



Conquer Higher School Certificate Examination

2022 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:** **Section I – 20 marks** (pages 2–8)
100
- Attempt Questions 1–20
 - Allow about 35 minutes for this section

- Section II – 80 marks** (pages 9–29)
- Attempt Questions 21–34
 - Allow about 2 hours and 25 minutes for this section

Examiner:
linglingwannabe#8958

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 What is the role of sulfuric acid in an esterification reaction?

- A. To produce an acidic environment and act as a dehydrating agent.
- B. To provide energy for the homolytic cleavage of the O-H bonds in alcohols.
- C. To provide a surface for the reactant molecules to collide.
- D. As a reactant for the production of the ester.

2 Which of the following rows of the table shows the correct flame colours produced by the listed metals?

	<i>Copper</i>	<i>Sodium</i>	<i>Calcium</i>	<i>Barium</i>
A.	Blue-green	Yellow	Yellow-green	Orange-red
B.	Yellow	Orange-red	Blue-green	Yellow-green
C.	Blue-green	Yellow	Orange-red	Yellow-green
D.	Yellow-green	Blue-green	Orange-red	Yellow

3 Which of the following methods show the correct order of steps used by Aboriginal and Torres Strait Islander people to prepare the cycad fruit for consumption?

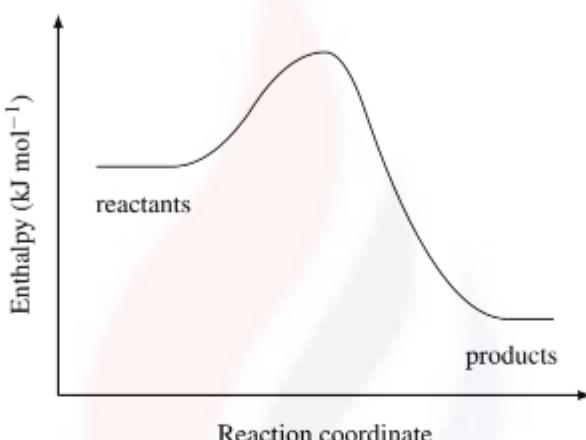
- A. The cycads were ground, then leached in a running stream for a long period of time in a running stream, before being cut open and baked.
- B. The cycads were cut open and ground, then leached in a running stream for a long period of time in a running stream, before being baked.
- C. The cycads were ground, then leached in a running stream for a short period of time before being cut open and baked.
- D. The cycads were cut open and ground, then leached in a running stream for a short period of time before being baked.

4 Propanoic acid was reacted with ethanamine at high temperatures to produce compound X.

Compound X is most likely to be

- A. *N*-propylethanamide.
- B. *N*-ethylpropanamide.
- C. *N*-propylethanamide.
- D. *N*-ethylpropan-1-amine.

- 5 The diagram shows an energy profile diagram for a certain chemical system.



If the chemical reaction occurring in the system is spontaneous at all temperatures, which of the following statements must be true?

- A. The chemical reaction increases the degree of randomness in the system.
 - B. No energy is required to initiate the chemical reaction at 25°C.
 - C. The reverse reaction of the chemical system can establish equilibrium at a certain temperature.
 - D. The chemical reaction decreases the number of possible particle arrangements in the system.
- 6 Which of the following rows of the table correctly allocates the physical and chemical properties of hexane, hexan-1-ol, and hexanoic acid?

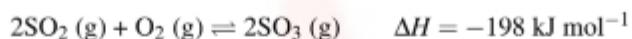
	<i>Highest boiling point</i>	<i>Highest solubility in benzene</i>	<i>Highest oxidation potential</i>
A.	Hexan-1-ol	Hexanoic acid	Hexan-1-ol
B.	Hexanoic acid	Hexane	Hexan-1-ol
C.	Hexane	Hexan-1-ol	Hexanoic acid
D.	Hexanoic acid	Hexanoic acid	Hexan-1-ol

- 7 Methyl violet is an acid-base indicator that changes colour from yellow to violet as the pH of a solution increases from 0.0 to 1.6.

Which 250 mL solution containing two drops of methyl violet will appear yellow?

- A. 1.0 mol L⁻¹ sulfuric acid
- B. 1.0 mol L⁻¹ acetic acid
- C. 2.0 mol L⁻¹ sodium hydroxide
- D. 0.10 mol L⁻¹ hydrochloric acid

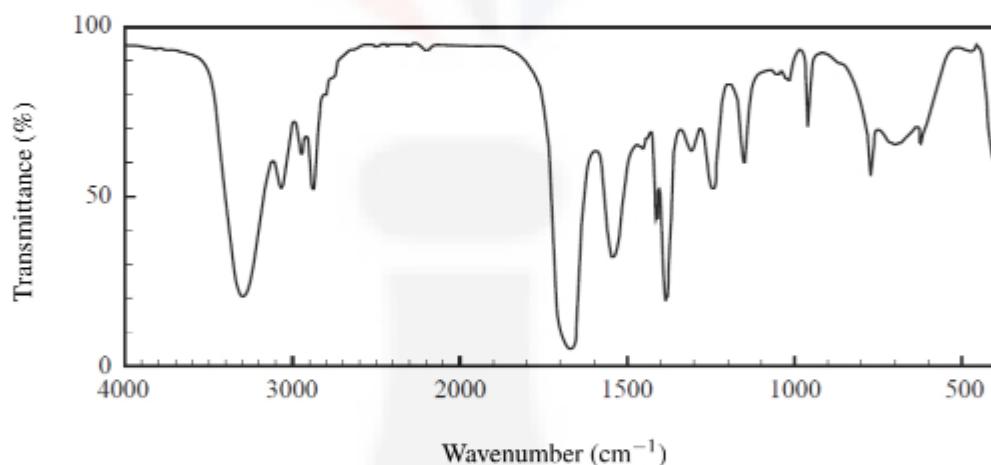
- 8 During the production of sulfuric acid in the Contact process, sulfur dioxide gas is converted to sulfur trioxide gas in the following equilibrium reaction:



Which of the following combinations of temperature and pressure will produce the highest initial rate of reaction of sulfur trioxide gas?

	Temperature ($^{\circ}\text{C}$)	Pressure (kPa)
A.	550	200
B.	400	200
C.	550	100
D.	400	100

- 9 The infrared spectrum of a certain organic compound is shown below.



Which class of organic compound is most likely to produce this spectrum?

- A. Alcohol
- B. Ester
- C. Aldehyde
- D. Amide

- 10 Which pair of substances is most likely to form an acidic buffer solution in 500 mL of water?

- A. 0.10 mol HCl and 0.20 mol NH₃
- B. 0.10 mol HCl and 0.10 mol NaOH
- C. 0.20 mol CH₃COOH and 0.10 mol NaOH
- D. 0.20 mol CH₃COOH and 0.20 mol NH₃

- 11** A method to produce ethanol involves the enzymatic hydrolysis of starch to produce glucose, which can be fermented in anaerobic conditions to form ethanol.

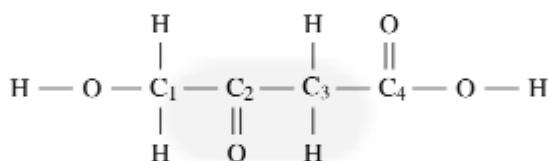
The sequence of chemical reactions of this method is shown below.



If 100 grams of starch was converted to 47.6 grams of ethanol using this method, what is the percentage yield of ethanol?

- A. 56.8%
- B. 61.7%
- C. 83.8%
- D. 87.7%

- 12** The structure of a compound is shown below, with its carbon atoms numbered from 1 to 4.



Which carbon atom in the compound is most likely to be the most deshielded?

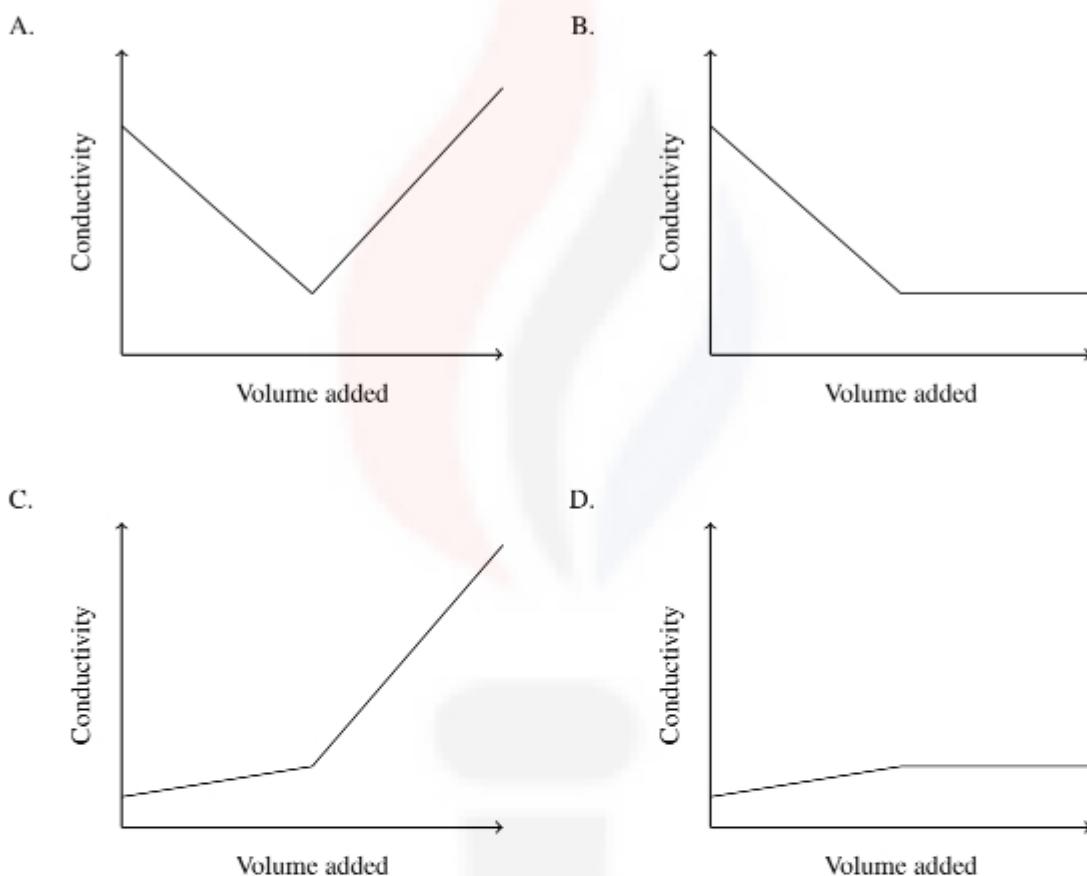
- A. Carbon 1
- B. Carbon 2
- C. Carbon 3
- D. Carbon 4

- 13** A student carried out a colourimetric investigation to determine the concentration of copper ions in a local river. They first diluted a 10 mL sample of the river water to 100 mL before adding a volume of the diluted sample to a 12.5 mm \times 12.5 mm \times 45 mm cuvette. A light of wavelength 512 nm with an initial intensity of 892 lumens was transmitted through the sample in the cuvette. A photometer recorded the intensity of the transmitted light to be 377 lumens.

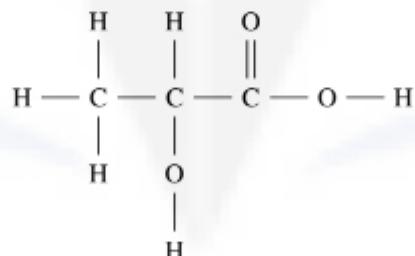
If the molar absorptivity constant of copper ions is $2.35 \times 10^4 \text{ L mol}^{-1} \text{ cm}^{-1}$, then the concentration of copper ions in the original river water sample, in parts per billion, is

- A. 762.
- B. 1439.
- C. 2248.
- D. 8092.

- 14 Hydrocyanic acid and lithium diisopropylamide have pK_a values of 9.2 and 36 at 25°C, respectively. Which of the following curves best represents the change in conductivity as hydrocyanic acid is titrated against lithium diisopropylamide?



- 15 The structure of the monomer used to produce the condensation polymer, polylactic acid is shown below.



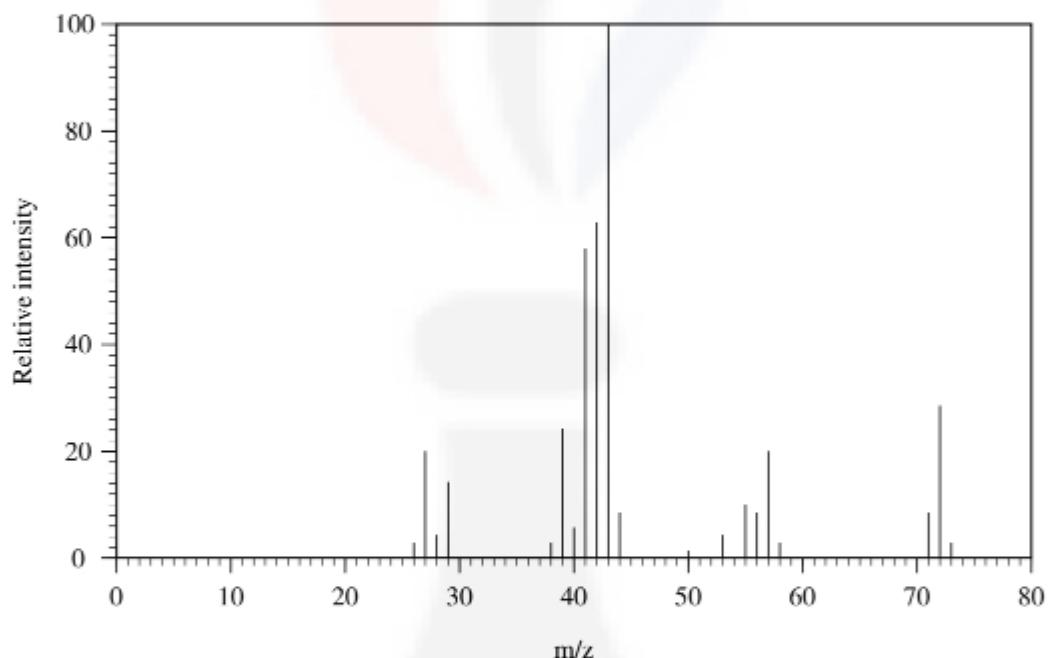
- What is the approximate mass of a polylactic acid polymer chain produced from 2.0×10^{25} monomers?
- A. 2400 g
B. 2600 g
C. 2800 g
D. 3000 g

- 16 20.0 mL of a 0.109 M sulfuric acid solution was mixed with 50.0 mL of a 0.252 M ammonia solution. Assume that sulfuric acid ionises completely, and the base dissociation constant of ammonia is 1.8×10^{-5} .

What is the pH of the resultant solution?

- A. 10.59
- B. 11.16
- C. 11.21
- D. 3.41

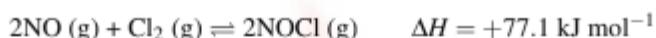
- 17 The mass spectrum of an unbranched alkane is shown below.



Which row of the table gives correct information about the alkane?

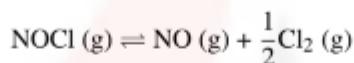
	<i>Alkane</i>	<i>Parent peak (m/z)</i>	<i>Base peak (m/z)</i>
A.	Butane	43	72
B.	Butane	72	43
C.	Pentane	43	72
D.	Pentane	72	43

- 18** Nitrosyl chloride, NOCl, is a toxic yellow gas that can be formed in the following equilibrium reaction.



The equilibrium constant of this chemical reaction at 40°C is 3.26×10^{-7} .

The following chemical system has an equilibrium constant denoted by Q at 20°C.



Which of the following best describes the value of Q ?

- A. $Q = 1.75 \times 10^3$
- B. $Q > 1.75 \times 10^3$
- C. $Q < 9.41 \times 10^{12}$
- D. $Q = 9.41 \times 10^{12}$

- 19** To determine the degree of hydration of chloroplatinic acid, a diprotic acid with formula $\text{H}_2\text{PtCl}_6 \cdot x\text{H}_2\text{O}$, 59.88 g of dry chloroplatinic acid was dissolved in 1.000 L of water. A 25.00 mL aliquot of this solution was neutralised by 23.61 mL of a 0.2448 M standardised sodium hydroxide solution.

What is the value of x , the degree of hydration of chloroplatinic acid?

- A. 3
- B. 4
- C. 5
- D. 6

- 20** The enthalpy of formation of barium hydroxide and its respective ions at 298 K are given in the table.

<i>Chemical species</i>	$\Delta_f H^\circ (\text{kJ mol}^{-1})$
$\text{Ba(OH)}_2(\text{s})$	-934.1
$\text{Ba}^{2+}(\text{aq})$	-538.4
$\text{OH}^-(\text{aq})$	-229.9

Assuming that the volume of the resultant solution remains constant with a specific heat capacity of $4.18 \text{ J g}^{-1} \text{ K}^{-1}$, what is the approximate change in temperature of 200 mL of water at the point of saturation with barium hydroxide?

