



NSW Education Standards Authority

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Centre Number

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Student Number

**2024** HIGHER SCHOOL CERTIFICATE EXAMINATION

# Chemistry

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## 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
- Write your Centre Number and Student Number at the top of this page

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## Total marks: 100

### Section I – 20 marks (pages 2–12)

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

### Section II – 80 marks (pages 13–40)

- Attempt Questions 21–39
- Allow about 2 hours and 25 minutes for this section

## Section I

20 marks

Attempt Questions 1–20

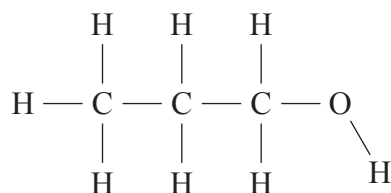
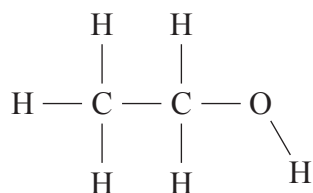
Allow about 35 minutes for this section

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

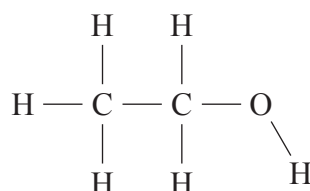
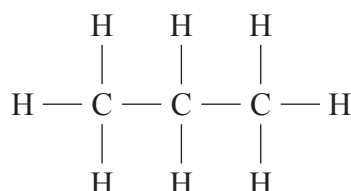
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1 Which two substances are members of the same homologous series?

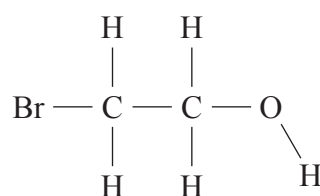
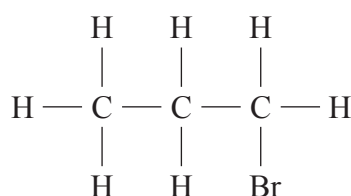
A.



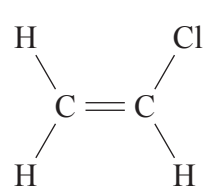
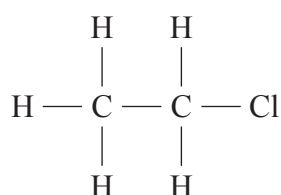
B.



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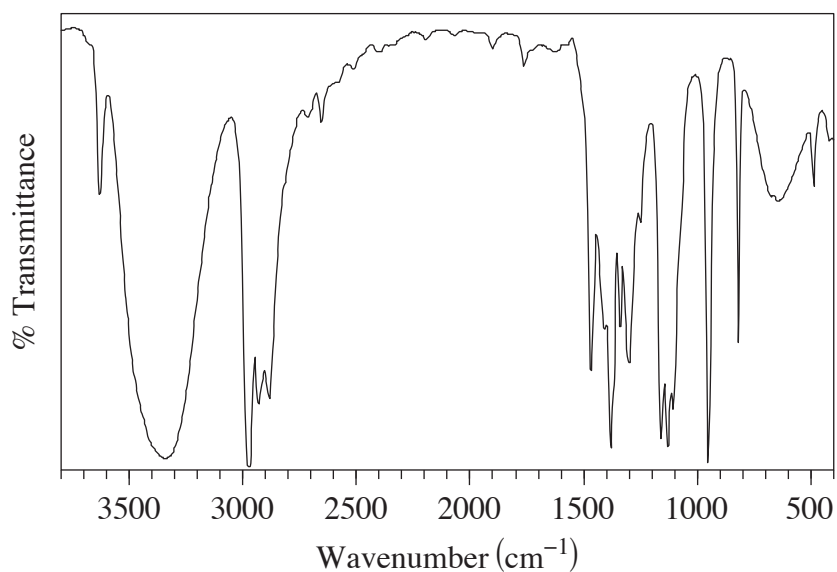


2 Aboriginal and Torres Strait Islander Peoples have used leaching in flowing water over several days to prepare various foods from plants that can be toxic to humans.

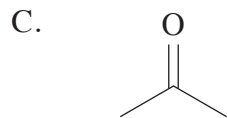
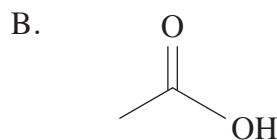
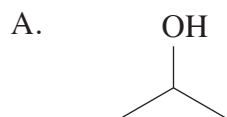
What was the reason for this?

