NSW GOVERNMENT

NSW Education Standards Authority

2021 HIGHER SCHOOL CERTIFICATE EXAMINATION

Chemistry

General Instructions

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

Total marks: 100

Section I – 20 marks (pages 3–12)

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

Section II – 80 marks (pages 13–32)

- Attempt Questions 21–36
- Allow about 2 hours and 25 minutes for this section

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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.

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1 Which pair of components must be equal for a chemical system to be at equilibrium?

A. The rate of the forward reaction and the rate of the reverse reaction

B. The concentrations of the reactants and the concentrations of the products

C. The enthalpy of the forward reaction and the enthalpy of the reverse reaction

D. The time that an atom exists in a reactant molecule and in a product molecule

2 Which ion can be detected using a precipitation reaction with silver nitrate?

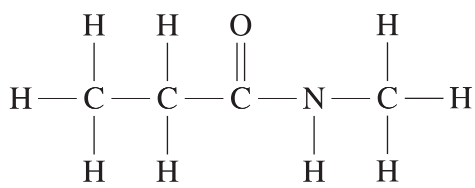
A. Ag^{+}

B. Cl^{-}

C. Mg^{2+}

D. NO_3^{-}

3 The structure of a compound is shown.



What is the preferred IUPAC name of this compound?

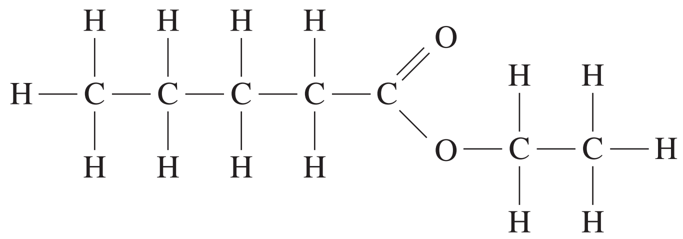
A. *N*-methylpropanamide

B. *N*-methylpropanamine

C. *N*-propanylamine

D. *N*-propylmethanamide

4 The structure of ethyl pentanoate is shown.



Which pair of chemicals would produce ethyl pentanoate by esterification?

A. Ethene and pentan-1-ol

B. Ethane and pentanoic acid

C. Ethanol and pentanoic acid

D. Ethanoic acid and pentan-1-ol

5 A student used the following method to titrate an acetic acid solution of unknown concentration with a standardised solution of dilute sodium hydroxide.

- Rinse burette with deionised water.
- Fill burette with sodium hydroxide solution.
- Rinse pipette and conical flask with acetic acid solution.
- Pipette 25.00 mL of acetic acid solution into conical flask.
- Add appropriate indicator to the conical flask.
- Titrate to endpoint and record volume of sodium hydroxide solution used.

Compared to the actual concentration of the acetic acid, the calculated concentration will be

A. lower.

B. higher.

C. the same.

D. different, but higher or lower cannot be predicted.

6 Which row of the table describes what happens when a solution of a weak acid is diluted? (Assume constant temperature.)

	K_a	*Extent of acid ionisation*
A.	Decreases	Increases
B.	Decreases	Decreases
C.	Remains the same	Increases
D.	Remains the same	Decreases

7 Methanol undergoes a substitution reaction using hydrogen bromide.

Compared to methanol, the product of this reaction has a

A. lower boiling point.

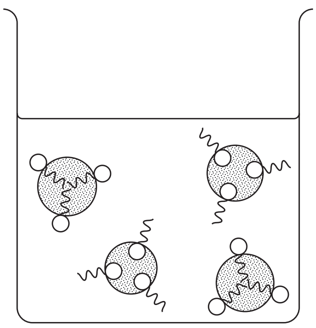
B. lower molecular mass.

C. greater solubility in water.

D. different molecular geometry at the carbon atom.

8 Which diagram shows the expected arrangement of soap anions in an emulsion?

A.



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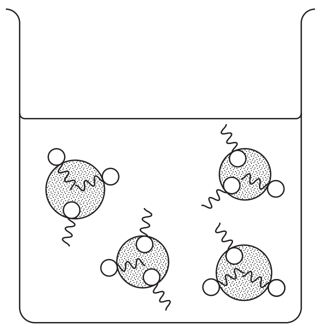

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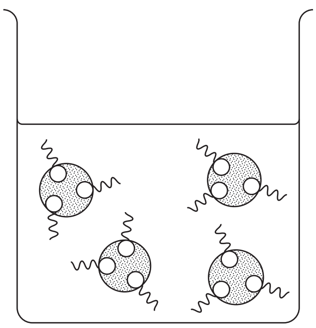

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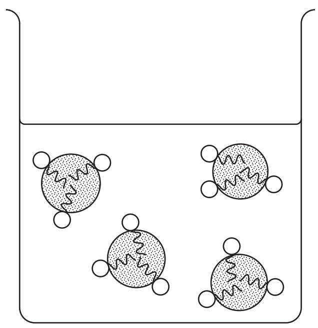
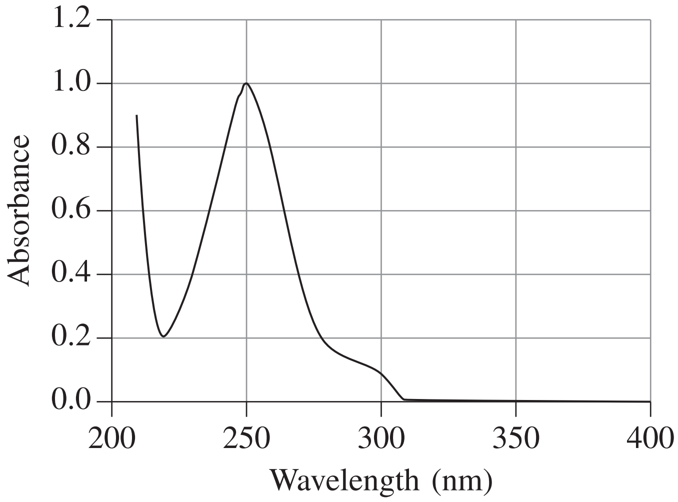


KEY Water Oil Soap anion

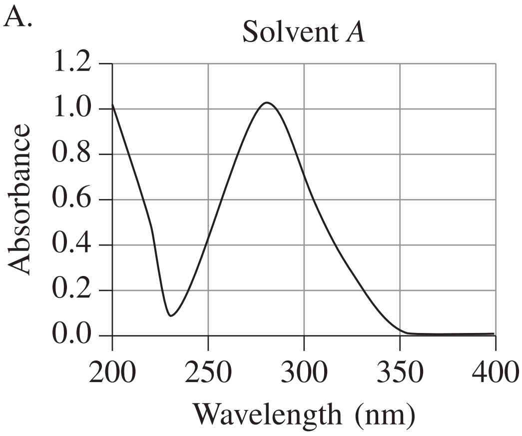
9 The amount of paracetamol in a sample needs to be determined.

The UV absorption spectrum of paracetamol is shown.



Based on the absorption spectra provided, which solvent should be used to determine the amount of paracetamol?

A.



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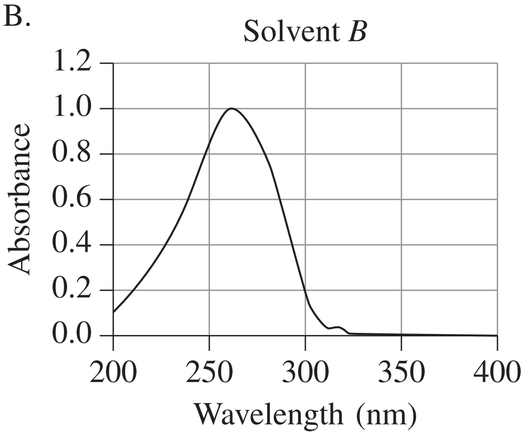

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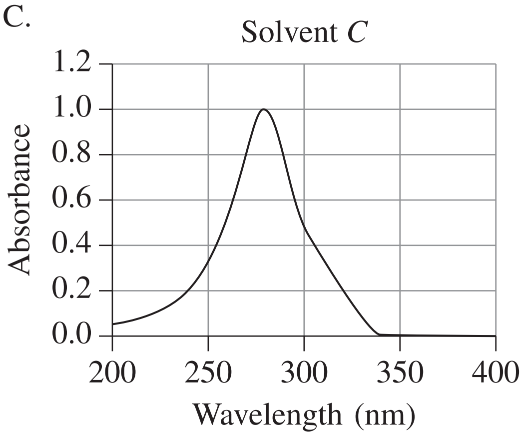

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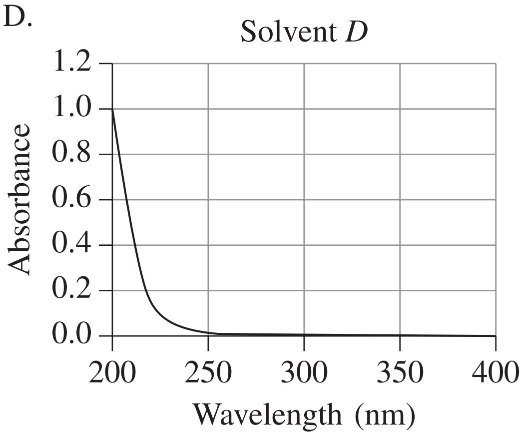
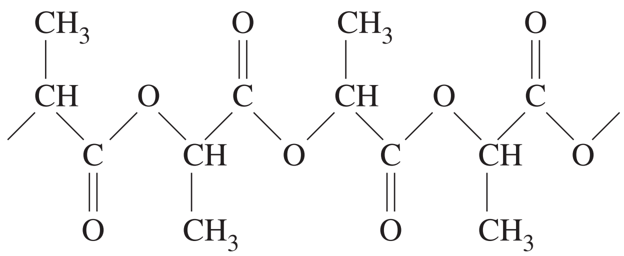
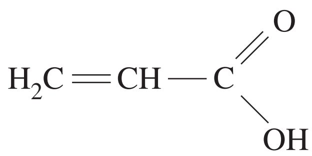


10 The structure of part of a polymer chain is shown.



Which is the monomer of this polymer?