- A. $+0.972^\circ\text{C}$
- B. $+0.613^\circ\text{C}$
- C. -3.06°C
- D. -0.792°C

Please turn over

Section II

80 marks

Attempt Questions 21-34

Allow about 2 hours and 25 minutes for this section

Answer the questions in the space given as they provide guidance for the expected length of the response.

Show all relevant working in questions involving calculations.

Question 21 (4 marks)

- (a) Using an example, relate the term 'amphiprotic' to a relevant acid-base theory.

3

- (b) Outline a limitation of the acid-base theory identified in part (a).

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Please turn over

Question 22 (4 marks)

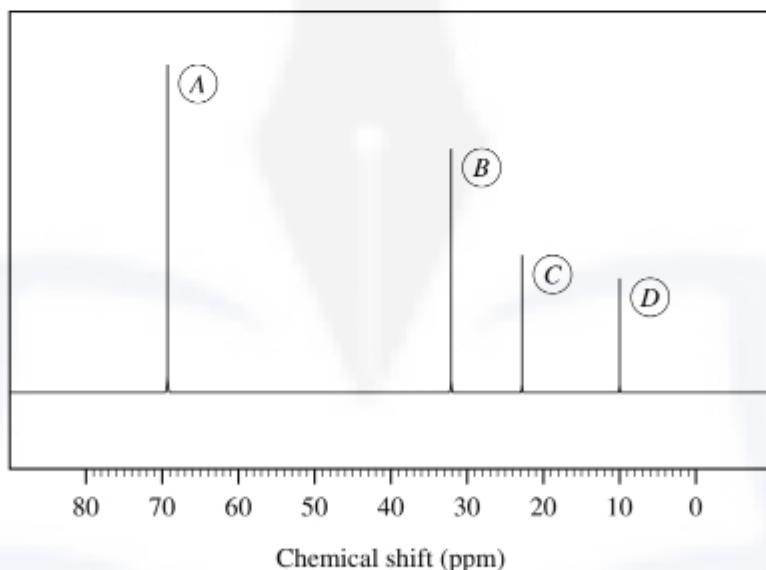
The ^1H NMR spectral data of a four-carbon alcohol is provided below.

Chemical shift (ppm)	Relative peak area	Splitting pattern
0.93	3	triplet (3)
1.17	3	doublet (2)
1.46	2	quintet (5)
2.37	1	singlet (1)
3.71	1	sextet (6)

- (a) With reference to the tabulated data, identify the four-carbon alcohol. 3

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- (b) The ^{13}C NMR spectrum of the same four-carbon alcohol is given below, with signals denoted by the letters *A* to *D*. 1



Identify the signal on the ^{13}C NMR spectrum that corresponds to the carbon atom bonded to the hydrogen atom producing the signal with a chemical shift of 3.71 ppm in the ^1H NMR spectral data.

Question 23 (4 marks)

Nitrogen dioxide is a brown, toxic gas that can be reacted to produce colourless dinitrogen tetroxide gas which is used widely as a rocket propellant. The chemical equation representing the synthesis of dinitrogen tetroxide gas from nitrogen dioxide gas is given below.

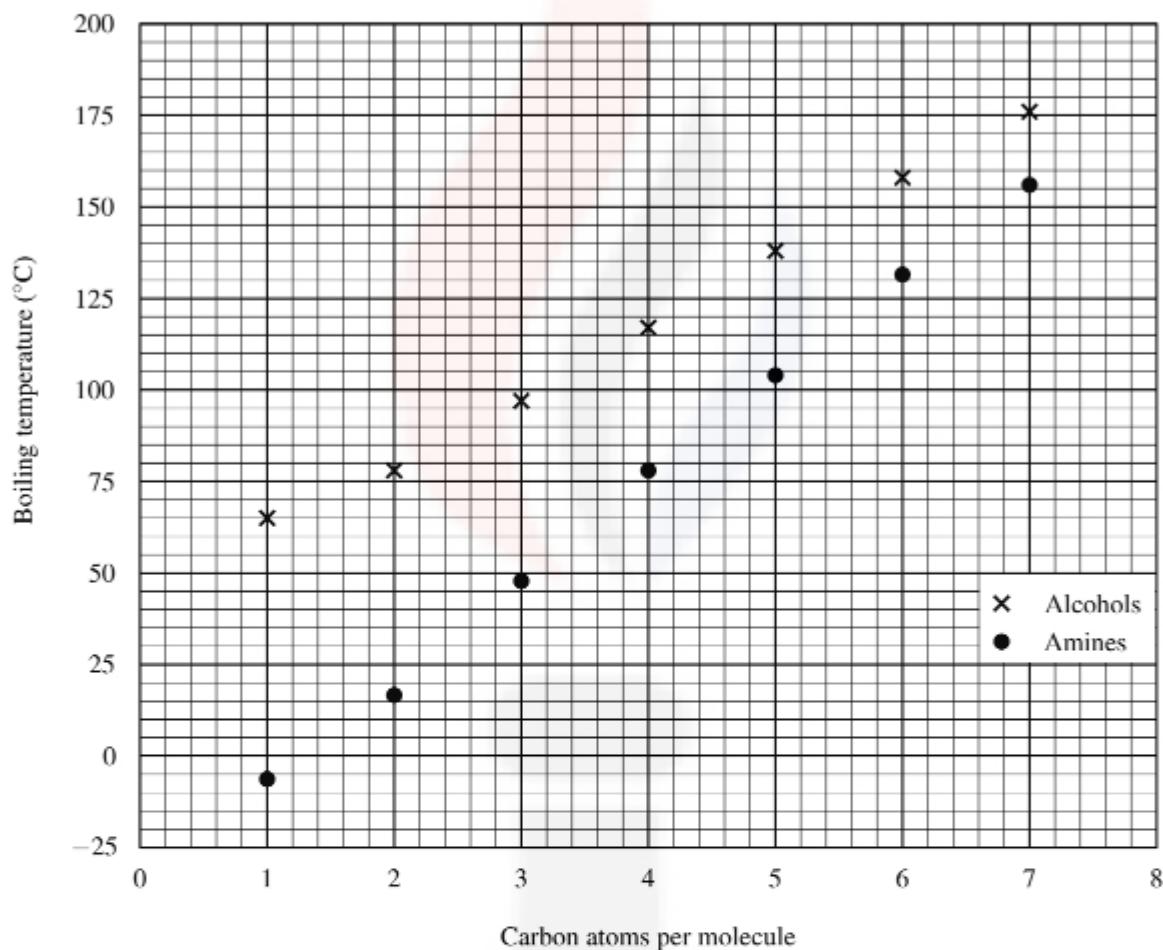


Analyse this process in terms of enthalpy and entropy, and explain why this synthesis reaction can act as an equilibrium system in a certain temperature range.

Please turn over

Question 24 (5 marks)

The boiling temperature of primary alcohols and primary amines is graphed against the number of carbon atoms per molecule in the diagram below.



- (a) Explain the trends of the boiling temperatures shown in the graph.

3

- (b) Identify a suitable test that can distinguish between the homologous series in part (a), and outline the expected observations.

2

Question 25 (4 marks)

A 0.10 mol L⁻¹ solution of an unknown salt is to be identified. It is known that the cation is one of sodium, iron (II) or lead (II), and that the anion is one of chloride, bromide or iodide.

4

Describe a sequence of tests to be conducted in a school laboratory that confirms the identity of the salt solution. Include expected observations and at least ONE balanced chemical equation in your answer.

Please turn over

Question 26 (5 marks)

Calcium nitrate is commonly used as a nitrogen fertiliser in agriculture to aid the growth of plants. A student used gravimetric analysis to determine the percentage mass of calcium nitrate in their fertiliser. Their procedure is provided below.

- Weigh out a 10.0 g of the fertiliser in a 150 mL beaker on an electronic balance.
- Dissolve the fertiliser sample in 100 mL of distilled water, stirring to ensure that no solid remains
- Add sufficient 1.00 mol L^{-1} sodium hydroxide solution to the dissolved fertiliser sample to form a precipitate, ensuring that no more solid forms
- Weigh a sheet of filter paper on the electronic balance
- Collect the precipitate formed by pouring the solution through the filter paper
- Evaporate the filter paper to dryness in a drying oven and weigh the filter paper on an electronic balance

The data obtained from the student's procedure is given in the table.

Item	Mass (g)
Filter paper before use	1.38
Filter paper after use	4.12

- (a) Suggest a way to improve the validity of the student's procedure. Explain your answer. 2

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- (b) Calculate the percentage mass of calcium nitrate in the 10.0 g sample of fertiliser. 3

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Question 27 (6 marks)

- (a) Explain why soaps and detergents display surfactant properties.

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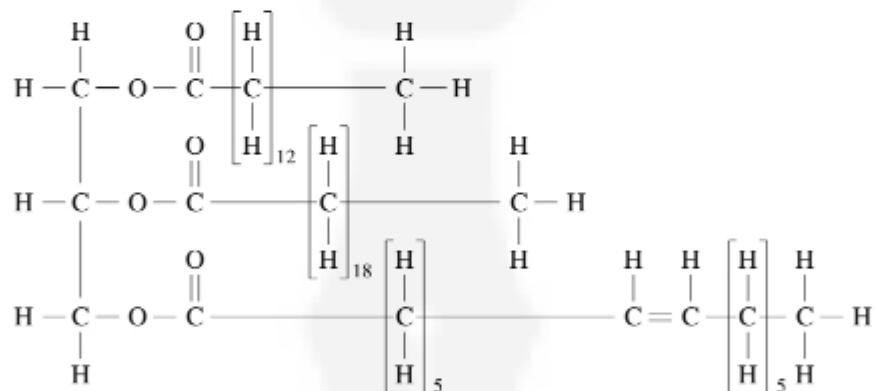
- (b) Compare the performance and types of soaps and detergents.

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- (c) The triglyceride molecule below undergoes saponification with hot, concentrated sodium hydroxide solution to produce four products. In this reaction, each ester group in the triglyceride and its corresponding carbon chain is substituted with a hydroxide ion to form glycerol, with systematic name propane-1,2,3-triol, and three soap ions.

2

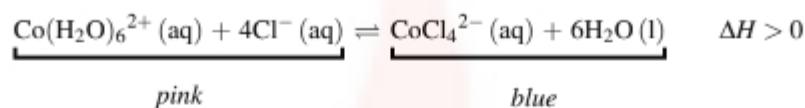


Draw the structural formulae of the four products formed in the boxes below. Do NOT name the products.

(1)	(2)
(3)	(4)

Question 28 (6 marks)

Consider the following solution equilibrium.



The value of the equilibrium constant of this chemical system is 1.70×10^{-3} at 298K and 100 kPa.

The initial concentrations of $\text{Co}(\text{H}_2\text{O})_6^{2+}$ (aq), Cl^- (aq), and CoCl_4^{2-} (aq) in a 250 mL container are 1.54 mol L^{-1} , 2.38 mol L^{-1} , and $8.40 \times 10^{-2} \text{ mol L}^{-1}$, respectively.

- (a) 2.55 L of gaseous hydrochloric acid gas was bubbled through the solution at equilibrium.

Calculate the number of moles of CoCl_4^{2-} (aq) present when the system reestablishes equilibrium.

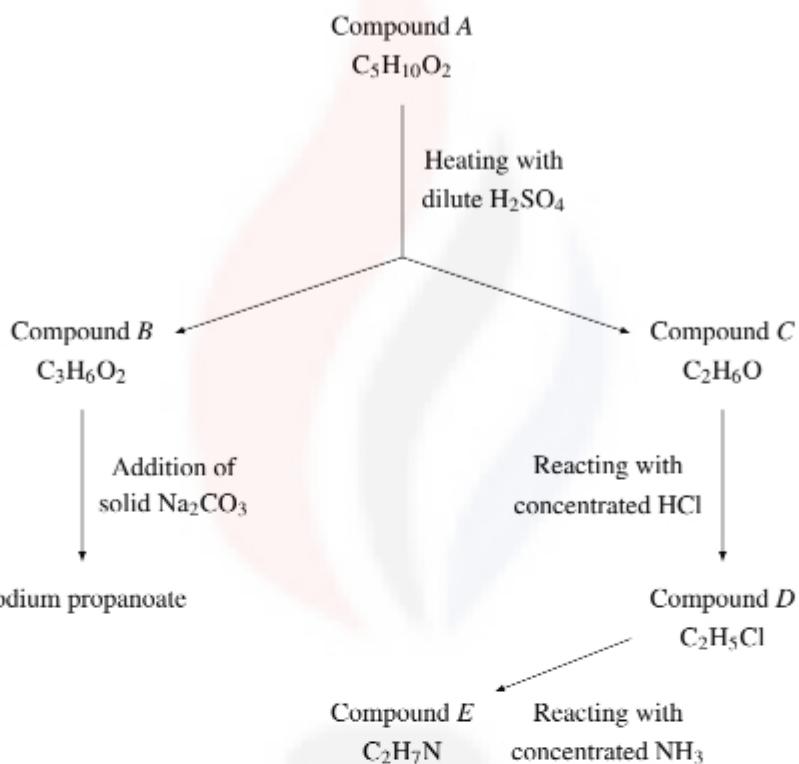
- (b) Explain any changes in the colour of the solution when its temperature is increased to 310K.

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Question 29 (5 marks)

The flow chart shows the chemical reactions of the organic compounds labelled A to E.

5



Determine the systematic name and structural formulae of compounds A to E. Provide a brief justification for each structural formula drawn.

Compound	Name and structural formula	Justification
A		
B		

Question 29 continues on page 18

Question 29 (continued)

<i>Compound</i>	<i>Name and structural formula</i>	<i>Justification</i>
<i>C</i>		
<i>D</i>		
<i>E</i>		

End of Question 29

Question 30 (10 marks)

- (a) Describe the application of neutralisation reactions in TWO different industries.

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To measure the enthalpy of neutralisation of the chemical reaction between ammonia and hydrochloric acid, 25 mL of 2.0 mol L⁻¹ hydrochloric acid solution was mixed with 50 mL of 2.0 mol L⁻¹ ammonia solution and the temperature of the solution was measured every 5 seconds.

The data obtained is given in the table below.

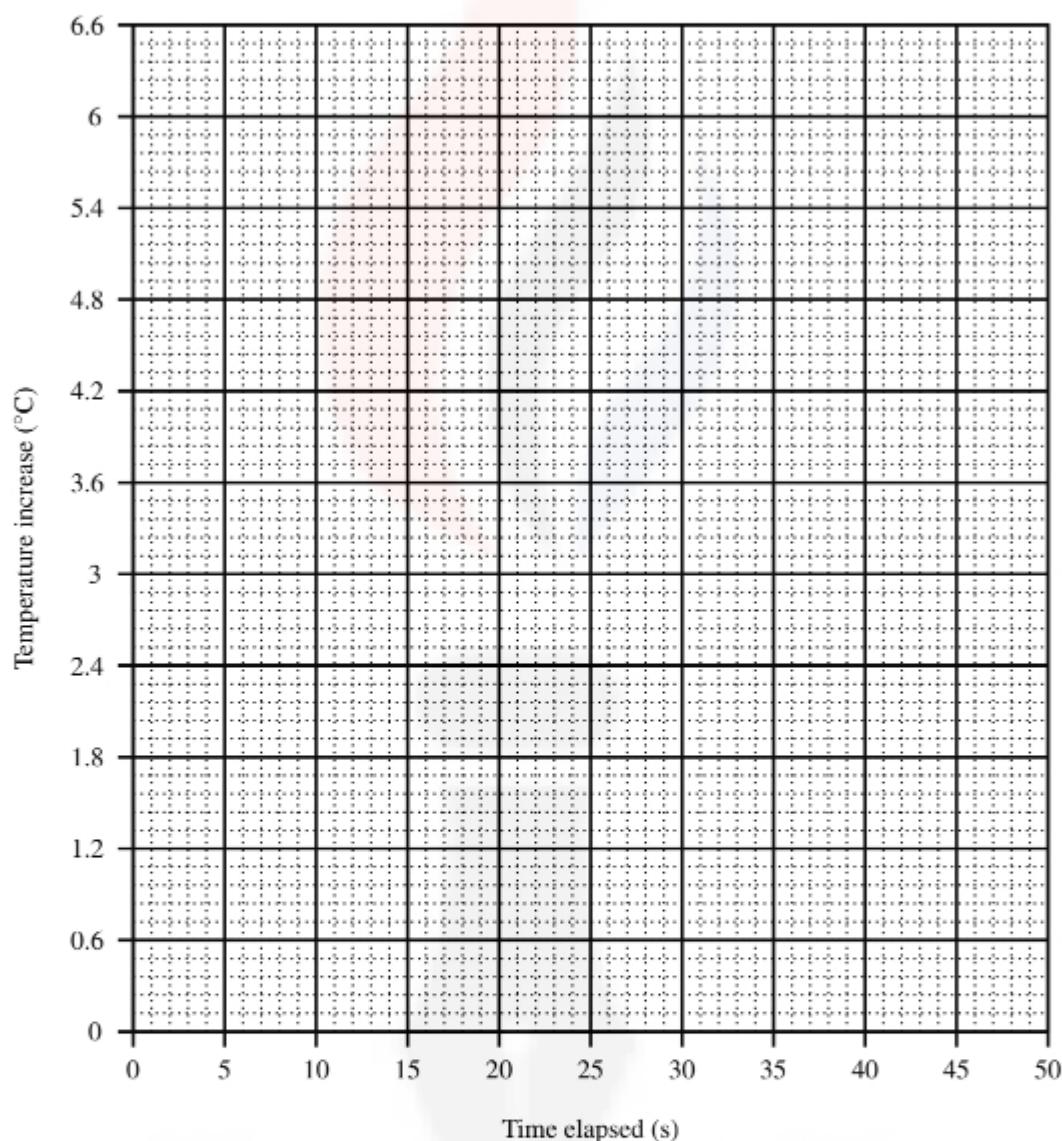
<i>Time elapsed (s)</i>	<i>Temperature of solution (°C)</i>
0	23.2
5	24.5
10	25.7
15	26.9
20	28.2
25	29.4
30	29.3
35	29.4
40	29.3

Question 30 continues on page 20

Question 30 (continued)

- (b) By plotting the data in the table and performing relevant calculations, determine the enthalpy of neutralisation of the reaction of ammonia and hydrochloric acid.