- A. To react with toxins
- B. To dissolve low solubility toxins
- C. To prevent the food from decomposing
- D. To break down compounds that are difficult to digest

- 3 Which of the following compounds can be correctly described as an Arrhenius base when dissolved in water?
- A. Sodium nitrate
  - B. Sodium sulfate
  - C. Sodium chloride
  - D. Sodium hydroxide
- 4 An infrared spectrum of an organic compound is shown.



Which of the following compounds would produce the spectrum shown?



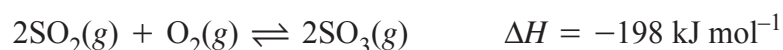
5 Which would be the best reagent to use to determine whether an unknown substance was 2-methylpropan-1-ol or 2-methylpropan-2-ol?

- A. Bromine water
- B. Potassium nitrate solution
- C. Sodium carbonate solution
- D. Acidified potassium permanganate solution

6 What is the hydroxide ion concentration of a solution of potassium hydroxide with a pH of 11?

- A.  $10^{-11} \text{ mol L}^{-1}$
- B.  $10^{-3} \text{ mol L}^{-1}$
- C.  $10^3 \text{ mol L}^{-1}$
- D.  $10^{11} \text{ mol L}^{-1}$

7 The following equilibrium was established in a container.



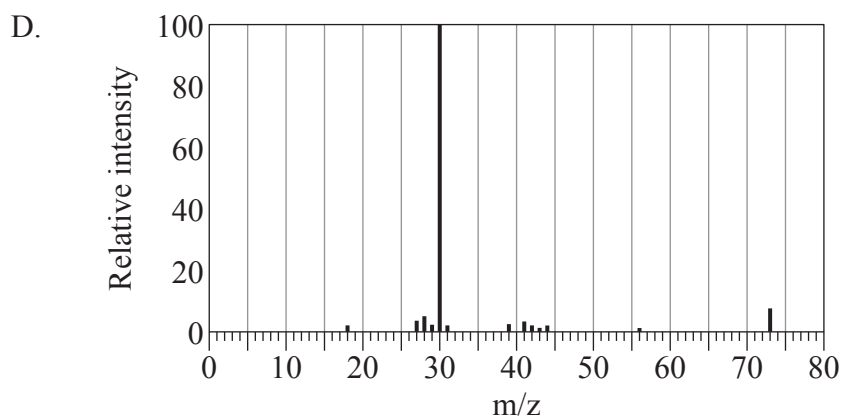
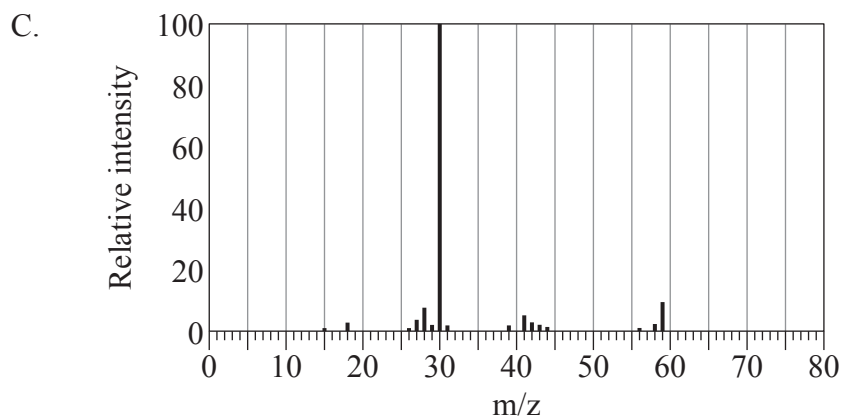
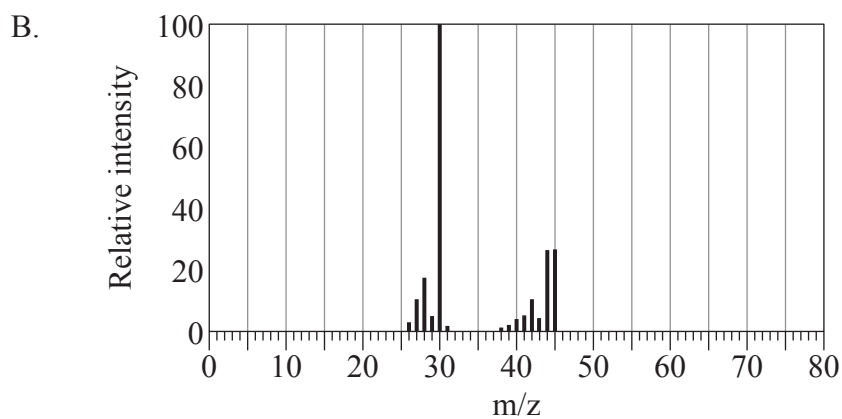
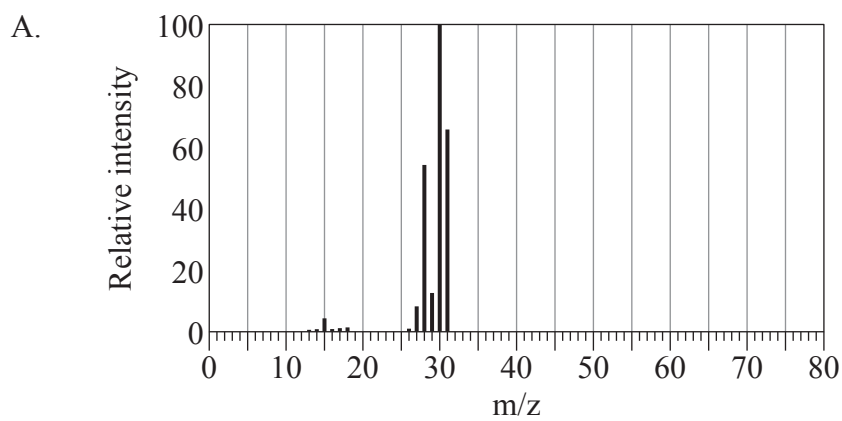
Which of the following would increase the yield of  $\text{SO}_3(\text{g})$ ?