A.



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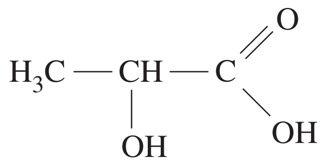

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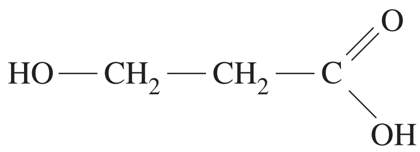

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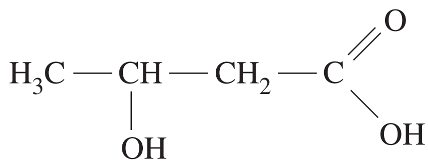


11 Consider this system in a fixed volume at constant temperature.

$$PCl_5(s) \rightleftharpoons PCl_3(l) + Cl_2(g)$$

This system is initially at equilibrium. A small amount of solid PCl_5 is added.

Which statement is correct?

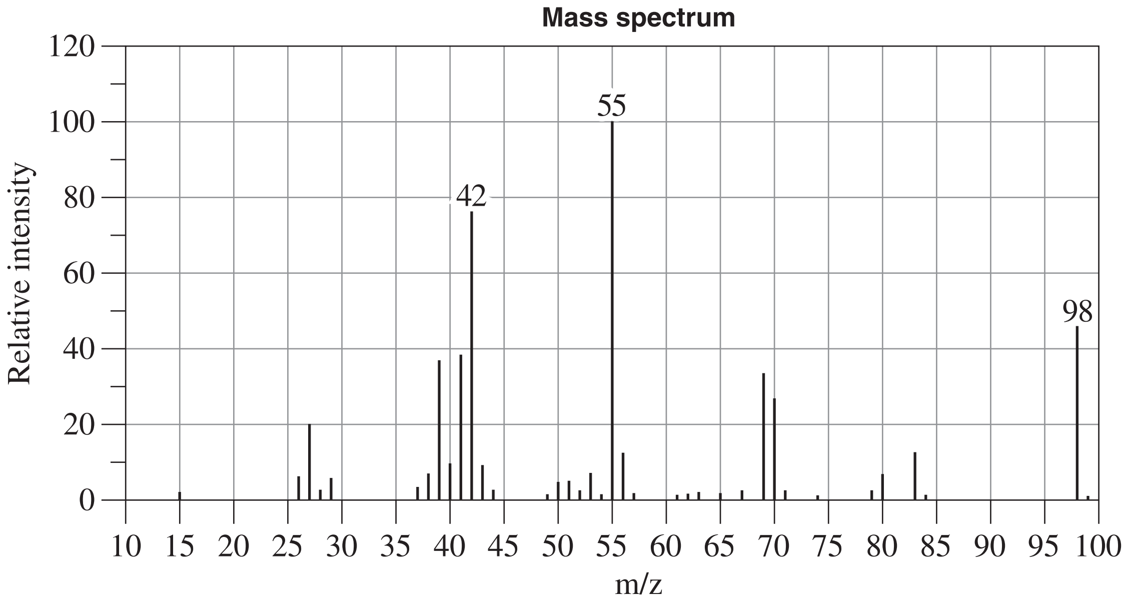
A. The amount of Cl_2 will increase.

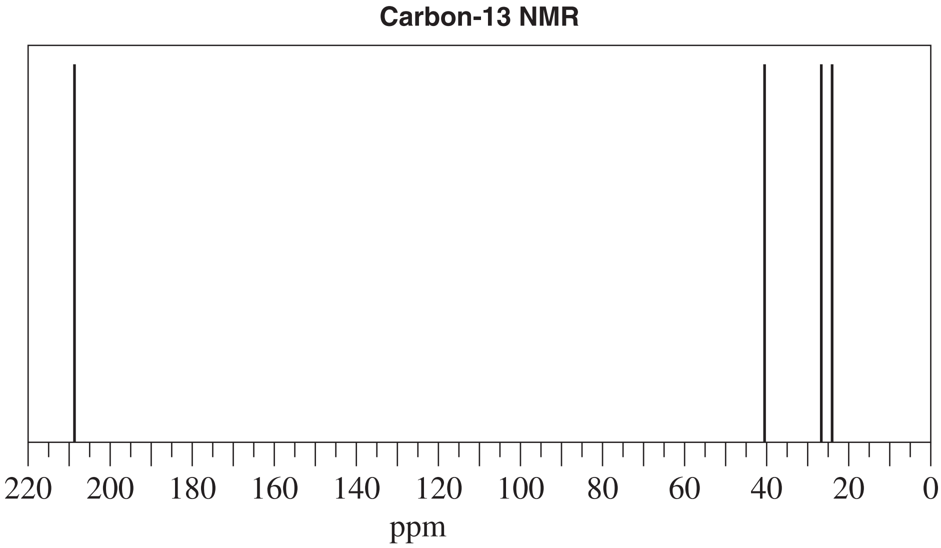
B. The amount of PCl_3 will decrease.

C. The amount of Cl_2 will not change.

D. The amount of PCl_5 will increase then decrease.

12 The mass spectrum and carbon-13 NMR for an organic compound are shown.



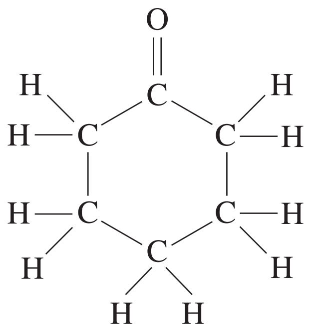


Question 12 continues on page 9

Question 12 (continued)

Which compound could produce the two spectra?

A.



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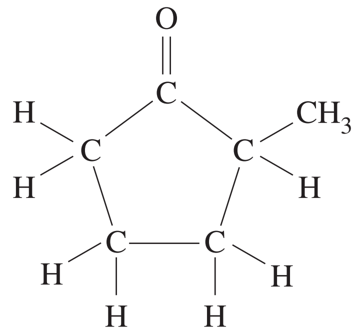

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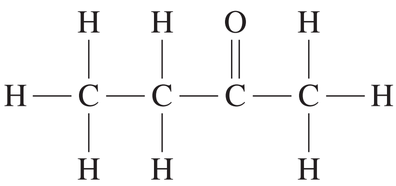

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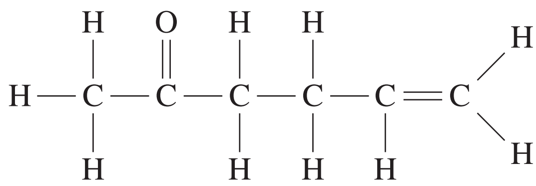


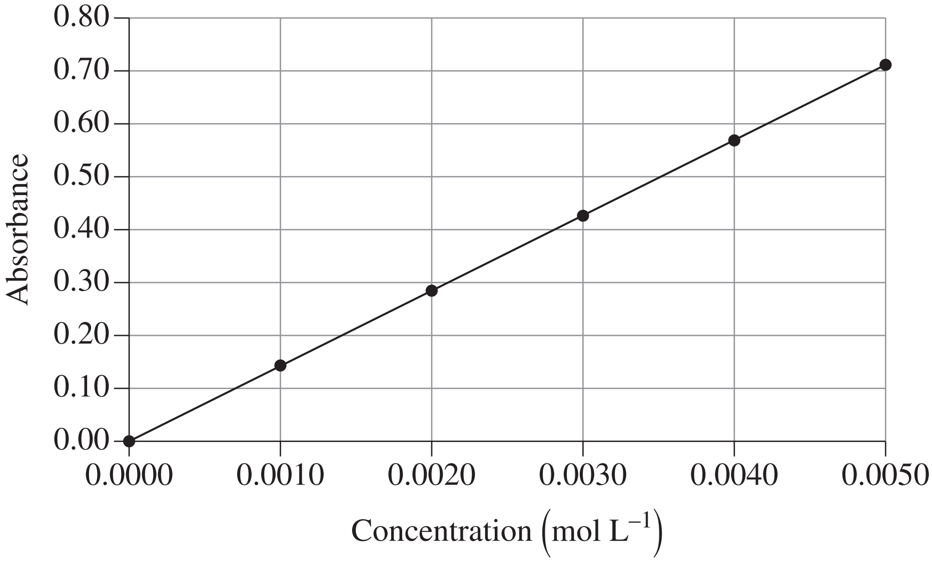
13 A chemist synthesises a substance using the following pathway.

$$X \xrightarrow{\text{hydration}} Y \xrightarrow{\text{oxidation}} Z$$

What are compounds X, Y and Z?