4



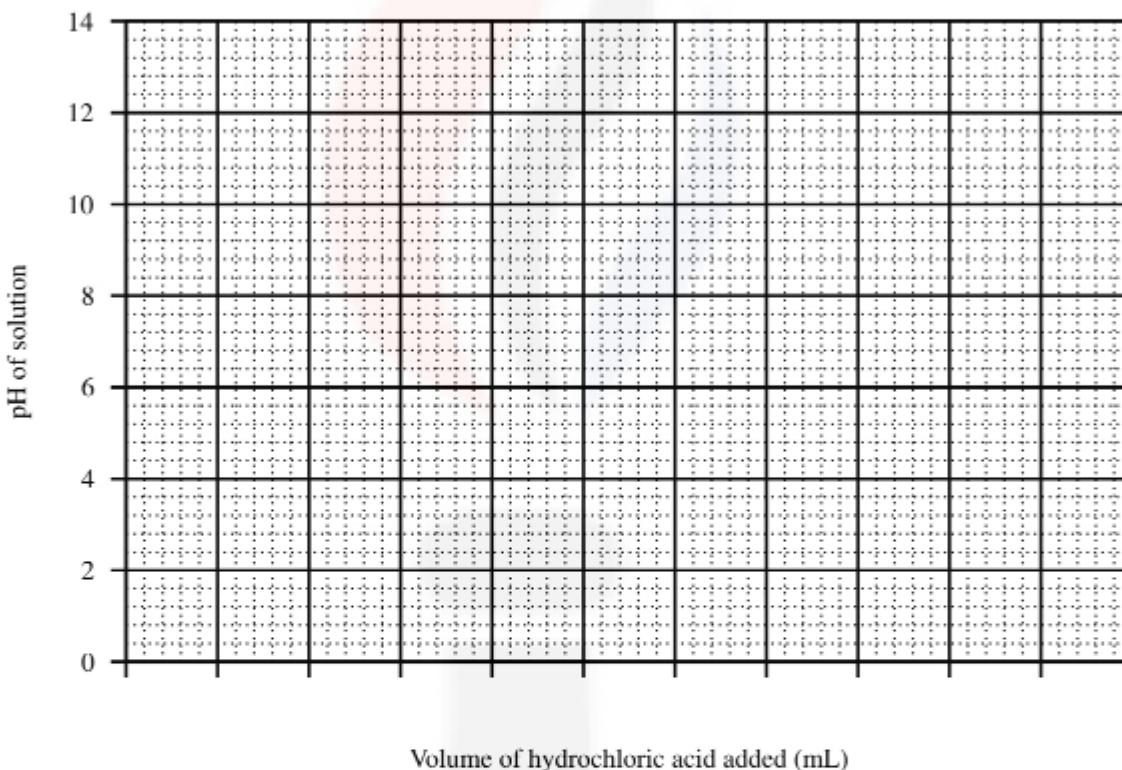
Question 30 continues on page 21

Question 30 (continued)

- (c) After the experiment in part (b), a 2.0 mol L^{-1} hydrochloric acid solution is continually added to the resultant solution.

4

If the base dissociation constant of ammonia is 1.8×10^{-5} , draw a curve on the graph below representing the pH of the solution as the hydrochloric acid solution is continually added. Support your answer with relevant calculations.



End of Question 30

Question 31 (6 marks)

Carbon serves as the foundation for organic chemistry and all life on Earth due to its versatility and variety of applications resulting from its ability to produce a diverse range of properties in organic molecules.

6

Justify this statement.

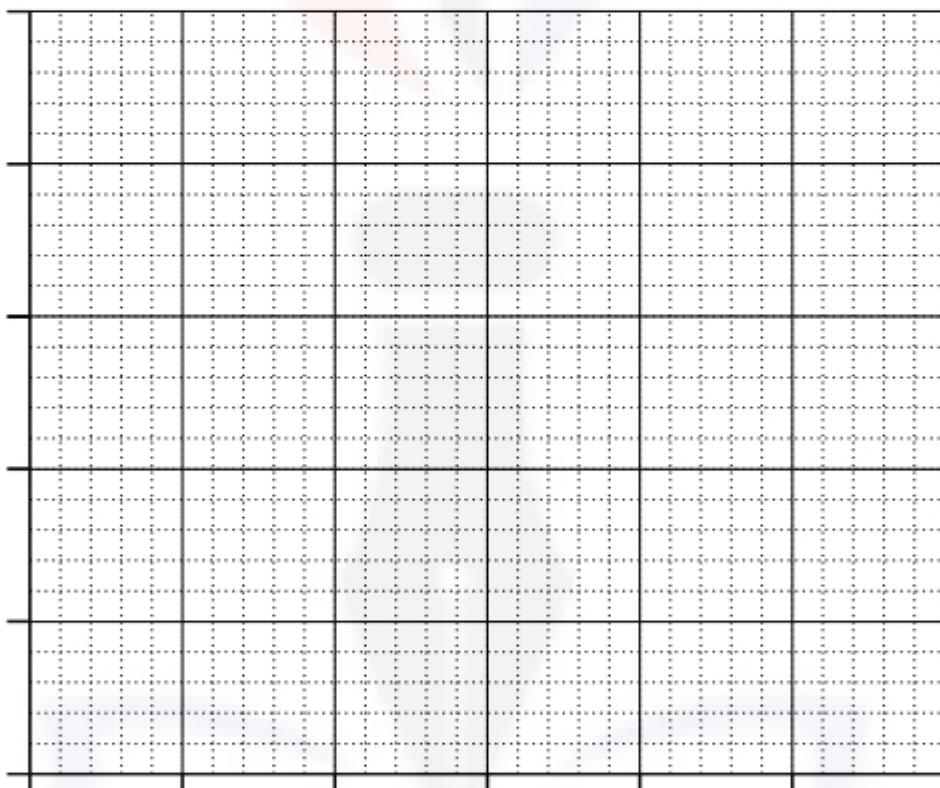
Question 32 (6 marks)

A student mixed a sodium phosphate solution with excess copper (II) sulfate solution to form a precipitate. They took a small sample of the solution above the precipitate and measured the concentration of copper (II) ions in the solution using atomic absorption spectroscopy. Their obtained data is given below.

<i>Concentration of copper (II) ions (ppb)</i>	<i>Absorbance</i>
0.500	0.160
1.00	0.330
1.50	0.470
2.00	0.630
2.50	0.800

- (a) Graph the data and draw a line of best fit on the grid provided below.

2



- (b) Using your graph, calculate the molar concentration of copper (II) ions in the sample solution if the measured absorbance was 0.530.

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Question 32 continues on page 24

Question 32 (continued)

- (c) Calculate the concentration (in g L⁻¹) of phosphate ions in the sample solution.

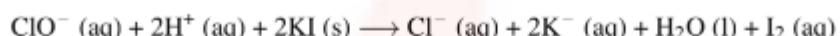
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End of Question 32

Question 33 (8 marks)

A major constituent of bleach, a household cleaning solution, is sodium hypochlorite, with formula NaClO.

The concentration of sodium hypochlorite in bleach can be determined using a titration. To do this, an excess of potassium iodide solid is reacted with the hypochlorite ions in a sample of the bleach to produce aqueous iodine.



A sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3$) solution was prepared and standardised beforehand using a titration with a potassium iodate (KIO_3) standard solution.



The sodium thiosulfate solution is then titrated against the iodine produced in the first step using a starch solution as the indicator which forms a deep blue complex with iodine that fades as they react with thiosulfate ions.



To prepare the potassium iodate standard solution, 1.55 g of cool, dry potassium iodate was dissolved in 500 mL of deionised water. The titration of a sodium thiosulfate solution with 25.0 mL aliquots of the potassium iodate standard solution yielded the following results.

Trial	Volume of $\text{Na}_2\text{S}_2\text{O}_3$ (aq) added (mL)
1	23.45
2	21.25
3	21.20
4	21.25

A 25.0 mL sample of the bleach solution was diluted to 500 mL. 3.2 g of solid potassium iodide was added to a 20.0 mL sample of the diluted bleach solution before being titrated against the standardised sodium thiosulfate solution. This was repeated four times, producing the results in the following table.

Trial	Volume of $\text{Na}_2\text{S}_2\text{O}_3$ (aq) added (mL)
1	15.30
2	13.75
3	14.20
4	13.85
5	13.80

Question 33 continues on page 26

Question 33 (continued)

- (a) Show that the molar concentration of the sodium thiosulfate solution is 0.102 mol L^{-1} .

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- (b) Calculate the concentration, in % m/v, of sodium hypochlorite in the bleach solution.

4

- (c) Outline the rinsing procedure of the glassware used in the standardisation of the sodium thiosulfate solution against the potassium iodate standard solution.

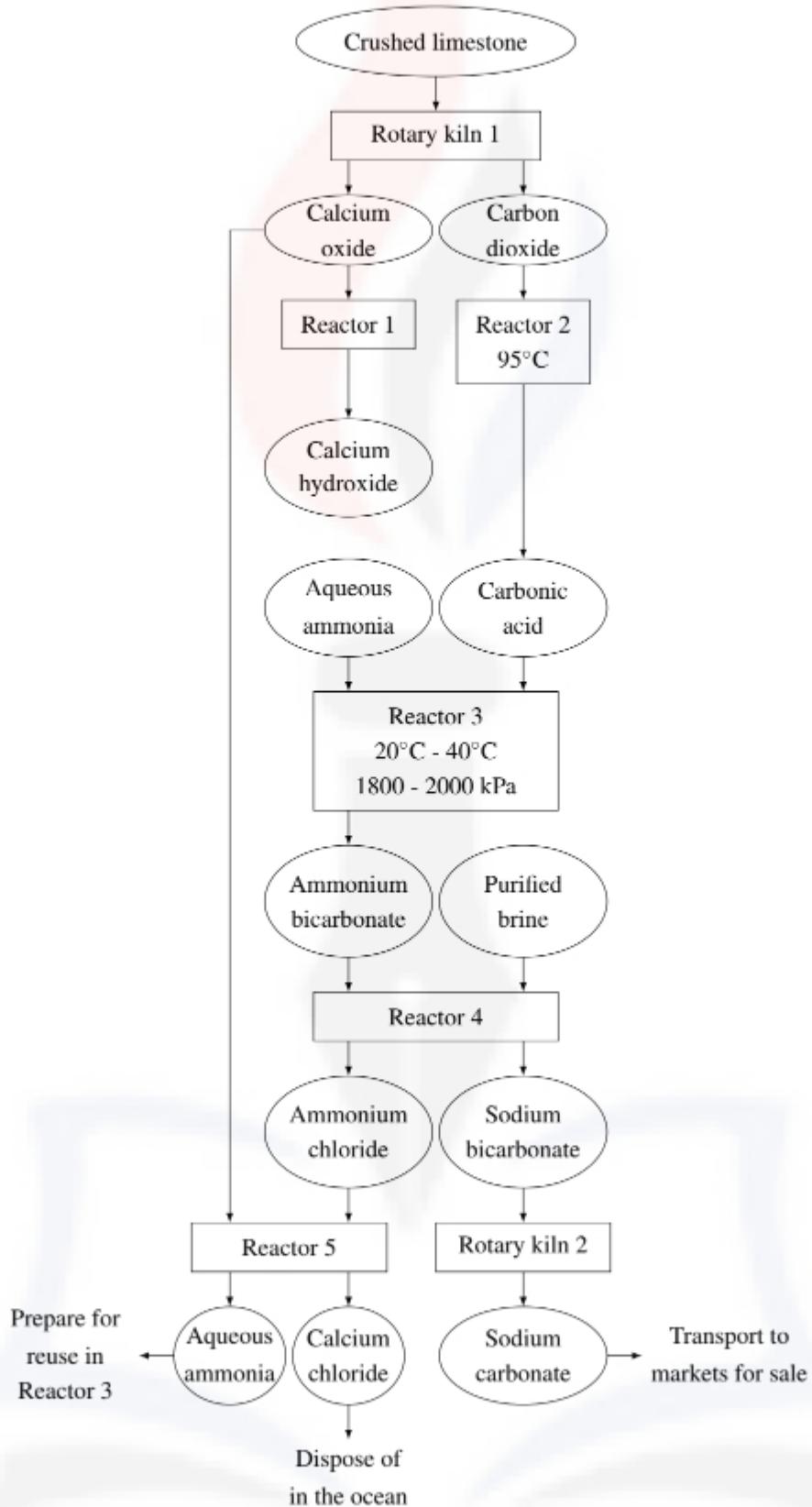
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End of Question 33

Question 34 (7 marks)

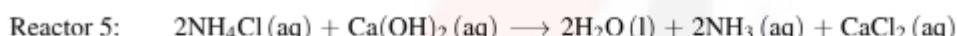
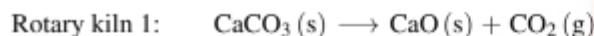
A large industrial plant is to be constructed on the coast of Tasmania in close proximity to a limestone mine and shipping port. The plant aims to produce sodium carbonate using the process shown in the flow chart below.



Question 34 continues on page 28

Question 34 (continued)

The chemical reactions occurring in rotary kilns 1 and 2, and reactors 1 to 5 are given.



The chemical reactions occurring in rotary kiln 1, and reactors 1 and 3 are endothermic, while the chemical reactions occurring in rotary kiln 2, and reactors 2, 4 and 5 are exothermic.

Assess the suitability of this process in the mass production of sodium carbonate with reference to the flow chart and the location of the plant.

