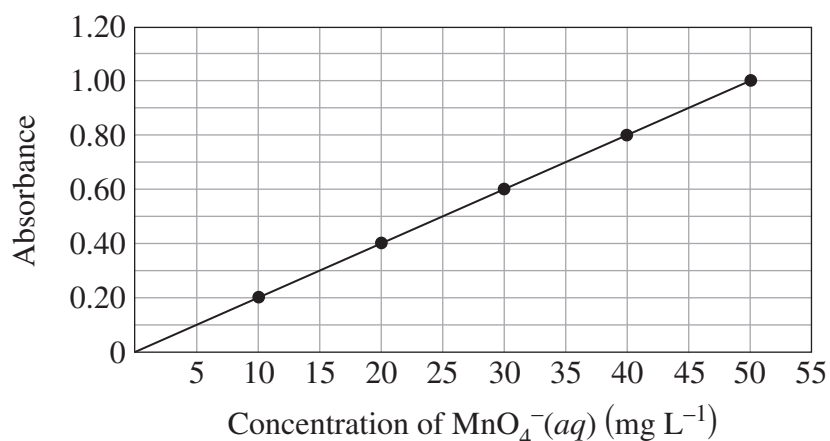
- 20 The manganese content in a 12.0-gram sample of steel was determined by measuring the absorbance of permanganate (MnO_4^-) using the following process.

The steel sample was dissolved in nitric acid and the $\text{Mn}^{2+}(\text{aq})$ ions produced were oxidised to $\text{MnO}_4^-(\text{aq})$ by periodate ions, $\text{IO}_4^-(\text{aq})$, according to the following equation.



The resulting solution was made up to a volume of 1.00 L, then 20.0 mL of this solution was diluted to 100.0 mL. The absorbance at 525 nm of the resulting solution was 0.50.

A calibration curve for $\text{MnO}_4^-(\text{aq})$ was constructed and is shown below.



What was the percentage by mass of manganese in the steel sample?

- A. 0.019%
- B. 0.096%
- C. 0.48%
- D. 1.0%

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Centre Number

Chemistry

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Student Number

Section II Answer Booklet

80 marks

Attempt Questions 21–34

Allow about 2 hours and 25 minutes for this section

Instructions

- Write your Centre Number and Student Number at the top of this page.
- 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 at the back of this booklet. If you use this space, clearly indicate which question you are answering.

Please turn over

Question 21 (7 marks)

- (a) The structural formula for 2-methylpropan-2-ol is shown in the table.

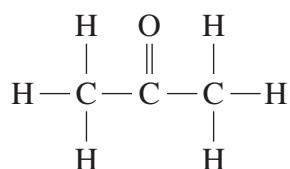
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Draw one structural isomer of this alcohol and state its name.

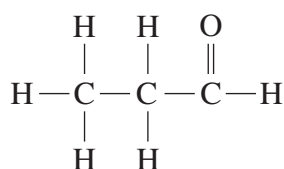
	<i>Alcohol</i>	<i>Isomer</i>
Structure	<pre> H OH H H — C ——— C ——— C — H H H—C—H H H </pre>	
Name	2-methylpropan-2-ol	

- (b) The structural formulae for two compounds are shown below.

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Isomer A



Isomer B

Why are these two compounds classed as functional group isomers?

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- (c) A chemical test is required to distinguish between the isomers in part (b).

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Identify a suitable test and explain the expected observations.

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Question 22 (4 marks)

A buffer was prepared with acetic acid and sodium acetate. A few drops of universal indicator were then added. When small amounts of either $0.1 \text{ mol L}^{-1} \text{ HCl(aq)}$ or $0.1 \text{ mol L}^{-1} \text{ NaOH(aq)}$ were added, no change in the colour of the solution was observed.

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Explain these observations. Support your answer with at least ONE chemical equation.

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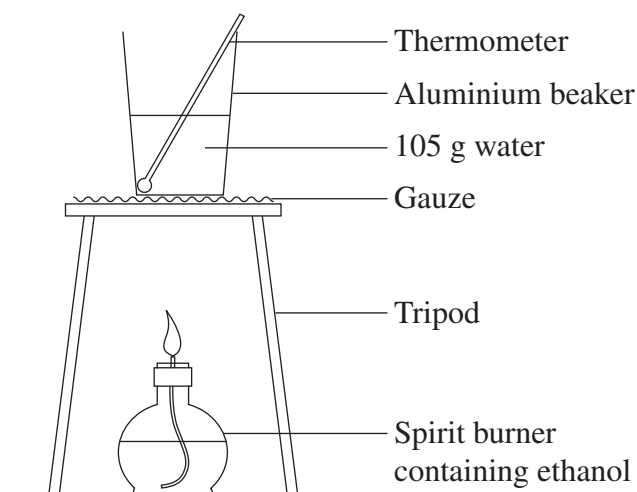
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Question 23 (6 marks)

The following apparatus was used in an experiment to determine the molar enthalpy of combustion of ethanol.



- (a) Calculate the experimental molar enthalpy of combustion ($\Delta_c H$) of ethanol when 0.370 g ethanol was used to raise the water temperature from 18.5°C to 30.0°C.

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Question 23 continues on page 17

Question 23 (continued)

- (b) Upon replication, the molar enthalpy of combustion obtained in the experiment was consistently much lower than the accepted value. **2**

Explain ONE change that could be made to the experiment that would improve the accuracy of the obtained value.

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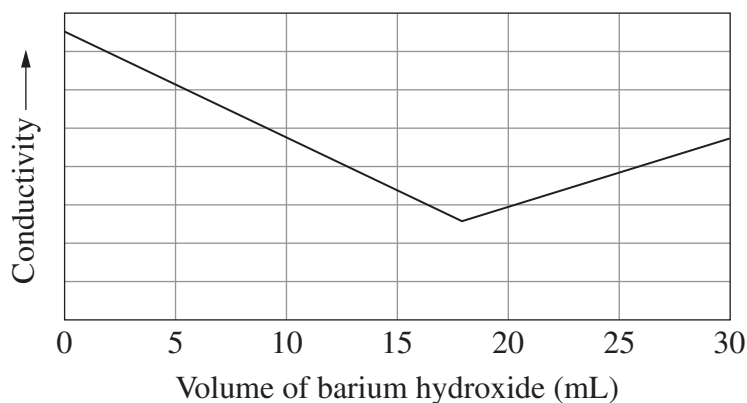
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End of Question 23

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Question 24 (7 marks)

A conductometric titration was undertaken to determine the concentration of a barium hydroxide solution. The solution was added to 250.0 mL of standardised $1.050 \times 10^{-3} \text{ mol L}^{-1}$ hydrochloric acid solution. The results of the titration are shown in the conductivity graph.



- (a) Explain the shape of the titration curve.

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- (b) The equivalence point was reached when a volume of 17.15 mL of barium hydroxide was added.

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Calculate the concentration of barium hydroxide (in mol L^{-1}), and give a relevant chemical equation.

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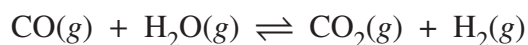
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Question 25 (5 marks)

The concentrations of reactants and products as a function of time for the following system were determined.