	X	Y	Z
A.	propane	propan-1-ol	propan-2-one
B.	propane	propan-1-ol	propanoic acid
C.	prop-1-ene	propan-2-ol	propan-2-one
D.	prop-1-ene	propan-2-ol	propanoic acid

14 A sample of nickel was dissolved in nitric acid to produce a solution with a volume of 50.00 mL. 10.00 mL of this solution was then diluted to 250.0 mL. This solution was subjected to colorimetric analysis. A calibration curve for this analysis is given.



The solution gave an absorbance value of 0.30.

What was the mass of the sample of nickel?

A. 0.0021 g

B. 0.031 g

C. 0.053 g

D. 0.15 g

15 What is the pH of the resultant solution after 20.0 mL of 0.20 mol L^{-1} HCl(*aq*) is mixed with 20.0 mL of 0.50 mol L^{-1} NaOH(*aq*)?

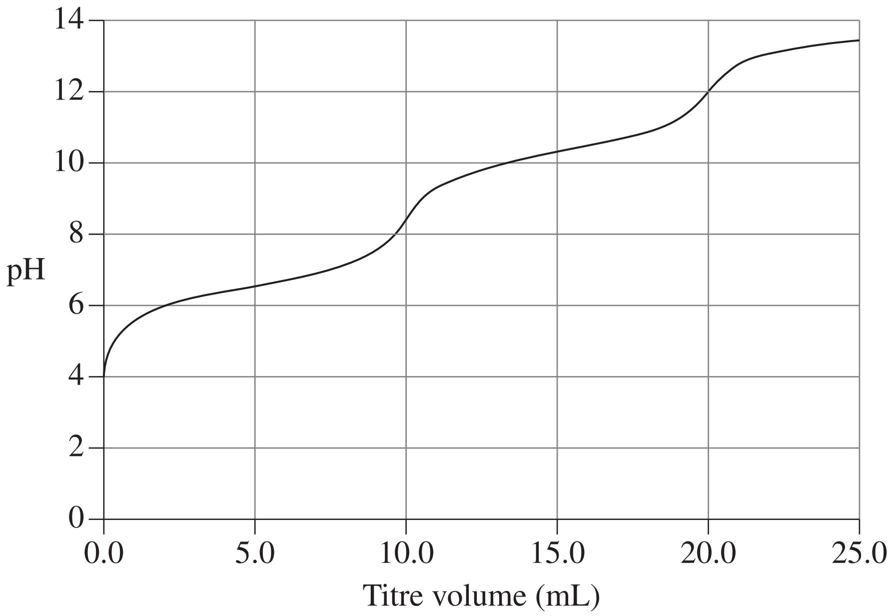
A. 11.8

B. 13.2

C. 13.5

D. 14.0

16 This titration curve is produced when an acid is titrated with a sodium hydroxide solution of the same concentration.



How many acidic protons does this acid possess?

A. 1

B. 2

C. 3

D. 4

17 A sample was contaminated with sodium phosphate. The sample was dissolved in water and added to an excess of acidified $(NH_4)_2MoO_4$ to produce a precipitate of $(NH_4)_3PO_4{\bullet}12MoO_3$ (MM = 1877 g mol^{-1}).

If 24.21 g of dry $(NH_4)_3PO_4{\bullet}12MoO_3$ was obtained, what was the mass of sodium phosphate in the original sample?

A. 1.225 g

B. 1.521 g

C. 1.818 g

D. 2.115 g

18 The table lists the information from a proton NMR spectrum.

Chemical shift (ppm)	*Multiplicity*	*Number of hydrogens*
1.0	Triplet	3
1.4	Singlet	3
1.8	Quartet	2

Which compound could have produced this spectrum?

A. 1,2,2-trichlorobutane

B. 1,3-dichloro-2-methylpropane

C. 2-chloro-2-methylbutane

D. 2,2-dichlorobutane

19 A quantity of silver nitrate is added to 250.0 mL of 0.100 mol L^{-1} potassium sulfate at 298 K in order to produce a precipitate. Silver nitrate has a molar mass of 169.9 g mol^{-1}.

What mass of silver nitrate will cause precipitation to start?

A. 0.00510 g

B. 0.186 g

C. 0.465 g

D. 0.854 g

20 The trimethylammonium ion, $[(CH_3)_3NH]^+$, is a weak acid. The acid dissociation equation is shown.

$$[(CH_3)_3NH]^+(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + (CH_3)_3N(aq) \qquad K_a = 1.55 \times 10^{-10}$$

At 20°C, a saturated solution of trimethylammonium chloride, $[(CH_3)_3NH]Cl$, has a pH of 4.46.

What is the K_{sp} of trimethylammonium chloride?

A. 1.26×10^{-9}

B. 7.76

C. 60.2

D. 5.01×10^{10}

2021 HIGHER SCHOOL CERTIFICATE EXAMINATION

Centre Number

Student Number

Chemistry

Section II Answer Booklet

80 marks
Attempt Questions 21–36
Allow about 2 hours and 25 minutes for this section

Instructions

- Write your Centre Number and Student Number at the top of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.

Please turn over

Question 21 (6 marks)

Four organic liquids are used in an experiment. The four liquids are

- hexane
- hex-1-ene
- propan-1-ol
- propanoic acid.

(a) State ONE safety concern associated with organic liquids and suggest ONE way to address this safety concern. **2**

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(b) The organic liquids are held separately in four flasks but the flasks are not labelled. Tests were conducted to identify these liquids. The outcomes of the tests are summarised below. **2**

Flask	*Reaction with acidified oxidant* $\left(KMnO_4/H^+\right)$*?*	*Miscible with water?*
1	No	Yes
2	Yes	No
3	Yes	Yes
4	No	No

Identify the FOUR liquids.

Flask	*Liquid*
1	
2	
3	
4	

Question 21 continues on page 15

(c) What chemical test, other than those used in part (b), could be used to confirm the identification of ONE of the liquids? Include the expected observation in your answer. **2**

Liquid: ....

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End of Question 21

Please turn over

Question 22 (3 marks)

Consider the following equilibrium system. **3**

$2CrO_4^{2-}(aq)$ + $2H^+(aq)$	$\rightleftharpoons$	$Cr_2O_7^{2-}(aq)$ + $H_2O(l)$	$\Delta H = -895 \text{ kJ mol}^{-1}$
yellow		*orange*	

The solution is orange.

Justify TWO ways to shift the equilibrium to the left to change the colour of the solution.

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Question 23 (4 marks)

Methanoic acid reacts with aqueous potassium hydroxide. A salt is produced in this reaction.

(a) Write a balanced chemical equation for this reaction. **2**

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(b) Is the salt acidic, basic or neutral? Justify your answer. **2**

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Question 24 (4 marks)

A straight-chained alkane has a molar mass of 72.146 g mol^{-1}. **4**

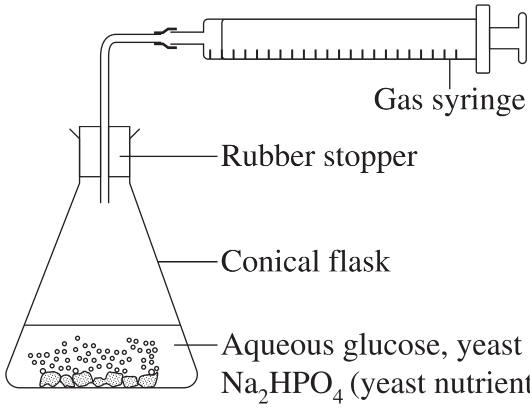
Provide the structural formulae for this alkane and all other isomers of it in the space provided.

Name these molecules using IUPAC conventions.

Structural formula	*Name*

Question 25 (4 marks)

A student conducted an experiment in the school laboratory under standard laboratory conditions (25°C, 100 kPa) to determine the volume of carbon dioxide gas produced during the fermentation of glucose. The following apparatus was set up. **4**



The following data were collected.

Day	*Total volume of gas* (mL)
1	489
2	677
3	899
4	1006
5	1006

Assume the total volume of gas produced was due to the production of carbon dioxide.

Calculate the mass of ethanol produced by the fermentation reaction. Include a relevant chemical equation in your answer.