More writing space is provided on page 29

Question 34 (continued)

End of paper

Section II extra writing space

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





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Chemistry

FORMULAE SHEET

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

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

$$PV = nRT$$

$$q = mc\Delta T$$

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

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

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

$$A = \varepsilon I c = \log_{10} \frac{I_o}{I}$$

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

<i>Compound</i>	K_{sp}	<i>Compound</i>	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
$\begin{array}{c} & \\ —\text{C} & —\text{C}— \\ & \end{array}$	5–40
$\begin{array}{c} \\ \text{R}—\text{C}—\text{Cl} \text{ or } \text{Br} \\ \end{array}$	10–70
$\begin{array}{c} \\ \text{R}—\text{C}=\text{C}— \\ \\ \text{O} \end{array}$	20–50
$\begin{array}{c} \\ \text{R}—\text{C}—\text{N} \\ \\ \backslash \quad / \end{array}$	25–60
$\begin{array}{c} \\ —\text{C}—\text{O}— \\ \end{array}$	alcohols, ethers or esters
$\begin{array}{c} \backslash \quad / \\ \diagdown \quad \diagup \\ \text{C}=\text{C} \\ \diagup \quad \diagdown \end{array}$	90–150
R—C≡N	110–125
	110–160
$\begin{array}{c} \\ \text{R}—\text{C}— \\ \\ \text{O} \end{array}$	esters or acids
$\begin{array}{c} \\ \text{R}—\text{C}— \\ \\ \text{O} \end{array}$	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	$\text{K}(s)$	-2.94 V
$\text{Ba}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ba}(s)$	-2.91 V
$\text{Ca}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ca}(s)$	-2.87 V
$\text{Na}^+ + \text{e}^-$	\rightleftharpoons	$\text{Na}(s)$	-2.71 V
$\text{Mg}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Mg}(s)$	-2.36 V
$\text{Al}^{3+} + 3\text{e}^-$	\rightleftharpoons	$\text{Al}(s)$	-1.68 V
$\text{Mn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Mn}(s)$	-1.18 V
$\text{H}_2\text{O} + \text{e}^-$	\rightleftharpoons	$\frac{1}{2}\text{H}_2(g) + \text{OH}^-$	-0.83 V
$\text{Zn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Zn}(s)$	-0.76 V
$\text{Fe}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Fe}(s)$	-0.44 V
$\text{Ni}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ni}(s)$	-0.24 V
$\text{Sn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Sn}(s)$	-0.14 V
$\text{Pb}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Pb}(s)$	-0.13 V
$\text{H}^+ + \text{e}^-$	\rightleftharpoons	$\frac{1}{2}\text{H}_2(g)$	0.00 V
$\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	$\text{SO}_2(aq) + 2\text{H}_2\text{O}$	0.16 V
$\text{Cu}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Cu}(s)$	0.34 V
$\frac{1}{2}\text{O}_2(g) + \text{H}_2\text{O} + 2\text{e}^-$	\rightleftharpoons	2OH^-	0.40 V
$\text{Cu}^+ + \text{e}^-$	\rightleftharpoons	$\text{Cu}(s)$	0.52 V
$\frac{1}{2}\text{I}_2(s) + \text{e}^-$	\rightleftharpoons	I^-	0.54 V
$\frac{1}{2}\text{I}_2(aq) + \text{e}^-$	\rightleftharpoons	I^-	0.62 V
$\text{Fe}^{3+} + \text{e}^-$	\rightleftharpoons	Fe^{2+}	0.77 V
$\text{Ag}^+ + \text{e}^-$	\rightleftharpoons	$\text{Ag}(s)$	0.80 V
$\frac{1}{2}\text{Br}_2(l) + \text{e}^-$	\rightleftharpoons	Br^-	1.08 V
$\frac{1}{2}\text{Br}_2(aq) + \text{e}^-$	\rightleftharpoons	Br^-	1.10 V
$\frac{1}{2}\text{O}_2(g) + 2\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	H_2O	1.23 V
$\frac{1}{2}\text{Cl}_2(g) + \text{e}^-$	\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
$\frac{1}{2}\text{Cl}_2(aq) + \text{e}^-$	\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
$\frac{1}{2}\text{F}_2(g) + \text{e}^-$	\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

Lanthanoids	57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm 150.4 Samarium	62 Sm 152.0 Europium	63 Eu 157.3 Gadolinium	64 Gd 158.9 Terbium	65 Tb 162.5 Dysprosium	66 Dy 164.9 Holmium	67 Ho 167.3 Erbium	68 Er 168.9 Thulium	69 Tm 173.1 Ytterbium	70 Yb 175.0 Lu 175.0 Lutetium
Actinoids														
Actinium	89 Ac	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

Actinoids

Standard atomic weights are obviated to four significant figures

Cumulative weight until significant figure.

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).

Answer Key

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

Worked solutions are provided on the next page

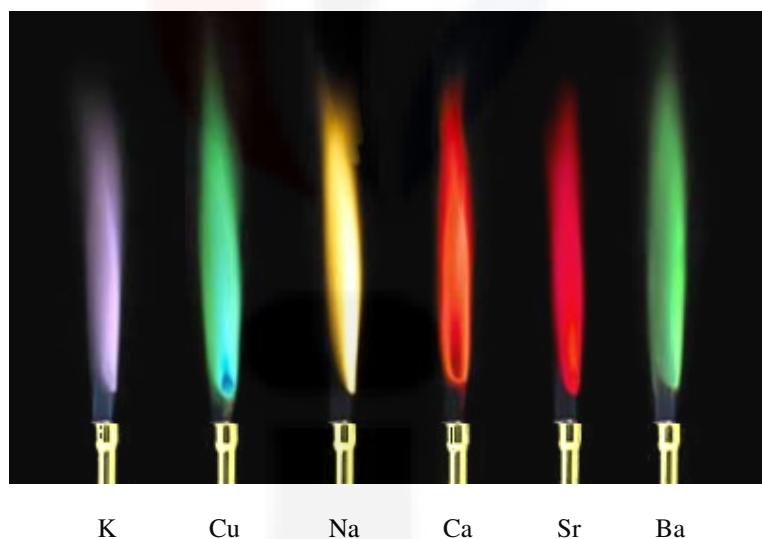
- 1** Esterification is given by the following generalised chemical equation:



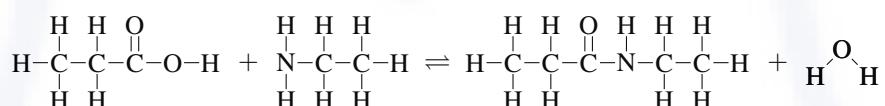
As concentrated sulfuric acid contains little water, it can absorb water produced from the esterification reaction, thereby favouring the forward reaction by Le Chatelier's principle, producing more of the ester in the process.

By producing an acidic environment, a nucleophilic reaction (OUT OF SYLLABUS) between the alcohol and the double-bonded oxygen atom of the acid may occur to form a tetrahedral intermediate which isomerises to produce water via proton migration.

- 2** Make sure to know your flame colours:



- 3** By cutting open and grounding, the surface area of the cycad containing the cycasin toxin increases, allowing more effective dissolution during the leaching process which takes a fair amount of time. The running stream enables the continuous replacement of the water supply, allowing cycasin to dissolve indefinitely.
- 4** In this high-temperature amidification reaction, the OH of the carboxyl group and a H of the amino group is removed to form water, allowing the two compounds to form an amide link:



The nitrogen atom of the amide splits the organic product into two carbon chains; the carbon chain containing the carbonyl carbon is given the suffix -amide, while the other carbon chain has the prefix *N*-. Therefore, the name of product *X* is most likely to be *N*-ethylpropanamide.

5 The enthalpy change of the reaction is the difference between the enthalpy of the products and reactants, which is negative from the energy profile diagram. As the reaction is spontaneous at ALL temperatures, then $\Delta G = \Delta H - T\Delta S < 0$ and thus $\Delta S > 0$ as $\Delta H < 0$ and $T > 0$. As ΔS is the entropy change of the system, then increasing entropy leads to a greater degree of randomness/disorder/number of particle arrangements in the system.

6 Hexanoic acid molecules can form strong hydrogen bonds and dipole-dipole interactions with the O–H and C=O within the carboxyl groups, while hexan-1-ol molecules can form hydrogen bonds between its hydroxyl groups. All three molecules form roughly the same number and strength of dispersion forces, and thus the cumulative strength of intermolecular forces is greatest for hexanoic acid, followed by hexan-1-ol then hexane. As more heat energy is required to overcome these intermolecular forces, hexanoic acid has the highest boiling point.

Benzene is a non-polar solvent, and thus dissolves substances by forming non-polar intermolecular forces; dispersion forces. As the dispersion forces formed between the solvent and the polar molecules hexan-1-ol or hexanoic acid have insufficient strength to overcome the polar intermolecular forces between the solute molecules, and so they cannot dissolve effectively. Meanwhile, hexane is only attracted to its own molecules by dispersion forces and so can be separated by the dispersion forces with benzene, allowing dissolution.

Hexane and hexanoic acid do not oxidise, while hexan-1-ol can oxidise to hexanal and hexanoic acid, and thus has the highest oxidation potential.

7 To appear yellow, the pH of the solution should be less than or equal to 0.0. Sulfuric acid is a strong diprotic acid, and so its first ionisation occurs completely, producing 1.0 mol L^{-1} of hydrogen ions, and slightly more in its second ionisation. So $[\text{H}^+] > 1.0 \text{ mol L}^{-1} \implies \text{pH} > -\log_{10}(1.0) = 0$. Acetic acid is a weak monoprotic acid and so the hydrogen ion concentration is less than 1.0 mol L^{-1} . Sodium hydroxide is a base, and hence has a pH greater than 7. The hydrochloric acid solution has a pH between 0.0 and 1.6.

8 The question asks for the highest initial RATE of reaction, so higher temperatures and pressures produce this due to the reactant particles being given more kinetic energy and less space to vibrate, allowing more frequent, higher-energy collisions to occur, leading to a higher successful collision frequency.

9 At first glance, the substance appears to be an alcohol due to the trough at 3300 cm^{-1} . However, with closer observation, there is a trough at 1680 cm^{-1} indicating the presence of a carbonyl group. Also, the wavenumber of N–H bonds is 3300 cm^{-1} . So the most likely class is the amide.

10 Out of all the options, we can rule out B. and D. as equimolar amounts of strong/weak acids and bases are present, causing the solution to most likely be neutral. A. forms a $\text{NH}_4^+/\text{NH}_3$ buffer system whereas C. forms a $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$ buffer system due to the reaction with the strong acid/base to produce 0.10 mol of the conjugate species. As the acid dissociation constant of ethanoic acid is greater than the base dissociation constant of ethanoate ions, the resultant buffer solution will be acidic, and vice versa for A.

- 11** Find the theoretical yield of ethanol by using the equimolar ratios of the chemical equations:

$$MM(C_6H_{10}O_5) = 12.01 \times 6 + 1.008 \times 10 + 16 \times 5 = 162.14 \text{ g mol}^{-1}$$

$$n(C_6H_{10}O_5) = \frac{m}{MM} = \frac{100}{162.14} = 0.617 \text{ mol}$$

$$n(C_6H_{10}O_5)_{\text{reacted}} = n(C_6H_{12}O_6)_{\text{produced}} \quad (1 : 1 \text{ molar ratio})$$

$$\therefore n(C_6H_{12}O_6) = 0.617 \text{ mol}$$

$$n(C_2H_5OH)_{\text{produced}} = 2n(C_6H_{12}O_6)_{\text{reacted}} \quad (1 : 2 \text{ molar ratio})$$

$$\therefore n(C_2H_5OH) = 1.23 \text{ mol}$$

$$MM(C_2H_5OH) = 12.01 \times 2 + 1.008 \times 6 + 16 = 46.068 \text{ g mol}^{-1}$$

$$m(C_2H_5OH) = n \times MM = 1.23 \times 46.068 = 56.8 \text{ g}$$

$$\therefore \% \text{ yield} = \frac{\text{actual}}{\text{theoretical}} \times 100\% = \frac{47.6}{56.8} \times 100\% = 83.8\%$$

- 12** In the ^{13}C NMR data, the carbonyl carbon of ketones has the highest chemical shift out of all functional groups in the compound, and coupled with the shielding hydroxyl group from carbon 1, carbon 2 is likely to be the most deshielded.

- 13** Use the Beer-Lambert law:

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

$$1.25 \times 2.35 \times 10^4 c = \log_{10} \frac{892}{377} \quad (\text{units are L mol}^{-1} \text{ cm}^{-1})$$

$$c = 1.27 \times 10^{-5} \text{ mol L}^{-1}$$

$$\therefore c_{\text{original}} = 1.27 \times 10^{-4} \text{ mol L}^{-1} \quad (1:10 \text{ dilution})$$

$$MM(\text{Cu}^{2+}) = 63.55 \text{ g mol}^{-1}$$

$$\therefore c = (1.27 \times 10^{-4} \times 63.55) \text{ g L}^{-1}$$

$$= 8092 \mu\text{g L}^{-1}$$

$$= 8092 \text{ ppb}$$

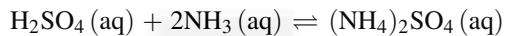
- 14** Hydrocyanic acid has a pK_a value of 9.2, and thus is weakly acidic, whereas lithium diisopropylamide has a pK_a value of 36, indicating its strong basicity. So the conductivity curve required is a weak-acid/strong-base shape.

A. and D. can be eliminated immediately as high initial and final conductivities indicate strong acids and bases, while low initial and final conductivities signify weak acids and bases. As hydrocyanic acid is titrated AGAINST lithium diisopropylamide, the base is in the burette, so the initial conductivity should be low as the weak acid is in the conical flask. Thus, the answer is C.

- 15** The carboxyl and hydroxyl groups of the lactic acid monomer form an ester link with water as a byproduct. So for every n monomers, there are $n - 1$ water molecules formed. Thus, the mass of the polylactic acid polymer chain will have a mass of:

$$\begin{aligned} & (2.0 \times 10^{25})m_{\text{lactic acid monomer}} - (2.0 \times 10^{25} - 1)m_{\text{water molecule}} \\ &= MM_{\text{lactic acid monomer}} \div (6.022 \times 10^{23}) \times (2.0 \times 10^{25}) - MM_{\text{water molecule}} \div (6.022 \times 10^{23}) \times (2.0 \times 10^{25} - 1) \\ &= \frac{(12.01 \times 3 + 16 \times 3 + 1.008 \times 6)(2.0 \times 10^{25})}{6.022 \times 10^{23}} - \frac{(16 + 1.008 \times 2)(6.022 \times 10^{23})}{6.022 \times 10^{23}} \\ &\approx 2400 \text{ g} \end{aligned}$$

- 16** The chemical equation representing the neutralisation of sulfuric acid and ammonia is:



Now find the amount of sulfuric acid/ammonia in excess:

$$\begin{aligned} n(\text{H}_2\text{SO}_4) &= cv \\ &= 0.109 \times 0.020 \\ &= 2.18 \times 10^{-3} \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{NH}_3) &= cv \\ &= 0.252 \times 0.050 \\ &= 1.26 \times 10^{-2} \text{ mol} \end{aligned}$$

$$n(\text{NH}_3)_{\text{reacted}} = 2n(\text{H}_2\text{SO}_4)_{\text{reacted}} \quad (2:1 \text{ molar ratio})$$

$$1.26 \times 10^{-2} > 2 \times 2.18 \times 10^{-3} = 4.36 \times 10^{-3}$$

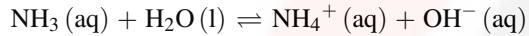
$$\begin{aligned} \implies n(\text{NH}_3)_{\text{excess}} &= n(\text{NH}_3)_{\text{initial}} - n(\text{NH}_3)_{\text{reacted}} \\ &= 1.26 \times 10^{-2} - 2 \times 2.18 \times 10^{-3} \\ &= 8.24 \times 10^{-3} \text{ mol} \end{aligned}$$

$$c(\text{NH}_3) = \frac{n}{v}$$

$$= 8.24 \times 10^{-3} \div (0.020 + 0.050)$$

$$= 0.118 \text{ mol L}^{-1}$$

The chemical equation representing the dissolution of ammonia is given by:



$$K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]} = 1.8 \times 10^{-5}$$

$$\frac{[\text{OH}^-]^2}{[\text{NH}_3]} = 1.8 \times 10^{-5} \quad ([\text{NH}_4^+] = [\text{OH}^-], 1:1 \text{ molar ratio})$$

$$[\text{OH}^-]^2 = 1.8 \times 10^{-5} \times 0.118 \quad (\text{assume that NH}_3 \text{ dissolved is negligible, small } K_b)$$

$$[\text{OH}^-] = 1.46 \times 10^{-3} \text{ mol L}^{-1}$$

$$\text{pOH} = -\log_{10}[\text{OH}^-] = -\log_{10}(1.02 \times 10^{-4}) = 2.84$$

$$\text{pH} + \text{pOH} = 14 \quad (\text{assuming that the temperature is 298K})$$

$$\therefore \text{pH} = 14 - 2.84 = 11.16$$

- 17** The base peak has the highest relative intensity on the mass spectrum and thus is the 43 m/z peak.

The parent peak has the highest m/z excluding ions containing carbon-13, which is 72 m/z.

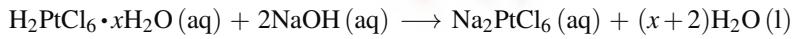
An unbranched alkane has general formula $\text{C}_n\text{H}_{2n+2}$, and its molar mass is 72 g mol^{-1} from the mass spectrum. Substituting $n = 5$ gives a molar mass of $72.146 \text{ g mol}^{-1}$ which satisfies the mass spectrum, and so the alkane is pentane.

18

$$\begin{aligned}Q &= \frac{[\text{Cl}_2]^{\frac{1}{2}} [\text{NO}]}{[\text{NOCl}]} \\&= \left(\frac{[\text{NOCl}]^2}{[\text{Cl}_2][\text{NO}]^2} \right)^{-\frac{1}{2}} \\&= (K_{eq})^{-\frac{1}{2}} \\&= (3.26 \times 10^{-7})^{-\frac{1}{2}} \\&= 1.75 \times 10^3\end{aligned}$$

The temperature has been decreased, and the reaction is reversed compared to the original and so the forward reaction is exothermic. By reducing the temperature from 40°C to 20°C, the forward reaction is favoured which produces more products, thereby increasing Q , and so $Q > 1.75 \times 10^3$.