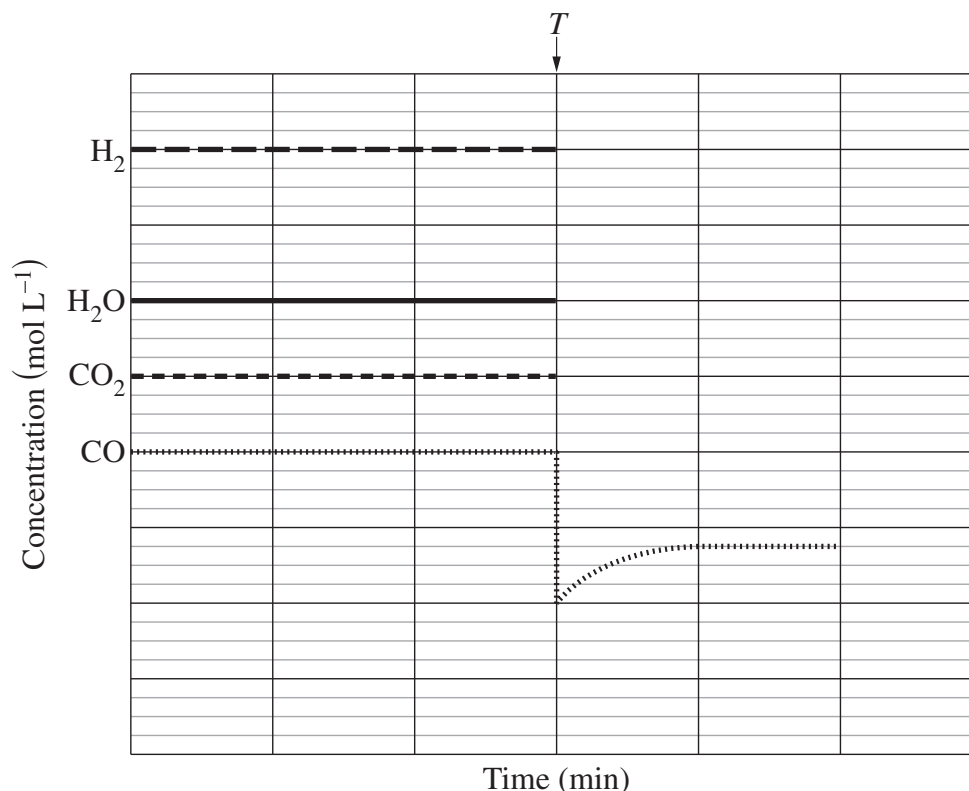


At time T , some $\text{CO}(g)$ was removed from the system.

- (a) The concentration of CO after time T is shown.

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Sketch the concentrations after time T for the remaining species.



- (b) Using collision theory, explain the change in the concentration of CO after time T .

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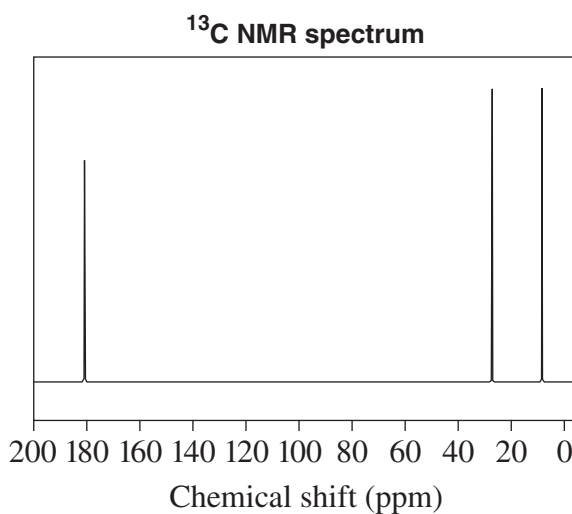
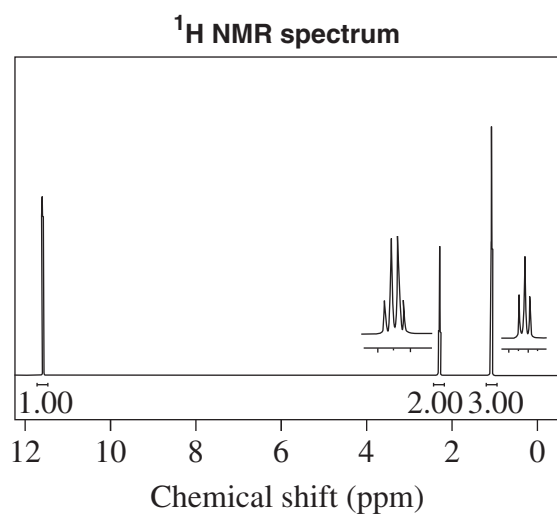
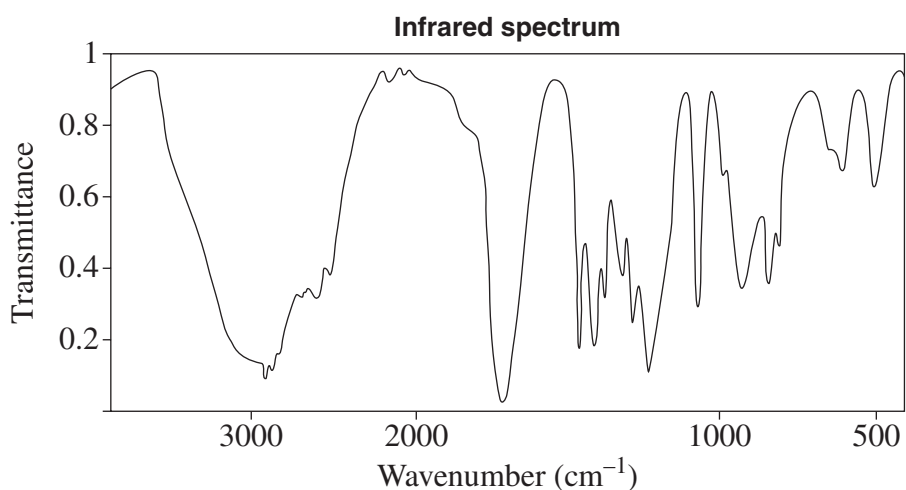
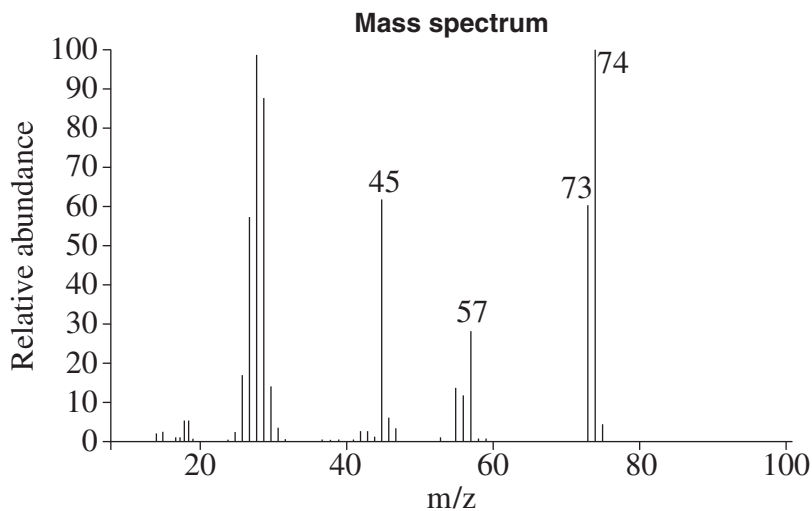
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Question 26 (8 marks)

The following data were obtained for an organic compound containing carbon, hydrogen and oxygen. The compound is a colourless liquid that reacts with sodium carbonate powder to produce bubbles.



Question 26 continues on page 21

Question 26 (continued)

- (a) What is the structural formula of this compound? Justify your answer with reference to the information given on its reactivity and to at least THREE of the provided spectra.

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- (b) Explain why a chemist should use more than one spectroscopic technique to identify an organic compound. Use TWO spectroscopic techniques to support your answer.

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End of Question 26

– 21 –

Question 27 (5 marks)

The relationship between the acid dissociation constant, K_a , and the corresponding conjugate base dissociation constant, K_b , is given by:

$$K_a \times K_b = K_w$$

Assume that the temperature for part (a) and part (b) is 25°C.

- (a) The K_a of hypochlorous acid (HOCl) is 3.0×10^{-8} .

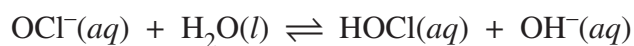
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Show that the K_b of the hypochlorite ion, OCl^- , is 3.3×10^{-7} .

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- (b) The conjugate base dissociation constant, K_b , is the equilibrium constant for the following equation:

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Calculate the pH of a 0.20 mol L^{-1} solution of sodium hypochlorite (NaOCl).

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Question 28 (5 marks)

Assess the usefulness of the Brønsted–Lowry model in classifying acids and bases.
Support your answer with at least TWO chemical equations.

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Question 29 (11 marks)

Stormwater from a mine site has been found to be contaminated with copper(II) and lead(II) ions. The required discharge limit is 1.0 mg L^{-1} for each metal ion. Treatment of the stormwater with $\text{Ca}(\text{OH})_2$ solid to remove the metal ions is recommended.