- A. Increasing the volume
- B. Increasing the temperature
- C. Removing the product as it is formed
- D. Keeping temperature and volume constant

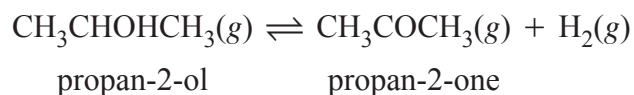
8 Which pair of ions produce different colours in a flame test?

- A.  $\text{Br}^-$  and  $\text{Cl}^-$
- B.  $\text{Ag}^+$  and  $\text{OH}^-$
- C.  $\text{Cu}^{2+}$  and  $\text{Ca}^{2+}$
- D.  $\text{CH}_3\text{OOO}^-$  and  $\text{H}_2\text{PO}_4^-$

9 Which of the following is the mass spectrum of ethanamine?



- 10 The following system is at equilibrium.



A catalyst is added to the system.

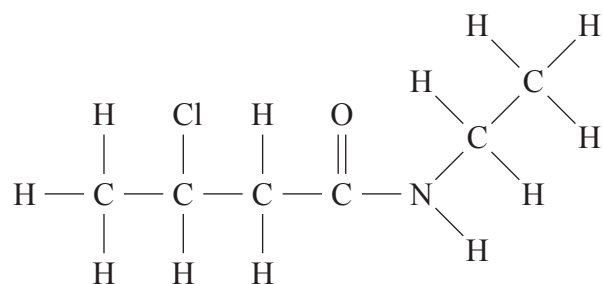
Which row of the table correctly identifies the change in the yield of propan-2-one and the reaction rates?

|    | <i>Yield of<br/>propan-2-one</i> | <i>Reaction rates</i>                                        |
|----|----------------------------------|--------------------------------------------------------------|
| A. | Remains the same                 | Both forward and reverse rates are unchanged.                |
| B. | Remains the same                 | Both forward and reverse rates increase equally.             |
| C. | Decreases                        | Reverse rate increases more than the forward rate increases. |
| D. | Increases                        | Forward rate increases more than the reverse rate increases. |

- 11 Which is the correct expression for calculating the solubility (in  $\text{mol L}^{-1}$ ) of lead(II) iodide in a  $0.1 \text{ mol L}^{-1}$  solution of NaI at  $25^\circ\text{C}$ ?