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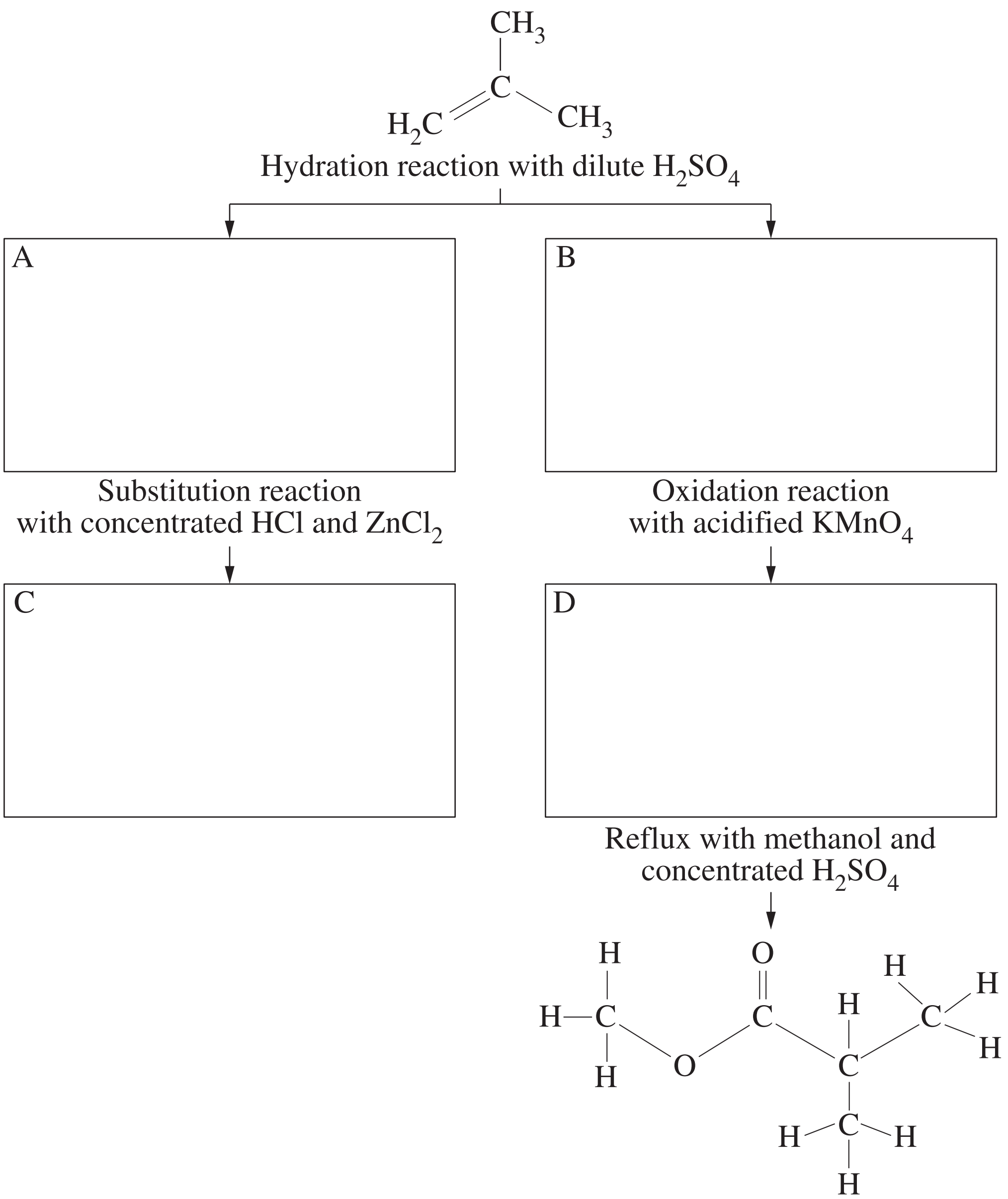
Question 26 (6 marks)

A sequence of chemical reactions, starting with 2-methylprop-1-ene, is shown in the flow chart.

(a) Complete the flow chart by drawing structural formulae for compounds A, B, C and D. **4**



Methyl 2-methylpropanoate

(b) Reflux is used in the synthesis of methyl 2-methylpropanoate. **2**

Provide TWO reasons for using this technique.

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Question 27 (6 marks)

An experiment is carried out to determine the K_{sp} value for lithium phosphate (Li_3PO_4). Five samples of Li^+ ion solution were prepared, and a different solution of PO_4^{3-} was added to each of them. Columns 2 and 3 of the table show the values before any reaction occurs.

Sample	$[Li^+]$ (mol L^{-1})	$[PO_4^{3-}]$ (mol L^{-1})	*Observation*
1	0.15	0.00010	No precipitate
2	0.15	0.0010	No precipitate
3	0.15	0.010	No precipitate
4	0.15	0.10	White precipitate
5	0.15	1.00	Heavy white precipitate

(a) Calculate the range within which the K_{sp} value of lithium phosphate lies. **4**

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(b) Justify ONE way in which the procedure of this investigation could be improved to increase the accuracy of the calculated result. **2**

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Question 28 (4 marks)

A 5.30 g sample of an alkali metal hydroxide was dissolved in water. After mixing with excess $Cu(NO_3)_2$, the precipitate was collected, dried, measured and found to have a mass of 4.61 g. **4**

Identify the alkali metal hydroxide. Support your answer with calculations and a balanced equation.

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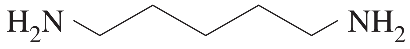
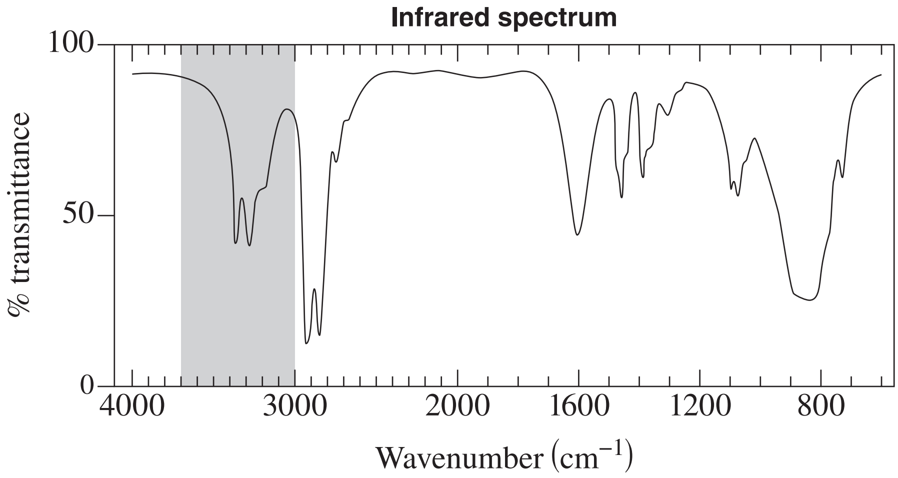
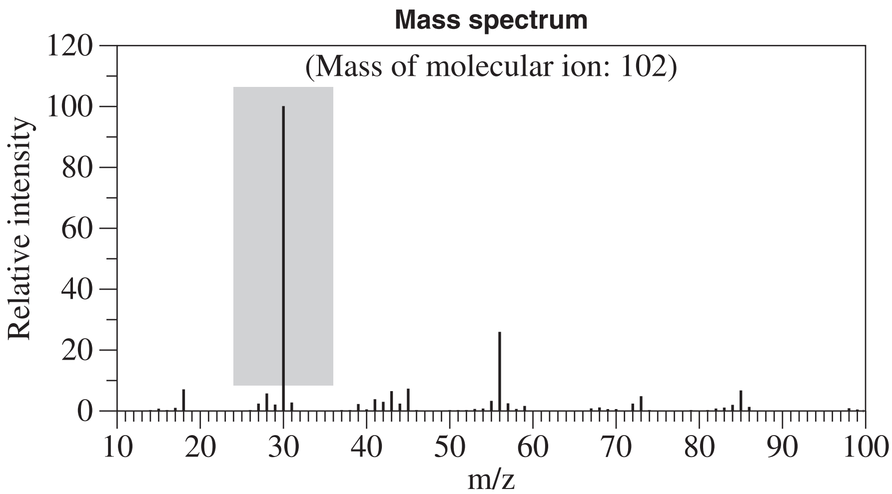
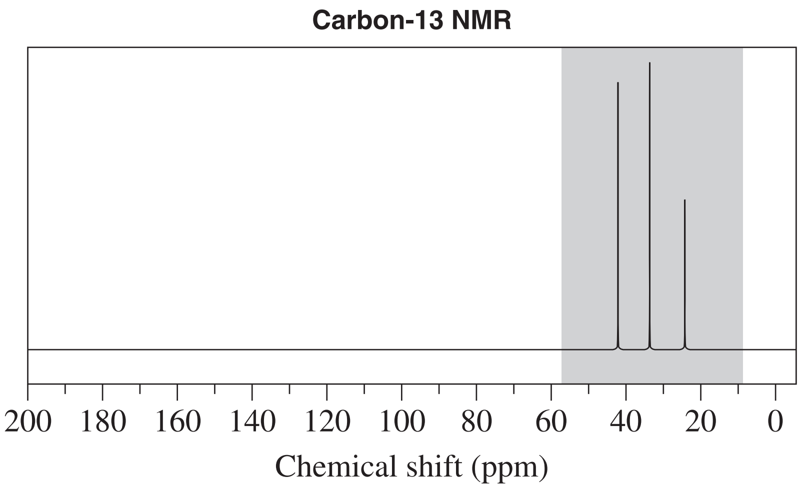
Question 29 (7 marks)