- (a) Explain the recommended treatment with reference to solubility. Include a relevant chemical equation. 2

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- (b) Explain why atomic absorption spectroscopy can be used to determine the concentrations of Cu^{2+} and Pb^{2+} ions in a solution containing both species. 2

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- (c) The data below were obtained after treatment of the stormwater. 7

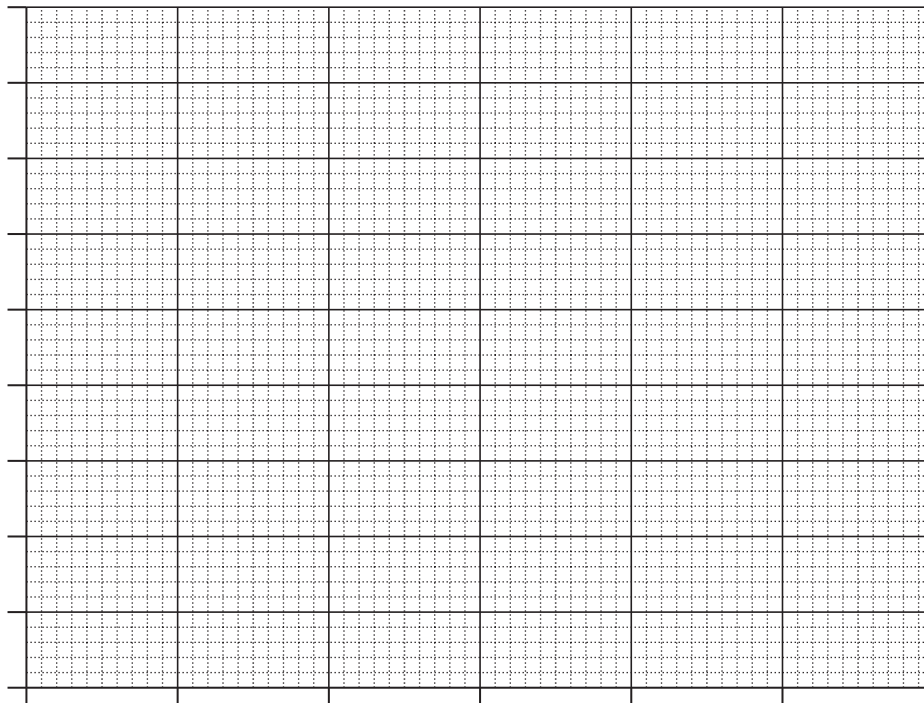
Data from atomic absorption spectroscopy

<i>Concentration</i> ($\times 10^{-5} \text{ mol L}^{-1}$) Cu^{2+} or Pb^{2+}	<i>Absorbance</i>	
	Cu^{2+}	Pb^{2+}
0.0	0.000	0.000
1.0	0.140	0.090
2.0	0.310	0.180
4.0	0.520	0.390
6.0	0.840	0.530
Water sample before treatment	0.820	0.440
Water sample after treatment	0.040	0.080

Question 29 continues on page 25

Question 29 (continued)

To what extent is the treatment effective in meeting the required discharge limit of 1.0 mg L^{-1} for each metal ion? Support your conclusion with calibration curves and calculations.



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End of Question 29

Question 30 (3 marks)

The following data apply to magnesium fluoride and magnesium chloride dissolving in water at 298 K.

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	<i>Magnesium fluoride</i>	<i>Magnesium chloride</i>
$\Delta_{\text{sol}}H^{\ominus}$ (kJ mol ⁻¹)	-7.81	-160
$\Delta_{\text{sol}}S^{\ominus}$ (J K ⁻¹ mol ⁻¹)	-223	-115
$T\Delta_{\text{sol}}S^{\ominus}$ (kJ mol ⁻¹)	-66.4	-34.2
$\Delta_{\text{sol}}G^{\ominus}$ (kJ mol ⁻¹)	+58.6	-125

Compare the effects of enthalpy and entropy on the solubility of these salts.

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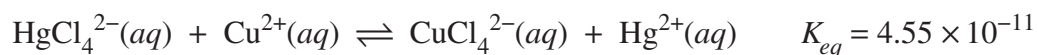
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Question 31 (4 marks)

The following reaction occurs in an aqueous solution.

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A solution containing a mixture of $\text{HgCl}_4^{2-}(\text{aq})$ and $\text{Cu}^{2+}(\text{aq})$ ions is prepared. The initial concentration of each ion is 0.100 mol L^{-1} and there are no other ions present.

Calculate the concentration of $\text{Hg}^{2+}(\text{aq})$ ions once the system has reached equilibrium.

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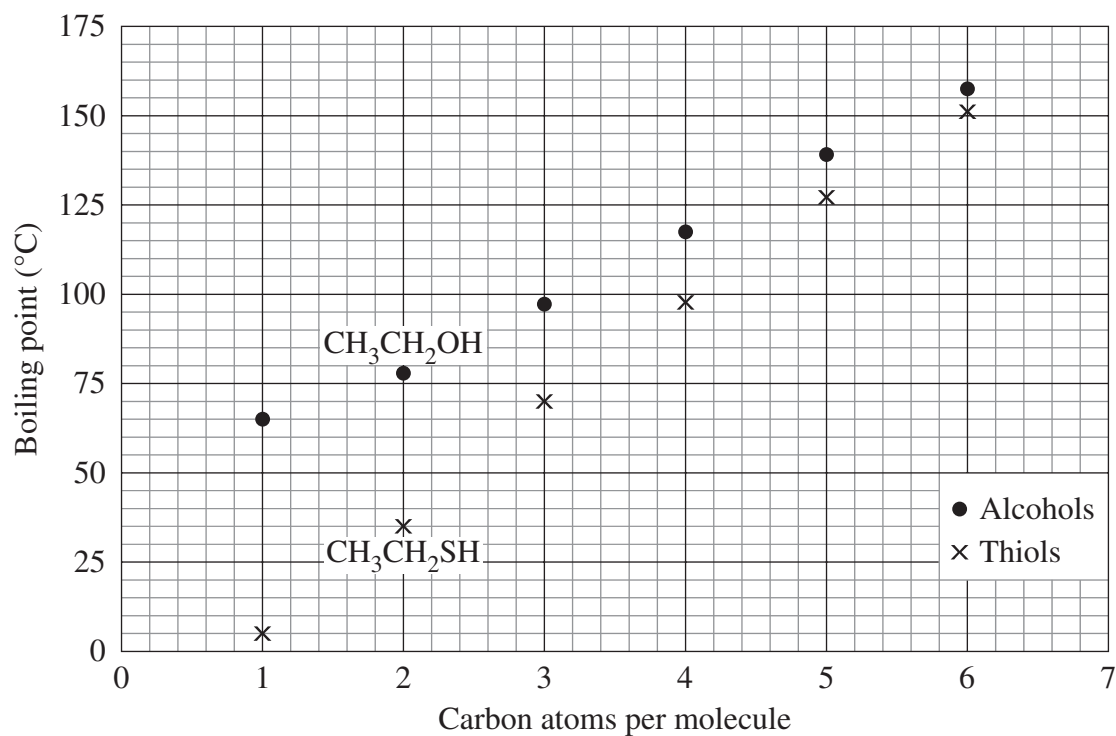
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Question 32 (4 marks)

Thiols are the sulfur analogues of alcohols in that the oxygen atom of the alcohol is replaced by a sulfur atom. For example, methanethiol (CH_3SH) is the analogue of methanol (CH_3OH). The boiling points of some straight chain alcohols and thiols are given in the following graph.



Explain the patterns of the boiling points shown in the graph.

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Question 33 (4 marks)

A student adds 1.17 g of $\text{Al}(\text{OH})_3(\text{s})$ to 0.500 L of $0.100 \text{ mol L}^{-1} \text{HCl}(\text{aq})$.

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Calculate the pH of the resulting solution. Assume that the volume of the resulting solution is 0.500 L.

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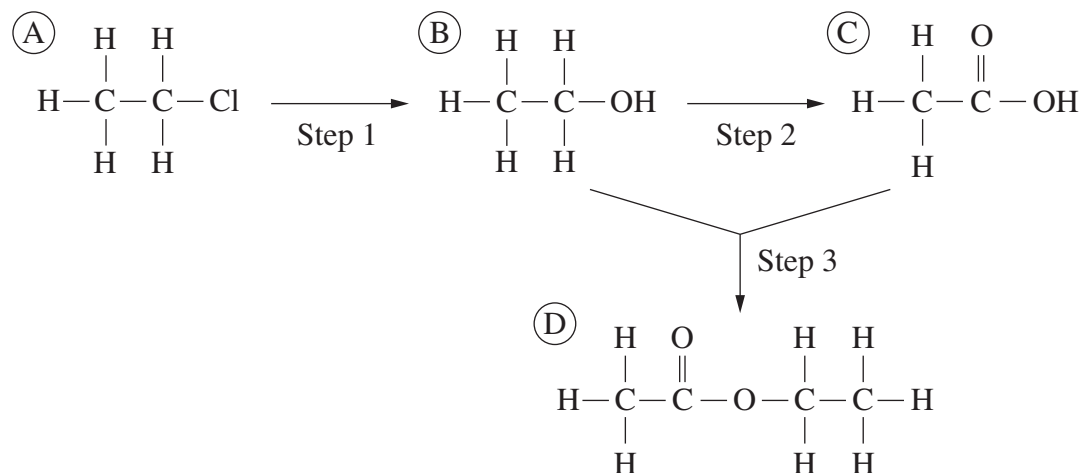
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Question 34 (7 marks)

The following reaction scheme can be used to synthesise ethyl ethanoate.