19 The chemical equation representing the neutralisation reaction is:



$$2n(\text{H}_2\text{PtCl}_6 \cdot x\text{H}_2\text{O})_{\text{reacted}} = n(\text{NaOH})_{\text{reacted}} \quad (1:2 \text{ molar ratio})$$

$$2c_{\text{H}_2\text{PtCl}_6 \cdot x\text{H}_2\text{O}} v_{\text{H}_2\text{PtCl}_6 \cdot x\text{H}_2\text{O}} = c_{\text{NaOH}} v_{\text{NaOH}}$$

$$2c_{\text{H}_2\text{PtCl}_6 \cdot x\text{H}_2\text{O}} \times 0.025 = 0.02361 \times 0.2448$$

$$\therefore c_{\text{H}_2\text{PtCl}_6 \cdot x\text{H}_2\text{O}} = 0.116 \text{ mol L}^{-1}$$

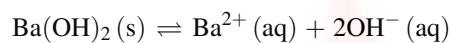
$$n_{\text{H}_2\text{PtCl}_6 \cdot x\text{H}_2\text{O}} = cv = \frac{m}{MM}$$

$$0.116 \times 1 = \frac{59.88}{1.008 \times 2 + 195.1 + 35.45 \times 6 + x(2 \times 1.008 + 16)}$$

$$47.54 + 0.116x(2 \times 1.008 + 16) = 59.88$$

$$x \approx 6$$

20 Use the formula $\Delta H^\circ = \Delta_f H^\circ(\text{products}) - \Delta_f H^\circ(\text{reactants})$ to find the enthalpy change of:



$$\Delta H = 2\Delta_f H^\circ(\text{OH}^-(\text{aq})) + \Delta_f H^\circ(\text{Ba}^{2+}(\text{aq})) - \Delta_f H^\circ(\text{Ba(OH)}_2(\text{s}))$$

$$= -538.4 - 229.9 \times 2 + 934.1$$

$$= -64.1 \text{ kJ mol}^{-1}$$

$$K_{sp} = [\text{Ba}^{2+}][\text{OH}^-]^2 = 2.55 \times 10^{-4}$$

$$4[\text{Ba}^{2+}]^3 = 2.55 \times 10^{-4} \quad ([\text{OH}^-] = 2[\text{Ba}^{2+}], \text{ 2:1 molar ratio})$$

$$[\text{Ba}^{2+}] = \sqrt[3]{\frac{2.55 \times 10^{-4}}{4}}$$

$$= 0.0399 \text{ mol L}^{-1}$$

$$\text{solubility of Ba(OH)}_2 = [\text{Ba}^{2+}] = 0.0399 \text{ mol L}^{-1} \quad (\text{1:1 molar ratio})$$

$$= 7.99 \times 10^{-3} \text{ mol (200 mL)}^{-1}$$

$$q = |n\Delta H|$$

$$= |7.99 \times 10^{-3} \times -64.1|$$

$$= 0.512 \text{ kJ}$$

$$q = mc\Delta T$$

$$512 = 200 \times 4.18 \times \Delta T \quad (\rho_{\text{H}_2\text{O}} = 1 \text{ g mL}^{-1})$$

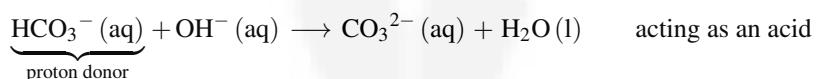
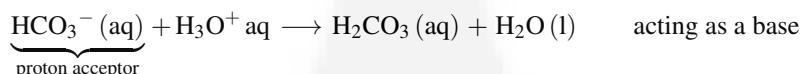
$$\therefore \Delta T = +0.613^\circ\text{C} \quad (\text{dissolution releases heat})$$

Question 21 (a)

Criteria	Marks
<ul style="list-style-type: none"> Describes the Bronsted-Lowry theory of acids and bases Defines the term ‘amphiprotic’ with relation to the Bronsted-Lowry theory Identifies an amphiprotic substance with chemical equations representing BOTH acidic and basic behaviour 	3
<ul style="list-style-type: none"> Identifies the Bronsted-Lowry theory Defines the term ‘amphiprotic’ with relation to the Bronsted-Lowry theory Identifies an amphiprotic substance with chemical equations representing BOTH acidic and basic behaviour 	2
OR	
<ul style="list-style-type: none"> Describes the Bronsted-Lowry theory of acids and bases Defines the term ‘amphiprotic’ with relation to the Bronsted-Lowry theory Identifies an amphiprotic substance WITHOUT both chemical equations 	
<ul style="list-style-type: none"> Identifies the Bronsted-Lowry theory 	
OR	
<ul style="list-style-type: none"> Defines the term ‘amphiprotic’ WITHOUT relation to the Bronsted-Lowry theory 	1
OR	
<ul style="list-style-type: none"> Identifies an amphiprotic substance WITHOUT both chemical equations 	

Sample Answer

The term ‘amphiprotic’ is specific to the Bronsted-Lowry acid-base theory which describes acids as substances that donate hydrogen ions/protons to bases, which accept protons. An amphiprotic substance, such as sodium bicarbonate (NaHCO_3), can act as both a Bronsted-Lowry acid or base depending on its surrounding environment.

**Question 21 (b)**

Criteria	Marks
<ul style="list-style-type: none"> Identifies a limitation of the Bronsted-Lowry theory of acids and bases 	1

Sample Answer

The Bronsted-Lowry acid-base theory fails to explain the acidic and basic behaviour of gaseous oxides (CO_2 , SO_2 , etc.) and metal carbonates (CaCO_3 , Na_2CO_3 , etc.), respectively.

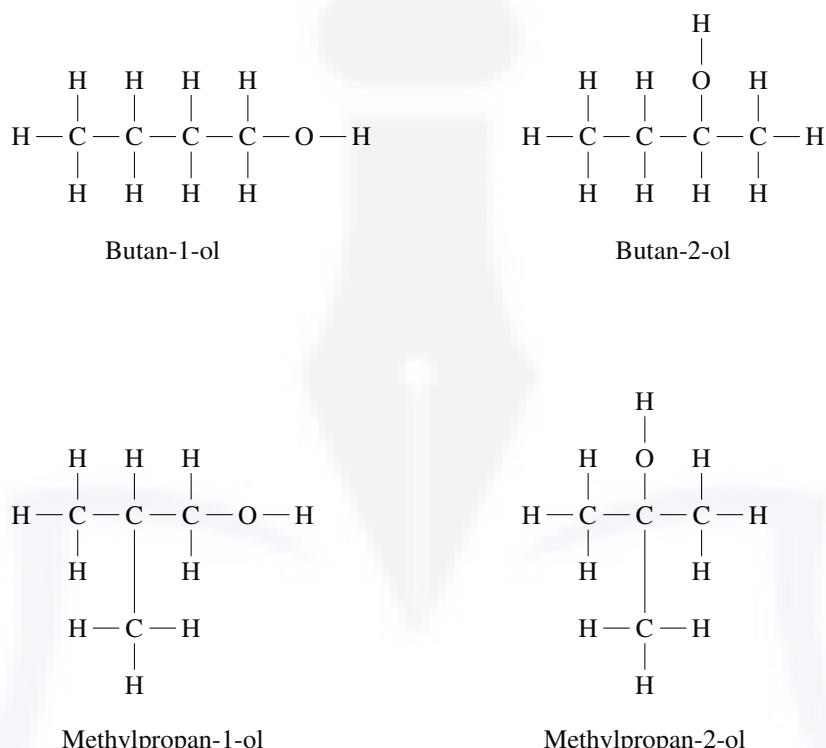
Note: No marks awarded for identifying a limitation of an incorrectly identified acid-base theory from part (a).

Question 22 (a)

Criteria	Marks
<ul style="list-style-type: none"> Identifies all four possible four-carbon alcohols (names and/or structural formulae) Identifies the four-carbon alcohol as butan-2-ol with reference to relative peak area AND splitting pattern data Justifies why all of butan-1-ol, methylpropan-1-ol, and methylpropan-2-ol are invalid with reference to the tabulated data 	3
<ul style="list-style-type: none"> Identifies all four possible four-carbon alcohols (names and/or structural formulae) AND Identifies the four-carbon alcohol as butan-2-ol with reference to relative peak area AND splitting pattern data OR Justifies why TWO of butan-1-ol, methylpropan-1-ol, and methylpropan-2-ol are invalid with reference to the tabulated data 	2
<ul style="list-style-type: none"> Identifies THREE of the possible four-carbon alcohols (names and/or structural formulae) AND Shows some relevant knowledge of ^1H NMR spectroscopic data 	1

Sample Answer

There are four possible four-carbon alcohols: butan-1-ol, butan-2-ol, methylpropan-1-ol, and methylpropan-2-ol.



From left to right, butan-1-ol has the following hydrogen splitting patterns: triplet, sextet, quintet, triplet, singlet as the hydrogen atoms are adjacent to two, five, four, two, and zero others, respectively. As the ^1H NMR spectrum of butan-1-ol is missing a doublet, the alcohol cannot be butan-1-ol.

From left to right, butan-2-ol has the following hydrogen splitting patterns: triplet, quintet, sextet, singlet, doublet as the hydrogen atoms are adjacent to two, four, five, zero, and one other, respectively. Thus, the splitting patterns observed align with the provided data. The relative peak areas from left to right are 3, 2, 1, 1, 3 which also corresponds with the data.

From left to right, methylbutan-1-ol has the following hydrogen splitting patterns: doublet, sextet, doublet, doublet, singlet as the hydrogen atoms are adjacent to one, five, one, one, and zero others, respectively. As the ^1H NMR spectrum of methylpropan-1-ol is missing a triplet and quintet, the alcohol cannot be methylpropan-1-ol.

From left to right, methylpropan-2-ol has the following hydrogen splitting patterns: singlet, singlet, singlet, singlet as all hydrogen atoms are adjacent to no others. This is inconsistent with the provided data, and so the alcohol cannot be methylpropan-2-ol.

Hence, the four-carbon alcohol is most likely to be butan-2-ol.

Question 22 (b)

Criteria	Marks
• Identifies signal A (no justification required)	1

Sample Answer

The hydrogen atom producing the sextet with a chemical shift of 3.71 ppm in the ^1H NMR spectral data is bonded to the carbon atom with the hydroxyl group. Thus, this carbon atom is highly deshielded due to the shielding effects from the hydroxyl group, corresponding to a high chemical shift. This is consistent with signal A.

Question 23

Criteria	Marks
<ul style="list-style-type: none">Relates the formation and breakage of covalent bonds to the negative enthalpy change of the reaction (explicitly states exothermic)Correctly identifies the entropy decrease of the reaction with valid justificationExplains how the signs of ΔH and ΔS of the reaction influence the spontaneity of the reactionRelates the opposing signs of ΔH and ΔS to equilibrium in a certain temperature range	4
<ul style="list-style-type: none">Relates the formation and breakage of covalent bonds to the negative enthalpy change of the reaction (might not have stated exothermic)Correctly identifies the entropy decrease of the reaction with valid justificationExplains how the signs of ΔH and ΔS of the reaction influence the spontaneity of the reaction WITHOUT reference to spontaneity at high temperatures and vice versaRelates the opposing signs of ΔH and ΔS to equilibrium in a certain temperature range	3
<ul style="list-style-type: none">Explains some aspects of the enthalpy and entropy changes of the reactionExplains how the signs of ΔH and ΔS of the reaction influence the spontaneity of the reaction WITHOUT reference to spontaneity at high temperatures and vice versaAttempts to relate the signs of ΔH and ΔS to equilibrium in a certain temperature range	2
<ul style="list-style-type: none">Provides some relevant information about TWO of enthalpy, entropy, and Gibbs free energy	1

Sample Answer

Synthesis reactions typically incur greater amounts of energy being released during the formation of new intramolecular bonds compared to the energy absorbed during the breakage of intramolecular bonds. Such is the case for the synthesis of N_2O_4 (g) from NO_2 (g) as indicated by the negative enthalpy change; the energy released from forming the covalent bonds in N_2O_4 (g) is greater than the energy absorbed from breaking the covalent bonds in NO_2 (g). Thus, the given chemical reaction is exothermic.

As two moles of gas are synthesised to form one mole of gas, the number of particle arrangements in the chemical system decreases as the reaction continues to progress. This corresponds to a decrease in the degree of disorder in the chemical system, and so the reaction leads to an entropy decrease.

The change in the Gibbs free energy of a chemical system is given by $\Delta G = \Delta H - T\Delta S$. This quantity determines the spontaneity of the chemical reaction; if $\Delta G < 0$, then the reaction is spontaneous whereas if $\Delta G > 0$, then the reaction is non-spontaneous. Thus, a negative enthalpy change in this reaction favours spontaneity while the negative entropy change opposes spontaneity. As the quantity $\Delta H < 0$ and $-T\Delta S > 0$, the reaction will be spontaneous at high temperatures and vice versa. Hence, there will be a certain temperature range where ΔG is close to zero which allows the reaction to act as an equilibrium system.

Question 24 (a)

Criteria	Marks
<ul style="list-style-type: none"> Explains why the boiling temperature of alcohols is consistently higher than amines with an equal number of carbon atoms per molecule Explains why the boiling temperatures of both series increases at a linear rate Explains why the difference in boiling temperatures between the series decreases with an equal number of carbon atoms per molecule Explicitly states the relationship between boiling temperature and intermolecular forces 	3
<ul style="list-style-type: none"> Explains TWO of the trends in the graph Explicitly states the relationship between boiling temperature and intermolecular forces <p>OR</p> <ul style="list-style-type: none"> Explains ALL trends in the graph Fails to state the relationship between boiling temperature and intermolecular forces 	2
<ul style="list-style-type: none"> Explains ONE of the trends in the graph <p>OR</p> <ul style="list-style-type: none"> Explicitly states the relationship between boiling temperature and intermolecular forces 	1

Sample Answer

The boiling temperature of a substance depends on the amount of heat energy required to overcome the intermolecular forces between their molecules which is directly related to their strength.

From the graph, it is evident that for all amines and alcohols with the same number of carbon atoms per molecule, alcohols have a higher boiling temperature than amines. This is due to the greater strength of the hydrogen bonding between the hydroxyl groups of the alcohol compared to the amino groups of the amine as oxygen atoms are more electronegative than nitrogen atoms, leading to stronger electrostatic attraction with the partially positive hydrogen atoms. There are roughly the same number and strength of dispersion forces between the non-polar alkyl chains of the amines and alcohols as the number of non-polar carbon and hydrogen atoms are equal.

The graph also shows the boiling temperatures of alcohols and amines increasing at a linear rate as the number and strength of dispersion forces increases proportionally with the carbon chain length.

Finally, the difference between boiling temperatures of alcohols and amines decreases as the number of carbon atoms per molecule increases as the stronger hydrogen bonding between alcohol molecules compared to amine molecules has decreasing influence on the total strength of intermolecular forces as the number and strength of dispersion forces takes precedence.

Question 24 (b)

Criteria	Marks
<ul style="list-style-type: none"> Identifies a suitable test that distinguishes between alcohols and amines without ambiguities AND outlines the expected observations 	1

Sample Answer

A strip of red litmus paper can be placed in a small sample of the substance as amines are basic, turning the colour of the litmus paper from red to blue while alcohols are neutral, creating no visible change.

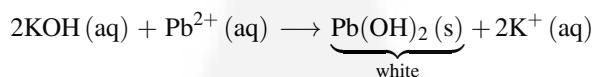
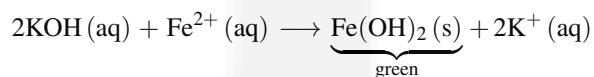
Note: Amines CAN be oxidised and thus oxidation by permanganate/dichromate ions is not a valid test.

Question 25

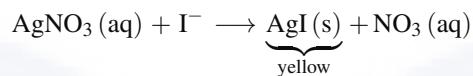
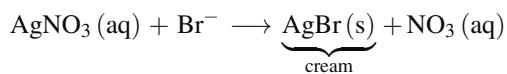
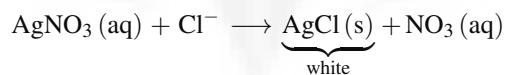
Criteria	Marks
<ul style="list-style-type: none"> Describes a sequence of valid tests that CAN be conducted in a school laboratory to distinguish between ALL anions and cations Outlines the expected observations of ALL tests conducted Identifies equipment and the volumes and concentrations of the solutions being used Includes at least ONE correctly balanced chemical equation 	4
<ul style="list-style-type: none"> Describes a sequence of valid tests that CAN be conducted in a school laboratory to distinguish between ALL anions and cations Outlines the expected observations of ALL tests conducted Includes at least ONE correctly balanced chemical equation 	3
<ul style="list-style-type: none"> Describes a sequence of valid tests that CAN be conducted in a school laboratory to distinguish between the listed anions OR cations Outlines the expected observations of ONE test conducted Includes at least ONE correctly balanced chemical equation 	2
Describes ONE valid test that CAN be conducted in a school laboratory to distinguish between at least TWO of the listed ions	1

Sample Answer

To distinguish between the cations, 3 mL of the unknown solution can be deposited into a small test tube using a pipette dropper before adding 2 mL of a 0.10 mol L^{-1} potassium hydroxide solution. If a green precipitate forms, then $\text{Fe(OH)}_2(s)$ is present, and thus the cation is Fe^{2+} . If a white precipitate forms, then $\text{Pb(OH)}_2(s)$ is present, so the cation is Pb^{2+} . Sodium hydroxide is very soluble in water, and hence if Na^+ ions are present then no visible change will occur.