A chemist obtained spectral data of pentane-1,5-diamine ($C_5H_{14}N_2$). **7**

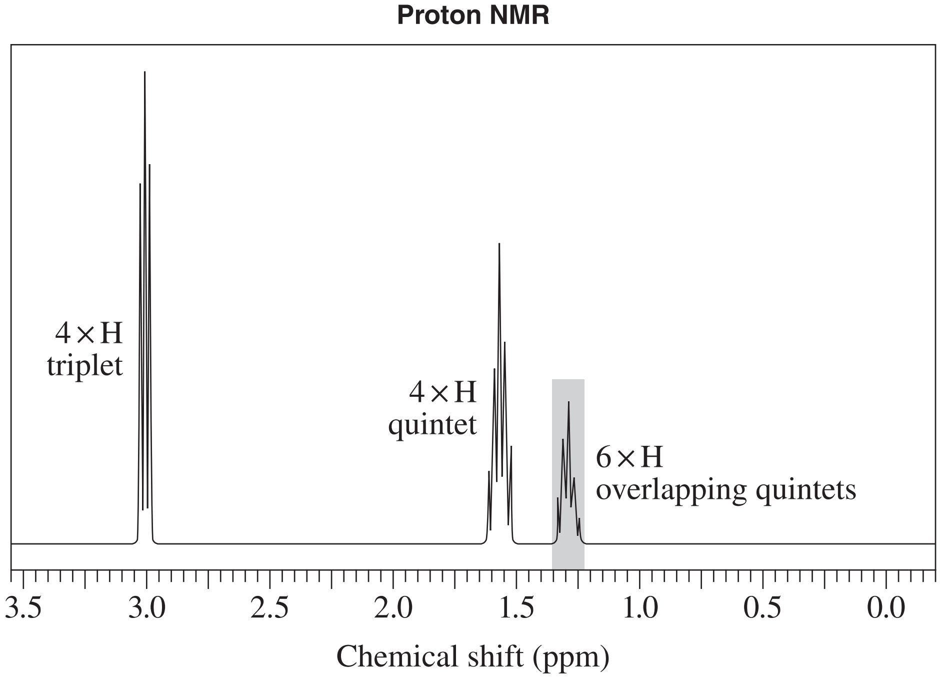








Question 29 continues on page 23



Relate the highlighted features of the spectra to the structure of pentane-1,5-diamine.

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Question 29 continues on page 24

End of Question 29

Question 30 (5 marks)

A student was trying to identify the ions present in a dilute aqueous solution. **5**

The solution contained ions of barium, calcium or magnesium, and ions of hydroxide or acetate.

The student performed the following tests and recorded their observations. A fresh sample of the solution was used for each test.

- When aqueous sodium chloride was added, no visible reaction was observed.
- When aqueous silver nitrate was added, brown precipitate was produced. The precipitate dissolved when dilute hydrochloric acid was added.
- When concentrated aqueous sodium sulfate was added, white precipitate was produced.

Evaluate this procedure as a method of identifying the ions.

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Question 31 (4 marks)

Ammonia is produced according to the following equilibrium equation. **4**

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

There are 4.50 moles of nitrogen gas, 1.00 mole of hydrogen gas and 5.80 moles of ammonia in a 10.0 L vessel. The system is at equilibrium at 298 K. The value of K_{eq} at this temperature is 748.

How many moles of nitrogen gas need to be added to the vessel to increase the amount of ammonia by 0.050 moles?

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Question 32 (4 marks)

The molar enthalpies of neutralisation of three reactions are given. **4**

Reaction 1:
$HCl(aq) + KOH(aq) \longrightarrow KCl(aq) + H_2O(l)$ $\Delta H = -57.6 \text{ kJ mol}^{-1}$

Reaction 2:
$HNO_3(aq) + KOH(aq) \longrightarrow KNO_3(aq) + H_2O(l)$ $\Delta H = -57.6 \text{ kJ mol}^{-1}$

Reaction 3:
$HCN(aq) + KOH(aq) \longrightarrow KCN(aq) + H_2O(l)$ $\Delta H = -12.0 \text{ kJ mol}^{-1}$

Explain why the first two reactions have the same enthalpy value but the third reaction has a different value.

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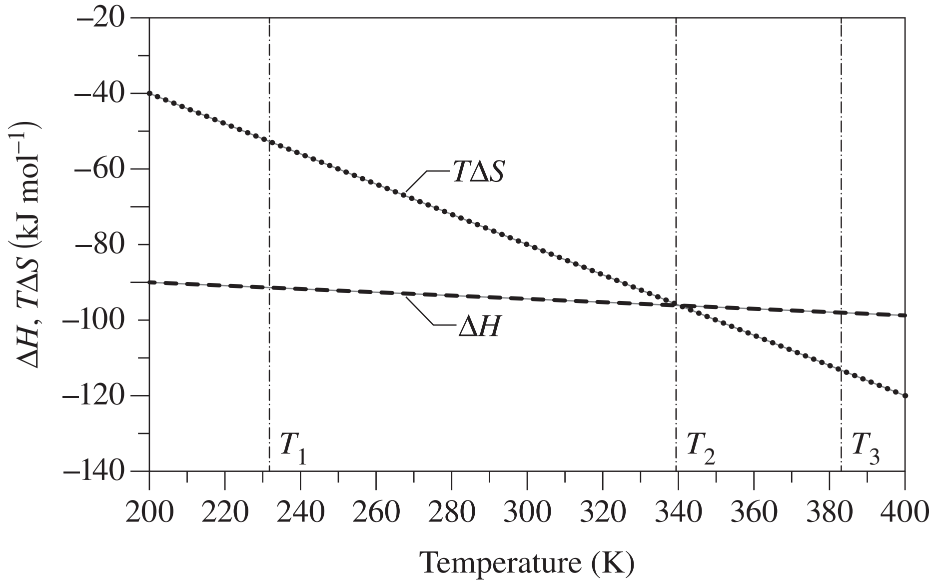
Question 33 (6 marks)

The relationships between ΔH and $T\Delta S$ with temperature for a chemical system are displayed in the graph.



(a) Calculate ΔG for this system at 300 K. **2**

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(b) What can be deduced about the system when the temperature is T_1, T_2 and T_3? Support your answer with reference to the graph. **4**

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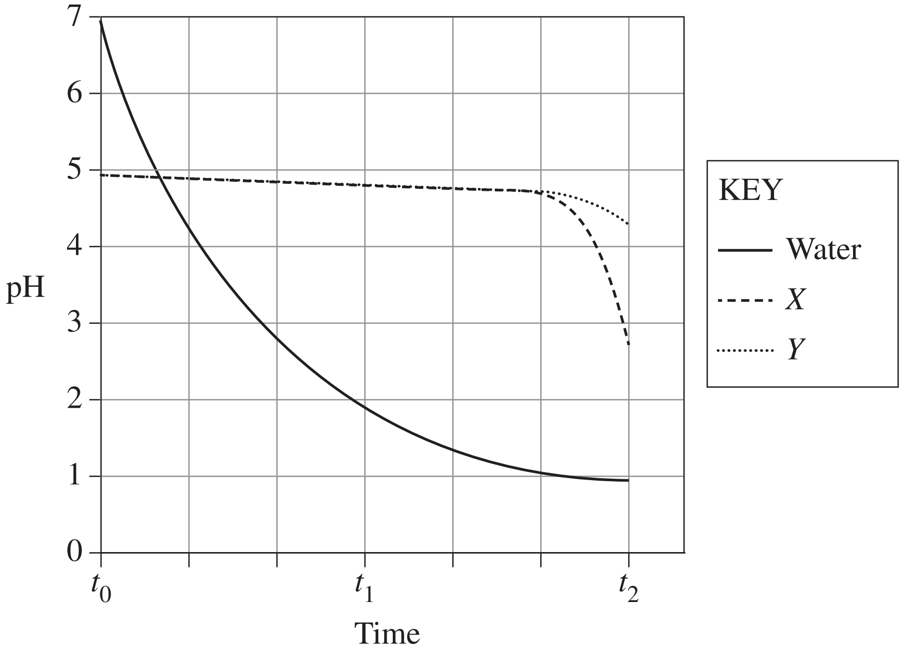
Question 34 (5 marks)

Gaseous HCl was bubbled into water and two solutions, *X* and *Y*. Solutions *X* and *Y* contain the same type of ions. The pH of each was monitored over time and recorded in the graph shown. **5**



Explain the observed pH of the water and each of the solutions at t_0, t_1 and t_2. Include a relevant balanced chemical equation in your answer.

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Question 35 (7 marks)

A manufacturer requires that its product contains at least 85% v/v ethanol. **7**

The concentration of ethanol in water can be determined by a back titration. Ethanol is first oxidised to ethanoic acid using an excess of acidified potassium dichromate solution.

$$3C_2H_5OH(aq) + 2Cr_2O_7^{2-}(aq) + 16H^+(aq) \longrightarrow 3CH_3COOH(aq) + 4Cr^{3+}(aq) + 11H_2O(l)$$

The remaining dichromate ions are reacted with excess iodide ions to produce iodine (I_2).

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6I^-(aq) \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l) + 3I_2(aq)$$

The iodine produced is then titrated with sodium thiosulfate ($Na_2S_2O_3$).

$$I_2(aq) + 2S_2O_3^{2-}(aq) \longrightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$$

A 25.0 mL sample of the manufacturer's product was diluted with distilled water to 1.00 L. A 25.0 mL aliquot of the diluted solution was added to 20.0 mL of 0.500 mol L^{-1} acidified potassium dichromate solution in a conical flask. Potassium iodide (2.0 g)* was added and the solution titrated with 0.900 mol L^{-1} sodium thiosulfate. This was repeated three times.

**The quantity of potassium iodide should be 5.0 g. This is not required for the calculation.*

The following results were obtained.

Time	*Volume of* $Na_2S_2O_3(aq)$ *added* (mL)
1	29.9
2	28.7
3	28.4
4	28.6

The density of ethanol is 0.789 g mL^{-1}.

Question 35 continues on page 31

Does the sample meet the manufacturer's requirements? Support your answer with calculations.