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Outline the reagents and conditions required for each step and how the product of each step could be identified.

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Section II extra writing space

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Chemistry

FORMULAE SHEET

$$n = \frac{m}{MM}$$

$$q = mc\Delta T$$

$$pK_a = -\log_{10}[K_a]$$

$$c = \frac{n}{V}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$A = \epsilon lc = \log_{10} \frac{I_0}{I}$$

$$PV = nRT$$

$$\text{pH} = -\log_{10}[\text{H}^+]$$

Avogadro constant, N_A $6.022 \times 10^{23} \text{ mol}^{-1}$

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 $8.314 \text{ J mol}^{-1} \text{ K}^{-1}$

Ionisation constant for water at 25°C (298.15 K), K_w 1.0×10^{-14}

Specific heat capacity of water $4.18 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

DATA SHEET

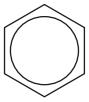
Solubility constants at 25°C

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

¹³C NMR chemical shift data

Type of carbon	δ/ppm
$\begin{array}{c} \quad \\ -C-C- \\ \quad \end{array}$	5–40
$\begin{array}{c} \\ R-C-Cl \text{ or } Br \\ \end{array}$	10–70
$\begin{array}{c} \\ R-C-C- \\ \quad \\ O \end{array}$	20–50
$\begin{array}{c} \quad / \\ R-C-N \\ \quad \backslash \end{array}$	25–60
$\begin{array}{c} \\ -C-O- \\ \end{array}$ alcohols, ethers or esters	50–90
$\begin{array}{c} \backslash \quad / \\ C=C \\ / \quad \backslash \end{array}$	90–150
R—C≡N	110–125
	110–160
$\begin{array}{c} R-C- \\ \\ O \end{array}$ esters or acids	160–185
$\begin{array}{c} R-C- \\ \\ O \end{array}$ 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

$\text{K}^+ + \text{e}^-$	\rightleftharpoons	K(s)	-2.94 V
$\text{Ba}^{2+} + 2\text{e}^-$	\rightleftharpoons	Ba(s)	-2.91 V
$\text{Ca}^{2+} + 2\text{e}^-$	\rightleftharpoons	Ca(s)	-2.87 V
$\text{Na}^+ + \text{e}^-$	\rightleftharpoons	Na(s)	-2.71 V
$\text{Mg}^{2+} + 2\text{e}^-$	\rightleftharpoons	Mg(s)	-2.36 V
$\text{Al}^{3+} + 3\text{e}^-$	\rightleftharpoons	Al(s)	-1.68 V
$\text{Mn}^{2+} + 2\text{e}^-$	\rightleftharpoons	Mn(s)	-1.18 V
$\text{H}_2\text{O} + \text{e}^-$	\rightleftharpoons	$\frac{1}{2}\text{H}_2(\text{g}) + \text{OH}^-$	-0.83 V
$\text{Zn}^{2+} + 2\text{e}^-$	\rightleftharpoons	Zn(s)	-0.76 V
$\text{Fe}^{2+} + 2\text{e}^-$	\rightleftharpoons	Fe(s)	-0.44 V
$\text{Ni}^{2+} + 2\text{e}^-$	\rightleftharpoons	Ni(s)	-0.24 V
$\text{Sn}^{2+} + 2\text{e}^-$	\rightleftharpoons	Sn(s)	-0.14 V
$\text{Pb}^{2+} + 2\text{e}^-$	\rightleftharpoons	Pb(s)	-0.13 V
$\text{H}^+ + \text{e}^-$	\rightleftharpoons	$\frac{1}{2}\text{H}_2(\text{g})$	0.00 V
$\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	$\text{SO}_2(\text{aq}) + 2\text{H}_2\text{O}$	0.16 V
$\text{Cu}^{2+} + 2\text{e}^-$	\rightleftharpoons	Cu(s)	0.34 V
$\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O} + 2\text{e}^-$	\rightleftharpoons	2OH^-	0.40 V
$\text{Cu}^+ + \text{e}^-$	\rightleftharpoons	Cu(s)	0.52 V
$\frac{1}{2}\text{I}_2(\text{s}) + \text{e}^-$	\rightleftharpoons	I^-	0.54 V
$\frac{1}{2}\text{I}_2(\text{aq}) + \text{e}^-$	\rightleftharpoons	I^-	0.62 V
$\text{Fe}^{3+} + \text{e}^-$	\rightleftharpoons	Fe^{2+}	0.77 V
$\text{Ag}^+ + \text{e}^-$	\rightleftharpoons	Ag(s)	0.80 V
$\frac{1}{2}\text{Br}_2(\text{l}) + \text{e}^-$	\rightleftharpoons	Br^-	1.08 V
$\frac{1}{2}\text{Br}_2(\text{aq}) + \text{e}^-$	\rightleftharpoons	Br^-	1.10 V
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	H_2O	1.23 V
$\frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^-$	\rightleftharpoons	Cl^-	1.36 V
$\frac{1}{2}\text{Cr}_2\text{O}_7^{2-} + 7\text{H}^+ + 3\text{e}^-$	\rightleftharpoons	$\text{Cr}^{3+} + \frac{7}{2}\text{H}_2\text{O}$	1.36 V
$\frac{1}{2}\text{Cl}_2(\text{aq}) + \text{e}^-$	\rightleftharpoons	Cl^-	1.40 V
$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^-$	\rightleftharpoons	$\text{Mn}^{2+} + 4\text{H}_2\text{O}$	1.51 V
$\frac{1}{2}\text{F}_2(\text{g}) + \text{e}^-$	\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

1 H 1.008 Hydrogen		KEY										2 He 4.003 Helium					
3 Li 6.941 Lithium		4 Be 9.012 Beryllium		Atomic Number Symbol		79 Au 197.0 Gold		Standard Atomic Weight Name		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	
				Standard Atomic Weight Name		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 Astatine	85 At Radon	86 Rn Radon
87 Fr Francium	88 Ra Radium	Actinoids	Rutherfordium	Dubnium	Seaborgium	Bohrium	Hassium	Meitnerium	Darmstadtium	Roentgenium	Copernicium	Nihonium	Flerovium	Moscovium	Livermorium	Tennessee	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
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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
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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.

2019 HSC Chemistry Marking Guidelines

Section I

Multiple-choice Answer Key

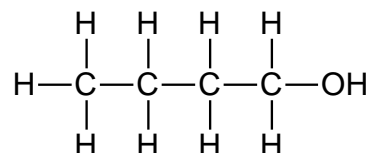
Question	Answer
1	D
2	B
3	A
4	B
5	C
6	A
7	D
8	A
9	B
10	D
11	C
12	C
13	B
14	A
15	B
16	B
17	D
18	A
19	D
20	C

Section II

Question 21 (a)

Criteria	Marks
• Provides an acceptable structure and name	2
• Provides some relevant information	1

Sample answer:



butan-1-ol

Answers could include:

Condensed or skeletal formulae. Other unambiguous systematic names are acceptable, eg 1-butanol.

Question 21 (b)

Criteria	Marks
• States why the two compounds are classed as functional group isomers	2
• Provides some relevant information	1

Sample answer:

Both compounds have the same molecular formula ($\text{C}_3\text{H}_6\text{O}$) but have different functional groups.

Question 21 (c)

Criteria	Marks
<ul style="list-style-type: none"> Identifies a suitable test Provides the appropriate observations Explains the observations 	3
<ul style="list-style-type: none"> Identifies the observations and the test reagent OR <ul style="list-style-type: none"> Explains the observations 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

Tollens' test could be used to distinguish between Isomer A (ketone) and Isomer B (aldehyde). Aldehydes are readily oxidised to carboxylic acids whereas ketones are not. Isomer B will therefore reduce the silver ions in the Tollens' reagent to form a silver mirror inside the test tube whereas Isomer A will not react.