- A.  $\frac{9.8 \times 10^{-9}}{2 \times 0.1}$
- B.  $\frac{9.8 \times 10^{-9}}{(2 \times 0.1)^2}$
- C.  $\frac{9.8 \times 10^{-9}}{0.1}$
- D.  $\frac{9.8 \times 10^{-9}}{(0.1)^2}$

- 12 The structure of an organic substance is shown.



What is the preferred IUPAC name for this substance?

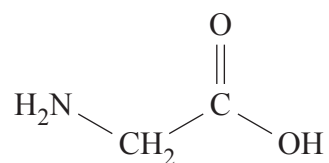
- A. 2-chloro-1-ethylbutanamide
  - B. 2-chloro-*N*-ethylpropanamide
  - C. 3-chloro-*N*-ethylbutanamide
  - D. 3-chloro-1-ethylpropanamide
- 13 A fuel has these enthalpies of combustion:  $-2057.8 \text{ kJ mol}^{-1}$  and  $-48.9 \text{ kJ g}^{-1}$ .

Which of the following correctly identifies the fuel?

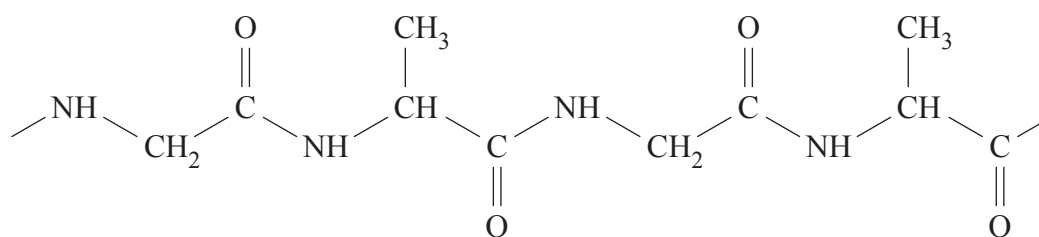
- A. Ethanol ( $MM = 46.1 \text{ g mol}^{-1}$ )
- B. Propane ( $MM = 44.1 \text{ g mol}^{-1}$ )
- C. Propene ( $MM = 42.1 \text{ g mol}^{-1}$ )
- D. Hydrogen ( $MM = 2.02 \text{ g mol}^{-1}$ )

- 14 Glycine, an amino acid, can react with itself or other amino acid monomers to form silk, a natural polymer.

Glycine has the structure:

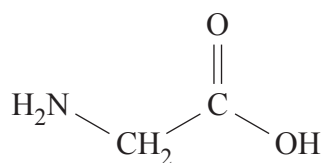


A section of silk polymer is shown.

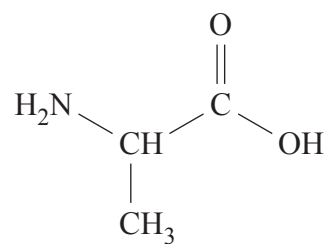


Which monomer could react with glycine to form this section of silk polymer?

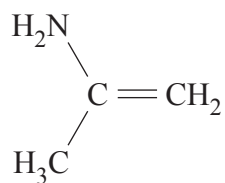
A.



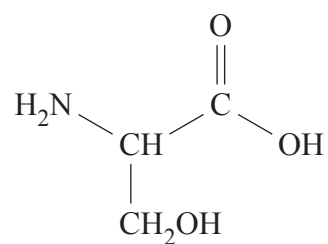
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C.



D.





- 15** The thermal decomposition of lithium peroxide ( $\text{Li}_2\text{O}_2$ ) is given by the equation shown.