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End of Question 35

Please turn over

Question 36 (5 marks)

The pK_a of sulfurous acid in the following reaction is 1.82. **5**

$$H_2SO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HSO_3^-(aq)$$

The pK_a of hydrogen sulfite in the following reaction is 7.17.

$$HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)$$

Calculate the equilibrium constant for the following reaction:

$$H_2SO_3(aq) + 2H_2O(l) \rightleftharpoons 2H_3O^+(aq) + SO_3^{2-}(aq).$$

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End of paper

Chemistry

FORMULAE SHEET

$n = \dfrac{m}{MM}$	$c = \dfrac{n}{V}$	$PV = nRT$
$q = mc\Delta T$	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$	$\mathrm{pH} = -\log_{10}[\mathrm{H}^+]$
$pK_a = -\log_{10}[K_a]$	$A = \varepsilon lc = \log_{10}\dfrac{I_o}{I}$	

Avogadro constant, N_A .... 6.022×10^{23} mol^{-1}

Volume of 1 mole ideal gas: at 100 kPa and
at 0°C (273.15 K) .... 22.71 L
at 25°C (298.15 K) .... 24.79 L

Gas constant .... 8.314 J mol^{-1} K^{-1}

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

Specific heat capacity of water .... 4.18×10^3 J kg^{-1} K^{-1}

DATA SHEET

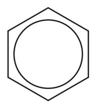
Solubility constants at 25°C

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

Infrared absorption data

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

^{13}C NMR chemical shift data

Type of carbon		δ/ppm
$-\overset{\mid}{\underset{\mid}{C}}-\overset{\mid}{\underset{\mid}{C}}-$		5–40
$R-\overset{\mid}{\underset{\mid}{C}}-Cl$ or Br		10–70
$R-\underset{O}{\underset{\Vert}{C}}-\overset{\mid}{\underset{\mid}{C}}-$		20–50
$R-\overset{\mid}{\underset{\mid}{C}}-N\genfrac{}{}{0pt}{}{/}{\backslash}$		25–60
$-\overset{\mid}{\underset{\mid}{C}}-O-$	alcohols, ethers or esters	50–90
$\genfrac{}{}{0pt}{}{\backslash}{/}C=C\genfrac{}{}{0pt}{}{/}{\backslash}$		90–150
$R-C\equiv N$		110–125
		110–160
$R-\underset{O}{\underset{\Vert}{C}}-$	esters or acids	160–185
$R-\underset{O}{\underset{\Vert}{C}}-$	aldehydes or ketones	190–220

UV absorption

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

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

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

Some standard potentials

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

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

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number	79
Symbol	Au
Standard Atomic Weight	197.0
Name	Gold

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

Lanthanoids

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

Actinoids

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

Standard atomic weights are abridged to four significant figures.
Elements with no reported values in the table have no stable nuclides.
Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (November 2016 version).
The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.

2021 HSC Chemistry Marking Guidelines

Section I

Multiple-choice Answer Key

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

Section II

Question 21 (a)

Criteria	Marks
• Identifies a safety concern associated with organic liquids • States how the safety concern could be addressed	2
• Provides some relevant information	1

Sample answer:

Organic solvents are generally flammable so no sources of ignition should be present.

Question 21 (b)

Criteria	Marks
• Correctly identifies all four liquids	2
• Correctly identifies one liquid	1

Sample answer:

Flask	*Liquid*
1	propanoic acid
2	hex-1-ene
3	propan-1-ol
4	hexane

Question 21 (c)

Criteria	Marks
• Provides a relevant test for the liquid • States the expected observation	2
• Provides some relevant information	1

Sample answer:

Liquid: propanoic acid

Add a small amount of solid sodium hydrogen carbonate to the organic liquid. Bubbles of gas are produced indicating propanoic acid.

Answers could include:

Liquid: propanoic acid

Add drops of universal indicator to the organic liquid. If it is propanoic acid, the indicator will change colour from green to yellow/orange/red.

Use of other indicators such at litmus paper or a pH probe.

Liquid: hex-1-ene

Add drops of bromine water to the organic liquid. If it is hex-1-ene, the bromine water will decolourise.

Liquid: propan-1-ol

Sodium metal or Lucas test.

Question 22

Criteria	Marks
• Justifies TWO relevant ways	3
• Justifies ONE relevant way OR • Identifies TWO relevant ways	2
• Provides some relevant information	1

Sample answer:

The concentration of hydrogen ions could be reduced. This would increase the concentration of chromate ions, which will make the solution more yellow.

Heating the solution will drive the reaction to the left, as the forward reaction is exothermic. Thus the concentration of yellow chromate ions would increase.

Question 23 (a)

Criteria	Marks
• Provides a substantially correct balanced equation	2
• Provides some relevant information	1

Sample answer:

$HCOOH(aq) + KOH(aq) \rightarrow KHCOO(aq) + H_2O(\ell)$.

Answers could include:

$HCOOH(aq) + KOH(aq) \rightarrow KHCOO(s) + H_2O(\ell)$.

Question 23 (b)

Criteria	Marks
• Correctly identifies salt as basic • Provides suitable justification	2
• Provides some relevant information	1

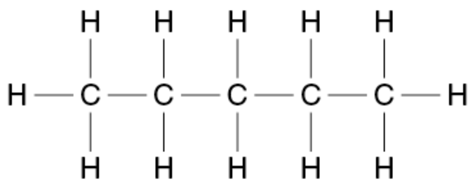
Sample answer:

Potassium methanoate is a basic salt as $HCOO^-$ is the conjugate base of a weak acid.

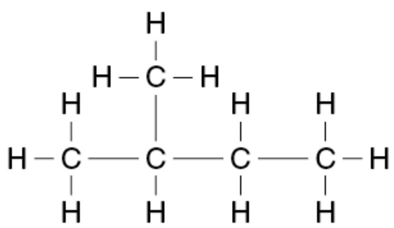
Question 24

Criteria	Marks
• Names pentane as the straight-chained alkane • Provides the structural formula • Correctly provides the structural formulae and names the other two isomers	4
• Provides THREE correct structural formulae and ONE correct name OR • Provides TWO correct structural formulae and TWO correct names	3
• Provides TWO correct structural formulae without names OR • Provides TWO correct names without structural formulae OR • Provides ONE correct structural formula and ONE correct name	2
• Provides some relevant information	1

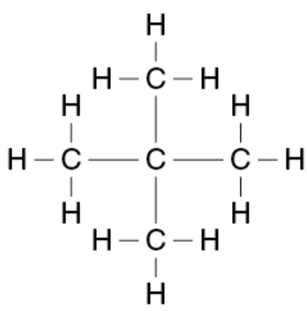
Sample answer:



Pentane – the straight-chained alkane



2-methylbutane



2,2-dimethylpropane

Question 25

Criteria	Marks
• Performs correct calculations • Includes a relevant chemical equation	4
• Provides the main steps • Includes a chemical equation	3
• Provides some relevant steps	2
• Provides some relevant information	1

Sample answer:

$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$

1006 mL = 1.006 L CO_2

1.006 L / 24.79 L mol^{-1} = 0.04058087939 moles of CO_2

$n_{CO_2} = n_{C_2H_5OH}$ = 0.04058087939 moles

$m_{C_2H_5OH} = n_{C_2H_5OH} \times MM_{C_2H_5OH}$ = 0.04058087939 mol $\times$ 46.068 g mol^{-1} = 1.869479952 g

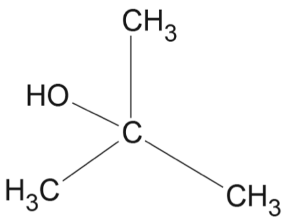
$m_{C_2H_5OH}$ = 1.869 g

Question 26 (a)

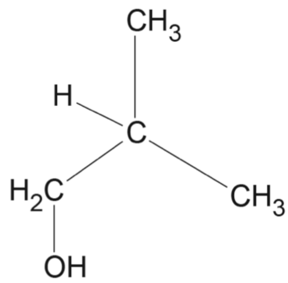
Criteria	Marks
• Draws correct structural formulae for compounds A–D	4
• Draws correct structural formulae for three compounds	3
• Draws structural formulae demonstrating an understanding of some different reactions	2
• Provides some relevant information	1

Sample answer:

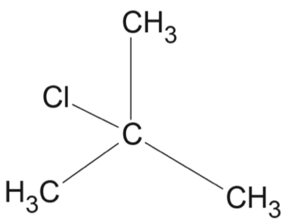
A



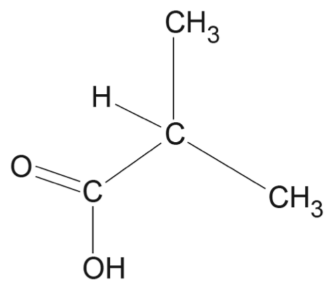
B



C



D



Question 26 (b)

Criteria	Marks
• Gives TWO reasons for refluxing reaction mixture	2
• Provides some relevant information	1

Sample answer:

Reflux uses heat to speed up the reaction.

The condenser retains the volatile reactants and products.