To distinguish between the anions, prepare a new 3 mL sample of the unknown solution in a small test tube before adding 2 mL of a 0.10 mol L^{-1} silver nitrate solution. If a white precipitate forms, then $\text{AgCl}(s)$ is present, and thus the anion is Cl^- . If a cream precipitate forms, then $\text{AgBr}(s)$ is present, and hence the anion is Br^- . If a yellow precipitate forms, then $\text{AgI}(s)$ is present, and therefore the anion is I^- .



Note: The anions can further be distinguished by adding dilute and concentrated ammonia solution. Only the $\text{AgCl}(s)$ precipitate will dissolve in dilute ammonia, while both the $\text{AgCl}(s)$ and $\text{AgBr}(s)$ precipitate will dissolve in concentrated ammonia. $\text{AgI}(s)$ will not dissolve in either concentration.

Question 26 (a)

Criteria	Marks
<ul style="list-style-type: none">Defines validity in the context of scientific proceduresSuggests AND explains ONE correct way to improve the validity of the procedure	2
<ul style="list-style-type: none">Suggests AND explains ONE correct way to improve the validity of the procedure	1

Sample Answer

Validity refers to the effectiveness of the scientific procedure used to address an aim while keeping relevant variables controlled and minimising error.

Taking fertiliser samples from different areas of the package reduces the error resulting from the uneven distribution of calcium nitrate in the fertiliser as the degree of uncertainty of the experimental results is minimised by removing outliers and taking an average. This contributes to the validity of the procedure by reducing error, thereby improving the effectiveness of the procedure.

OR

The precipitation of a white calcium hydroxide solid will occur when sodium hydroxide is added to the fertiliser solution. However, the filtering capacity of the filter paper may not capture all $\text{Ca}(\text{OH})_2$ solid due to its fineness, leading to experimental error. A sintered glass crucible may instead be used to filter the solid to minimise the mass seeping through, thereby reducing error and improving validity.

Question 26 (b)

Criteria	Marks
<ul style="list-style-type: none"> • Correctly calculates the percentage mass of calcium nitrate showing ALL relevant working • Includes a correctly balanced chemical equation 	3
<ul style="list-style-type: none"> • Provides most of the steps in correctly calculating the percentage mass of calcium nitrate • Includes a correctly balanced chemical equation <p>OR</p> <ul style="list-style-type: none"> • Provides ALL steps in calculating the percentage mass of calcium nitrate with ONE error • Includes a correctly balanced chemical equation 	2
<ul style="list-style-type: none"> • Correctly calculates the moles of calcium hydroxide solid formed <p>OR</p> <ul style="list-style-type: none"> • Includes a correctly balanced chemical equation 	1

Sample Answer

$$m[\text{Ca}(\text{OH})_2 \text{ (s)}] = m_{\text{filter paper after use}} - m_{\text{filter paper before use}}$$

$$= 4.12 - 1.38$$

$$= 2.74 \text{ g}$$

$$MM[\text{Ca}(\text{OH})_2] = 40.08 + 16 \times 2 + 1.008 \times 2$$

$$= 74.096 \text{ g mol}^{-1}$$

$$n[\text{Ca}(\text{OH})_2] = \frac{m}{MM}$$

$$= \frac{2.74}{74.096}$$

$$= 3.7 \times 10^{-2} \text{ mol}$$



$$\implies n[\text{Ca}(\text{OH})_2]_{\text{formed}} = n[\text{Ca}(\text{NO}_3)_2]_{\text{reacted}} \quad (1:1 \text{ molar ratio})$$

$$\therefore n[\text{Ca}(\text{NO}_3)_2] = 3.7 \times 10^{-2} \text{ mol}$$

$$MM[\text{Ca}(\text{NO}_3)_2] = 40.08 + 14.01 \times 2 + 16 \times 6$$

$$= 164.1 \text{ g mol}^{-1}$$

$$m[\text{Ca}(\text{NO}_3)_2] = n \times MM$$

$$= 3.7 \times 10^{-2} \times 164.1$$

$$= 6.068 \text{ g}$$

Please turn over

$$\therefore \% \text{ mass} = \frac{m[\text{Ca}(\text{NO}_3)_2]}{m_{\text{fertiliser}}} \times 100\%$$
$$= \frac{6.068}{10.0} \times 100\%$$
$$= 60.7\% \quad (\text{3 significant figures})$$

Question 27 (a)

Criteria	Marks
<ul style="list-style-type: none">Describes the structure of soaps and detergentsOutlines the forces formed with water and oil droplets in relation to polarityRelates polarity to the surfactant properties of soaps and detergents	2
Attempts to use structure to explain the surfactant properties of soaps and detergents	1

Sample Answer

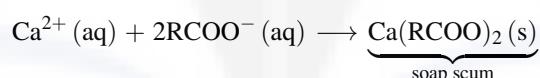
Soaps and detergents possess a polar, hydrophilic head (a functional group or ion), and a long, non-polar and hydrophobic alkyl tail. The combination of polar and non-polar components allows soaps and detergents to dissolve in both polar and non-polar substances. In this situation, the head can form ion-dipole or dipole-dipole attractions with polar water molecules, enabling dissolution, whereas the tail can form dispersion forces with non-polar oil/grease droplets. These forces reduce the tension between the oil droplet and the surface, thereby displaying surfactant properties.

Question 27 (b)

Criteria	Marks
<ul style="list-style-type: none">Compares the types of soaps and detergents (anionic, cationic, non-ionic)Compares the performance of soaps and detergents, not limited to hard water	2
Compares the performance OR types of soaps and detergents	1

Sample Answer

As soaps are manufactured from plant and animal fats containing three ester groups (triglyceride), the resultant soap ions contain a negatively charged carboxylate head (COO^-), and thus are natural anionic detergents. Detergents are synthetically produced with three types: cationic, anionic, and non-ionic. Detergents are able to clean grease in hard water (water containing a substantial concentration of Ca^{2+} and Mg^{2+} ions) whereas soaps form a solid white scum due to precipitate, and thus is less effective.



Question 27 (c)

Criteria	Marks
• Correctly draws ALL four structural formulae of the products	2
• Correctly draws at least TWO of the structural formulae of the products	1

Sample Answer

(1) $\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{O}-\text{H} \\ \\ \text{H}-\text{C}-\text{O}-\text{H} \\ \\ \text{H}-\text{C}-\text{O}-\text{H} \\ \\ \text{H} \end{array}$	(2) $\begin{array}{c} \text{H} & & \left[\begin{array}{c} \text{H} \\ \\ \text{C} \\ \\ \text{H} \end{array} \right] & \text{O} \\ & & & \\ \text{H}-\text{C} & -\text{C}- & \text{C}-\text{O}^- \\ & & & \\ \text{H} & & \left[\begin{array}{c} \text{H} \\ \\ \text{H} \end{array} \right]_{12} & \end{array}$
(3) $\begin{array}{c} \text{H} & & \left[\begin{array}{c} \text{H} \\ \\ \text{C} \\ \\ \text{H} \end{array} \right] & \text{O} \\ & & & \\ \text{H}-\text{C} & -\text{C}- & \text{C}-\text{O}^- \\ & & & \\ \text{H} & & \left[\begin{array}{c} \text{H} \\ \\ \text{H} \end{array} \right]_{18} & \end{array}$	(4) $\begin{array}{c} \text{H} & & \left[\begin{array}{c} \text{H} \\ \\ \text{C} \\ \\ \text{H} \end{array} \right]_5 & \text{H} & \text{H} & \left[\begin{array}{c} \text{H} \\ \\ \text{C} \\ \\ \text{H} \end{array} \right]_5 & \text{O} \\ & & & & & & \\ \text{H}-\text{C} & -\text{C}- & \text{C}=\text{C}- & \text{C}- & \text{C}- & \text{C}-\text{O}^- \\ & & & & & \\ \text{H} & & \text{H} & & \text{H} & \text{H} \end{array}$

Note: A sodium ion may be placed to the right of the negatively charged oxygen atom.

Question 28 (a)

Criteria	Marks
• Correctly calculates the number of moles of CoCl_4^{2-} (aq) when equilibrium is reestablished, showing all relevant working	4
• Shows the main steps in calculating the moles of CoCl_4^{2-} (aq) with ONE error/omission	3
• Shows some steps and understanding of the calculation and scenario	2
• Provides some relevant information in the calculation	1

Sample Answer

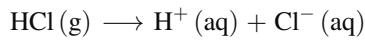
First determine the moles of chloride ions added to the system:

$$PV = nRT \quad (\text{ideal gas law})$$

$$100 \times 2.55 = n \times 8.314 \times 298$$

$$\therefore n(\text{HCl}) = \frac{100 \times 2.55}{8.314 \times 298}$$

$$= 0.103 \text{ mol}$$



$$\therefore n(\text{Cl}^-)_{\text{added}} = n(\text{HCl}) = 0.103 \text{ mol} \quad (1:1 \text{ molar ratio})$$

Now find the new number of moles of Cl^- (aq):

$$n(\text{Cl}^-)_{\text{new}} = n(\text{Cl}^-)_{\text{initial}} + n(\text{Cl}^-)_{\text{added}}$$

$$= cv + 0.103$$

$$= 2.38 \times 0.25 + 0.103$$

$$= 0.698 \text{ mol}$$

Please turn over

By Le Chatelier's principle, the addition of Cl^- (aq) favours the forward reaction to partially counteract the change to the equilibrium system. Hence, if x moles of $\text{Co}(\text{H}_2\text{O})_6^{2+}$ (aq) reacts, then $4x$ moles of Cl^- (aq) reacts and x moles of CoCl_4^{2-} (aq) is produced using the 1:4:1 molar ratios.

$$c_{\text{new}} = \frac{n_{\text{original}} - n_{\text{reacted}}}{v} = \frac{c_{\text{original}} \times 0.25 - n_{\text{reacted}}}{0.25} \text{ mol L}^{-1}$$

$$\therefore [\text{Co}(\text{H}_2\text{O})_6^{2+}] = \frac{0.25 \times 1.54 - x}{0.25} \text{ mol L}^{-1}$$

$$[\text{Cl}^-] = \frac{0.25 \times 2.38 + 0.103 - 4x}{0.25} \text{ mol L}^{-1}$$

$$c_{\text{new}} = \frac{n_{\text{original}} + n_{\text{produced}}}{v} = \frac{c_{\text{original}} \times 0.25 + n_{\text{produced}}}{0.25}$$

$$\therefore [\text{CoCl}_4^{2-}] = \frac{8.4 \times 10^{-2} \times 0.25 + x}{0.25} \text{ mol L}^{-1}$$

At equilibrium, $Q = K_{eq}$ so:

$$K_{eq} = \frac{[\text{CoCl}_4^{2-}]}{[\text{Co}(\text{H}_2\text{O})_6^{2+}][\text{Cl}^-]^4} = 1.70 \times 10^{-3}$$

$$\frac{\frac{8.4 \times 10^{-2} \times 0.25 + x}{0.25}}{\frac{0.25 \times 1.54 - x}{0.25} \times \left(\frac{0.25 \times 2.38 + 0.103 - 4x}{0.25} \right)^4} = 1.70 \times 10^{-3}$$

As K_{eq} is negligible, assume that minimal $\text{Co}(\text{H}_2\text{O})_6^{2+}$ (aq) and Cl^- (aq) reacts, so $x \rightarrow 0$:

$$\Rightarrow \frac{\frac{8.4 \times 10^{-2} \times 0.25 + x}{0.25}}{\frac{0.25 \times 1.54}{0.25} \times \left(\frac{0.25 \times 2.38 + 0.103}{0.25} \right)^4} = 1.70 \times 10^{-3}$$

$$8.4 \times 10^{-2} \times 0.25 + x = 1.70 \times 10^{-3} \times \left[\frac{0.25 \times 1.54}{0.25} \times \left(\frac{0.25 \times 2.38 + 0.103}{0.25} \right)^4 \right]$$

$$\therefore x = 0.138 \text{ mol}$$

$$\therefore n(\text{CoCl}_4^{2-})_{\text{final}} = 8.40 \times 10^{-2} \times 0.25 + 0.138$$

$$= 0.159 \text{ mol}$$

Question 28 (b)

Criteria	Marks
<ul style="list-style-type: none">• Correctly describes the colour change in the system following a temperature increase• Provides a valid justification using Le Chatelier's principle OR collision theory	2
• Shows some knowledge of changes to an equilibrium system	1

Sample Answer

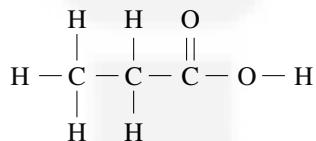
Increasing the temperature to 310K favours the endothermic forward reaction to absorb the heat introduced to the system in order to reestablish equilibrium, thereby minimising disturbance by Le Chatelier's principle. More CoCl_4^{2-} (aq) and H_2O (l) is produced in the process, so the solution will appear more blue than before.

Question 29

Criteria	Marks
<ul style="list-style-type: none"> Provides the correct systematic name AND structural formulae for ALL five compounds Provides a justification for ALL five compounds and the types of reactions occurring 	5
<ul style="list-style-type: none"> Provides the correct systematic name AND structural formulae for FOUR compounds Provides a justification for FOUR compounds and the types of reactions occurring 	4
<ul style="list-style-type: none"> Provides the correct systematic name AND structural formulae for THREE compounds Provides a justification for THREE compounds and the types of reactions occurring 	3
<ul style="list-style-type: none"> Provides the correct systematic name AND structural formulae for TWO compounds Provides a justification for TWO compounds and the types of reactions occurring 	2
<ul style="list-style-type: none"> Provides the correct systematic name AND structural formulae for ONE compound Provides a justification for ONE compound and the type of reaction occurring 	1

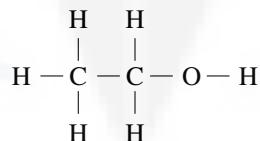
Sample Answer

As compound A has the molecular formula $C_5H_{10}O_2$, it can be a carboxylic acid or an ester; pentanediols have the molecular formula $C_5H_{12}O_2$ and pentanediols/pentanediones have the molecular formulae $C_5H_8O_2$. It is heated with dilute H_2SO_4 to form compound B which reacts with solid Na_2CO_3 to form sodium propanoate. This is indicative of an acid-base reaction that forms a sodium propanoate salt, and so compound B must be a three-carbon carboxylic acid: propanoic acid.



Propanoic acid

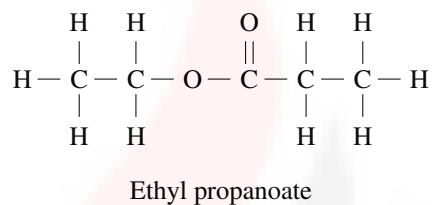
Hence, compound A has undergone ester hydrolysis using heated dilute H_2SO_4 to produce propanoic acid and a two-carbon alcohol: ethanol, which must be compound C.



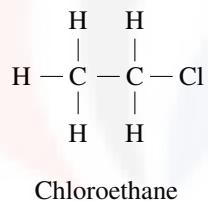
Ethanol

Please turn over

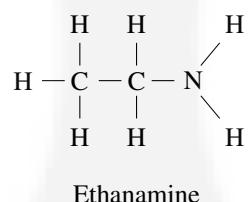
Compound A must therefore be ethyl propanoate, the product of the esterification reaction between ethanol and propanoic acid.



Compound C then undergoes a halogen substitution reaction with concentrated HCl and thus the hydroxyl group is substituted with a chlorine atom to form Compound D, chloroethane.



Compound D then undergoes another substitution reaction with concentrated ammonia to form a nitrogen-based organic compound. In this reaction, the chlorine atom is substituted with an amino group in a nucleophilic substitution reaction (not in syllabus) to form Compound E, ethanamine.



Question 30 (a)

Criteria	Marks
• Describes the use of neutralisation reactions in TWO industries (provides specific examples)	2
• Outlines the use of neutralisation reactions in TWO industries OR • Describes the use of neutralisation reactions in ONE industry	1

Sample Answer

Neutralisation reactions are widely used in the agricultural industry to generate the best growing conditions for crops as some plants require acidic soils while others need alkaline soils to grow optimally. To acidify soil, organic matter is deposited onto the soil which decomposes to form carbon dioxide, dissolving in the water in the soil to form carbonic acid. To alkaliise soil, garden lime (calcium carbonate) can be added to produce hydroxide ions.