Answers could include:

Other oxidants that can oxidise Isomer B but not Isomer A, eg $\text{Cr}_2\text{O}_7^{2-}$, MnO_4^- .

I_2/OH^- will give iodoform with Isomer A but not with Isomer B.

The orange dichromate solution will change to green.

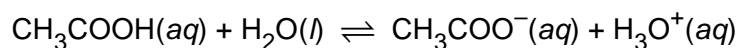
The purple permanganate solution will decolourise.

Question 22

Criteria	Marks
<ul style="list-style-type: none"> Identifies that the observed effect is due to small variation in pH Explains what occurs when acid and base are added Includes at least one equation 	4
<ul style="list-style-type: none"> Identifies that the observed effect is due to small variation in pH Explains what occurs when acid or base is added Includes a substantially correct equation 	3
<ul style="list-style-type: none"> Provides a correct equation OR Includes a partially correct equation and shows some understanding of what occurs when acid or base is added 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

The colour of the universal indicator did not change because the pH did not change very much despite the addition of acid and/or base. This is due to the equilibrium position of the buffer equation shifting in response to the addition of acid and/or base in accordance with Le Chatelier's Principle.



If acid is added the equilibrium position will shift left and if base is added the equilibrium position shifts right. In both cases the concentration of H_3O^+ remains nearly constant.

Question 23 (a)

Criteria	Marks
<ul style="list-style-type: none"> Correctly calculates $\Delta_c H$ with units Uses correct significant figures 	4
<ul style="list-style-type: none"> Provides substantially correct working 	3
<ul style="list-style-type: none"> Provides some relevant steps 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

$$\begin{aligned}\text{Moles ethanol } (n) &= 0.370 \text{ g} / (12.01 \times 2 + 1.008 \times 6 + 16.00 \text{ g mol}^{-1}) \\ &= 0.008032 \text{ mol}\end{aligned}$$

$$q = mC\Delta T$$

$$= 105 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ K}^{-1} \times (30 - 18.5) \text{ K}$$

$$= 5047.35 \text{ J}$$

$$\Delta_c H = -\frac{q}{n} = -\frac{5047.35 \text{ J}}{0.008032 \text{ mol}}$$

$$= -628405 \text{ J mol}^{-1}$$

$$= -628 \text{ kJ mol}^{-1} \quad (3 \text{ significant figures})$$

Question 23 (b)

Criteria	Marks
<ul style="list-style-type: none"> Provides a change that would improve accuracy Gives a reason for the low molar enthalpy of combustion related to the change 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

The experimental value for the molar enthalpy of combustion is low, primarily due to heat loss to the environment.

A change that would reduce heat loss and improve accuracy is moving the spirit burner closer to the beaker.

(There are many other possible improvements that are acceptable.)

Question 24 (a)

Criteria	Marks
• Explains the shape of the titration curve, in terms of ions present, as it falls, at equivalence point and as it rises	3
• Describes the trend in the titration curve and makes an explanation	2
• Provides some relevant information	1

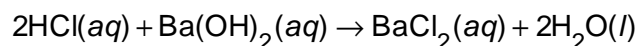
Sample answer:

The curve steadily falls as OH^- ions are added because they react and remove the highly conductive H^+ ions from the solution. At equivalence point, conductivity is lowest because the solution contains only Ba^{2+} and Cl^- ions, which are much less mobile than the H^+ or OH^- ions. The curve then rises as more OH^- ions are added.

Question 24 (b)

Criteria	Marks
• Provides correct calculation, and a balanced equation with states	4
• Provides partially correct calculation and a correct balanced equation OR • Provides substantially correct calculation	3
• Provides some relevant steps	2
• Provides some relevant information	1

Sample answer:



$$n(\text{HCl}) = c \times v = 1.050 \times 10^{-3} \text{ mol L}^{-1} \times 250.0$$

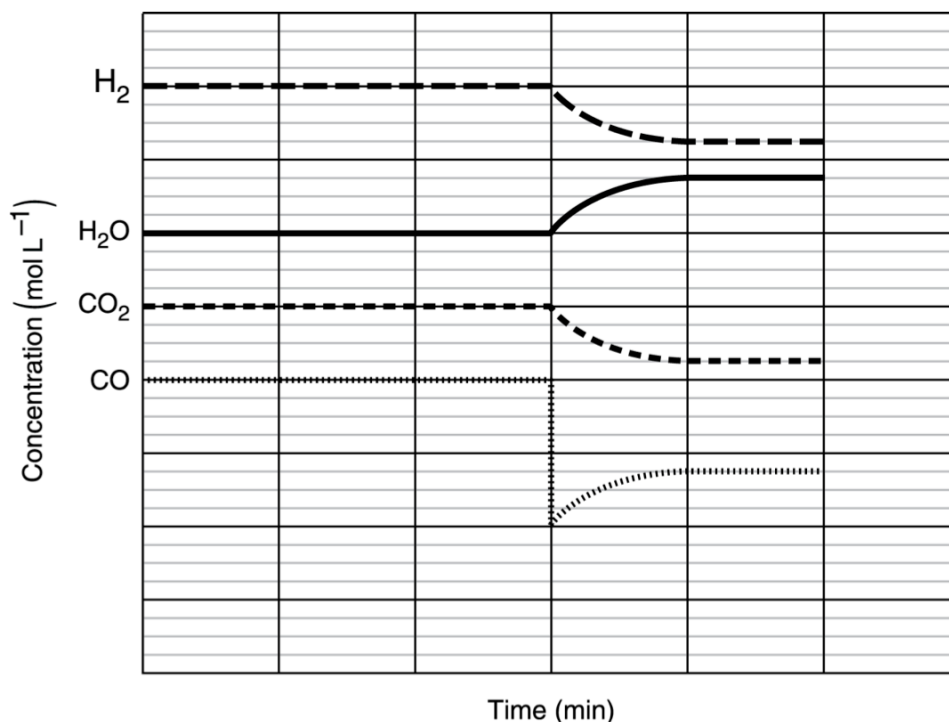
$$n(\text{Ba}(\text{OH})_2) = n(\text{HCl}) \times \frac{1}{2} \quad (\text{as reaction ratio is } 2 : 1)$$

$$\begin{aligned} \text{Concentration } \text{Ba}(\text{OH})_2 &= \frac{n}{v} = \frac{1.050 \times 10^{-3} \times 0.2500 \text{ L}}{0.01715 \times 2} \\ &= 7.653 \times 10^{-3} \text{ mol L}^{-1} \end{aligned}$$

Question 25 (a)

Criteria	Marks
• Sketches the concentrations correctly	2
• Provides some correct features	1

Sample answer:



Question 25 (b)

Criteria	Marks
• Provides a thorough explanation of the change in the concentration of CO	3
• Provides some explanation of the change in the concentration of CO	2
• Provides some relevant information	1

Sample answer:

At time T , the concentration of CO was decreased.

A decrease in the concentration of CO results in a decrease in the rate of the forward reaction due to fewer collisions between CO and H_2O molecules.

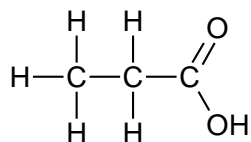
The rate of the reverse reaction is now greater than the forward reaction so the concentrations of $\text{H}_2(\text{g})$ and $\text{CO}_2(\text{g})$ decrease. As this occurs, the concentrations of $\text{CO}(\text{g})$ and $\text{H}_2\text{O}(\text{g})$ gradually increase.

The rate of the forward reaction subsequently increases until at some point the rate of the reverse reaction will be the same as the rate of the forward reaction as equilibrium is established.

Question 26 (a)

Criteria	Marks
<ul style="list-style-type: none"> Gives correct structure and justifies using reactivity and at least three spectra 	5
<ul style="list-style-type: none"> Gives substantially correct structure and justifies using reactivity and at least two spectra OR <ul style="list-style-type: none"> Gives a correct structure and justifies using at least three spectra 	4
<ul style="list-style-type: none"> Gives substantially correct structure and some correct analyses OR <ul style="list-style-type: none"> Gives substantially correct analyses with incorrect structure 	2–3
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:



Reaction with sodium carbonate implies that it is an organic acid as shown.