Question 27 (a)

Criteria	Marks
• Correctly calculates the range with the correct significant figures	4
• Provides some relevant steps	2–3
• Provides some relevant information	1

Sample answer:

$$K_{sp} = \left[Li^{+}\right]^{3}\left[PO_4^{\ 3-}\right]$$

Sample 3

$$K_{sp} = \left[Li^{+}\right]^{3}\left[PO_4^{\ 3-}\right]$$

$$= \left(0.15\right)^{3} \times \left(0.010\right) = 0.00003375$$

$$= 0.000034 \quad \text{to 2 significant figures}$$

Sample 4

$$K_{sp} = \left[Li^{+}\right]^{3}\left[PO_4^{\ 3-}\right]$$

$$= \left(0.15\right)^{3} \times \left(0.10\right) = 0.0003375$$

$$= 0.00034 \quad \text{to 2 significant figures}$$

Precipitation will occur somewhere between sample 3 and sample 4. The K_{sp} value is between 3.4×10^{-5} and 3.4×10^{-4}.

Question 27 (b)

Criteria	Marks
• States one way to improve the investigation and relates that to the accuracy of the calculated result	2
• Provides some relevant information	1

Sample answer:

Increase the number of solutions of $PO_4^{\ 3-}$ ions in the concentration range of 0.010 mol L^{-1} to 0.10 mol L^{-1}. This will narrow the range of values and bring the estimated value closer to the SI value of lithium phosphate.

Answers could include:

Titrate the Li^{+} ions against a $PO_4^{\ 3-}$ ion solution until a permanent precipitate is formed. This will give an experimental value that is correct or close to correct to the SI value for lithium phosphate.

Question 28

Criteria	Marks
• Correctly identifies the alkali hydroxide • Provides correct calculations and a balanced equation	4
• Provides the main steps of the calculation	3
• Provides some relevant steps	2
• Provides some relevant information	1

Sample answer:

Alkali metals = group 1

$$Cu(NO_3)_2(aq) + 2XOH(aq) \rightarrow Cu(OH)_2(s) + 2XNO_3(aq)$$

Net Ionic equation: $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$

Mass $Cu(OH)_2(s) = 4.61$ g

$$\begin{aligned} \text{Moles } Cu(OH)_2(s) &= 4.61 \text{ g} \div MM(Cu(OH)_2) \\ &= 4.61 \text{ g} \div 97.566 \text{ g mol}^{-1} \\ &= 0.04725 \text{ mol} \end{aligned}$$

$n_{Cu(OH)_2} = 2n_{OH^-} = 0.09450$ mol OH^-

$2n_{OH^-} = n_{XOH^-} = 0.09450$ mol

amount = mass ÷ molar mass

∴ molar mass = mass ÷ amount

$MM = 5.30 \text{ g} \div 0.09450 \text{ mol} = 56.085 \text{ g mol}^{-1}$

Mass of OH = (16 + 1.008) = 17.008 g mol^{-1}

Mass of Alkali Metal = 56.085 g mol^{-1} – 17.008 g mol^{-1} = 39.077 g mol^{-1}

39.077 g $\text{mol}^{-1} \cong$ 39.10 g mol^{-1} (Molar Mass of *K* from Periodic table)

Therefore, the unknown alkali hydroxide = Potassium Hydroxide.

Question 29

Criteria	Marks
• Demonstrates a comprehensive understanding of the relationship between the highlighted features of the spectra and the structure of pentane-1,5-diamine • Refers to the relevant spectroscopic data in each of the four spectra	7
• Demonstrates a thorough understanding of the relationship between the highlighted features of the spectra and the structure of pentane-1,5-diamine • Refers to relevant spectroscopic data in at least three of the spectra	6
• Demonstrates a sound understanding of the relationship between the highlighted features of the spectra and the structure of pentane-1,5-diamine • Refers to relevant spectroscopic data in at least two of the spectra	4–5
• Demonstrates some understanding of the interpretation of spectroscopic data	2–3
• Provides some relevant information	1

Answers could include:

Infrared spectrum

- Peak at wave number range 3300–3400 cm^{-1} is due to N-H group (amino group)
  The spectrum confirms the presence of amino group.

Mass spectrum

- The highlighted feature is the fragment $CH_2NH_2^+$ ($12 \times 1 + 1.0 \times 4 + 14 \times 1 = 30$)

Carbon-13 NMR spectrum

- There are 5 carbon atoms in the molecule, however, there are only three peaks (three signals) shown in the spectrum.
- Due to symmetry, carbon atoms 1 and 5 are in identical environments. The same is true for carbon atoms 2 and 4. Carbon atom 3 is in a unique environment.
- The signals at 24 and 33 ppm are consistent with $–CH_2–CH_2–$ carbon atoms (5−40 ppm)
- The signal at 42 ppm is due to the C-N-H groups (25−60 ppm)

Proton NMR

- Quintets arise from H atoms with four H atoms on neighbouring C atoms, e.g. the H atoms on C-3 have four neighbouring H atoms on C-2 and C-4.
- The highlighted signal results from similar chemical shifts of protons in two different environments.
- The highlighted signal results from overlap of a 2H signal and a 4H signal, giving 6 H.

Question 30

Criteria	Marks
• Shows a comprehensive understanding of the procedure • Outlines positive and negative aspects of the procedure • Makes an informed judgement	5
• Outlines some positive and negative aspects of the procedure • Makes a judgement	4
• Outlines some positive and/or negative aspects of the procedure	3
• Identifies positive and/or negative aspects of the procedure OR • Outlines a positive OR negative aspect of the procedure	2
• Provides some relevant information	1

Sample answer:

The first test is not necessary to identify either the anion or cation. Sodium won't precipitate with either of the anions and chloride will not precipitate with any of the possible cations.

Adding silver ions to the solution in the second test is appropriate to identify the anion. Silver acetate is a soluble salt, but silver hydroxide is an insoluble, brown salt which dissolves when HCl is added. Therefore the anion must be hydroxide.

The second test also eliminates magnesium as the cation, as magnesium hydroxide is insoluble.

A third test is needed to distinguish between barium and calcium. However, both barium and calcium will produce a precipitate with concentrated sulfate ions as seen in the observations, so this test can't accurately distinguish between barium and calcium ions.

This procedure is insufficient to completely identify both ions in the compound and so is not an appropriate method to identify the unknown compound. A flame test is needed to identify the cation.

Question 31

Criteria	Marks
• Correctly calculates the moles of nitrogen	4
• Provides the main steps of the calculation	3
• Provides some relevant steps of the calculation	2
• Provides some relevant information	1

Sample answer:

N_2	+	$3H_2$	$\rightleftharpoons$	$2NH_3$
4.5 moles + x moles		1.0 moles		5.8 moles
− 0.025 moles		− 0.075 moles		+ 0.05 moles
$4.475 + x$ moles		0.925 moles		5.85 moles
$\frac{4.475 + x}{10}$ mol L^{-1}		0.0925 mol L^{-1}		0.585 mol L^{-1}

$$K_{eq} = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

$$748 = \frac{0.585^2}{\frac{4.475 + x}{10} \times 0.0925^3}$$

$$748 \times \left(\frac{4.475 + x}{10} \times 0.0925^3\right) = 0.585^2$$

$$\frac{4.475 + x}{10} \times 0.0925^3 = \frac{0.585^2}{748}$$

$$\frac{4.475 + x}{10} = \frac{0.585^2}{748 \times 0.0925^3}$$

$$4.475 + x = \frac{10 \times 0.585^2}{748 \times 0.0925^3}$$

$$x = \frac{10 \times 0.585^2}{748 \times 0.0925^3} - 4.475$$

$$x = 1.3 \text{ moles}$$

1.3 moles of nitrogen must be added to the equilibrium mixture.

Question 32

Criteria	Marks
• Shows a thorough understanding of why the first two values are the same and why the last value is different	4
• Shows a sound understanding of why the first two values are the same and why the last value is different	3
• Shows some understanding of the reactions	2
• Provides some relevant information	1

Sample answer:

The net ionic equation for all three reactions is $H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell)$.

HCl and HNO_3 are strong acids and completely ionised. When they react with aqueous KOH they both have the same exothermic enthalpy value due to the same net ionic equation.

When weak acid HCN reacts with aqueous KOH, HCN starts off only partially ionised in an equilibrium reaction with water $HCN(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$. As the reaction proceeds, the HCN will further ionise as the equilibrium shifts to the right. This is endothermic so it removes some heat from the system and the overall reaction is less exothermic than the first two reactions. The reaction has a smaller but still exothermic $\Delta H^\ominus$ value.

Question 33 (a)

Criteria	Marks
• Correctly calculates ΔG	2
• Provides some relevant information	1

Sample answer:

From graph, $T\Delta S$ = –78 kJ/mol, ΔH = –93 kJ/mol

$\Delta G = \Delta H - T\Delta S$ = –93 kJ/mol – –78 kJ/mol = –15 kJ/mol

Answers could include:

Acceptable range of ΔH and $T\Delta S$ to be determined at Marking Centre.

Question 33 (b)

Criteria	Marks
• Makes correct deductions about the system at temperatures T_1, T_2 and T_3 • Supports answer with reference to the graph	4
• Makes correct deductions about the system at two of the temperatures • Refers to the graph	3
• Makes a relevant deduction about the system at temperature(s) T_1 and/or T_2 and/or T_3	2
• Provides some relevant information	1

Sample answer:

At all three temperatures the reaction is exothermic, as ΔH is negative. The entropy of reaction, ΔS is also negative as $T\Delta S$ is negative, and T is always positive. From the relationship $\Delta G = \Delta H - T\Delta S$ we can see that at T_1, ΔG is negative and therefore the reaction is spontaneous. At T_2 $\Delta G = 0$ and therefore the system is in equilibrium. At T_3, ΔG is positive and therefore the reaction is non-spontaneous.