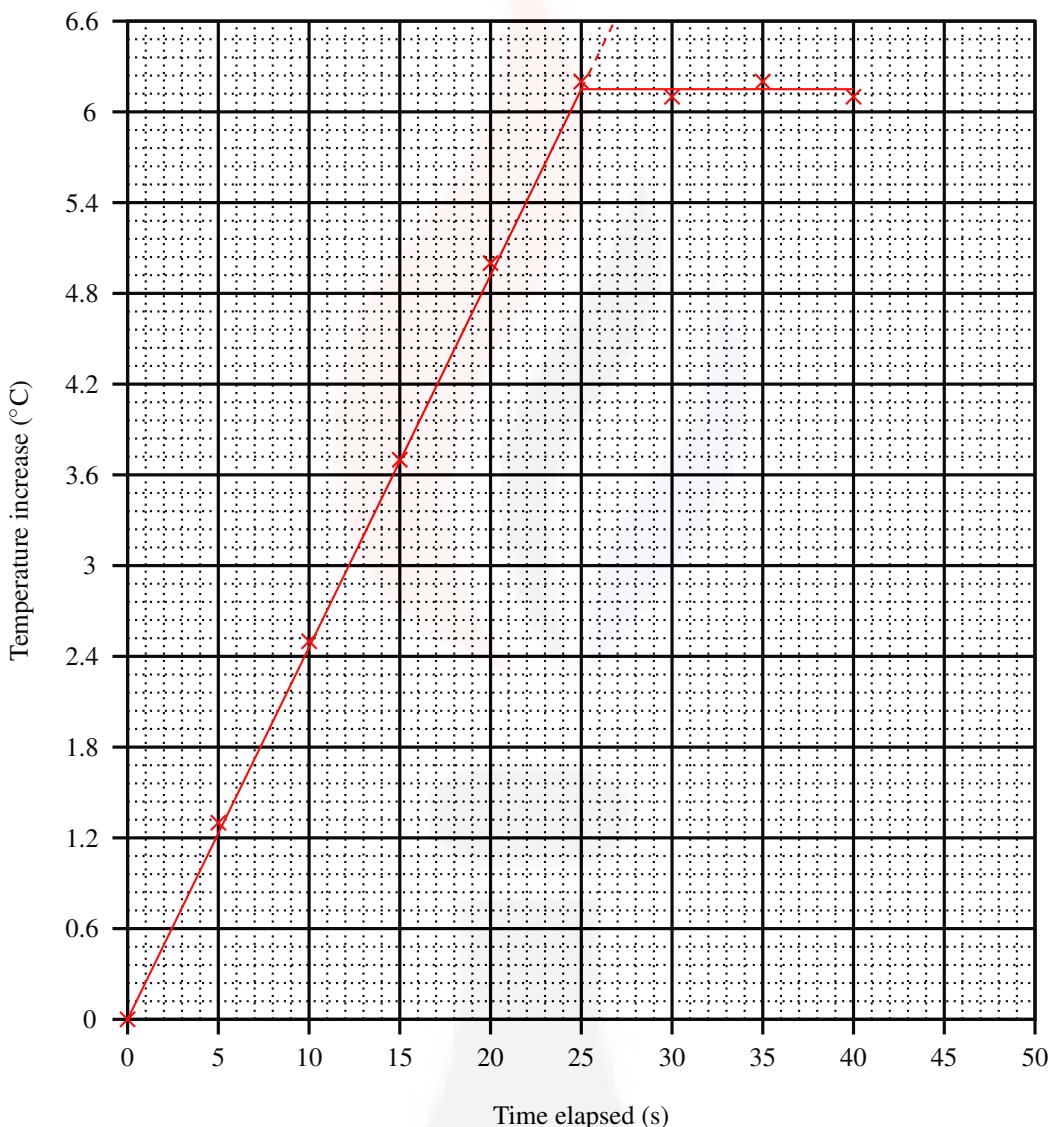
In the health industry, neutralisation reactions are used for several purposes including antacids and insect stings. For example, magnesium hydroxide is commonly used in common antacids to neutralise excess stomach acid, and vinegar is applied to alkaline wasp stings.

Question 30 (b)

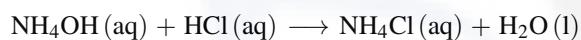
Criteria	Marks
• Provides a graph with <ul style="list-style-type: none">— accurately plotted points— correct line(s) of best fit	4
• Correctly calculates the enthalpy of neutralisation using the graph and showing all working	
• Provides a correct graph with most of the steps for calculating the enthalpy of neutralisation	3
• Provides a substantially correct graph with some relevant steps in the calculation of the enthalpy of neutralisation	2
• Provides a graph with some correct features OR • Provides some relevant steps in the calculation of the enthalpy of neutralisation	1

Please turn over

Sample Answer



From the graph, the temperature increase of the solution when the reaction achieves completion is 6.15°C , so $\Delta T = +6.15\text{ K}$. Performing the following calculations,



$$\begin{aligned} n(\text{NH}_4\text{OH}) &= cv \\ &= 2.0 \times 0.050 \\ &= 0.10 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{HCl}) &= cv \\ &= 2.0 \times 0.025 \\ &= 0.05 \text{ mol} \end{aligned}$$

Please turn over

From the chemical equation, $n(\text{NH}_4\text{OH})_{\text{reacted}} = n(\text{HCl})_{\text{reacted}}$ (1:1 molar ratio).

$$n(\text{NH}_4\text{OH}) = 0.10 \text{ mol} > 0.05 \text{ mol} = n(\text{HCl})$$

$\therefore \text{HCl (aq)}$ is the limiting reagent

$$\implies n(\text{HCl})_{\text{reacted}} = n(\text{H}_2\text{O})_{\text{produced}} \quad (1:1 \text{ molar ratio})$$

$$= 0.05 \text{ mol}$$

Assume that the specific heat capacity and density of the resultant solution is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$ and 1 g mL^{-1} , respectively.

$$q = mc\Delta T$$

$$= \rho v c \Delta T$$

$$= 1 \times (25 + 50) \times 4.18 \times 6.15$$

$$= 1928 \text{ J}$$

$$= 1.928 \text{ kJ}$$

$$\Delta H = -\frac{q}{n(\text{H}_2\text{O})_{\text{produced}}}$$

$$= -\frac{1.928}{0.05}$$

$$= -38.6 \text{ kJ mol}^{-1}$$

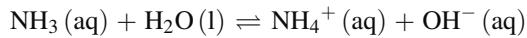
Question 30 (c)

Criteria	Marks
<ul style="list-style-type: none">• Provides a graph with<ul style="list-style-type: none">– correct shape (strong acid-weak base without the initial dip)– correct location of initial pH– correct location of the equivalence point– suitable scale and graph space used• Correctly calculates the initial and equivalence point pH values, showing all steps	4
<ul style="list-style-type: none">• Provides a substantially correct graph showing most features• Calculates the initial and equivalence point pH values with ONE error in the main steps	3
<ul style="list-style-type: none">• Provides a graph showing some correct features• Attempts to calculate the initial and equivalence point pH values with some relevant steps	2
<ul style="list-style-type: none">• Provides a graph with ONE correct feature• Shows some knowledge in calculating the initial and equivalence point pH values	1

Please turn over

Sample Answer

Initially, $n(\text{NH}_3) = 0.05 \text{ mol}$, and therefore $[\text{NH}_3] = \frac{n}{v} = \frac{0.05}{0.075} = 0.67 \text{ mol L}^{-1}$.



$$\implies K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]} = 1.8 \times 10^{-5}$$

Exactly half of the ammonia solution has reacted from part (b), so $[\text{NH}_3] = [\text{NH}_4^+]$.

$$\implies [\text{OH}^-] = 1.8 \times 10^{-5}$$

$$[\text{H}_3\text{O}^+] \times [\text{OH}^-] = 1.0 \times 10^{-14}$$

$$\therefore [\text{H}_3\text{O}^+] = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}}$$

$$= 5.6 \times 10^{-10} \text{ mol L}^{-1}$$

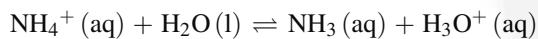
$$\text{pH}_{\text{initial}} = -\log_{10}[\text{H}_3\text{O}^+]$$

$$= -\log_{10}(5.6 \times 10^{-10})$$

$$= 9.26$$

Using part (b), another 25 mL of the 2.0 mol L^{-1} hydrochloric acid solution is needed to neutralise all ammonia solution. Hence, $n(\text{NH}_4^+) = cv = 2.0 \times 0.05 = 0.10 \text{ mol} \implies [\text{NH}_4^+] = \frac{n}{v_{\text{final}}} = \frac{0.10}{0.10} = 1.0 \text{ mol L}^{-1}$.

Also, $K_a K_b = 1.0 \times 10^{-14}$ for conjugate acid-base pairs, and thus $K_a(\text{NH}_4^+) = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.6 \times 10^{-10}$.



$$K_a = \frac{[\text{NH}_3][\text{H}_3\text{O}^+]}{[\text{NH}_4^+]} = 5.6 \times 10^{-10}$$

$$\frac{[\text{H}_3\text{O}^+]^2}{[\text{NH}_4^+]} = 5.6 \times 10^{-10} \quad ([\text{NH}_3] = [\text{H}_3\text{O}^+], 1:1 \text{ molar ratio})$$

Assume that minimal NH_4^+ (aq) hydrolyses due to the negligible magnitude of K_a , so $[\text{NH}_4^+] = 1.0 \text{ mol L}^{-1}$.

Please turn over

$$\implies \frac{[\text{H}_3\text{O}^+]^2}{1.0} = 5.6 \times 10^{-10}$$

$$[\text{H}_3\text{O}^+] = \sqrt{5.6 \times 10^{-10}}$$

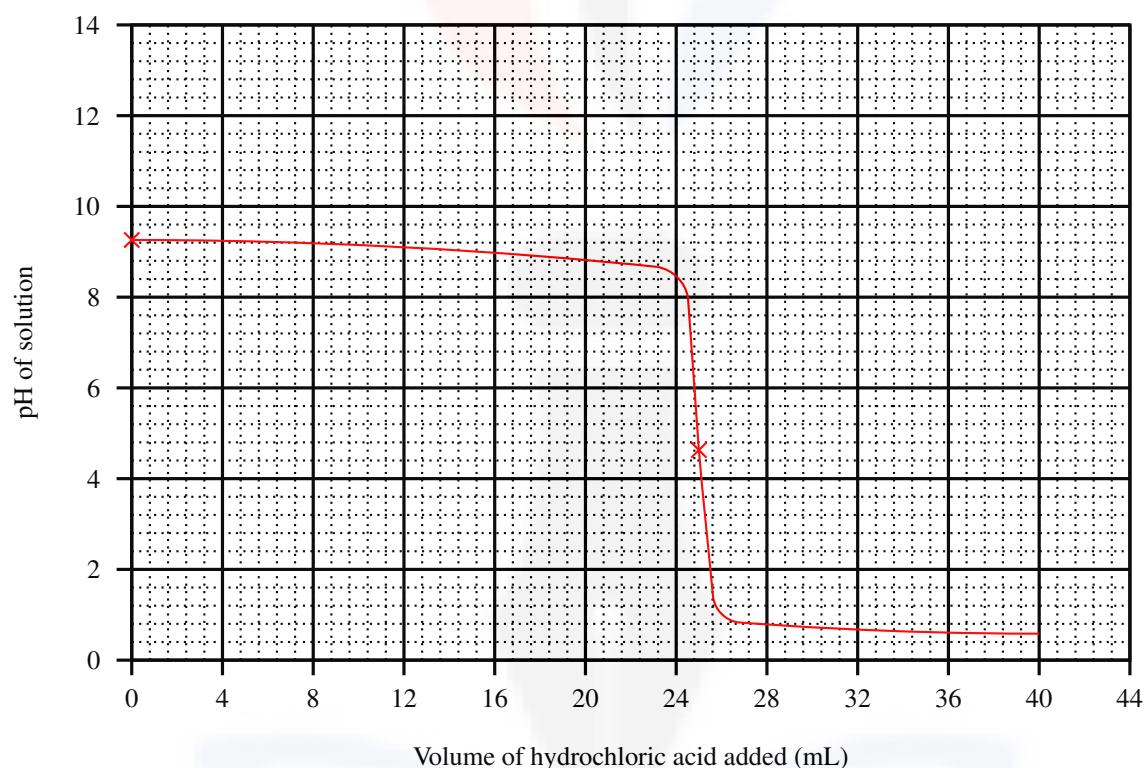
$$= 2.36 \times 10^{-5} \text{ mol L}^{-1}$$

$$\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$$

$$= -\log_{10}(2.36 \times 10^{-5})$$

$$= 4.63$$

Keep in mind that there was initially equimolar amounts of ammonia and ammonium ions in solution, and thus shows buffering action when the hydrochloric acid solution is added (resists pH changes until buffering capacity is exceeded). Hence, the graph will have the following shape:



Question 31

Criteria	Marks
<ul style="list-style-type: none">• Provides a strong justification with a comprehensive understanding of<ul style="list-style-type: none">– the relationship between the valency and bonding of carbon atoms– the functional groups of organic compounds– the physical and chemical properties of organic compounds– the uses of organic compounds• Supports answer with a range of specific examples• Answer is written and structured in a logical and concise manner	6
<ul style="list-style-type: none">• Provides a strong justification with a thorough understanding of organic chemistry• Supports answer with a range of examples• Answer is written and structured in a logical and concise manner	5
<ul style="list-style-type: none">• Provides a strong justification with an informed understanding of organic chemistry• Supports answer with a range of examples• Answer is written and structured in a logical manner	4
<ul style="list-style-type: none">• Provides a justification with a sound understanding of organic chemistry• Supports answer with some examples	3
<ul style="list-style-type: none">• Attempts to justify the statement with some understanding of organic chemistry• Provides at least ONE example	2
• Shows limited understanding of organic chemistry	1

Sample Answer

Carbon is an incredibly versatile element due to its four valence electrons which allows the formation of a variety of covalent bonds, including single bonds with hydrogen, nitrogen, and oxygen atoms, double bonds with oxygen atoms, and triple bonds with nitrogen atoms, as well as bonds with other carbon atoms. This diversity of bonding gives rise to countless functional groups, including carbonyl ($\text{C} = \text{O}$) to produce aldehydes and ketones, hydroxyl ($\text{C} - \text{O} - \text{H}$) to produce alcohols, and the carbon-carbon double bond ($\text{C} = \text{C}$) to produce alkenes.

The nature of these bonds gives rise to a variety of properties. Some physical properties include boiling temperature and solubility, both of which are influenced by the types of covalent bonds formed, and the relative strength of intermolecular forces with other molecules or solvents. For example, hexan-1-ol has a higher boiling temperature and solubility in water compared to hexane due to its ability to form strong hydrogen bonds with both its own molecules and water molecules from the polar hydroxyl group (large electronegativity difference between oxygen and hydrogen). Both organic compounds possess dispersion forces which increase in number and strength as the number of carbon atoms per molecule increases due to the non-polar $\text{C} - \text{C}$ and $\text{C} - \text{H}$ bonds. Hence, the cumulative strength of intermolecular forces between hexan-1-ol is greater than hexane, leading to a higher heat energy requirement to separate its molecules and hence a higher boiling point. This has the add-on effect of separating water molecules from each other due to hexan-1-ol's electrostatic attraction, allowing greater solubility. These bonds also give rise to chemical properties including acidity, basicity, and reactivity. The ability of compounds such as carboxylic acids including ethanoic acid to donate hydrogen ions, and amines including ethanamine to accept hydrogen ions contributes to their weak acidity and basicity, respectively. Also, some organic compounds are more reactive than others due to their unstable functional groups. For example, the carbon-carbon double bond in alkenes such as ethene can be broken to form alkanes, haloalkanes, and alcohols through addition reactions.