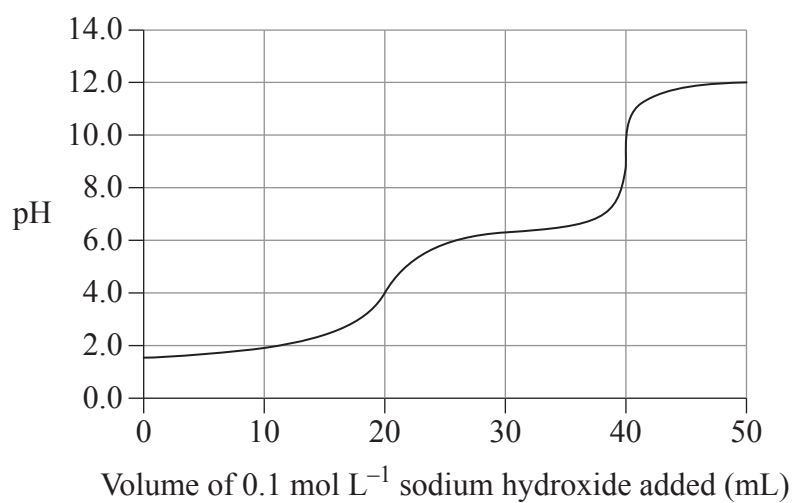


Mixtures of  $\text{Li}_2\text{O}_2$ ,  $\text{Li}_2\text{O}$  and  $\text{O}_2$  were allowed to reach equilibrium in two identical, closed containers, P and Q, at the same temperature. The amount of  $\text{Li}_2\text{O}_2(s)$  in container P is double that in container Q. The amount of  $\text{Li}_2\text{O}(s)$  is the same in each container.

What is the ratio of  $[\text{O}_2(g)]$  in container P to  $[\text{O}_2(g)]$  in container Q?

- A. 1 : 1
  - B. 2 : 1
  - C. 3 : 2
  - D. 5 : 4
- 16** Which of the following is the overall reaction that takes place when a strong acid is added to a buffer containing equal amounts of acetic acid and acetate ions?
- A.  $\text{HCOO}^- + \text{H}_3\text{O}^+ \rightarrow \text{HCOOH} + \text{H}_2\text{O}$
  - B.  $\text{CH}_3\text{COOH} + \text{OH}^- \rightarrow \text{CH}_3\text{COO}^- + \text{H}_2\text{O}$
  - C.  $\text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+ \rightarrow \text{CH}_3\text{COOH} + \text{H}_2\text{O}$
  - D.  $\text{CH}_3\text{COOH} + \text{H}_3\text{O}^+ \rightarrow \text{CH}_3\text{C}(\text{OH})_2^+ + \text{H}_2\text{O}$

- 17 20 mL of a  $0.1 \text{ mol L}^{-1}$  solution of an acid is titrated against a  $0.1 \text{ mol L}^{-1}$  solution of sodium hydroxide. A graph of pH against the volume of sodium hydroxide for this experiment is shown.



Which of the following acids was used in the titration?

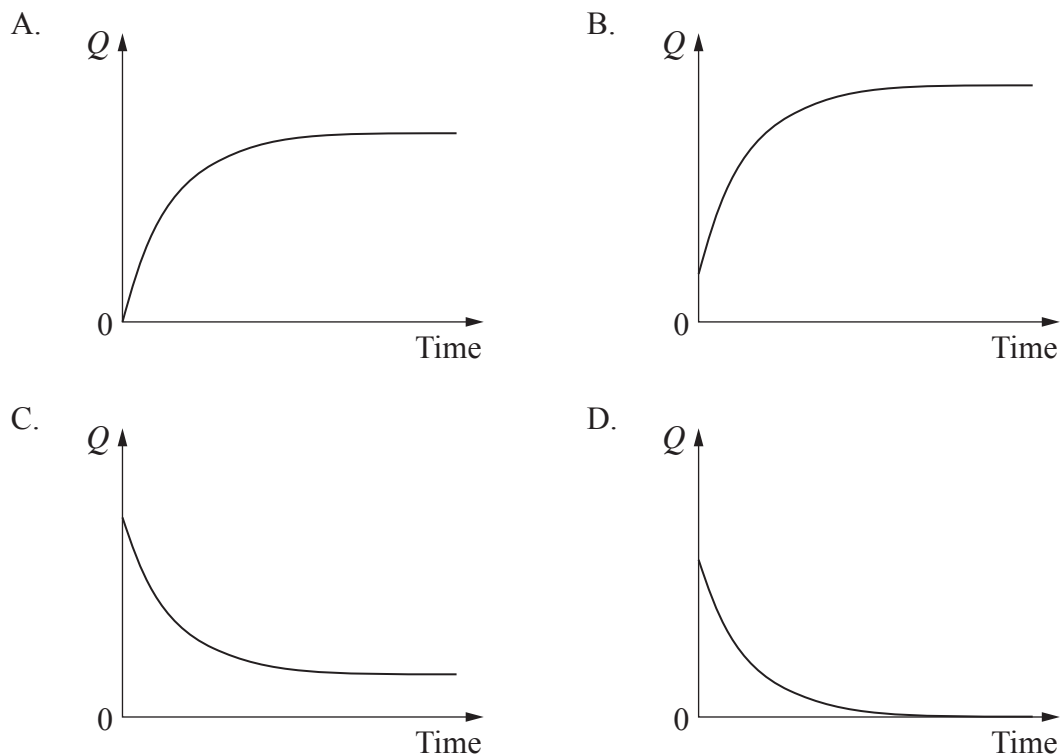
|    | <i>Acid</i> | $pK_{a1}$ | $pK_{a2}$ |
|----|-------------|-----------|-----------|
| A. | 1           | 4.76      | —         |
| B. | 2           | Strong    | —         |
| C. | 3           | 1.91      | 6.30      |
| D. | 4           | 4.11      | 9.61      |