The ^{13}C NMR spectrum has three peaks; the peak at 180 ppm confirms the presence of a COOH group.

The ^1H NMR spectrum shows 3 separate proton environments – the splitting and integration indicate a CH_3 group and a CH_2 group.

The mass spectrum has a parent ion at 74, indicating that the compound must have a molar mass of 74 g mol^{-1} .

Answers could include:

Condensed or skeletal formula.

Could use infrared to confirm the presence of a carboxylic acid group.

Question 26 (b)

Criteria	Marks
<ul style="list-style-type: none"> Explains why more than one spectroscopic technique should be used Supports answer with two spectroscopic techniques 	3
<ul style="list-style-type: none"> Outlines why more than one spectroscopic technique should be used Supports answer with at least one spectroscopic technique 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

Different techniques are used in the identification of organic molecules but give different information about structure.

For example, ^1H NMR provides information about the chemical environment and relative number of hydrogen nuclei. This can be used to identify functional groups and distinguish between isomers.

Mass spectrometry gives information about the molecular weight of a molecule and its characteristic fragments.

Question 27 (a)

Criteria	Marks
<ul style="list-style-type: none"> Provides correct method for calculating K_b 	1

Sample answer:

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{3.0 \times 10^{-8}} = 3.3 \times 10^{-7}$$

Question 27 (b)

Criteria	Marks
• Correctly calculates pH, showing all working	4
• Provides substantially correct working	3
• Provides some relevant steps	2
• Provides some relevant information	1

Sample answer:

$$\frac{[\text{HOCl}][\text{OH}^-]}{[\text{OCl}^-]} = 3.3 \times 10^{-7}$$

Because K_b is very small we can assume that the equilibrium concentration of OCl^- is essentially unchanged.

	$\text{H}_2\text{O} + \text{OCl}^- \rightleftharpoons \text{HOCl} + \text{OH}^-$		
I	0.20	0	0
C	-x	+x	+x
E	≈ 0.20	x	x

Now, $[\text{HOCl}] = [\text{OH}^-]$ at equilibrium

$$\therefore \frac{x^2}{0.20} = 3.3 \times 10^{-7}$$

$$x = \sqrt{(3.3 \times 10^{-7}) \times 0.20}$$

$$= 2.5690 \times 10^{-4} \text{ mol L}^{-1}$$

$$\therefore [\text{OH}^-] = 2.5690 \times 10^{-4} \text{ mol L}^{-1}$$

$$\text{pOH} = -\log([\text{OH}^-]) = -\log(2.5690 \times 10^{-4})$$

$$= 3.59$$

$$\text{pH} = 14 - \text{pOH}$$

$$= 10.41$$

Question 28

Criteria	Marks
<ul style="list-style-type: none"> Makes an informed judgement about the usefulness of the B–L model Considers an advantage and a limitation of the model Includes at least TWO relevant equations 	5
<ul style="list-style-type: none"> Makes a judgement about the usefulness of the B–L model Considers an advantage and a limitation of the model Includes at least ONE relevant equation OR <ul style="list-style-type: none"> Outlines an advantage and a limitation of the B–L model Includes at least TWO relevant equations 	4
<ul style="list-style-type: none"> Outlines an advantage and/or a limitation of the model AND/OR <ul style="list-style-type: none"> Includes at least ONE relevant equation 	2–3
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

The Brønsted–Lowry model describes acids as proton donors and bases as proton acceptors. It was an improvement on the Arrhenius theory as it describes more acid and base behaviour.

For example, in the reaction $\text{NH}_3(g) + \text{HCl}(g) \rightarrow \text{NH}_4\text{Cl}(s)$, ammonia is classified as a Brønsted–Lowry base and hydrogen chloride as a Brønsted–Lowry acid, as a proton has been transferred from the hydrogen chloride to the ammonia. Ammonia is not an Arrhenius base as it does not dissociate to form OH^- ions.

However, the Brønsted–Lowry model does not explain the acidity of acidic oxides such as SO_2 and SO_3 and their reaction with basic oxides such as CaO . For example, in the reaction $\text{CaO}(s) + \text{SO}_3(g) \rightarrow \text{CaSO}_4(s)$ there is no proton transfer, so Brønsted–Lowry theory cannot be used to explain this as an acid–base reaction.

The Brønsted–Lowry model is useful to explain many acid–base reactions but has its limitations.

Answers could include

Descriptions of Lewis acid–base reactions.

Question 29 (a)

Criteria	Marks
<ul style="list-style-type: none"> Explains the treatment with reference to solubility Provides a correct chemical equation 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

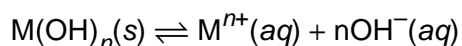
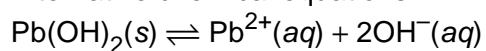
Sample answer:

Calcium hydroxide, Ca(OH)_2 , is slightly soluble in water. Copper(II) hydroxide and lead(II) hydroxide are both very insoluble in water shown by their small K_{sp} values, which will result in most of the metal ions precipitating.

A chemical equation $\text{Cu(OH)}_2(\text{s}) \rightleftharpoons \text{Cu}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq})$

Answers could include:

Alternative chemical equations:

**Question 29 (b)**

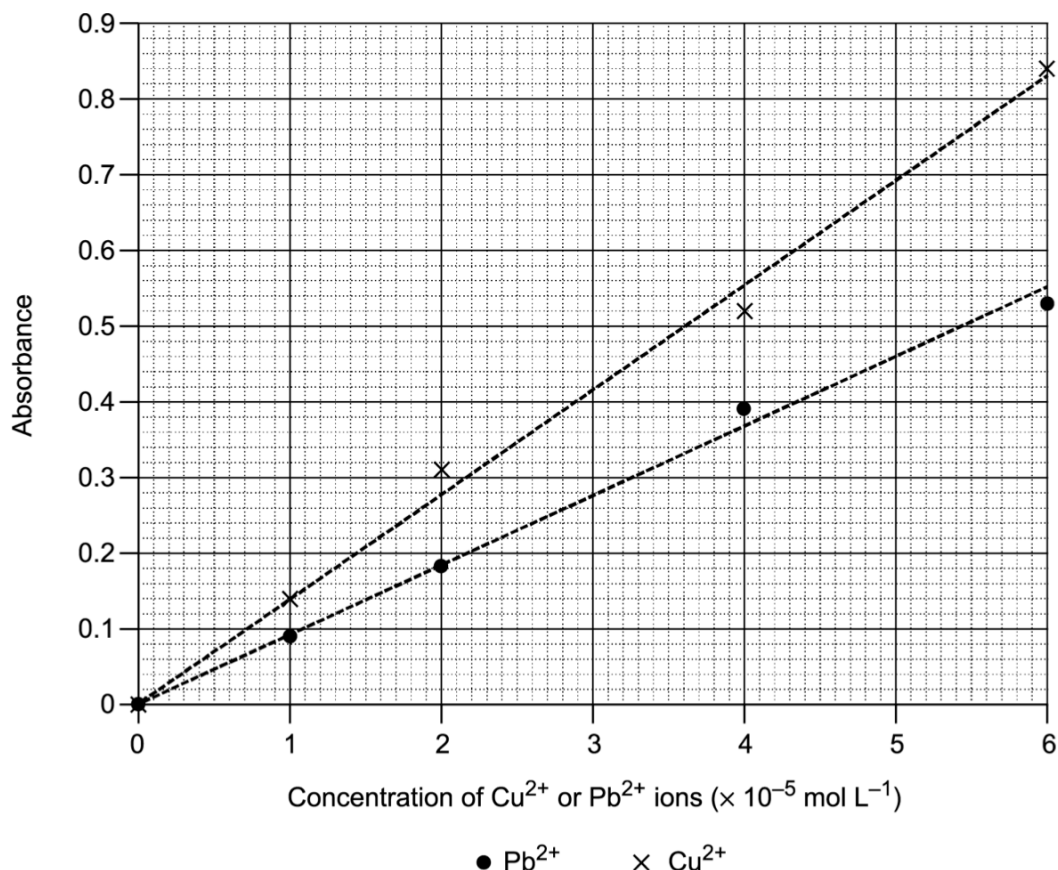
Criteria	Marks
<ul style="list-style-type: none"> Provides a valid explanation 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

AAS determines the concentration of metal ions by measuring the absorbance of light at different characteristic wavelengths for each metal. This allows the determination of the concentration of one metal without interference from the other metal.