Question 34

Criteria	Marks
• Explains the pH of water, solution *X* and solution *Y* • Includes a relevant balanced equation	5
• Shows a sound understanding of the pH of the water, solution *X* and solution *Y* • Includes a balanced equation	4
• Shows some understanding of the pH of the water and/or solution *X* and/or solution *Y* AND/OR • Includes a balanced equation	2–3
• Provides some relevant information	1

Sample answer:

At t_0 the pH of water is 7. *X* and *Y* have pH 4.9 so are acidic.

At t_1, the pH of water is dropping rapidly due to production of H_3O^+. The pH of *X* and *Y* have only dropped slightly, therefore they are buffers. When HCl is added it donates a proton to the base, producing HA instead of H_3O^+ minimising the change in pH:

$HCl(g) + A^-(aq) \rightleftharpoons HA(aq) + Cl^-(aq)$

At t_2, the pH of *X* and *Y* have begun to decrease, but the pH of *X* is lower. A^- has been used up so $[H_3O^+]$ increases lowering the pH. The pH is lower for *X* because it was a less concentrated buffer initially and the A^- was used up more rapidly.

Question 35

Criteria	Marks
• Correctly calculates the concentration of ethanol in the undiluted sample in % v/v • Removes the outlier from the calculation of thiosulfate volume • Provides a judgement about the ethanol concentration consistent with the calculations	7
• Provides substantially correct steps for calculating the concentration of ethanol • Provides a judgement about the ethanol concentration consistent with the calculations	6
• Provides the main steps for calculating the concentration of ethanol	4–5
• Provides some steps for calculating the concentration of ethanol	2–3
• Provides some relevant information	1

Sample answer:

Titration 1 is an outlier and excluded from the average.

$$\text{Average } V\left(S_2O_3^{2-}\right) = \frac{28.7 + 28.4 + 28.6}{3} = 28.5667 \text{ mL} = 0.0285667 \text{ L}$$

$$n\left(S_2O_3^{2-}\right) = cV = 0.900 \text{ mol L}^{-1} \times 0.0285667 \text{ L} = 0.02571 \text{ mol}$$

$$n\left(S_2O_3^{2-}\right) = n\left(I_2\right) = 2:1 \qquad \therefore\ n\left(I_2\right) = \frac{1}{2} \times 0.02571 = 0.012853 \text{ mol}$$

$$n\left(I_2\right) : n\left(\text{excess } Cr_2O_7^{2-}\right) = 3:1$$

$$\therefore\ n\left(\text{excess } Cr_2O_7^{2-}\right) = \frac{1}{3} \times 0.012853 = 0.004285 \text{ mol}$$

$$n\left(\text{initial } Cr_2O_7^{2-}\right) = cV = 0.500 \text{ mol L}^{-1} \times 0.0200 \text{ L} = 0.0100 \text{ mol}$$

$$n\left(Cr_2O_7^{2-} \text{ reacted with ethanol}\right) = n\left(\text{initial } Cr_2O_7^{2-}\right) - n\left(\text{excess } Cr_2O_7^{2-}\right)$$

$$= 0.0100 - 0.004285 = 0.005715 \text{ mol}$$

$$n\left(Cr_2O_7^{2-} \text{ reacted with ethanol}\right) : n\left(\text{ethanol}\right) = 2:3$$

$$\therefore\ n\left(\text{ethanol}\right) = \frac{3}{2} \times 0.005715 = 0.0085725 \text{ mol}$$

$$m\left(C_2H_5OH\right) = n \times MM = 0.0085725 \text{ mol} \times (2 \times 12.01 + 6 \times 1.008 + 16.00) \text{ g mol}^{-1}$$

$$= 0.00857 \text{ mol} \times 46.068 \text{ g mol L}^{-1} = 0.394918 \text{ g in 25.0 mL diluted solution}$$

$$m\left(C_2H_5OH\right) = \frac{1000.0}{25.0} \times 0.394918\ldots = 15.797\ldots \text{ g in 25.0 mL undiluted sample}$$

$$V\left(C_2H_5OH\right) = 15.797\ldots \text{ g} \div 0.789 \text{ g mL}^{-1} = 20.02\ldots \text{ mL}$$

$$\%\left(C_2H_5OH\right) = (20.02 \text{ mL} \div 25.0 \text{ mL}) \times 100 = 80.08\%\ldots = 80\% \text{ v/v}$$

As the concentration found is under 85%, the product does not meet the manufacturer's requirement.

Question 36

Criteria	Marks
• Calculates K_{eq}	5
• Provides the main steps of the calculation	4
• Provides some relevant steps of the calculation	2–3
• Provides some relevant information	1

Sample answer:

The pK_a of sulfurous acid in the following reaction is 1.82.

$$H_2SO_3(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HSO_3^-(aq)$$

K_a for sulfurous acid is:

$K_a = 10^{-pK}$

$K_a = 10^{-1.82} = 0.01513561248 = 1.51 \times 10^{-2}$

K_a for hydrogen sulfite is:

$K_a = 10^{-pK_a}$

$K_a = 10^{-7.17} = 0.0000000676 = 6.76 \times 10^{-8}$

(1) $H_2SO_3(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HSO_3^-(aq) \quad K_a(1) = 1.51 \times 10^{-2}$

(2) $HSO_3^-(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(\ell) \quad K_a(2) = 6.76 \times 10^{-8}$

$$K_a(1) = \frac{\left[H_3O^+\right]\left[HSO_3^-\right]}{\left[H_2SO_3\right]}$$

$$K_a(2) = \frac{\left[H_3O^+\right]\left[SO_3^{2-}\right]}{\left[HSO_3^-\right]}$$

For $H_2SO_3(aq) + 2H_2O(\ell) \rightleftharpoons 2H_3O^+(aq) + SO_3^{2-}(aq)$

$$K_{eq} = \frac{\left[H_3O^+\right]^2\left[SO_3^{2-}\right]}{\left[H_2SO_3\right]}$$

$$K_a(1) \times K_a(2) = \frac{\left[H_3O^+\right]^2\left[HSO_3^{\ -}\right]\left[SO_3^{\ 2-}\right]}{\left[HSO_3^{\ -}\right]\left[H_2SO_3\right]}$$

$$= \frac{\left[H_3O^+\right]^2\cancel{\left[HSO_3^{\ -}\right]}\left[SO_3^{\ 2-}\right]}{\cancel{\left[HSO_3^{\ -}\right]}\left[H_2SO_3\right]}$$

$$= \frac{\left[H_3O^+\right]^2\left[SO_3^{\ 2-}\right]}{\left[H_2SO_3\right]}$$

$$= K_{eq}$$

$$K_{eq} = 1.51 \times 10^{-2} \times 6.76 \times 10^{-8}$$

$$= 1.0 \times 10^{-9}$$

2021 HSC Chemistry Mapping Grid

Section I

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

Section II

Question	Marks	Content	Syllabus outcomes
21 (a)	2	Mod 7 Hydrocarbons	12-2, 12-14
21 (b)	2	Mod 8 Analysis of organic substances	12-5, 12-15
21 (c)	2	Mod 8 Analysis of organic substances	12-3, 12-15
22	3	Mod 5 Factors affecting equilibrium	12-6, 12-12
23 (a)	2	Mod 6 Using Brønsted–Lowry, reactions of organic acids and bases	12-6, 12-13
23 (b)	2	Mod 6 Using Brønsted–Lowry, reactions of organic acids and bases	12-6, 12-13
24	4	Mod 7 Nomenclature	12-6, 12-7, 12-14
25	4	Mod 7 Alcohols	12-5, 12-6, 12-14

Question	Marks	Content	Syllabus outcomes
26 (a)	4	Mod 7 Alcohols Mod 7 Reactions of organic acids and bases	12-6,12-7,12-14
26 (b)	2	Mod 7 Reactions of organic acids and bases	12-2, 12-14
27 (a)	4	Mod 5 Solution equilibria	12-5, 12-6, 12-12
27 (b)	2	Mod 5 Solution equilibria	12-2, 12-12
28	4	Mod 8 Analysis of inorganic substances	12-6, 12-15
29	7	Mod 8 Analysis of organic substances	12-4,12-5, 12-6,12-15
30	5	Mod 8 Analysis of inorganic substances	12-2, 12-4, 12-15
31	4	Mod 5 Calculating the equilibrium constant	12-5, 12-6, 12-12
32	4	Mod 6 Properties of acids and bases Mod 6 Quantitative analysis	12-4, 12-5, 12-6, 12-13
33 (a)	2	Mod 5 Static and dynamic equilibrium	12-4, 12-5, 12-12
33 (b)	4	Mod 5 Static and dynamic equilibrium	12-4, 12-5, 12-6, 12-12
34	5	Mod 6 Quantitative analysis	12-4, 12-5, 12-6, 12-13
35	7	Mod 6 Quantitative analysis Mod 7 Alcohols	12-4, 12-6, 12-13, 12-14
36	5	Mod 6 Quantitative analysis	12-4, 12-6, 12-13