- 18 A reaction mixture, not at equilibrium, is composed of both  $\text{N}_2\text{O}_4(g)$  and  $\text{NO}_2(g)$  in a closed container. The reaction quotient for the system,  $Q$ , is given.

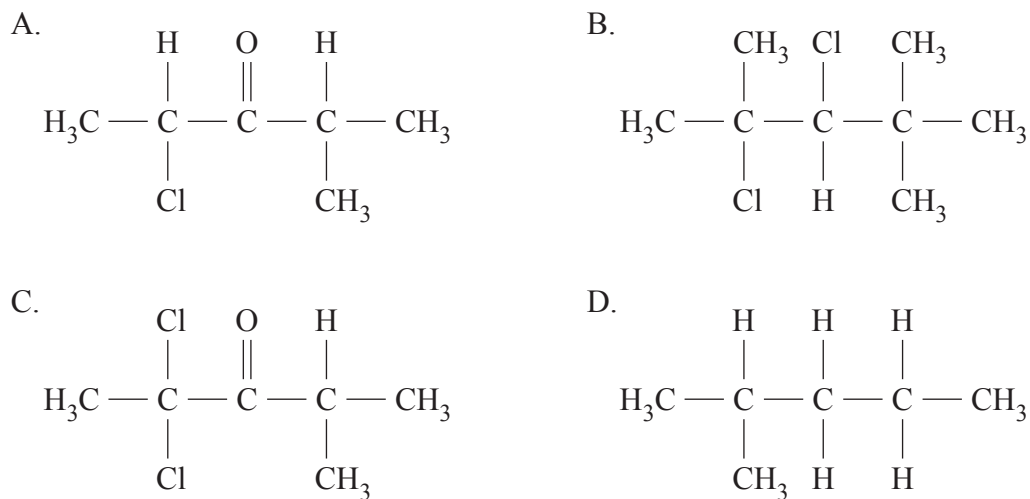
$$Q = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$$

The rate of the forward reaction is initially greater than the rate of the reverse reaction.

Which diagram shows how  $Q$  changes over time for this mixture?



- 19 Which of the following compounds produces TWO doublets in the  $^1\text{H}$  NMR spectrum?



**20** The concentration of ascorbic acid ( $MM = 176.124 \text{ g mol}^{-1}$ ) in solution A was determined by titration.

- A 25.00 mL sample of solution A was titrated with potassium hydroxide solution.
- 50.00 mg of ascorbic acid was added to a second 25.00 mL sample of solution A, which was titrated in the same way.

Titration volumes for both titrations are given.

| <i>Solution</i>                                    | <i>Titre (mL)</i> |
|----------------------------------------------------|-------------------|
| 25.00 mL solution A                                | 17.50             |
| 25.00 mL solution A +<br>50.00 mg of ascorbic acid | 33.10             |

What is the concentration of ascorbic acid in solution A?