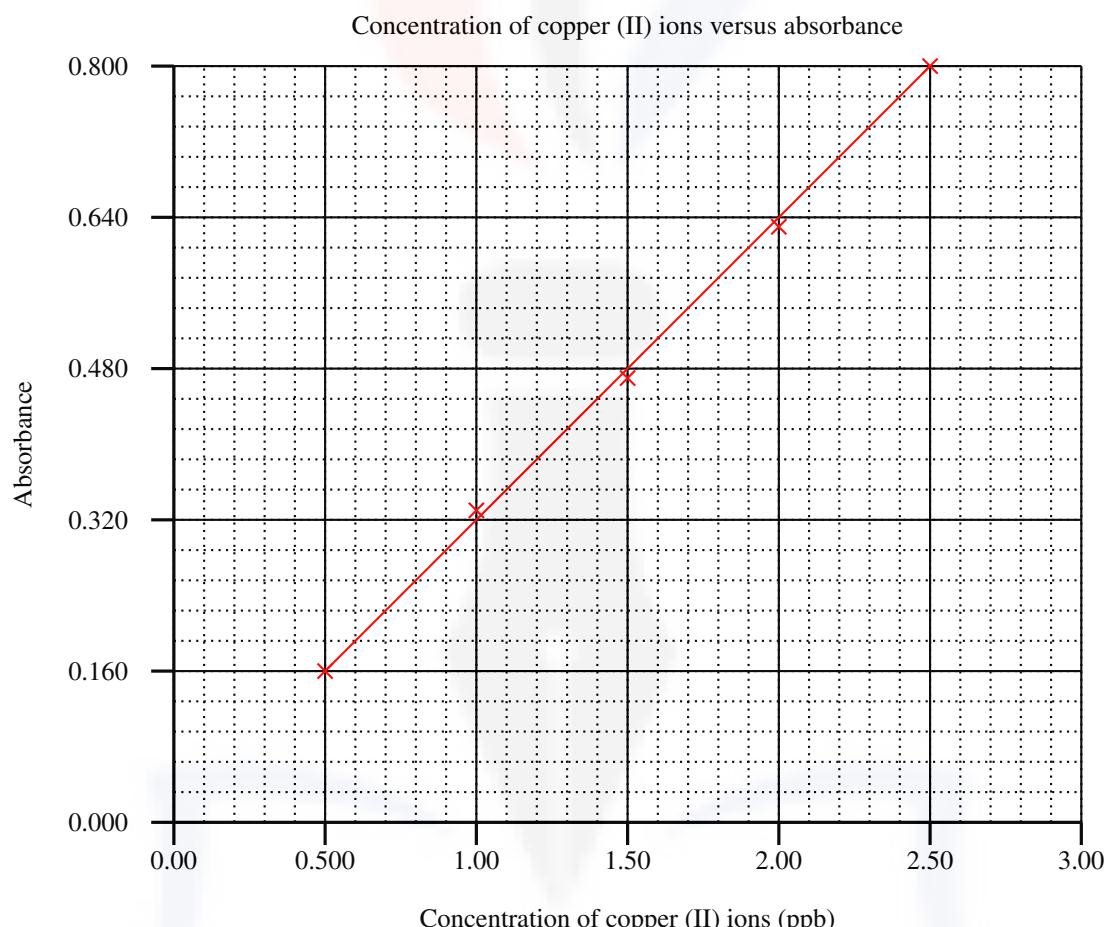
Please turn over

Consequently, organic compounds can be used in a variety of applications, including octane and diesel as fuel sources due to their high heat of combustion, and ethene and tetrafluoroethene as monomers for polymerisation to polyethylene and polytetrafluoroethylene and other plastics. All life is also made up of organic compounds including enzymes and proteins from amino acids due to its variety of functions arising from its bonding.

Question 32 (a)

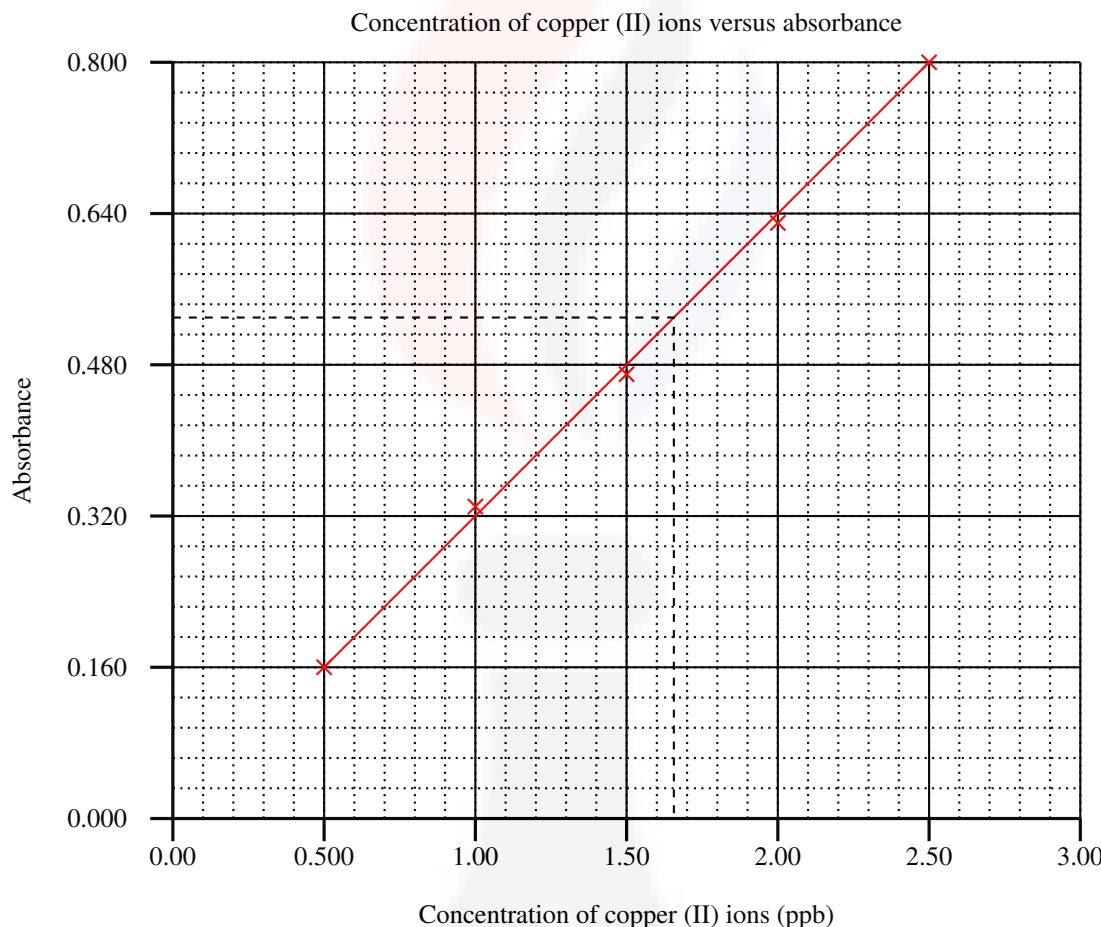
Criteria	Marks
<ul style="list-style-type: none">Provides a graph with<ul style="list-style-type: none">an appropriate titlecorrectly labelled axes including units where relevantappropriate scaleaccurately plotted pointscorrect line of best fitDoes not extrapolate the line of best fit	2
Provides a graph with some correct features	1

Sample Answer



Question 32 (b)

Criteria	Marks
• Correctly calculates the molar concentration of copper (II) ions by interpolation	1

Sample Answer

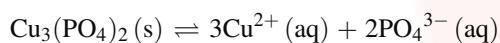
From the interpolation of the graph, an absorbance of 0.530 corresponds to $[\text{Cu}^{2+}] = 1.66 \text{ ppb} = 1.66 \times 10^{-6} \text{ g L}^{-1}$.

The molar mass of copper (II) ions is 63.55 g mol^{-1} , and thus $[\text{Cu}^{2+}] = \frac{1.66 \times 10^{-6}}{63.55} \text{ mol L}^{-1} = 2.61 \times 10^{-8} \text{ mol L}^{-1}$ to three significant figures.

Question 32 (c)

Criteria	Marks
<ul style="list-style-type: none"> • Correctly calculates the concentration of PO_4^{3-} (aq) in g L^{-1}, showing all relevant working • Rounds the answer to three significant figures 	3
<ul style="list-style-type: none"> • Correctly calculates the concentration of PO_4^{3-} (aq) in g L^{-1}, missing some steps OR <ul style="list-style-type: none"> • Gives a substantially correct approach to calculating the concentration of PO_4^{3-} (aq) in g L^{-1} • Rounds the answer to three significant figures 	2
• Shows some knowledge in calculating the concentration of PO_4^{3-} (aq) in g L^{-1}	1

Sample Answer



$$K_{sp} = [\text{Cu}^{2+}]^3[\text{PO}_4^{3-}]^2 = 1.40 \times 10^{-37} \quad \text{using the data sheet}$$

Using part (b), $[\text{Cu}^{2+}] = 2.61 \times 10^{-8} \text{ mol L}^{-1}$, and so

$$(2.61 \times 10^{-8})^3 \times [\text{PO}_4^{3-}]^2 = 1.40 \times 10^{-37}$$

$$[\text{PO}_4^{3-}] = \sqrt{\frac{1.40 \times 10^{-37}}{(2.61 \times 10^{-8})^3}} = 8.86 \times 10^{-8} \text{ mol L}^{-1}$$

$$MM(\text{PO}_4^{3-}) = 30.97 + 16 \times 4 = 94.97 \text{ g mol}^{-1}$$

$$\therefore c(\text{PO}_4^{3-}) = 8.86 \times 10^{-8} \times 94.97 = 8.42 \times 10^{-6} \text{ g L}^{-1}$$

Question 33 (a)

Criteria	Marks
• Correctly shows that the concentration of the sodium thiosulfate solution is 0.102 M with all relevant working	2
• Correctly calculates the concentration of the potassium iodate solution, or equivalent merit	1

Sample Answer

$$MM(\text{KIO}_3) = 40.08 + 126.9 + 16 \times 3$$

$$= 214.98 \text{ g mol}^{-1}$$

$$n(\text{KIO}_3) = \frac{m}{MM} = \frac{1.55}{214.98}$$

$$= 7.21 \times 10^{-3} \text{ mol}$$

$$c(\text{KIO}_3) = \frac{n}{v} = \frac{7.21 \times 10^{-3}}{0.500}$$

$$= 1.44 \times 10^{-2} \text{ mol L}^{-1}$$

$$v(\text{Na}_2\text{S}_2\text{O}_3) = \frac{1}{3} (21.25 + 21.20 + 21.25)$$

$$= 21.23 \text{ mL} \quad (\text{concordant titres})$$

$$n(\text{Na}_2\text{S}_2\text{O}_3)_{\text{reacted}} = 6n(\text{KIO}_3)_{\text{reacted}} \quad (6:1 \text{ molar ratio})$$

$$c(\text{Na}_2\text{S}_2\text{O}_3)v(\text{Na}_2\text{S}_2\text{O}_3) = 6c(\text{KIO}_3)v(\text{KIO}_3)$$

$$\therefore c(\text{Na}_2\text{S}_2\text{O}_3) = \frac{6 \times 1.44 \times 10^{-2} \times 0.025}{0.02123}$$

$$= 0.102 \text{ M}$$

Question 33 (b)

Criteria	Marks
• Correctly calculates the concentration, in % m/v, of sodium hypochlorite in the bleach solution, showing all relevant working	4
• Correctly calculates the concentration, in % m/v, of sodium hypochlorite in the bleach solution, showing the main steps	
OR	3
• Shows all relevant steps in the calculation of the concentration, in % m/v, of sodium hypochlorite in the bleach solution with ONE minor error	
• Makes some progress in calculating the concentration of sodium hypochlorite in the bleach solution, or equivalent	2
• Shows some understanding of multistep reaction titration calculations	1

Sample Answer

First find the number of moles of iodine that was titrated against the standardised sodium thiosulfate solution:

$$n(\text{S}_2\text{O}_3^{2-})_{\text{reacted}} = 2n(\text{I}_2)_{\text{reacted}} \quad (\text{2:1 molar ratio})$$

$$\begin{aligned} n(\text{I}_2)_{\text{reacted}} &= n(\text{Na}_2\text{S}_2\text{O}_3) \div 2 \quad (n(\text{Na}_2\text{S}_2\text{O}_3) = n(\text{S}_2\text{O}_3^{2-}), \text{1:1 molar ratio}) \\ &= c(\text{Na}_2\text{S}_2\text{O}_3)v(\text{Na}_2\text{S}_2\text{O}_3) \div 2 \\ &= 0.102 \times \frac{1}{3} (13.75 + 13.85 + 13.80) \div 1000 \div 2 \quad (\text{concordant titres, and using part (a)}) \\ &= 7.038 \times 10^{-4} \text{ mol} \end{aligned}$$

$n(\text{I}_2)_{\text{reacted}} = n(\text{I}_2)$ produced in the reaction of hypochlorite ions with potassium iodide solid

$$n(\text{I}_2)_{\text{produced}} = n(\text{ClO}^-)_{\text{reacted}} \quad (\text{1:1 molar ratio})$$

$$c(\text{ClO}^-)v(\text{ClO}^-) = 7.038 \times 10^{-4}$$

$$\therefore c(\text{ClO}^-) = \frac{7.038 \times 10^{-4}}{0.020}$$

$$= 3.519 \times 10^{-2} \text{ mol L}^{-1}$$

Please turn over

This is the concentration of hypochlorite ions in the diluted bleach solution. To produce 500 mL from 25 mL, the original bleach solution was diluted by a factor of 20.

$$\therefore c(\text{ClO}^-) = 3.519 \times 10^{-2} \times 20$$

$$= 0.7038 \text{ mol L}^{-1}$$

$$c(\text{NaClO}) = c(\text{ClO}^-) \quad (\text{1:1 molar ratio})$$

$$MM(\text{NaClO}) = 22.99 + 35.45 + 16$$

$$= 74.44 \text{ g mol}^{-1}$$

$$\therefore c(\text{NaClO}) = (0.7038 \times 74.44) \text{ g L}^{-1}$$

$$= 52.4 \text{ g L}^{-1}$$

$$= 5.24 \text{ g/100 mL}$$

$$= 5.24\% \text{ m/v}$$

Question 33 (c)

Criteria	Marks
<ul style="list-style-type: none">• Correctly outlines the rinsing process of the glassware containing the potassium iodate standard solution• Correctly outlines the rinsing process of the glassware containing the sodium thiosulfate solution• Correctly names the volumetric glassware containing BOTH solutions	2
<ul style="list-style-type: none">• Correctly outlines the rinsing process of the glassware containing the potassium iodate standard solution <p>AND</p> <ul style="list-style-type: none">• Correctly names the volumetric glassware containing the potassium iodate solution <p>OR</p> <ul style="list-style-type: none">• Correctly outlines the rinsing process of the glassware containing the sodium thiosulfate solution <p>AND</p> <ul style="list-style-type: none">• Correctly names the volumetric glassware containing the sodium thiosulfate solution	1

Sample Answer

The conical flasks containing the 25.0 mL aliquots of the potassium iodate standard solution must be rinsed with deionised water, whereas the burette containing the sodium thiosulfate solution must be rinsed with deionised water before rinsing again with the sodium thiosulfate solution to be used. This ensures that an accurately known number of moles of the potassium iodate solution is titrated against the sodium thiosulfate solution with a consistent concentration as no dilution has occurred.

Note: No explanation is required as the verb used is ‘outline’, but one is included for clarity.

Question 34

Criteria	Marks
<ul style="list-style-type: none">Provides a valid assessment of the suitability of the process with reference to the flow chartExplains the suitability of the location of the industrial plant with THREE factorsExplains why the reaction conditions in Reactors 2 and 3 are unsuitable overall with reference to yield, rate of reaction, safety, and Le Chatelier's principleExplains the contribution of the recyclability of ammonia to the suitability of the process	7
<ul style="list-style-type: none">Provides a valid assessment of the suitability of the process with reference to the flow chartExplains the factors affecting the suitability of the process with ONE omission	6
<ul style="list-style-type: none">Provides a valid assessment of the suitability of the process with reference to the flow chartExplains the factors affecting the suitability of the process with TWO omissions	5
Explains most of the factors affecting the suitability of the process	4
Explains some of the factors affecting the suitability of the process	3
Outlines some of the factors affecting the suitability of the process	2
Shows some understanding of the factors affecting the suitability of the process	1

Sample Answer

Although the majority of the process is suitable for the mass production of sodium carbonate, the reaction conditions in Reactor 2 and Reactor 3 are unfavourable due to its impact on yield, rate of reaction, and safety.

By constructing the industrial plant in close proximity to a limestone mine, crushed limestone and purified brine, two of the raw materials of the mass production process, may easily be obtained. Also, having the plant close to a shipping port enables the ease of transportation of the sodium carbonate product to markets for sale, as well as overseas exportation if required. Finally, the coastal region of the plant allows the calcium chloride to be easily disposed of in the ocean with negligible impact on marine life due to the ocean's extensive volume. Therefore, the location of the industrial plant is very suitable for the mass production of sodium carbonate.

However, it is known that the dissolution of carbon dioxide in Reactor 2 to form carbonic acid is an exothermic reaction, and thus dissolving carbon dioxide in almost-boiling water is highly unfavourable for the formation of carbonic acid as the reverse reaction is favoured with higher temperatures to absorb excess heat by Le Chatelier's principle. Ideally, colder water should be used to dissolve carbon dioxide in Reactor 2. Also, the reaction between aqueous ammonia and carbonic acid to form ammonium bicarbonate in Reactor 3 is an endothermic reaction, so the low temperature of 20°C - 40°C is unfavourable for the yield of NH_4HCO_3 (aq) as the exothermic reverse reaction will proceed to produce heat by Le Chatelier's principle. Also, the low temperature reduces the rate of the forward reaction as the reactant molecules collide less frequently and with lower energy levels. Hence, a higher temperature should be used in Reactor 3 to optimise yield and reaction rate. Finally, although the high pressure of 1800 - 2000 kPa favours the forward reaction as two aqueous molecules react to form one, thereby reducing the pressure by Le Chatelier's principle, using such a high pressure introduces safety risks as the reactor could potentially explode, creating noise and chemical hazards. Therefore, a lower pressure should be used to uphold the safety of the process.

Finally, the recycling of the aqueous ammonia produced in Reactor 5 improves the atom economy, and thus, the economy feasibility of the process as a smaller amount of raw materials are required.

End of solutions