Question 29 (c)

Criteria	Marks
<ul style="list-style-type: none"> Provides correct graph <ul style="list-style-type: none"> Labels axes correctly, including units Uses appropriate scale Plots both sets of data Draws two lines of best fit Provides a key Provides correct concentration values Converts concentration data from mol L^{-1} to mg L^{-1} Compares to discharge limit and makes correct judgement of treatment success 	7
<ul style="list-style-type: none"> Provides a substantially correct answer with a minor error 	6
<ul style="list-style-type: none"> Provides correct graph, provides correct concentration values and applies conversion OR <ul style="list-style-type: none"> Provides a substantially correct graph, provides concentration values, applies conversion and attempts judgement 	5
<ul style="list-style-type: none"> Provides correct graph and provides correct concentration values OR <ul style="list-style-type: none"> Provides a graph with some correct features, provides concentration values and applies conversion 	4
<ul style="list-style-type: none"> Provides correct graph OR <ul style="list-style-type: none"> Provides a graph with some correct features and provides some concentration values 	3
<ul style="list-style-type: none"> Provides a substantially correct graph OR <ul style="list-style-type: none"> Provides a graph with two correct features and extracts some relevant sample data OR <ul style="list-style-type: none"> Provides a graph with one correct feature, extracts some relevant sample data and attempts a relevant conversion 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

Concentrations of metals ions in mol L⁻¹

Sample	Cu ²⁺ × 10 ⁻⁵ mol L ⁻¹	Pb ²⁺ × 10 ⁻⁵ mol L ⁻¹
Water sample pre-treatment	5.95	4.75
Water sample post-treatment	0.25	0.85

The copper and lead concentrations have both been lowered by the treatment. To compare the post treatment concentrations to the discharge standard, the sample concentrations need to be converted to mg L⁻¹.

$$\text{Cu}^{2+}: 5.95 \times 10^{-5} \text{ mol L}^{-1} \times 63.55 \text{ g mol}^{-1} \times 1000 \text{ mg g}^{-1} = 3.78 \text{ mg L}^{-1}$$

$$0.25 \times 10^{-5} \text{ mol L}^{-1} \times 63.55 \text{ g mol}^{-1} \times 1000 \text{ mg g}^{-1} = 0.20 \text{ mg L}^{-1}$$

$$\text{Pb}^{2+}: 4.75 \times 10^{-5} \text{ mol L}^{-1} \times 207.2 \text{ g mol}^{-1} \times 1000 \text{ mg g}^{-1} = 9.84 \text{ mg L}^{-1}$$

$$0.85 \times 10^{-5} \text{ mol L}^{-1} \times 207.2 \text{ g mol}^{-1} \times 1000 \text{ mg g}^{-1} = 1.8 \text{ mg L}^{-1}$$

Conclusion: The copper ion concentration has been successfully lowered to less than the discharge limit. However, the lead ion concentration, although reduced, remains above the discharge limit. The treatment is only partially successful.

Question 30

Criteria	Marks
<ul style="list-style-type: none"> Compares the effects of enthalpy and entropy in relation to the solubility of both salts 	3
<ul style="list-style-type: none"> Compares enthalpy and entropy values for both salts Identifies the solubility of both salts 	2
<ul style="list-style-type: none"> Provides some relevant information 	1

Sample answer:

Magnesium chloride has a negative $\Delta_{\text{sol}} G^{\ominus}$ (-125 kJ mol^{-1}) and hence dissolves in water spontaneously, whereas the corresponding value for magnesium fluoride is $+58.6 \text{ kJ mol}^{-1}$, so magnesium fluoride does not dissolve in water spontaneously.

Both salts have a negative $\Delta_{\text{sol}} S^{\ominus}$; both result in a positive $-T\Delta_{\text{sol}} S^{\ominus}$ contribution to $\Delta_{\text{sol}} G^{\ominus}$.

Both salts have a negative $\Delta_{\text{sol}} H^{\ominus}$, however magnesium chloride has a significantly negative $\Delta_{\text{sol}} H^{\ominus}$ (-160 kJ mol^{-1}) which is greater than the $-T\Delta_{\text{sol}} S^{\ominus}$ contribution ($+34.2 \text{ kJ mol}^{-1}$), resulting in a negative $\Delta_{\text{sol}} G^{\ominus}$. On the other hand, magnesium fluoride has a relatively small negative $\Delta_{\text{sol}} H^{\ominus}$ ($-7.81 \text{ kJ mol}^{-1}$) which is smaller than the $-T\Delta_{\text{sol}} S^{\ominus}$ contribution ($+66.4 \text{ kJ mol}^{-1}$), resulting in a positive $\Delta_{\text{sol}} G^{\ominus}$.

Question 31

Criteria	Marks
• Calculates the concentration of Hg^{2+} ions showing all working	4
• Provides substantially correct working	3
• Provides some correct steps	2
• Provides some relevant information	1

Sample answer:

$$K_{\text{eq}} = \frac{[\text{CuCl}_4^{2-}][\text{Hg}^{2+}]}{[\text{HgCl}_4^{2-}][\text{Cu}^{2+}]}$$

	$[\text{HgCl}_4^{2-}]$	$[\text{Cu}^{2+}]$	$[\text{CuCl}_4^{2-}]$	$[\text{Hg}^{2+}]$
I	0.100	0.100	0	0
C	-x	-x	+x	+x
E	$0.100 - x$	$0.100 - x$	x	x

$$K = \frac{x^2}{(0.100 - x)^2} = 4.55 \times 10^{-11}$$

Solving for x (take square root OR assume that $x \leq 0.100$ OR use the quadratic formula),

$$x = 6.75 \times 10^{-7} \text{ mol L}^{-1}$$

$$\text{So } [\text{Hg}^{2+}] = 6.75 \times 10^{-7} \text{ mol L}^{-1}$$

Question 32

Criteria	Marks
• Explains patterns in the boiling points	4
• Explains most of the patterns in the boiling points	3
• Describes the patterns in the boiling point OR • Explains a pattern in the boiling points	2
• Provides some relevant information	1

Sample answer:

Boiling points for both series increase with increasing number of carbon atoms. This is due to dispersion forces increasing with increasing chain length.

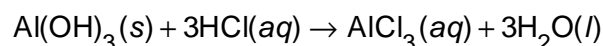
The boiling point of the alcohol is always higher than the analogous thiol. This is due to hydrogen bonding between alcohols being stronger than the dispersion forces between thiols.

The difference between the boiling points of analogous alcohols and thiols decreases with increasing chain length. This is due to the hydrogen bonding having a smaller and smaller contribution to total intermolecular forces as chain length increases.

Question 33

Criteria	Marks
• Calculates pH correctly showing all working	4
• Provides substantially correct working	3
• Provides some correct steps	2
• Provides some relevant information	1

Sample answer:



$$n(\text{Al}(\text{OH})_3) = \frac{1.17 \text{ g}}{78.004 \text{ g mol}^{-1}} = 0.0150 \text{ mol}$$

$$n(\text{HCl}) = 0.500 \text{ L} \times 0.100 \text{ mol L}^{-1} = 0.0500 \text{ mol}$$

$$n(\text{HCl reacting with Al}(\text{OH})_3) = 3 \times 0.0150 \text{ mol} = 0.0450 \text{ mol}$$

$$n(\text{HCl in excess}) = 0.0500 \text{ mol} - 0.0450 \text{ mol} = 0.0050 \text{ mol}$$

$$[\text{HCl}] = \frac{0.0050 \text{ mol}}{0.500 \text{ L}} = 0.010 \text{ mol L}^{-1}$$

$$\text{pH} = -\log_{10}(0.010) = 2.00$$

Question 34

Criteria	Marks
<ul style="list-style-type: none"> • Outlines the appropriate reagents and conditions • Outlines differences in chemical reactivity or spectroscopic data for products of all three steps 	7
<ul style="list-style-type: none"> • Outlines the appropriate reagents and conditions • Outlines differences in chemical reactivity or spectroscopic data for products of two steps 	6
<ul style="list-style-type: none"> • Outlines some appropriate reagents and conditions • Outlines chemical reactivity or spectroscopic data for the products of some steps 	4–5
<ul style="list-style-type: none"> • Outlines an appropriate reagent and/or condition AND/OR <ul style="list-style-type: none"> • Outlines chemical reactivity or spectroscopic data for the products 	2–3
<ul style="list-style-type: none"> • Provides some relevant information 	1

Sample answer:

In step 1, chloroethane (A) can be converted to ethanol (B) by heating with dilute aqueous potassium hydroxide. The mass spectrum of ethanol will have a single molecular ion peak at $m/z = 46$, whereas chloroethane will give two peaks at m/z 64 and 66.