- A.  $5.352 \times 10^{-3} \text{ mol L}^{-1}$
- B.  $6.004 \times 10^{-3} \text{ mol L}^{-1}$
- C.  $1.012 \times 10^{-2} \text{ mol L}^{-1}$
- D.  $1.274 \times 10^{-2} \text{ mol L}^{-1}$

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Centre Number

# Chemistry

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Student Number

## Section II Answer Booklet

**80 marks**

**Attempt Questions 21–39**

**Allow about 2 hours and 25 minutes for this section**

### Instructions

- Write your Centre Number and Student Number at the top of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.
- Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which question you are answering.

**Please turn over**

**Question 21** (2 marks)

A solution of acetic acid reacts with magnesium metal.

2

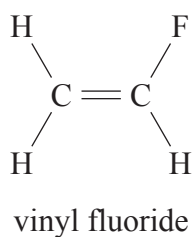
Write the names of the products of this reaction in the boxes provided.



**Question 22** (2 marks)

Vinyl fluoride can be polymerised.

2

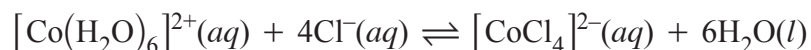


In the box provided, draw the structural formula for a six-carbon section of the polymer formed from the polymerisation of vinyl fluoride.

Do NOT write in this area.

**Question 23** (3 marks)

Consider the following equilibrium system.

**3**

$[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$  is pink and  $[\text{CoCl}_4]^{2-}(\text{aq})$  is blue. When a solution of these ions and chloride ions is heated, the mixture becomes more blue.

Relate the observed colour change to the change in  $K_{eq}$ .

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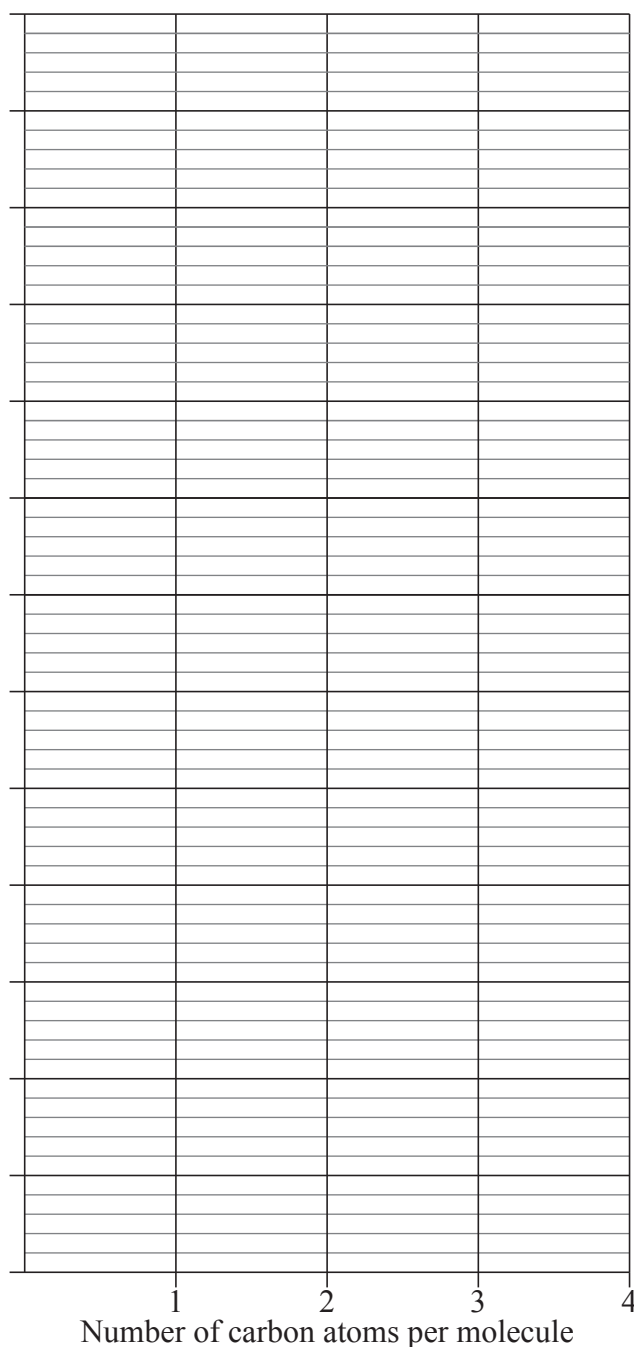
**Please turn over**