In step 2, ethanol (B) can be converted to ethanoic acid (C) using a strong oxidant, for example: acidified potassium permanganate. A $C=O$ peak will appear in the IR spectrum ($1680\text{--}1750\text{ cm}^{-1}$) or in the ^{13}C NMR spectrum ($160\text{--}185\text{ ppm}$); ethanol will show neither peak.

In step 3, ethyl ethanoate (D) can be synthesised by heating a mixture of ethanol, ethanoic acid and concentrated sulfuric acid under reflux. The ^1H NMR spectrum of ethyl ethanoate will have 3 signals, whereas both ethanol and ethanoic acid will have 2.

Answers could include:

Ethanol (B) can be identified in a number of ways, for example:

- Reactivity tests eg turns acidified potassium dichromate solution from orange to green, or decolourises acidified potassium permanganate solution from purple. Also gives a red colour with ceric ammonium nitrate, or gives hydrogen gas with sodium. Chloroethane reacts with none of these reagents.
- An O–H peak will appear in the IR spectrum (broad peak at $3230\text{--}3550\text{ cm}^{-1}$) and in the ^1H NMR spectrum (variable chemical shift, $1\text{--}6\text{ ppm}$, concentration-dependent); the IR spectrum of chloroethane will not contain this peak.
- The ^1H NMR spectrum of ethanol will have 3 signals, whereas that of chloroethane will have 2.
- The mass spectrum of ethanol will have a single molecular ion peak at $m/z = 46$, whereas chloroethane will give two peaks at m/z 64 and 66.

In step 2, ethanol (B) can be converted to ethanoic acid (C) using a strong oxidant, for example: Jones' reagent (CrO_3 in H_2SO_4), and many others.

Ethanoic acid (C) can be identified in a number of ways, for example:

- Indicators (eg blue litmus turning red), carbon dioxide given off when reacted with sodium carbonate or sodium hydrogencarbonate. Ethanol will do neither.
- $\text{C}=\text{O}$ peak will appear in the IR spectrum ($1680\text{--}1750\text{ cm}^{-1}$) and in the ^{13}C NMR spectrum ($160\text{--}185\text{ ppm}$); ethanol will show neither peak.
- The ^1H NMR spectrum of ethanoic acid will not have a peak in $3.3\text{--}4.8\text{ ppm}$ range; the ^{13}C NMR spectrum will not have a peak in the $50\text{--}90\text{ ppm}$ range. Ethanol will have a peak in both ranges due to the CH_2 group.
- The ^1H NMR spectrum of ethanoic acid will have 2 signals, whereas that of ethanol will have 3.
- The mass spectrum of ethanoic acid will have a molecular ion peak at $m/z = 60$, whereas that of ethanol is at $m/z = 46$.

Ethyl ethanoate (D) can be identified in a number of ways, for example:

- Ethyl ethanoate will have no O-H peaks in the IR spectrum (broad peak at $3230\text{--}3550\text{ cm}^{-1}$) and the ^1H NMR spectrum (variable chemical shift, $1\text{--}6\text{ ppm}$, concentration-dependent). These peaks are present in the spectra of ethanol and ethanoic acid.
- The mass spectrum of ethyl ethanoate will have a molecular ion peak at $m/z = 102$; ethanoic acid will have a molecular ion peak at $m/z = 60$ and ethanol at $m/z = 46$.
- Ethyl ethanoate has a distinct smell.

2019 HSC Chemistry Mapping Grid

Section I

Question	Marks	Content	Syllabus outcomes
1	1	Mod 7 Nomenclature	12-7, 12-14
2	1	Mod 6 Properties of acids and bases	12-7, 12-13
3	1	Mod 5 Solution equilibria	12-5, 12-6, 12-12
4	1	Mod 8 Analysis of organic substances	12-5, 12-6, 12-7, 12-15
5	1	Mod 6 Properties of acids and bases Mod 6 Quantitative analysis	12-4, 12-13
6	1	Mod 6 Quantitative analysis	12-5, 12-6, 12-7, 12-13
7	1	Mod 5 Factors that affect equilibrium	12-6, 12-12
8	1	Mod 7 Reactions of organic acids and bases	12-5, 12-6, 12-7, 12-14
9	1	Mod 7 Reactions of organic acids and bases Mod 7 Hydrocarbons Mod 7 Alcohols	12-4, 12-5, 12-6, 12-7, 12-14
10	1	Mod 7 Nomenclature Mod 7 Reactions of organic acids and bases	12-6, 12-14
11	1	Mod 5 Static and dynamic equilibrium	12-5, 12-6, 12-12
12	1	Mod 5 Factors that affect equilibrium	12-5, 12-12
13	1	Mod 7 Polymers	12-4, 12-5, 12-6, 12-14
14	1	Mod 8 Analysis of organic substances	12-5, 12-6, 12-15
15	1	Mod 6 Using Brønsted–Lowry theory	12-4, 12-5, 12-6, 12-13
16	1	Mod 5 Calculating the equilibrium constant	12-4, 12-5, 12-6, 12-12
17	1	Mod 5 Calculating the equilibrium constant	12-4, 12-5, 12-6, 12-7, 12-12
18	1	Mod 5 Solution equilibria	12-4, 12-5, 12-6, 12-12
19	1	Mod 8 Analysis of organic substances	12-4, 12-5, 12-6, 12-7, 12-15
20	1	Mod 8 Analysis of inorganic substances	12-4, 12-5, 12-6, 12-15

Section II

Question	Marks	Content	Syllabus outcomes
21 (a)	2	Mod 7 Nomenclature Mod 7 Alcohols	12-5, 12-7, 12-14
21 (b)	2	Mod 7 Nomenclature	12-5, 12-7, 12-14
21 (c)	3	Mod 7 Alcohols Mod 7 Reactions of organic acids and bases	12-2, 12-3, 12-7, 12-14
22	4	Mod 6 Quantitative analysis	12-4, 12-5, 12-13
23 (a)	4	Mod 7 Alcohols	12-4, 12-5, 12-6, 12-14
23 (b)	2	Mod 7 Alcohols	12-1, 12-2, 12-5, 12-14
24 (a)	3	Mod 6 Quantitative analysis	12-5, 12-7, 12-13
24 (b)	4	Mod 6 Quantitative analysis	12-4, 12-5, 12-6, 12-13
25 (a)	2	Mod 5 Factors that affect equilibrium	12-4, 12-5, 12-6, 12-7, 12-12

Question	Marks	Content	Syllabus outcomes
25 (b)	3	Mod 5 Factors that affect equilibrium	12-5, 12-6, 12-12
26 (a)	5	Mod 8 Analysis of organic substances	12-4, 12-5, 12-6, 12-7, 12-15
26 (b)	3	Mod 8 Analysis of organic substances	12-2, 12-6, 12-15
27 (a)	1	Mod 5 Calculating the equilibrium constant Mod 6 Using Brønsted–Lowry theory Mod 6 Quantitative analysis	12-5, 12-6, 12-12, 12-13
27 (b)	4	Mod 5 Calculating the equilibrium constant Mod 6 Using Brønsted–Lowry theory Mod 6 Quantitative analysis	12-5, 12-6, 12-12, 12-13
28	5	Mod 6 Properties of acids and bases	12-6, 12-7, 12-13
29 (a)	2	Mod 5 Solution equilibria Mod 8 Analysis of inorganic substances	12-5, 12-6, 12-12, 12-15
29 (b)	2	Mod 8 Analysis of inorganic substances	12-2, 12-6, 12-15
29 (c)	7	Mod 8 Analysis of inorganic substances	12-1, 12-4, 12-5, 12-6, 12-7, 12-15
30	3	Mod 5 Static and dynamic equilibrium	12-5, 12-6, 12-7, 12-12
31	4	Mod 5 Calculating the equilibrium constant	12-5, 12-6, 12-12
32	4	Mod 7 Alcohols	12-5, 12-6, 12-7, 12-14
33	4	Mod 6 Using Brønsted–Lowry theory	12-4, 12-5, 12-6, 12-13
34	7	Mod 7 Reactions of organic acids and bases	12-2, 12-4, 12-5, 12-6, 12-7, 12-14