**Question 24** (7 marks)

The boiling points for two series of compounds are listed.

| <i>Amine</i>   | <i>Boiling point (°C)</i> | <i>Alcohol</i> | <i>Boiling point (°C)</i> |
|----------------|---------------------------|----------------|---------------------------|
| Methanamine    | −6                        | Methanol       | 65                        |
| Ethanamine     | 17                        | Ethanol        | 78                        |
| Propan-1-amine | 48                        | Propan-1-ol    | 97                        |
| Butan-1-amine  | 78                        | Butan-1-ol     | 118                       |

- (a) Plot the boiling points for each series of compounds against the number of carbon atoms per molecule.

**3****Question 24 continues on page 17**



Question 24 (continued)

- (b) With reference to hydrogen bonding and dispersion forces, explain the trends in the boiling point data of these compounds, within each series and between the series.

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**End of Question 24**

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**Question 25** (4 marks)

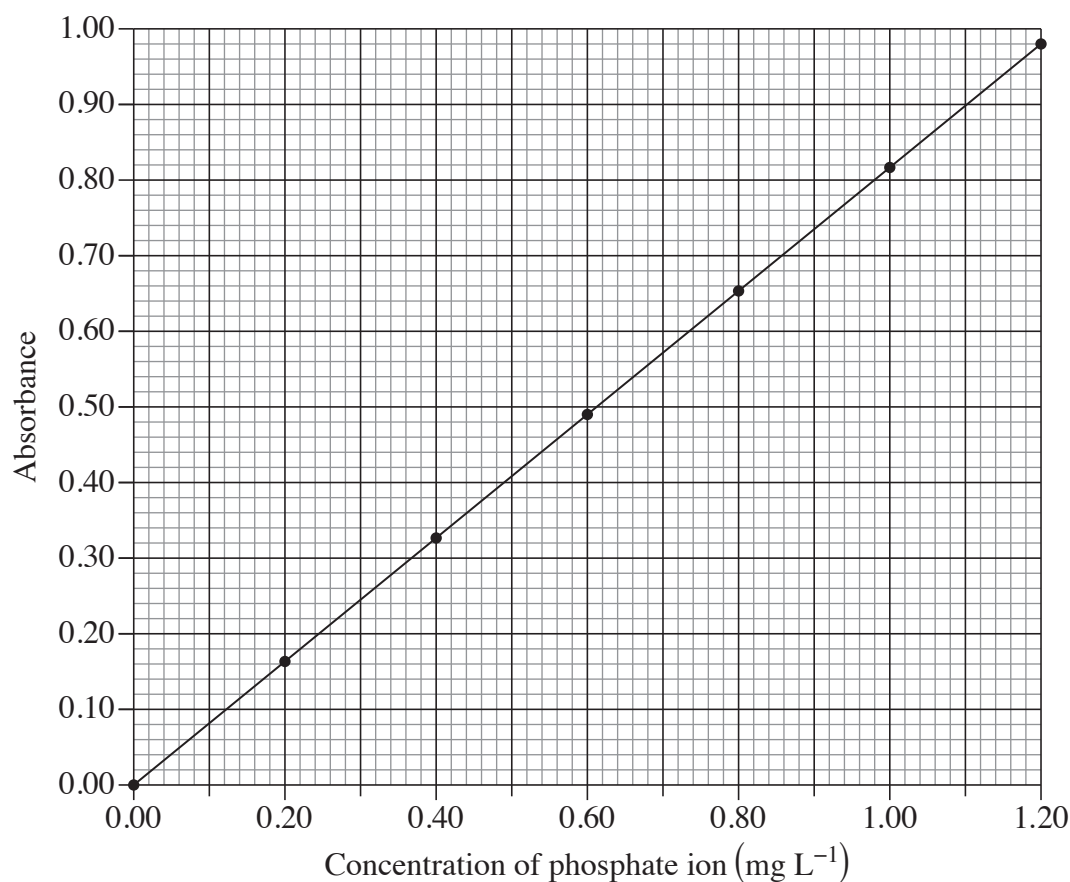
The concentration of phosphate ions in washing machine waste water can be determined using colourimetry.

4

A sample of washing machine waste water was collected and diluted by quantitatively transferring 1.00 mL of the solution to a volumetric flask and making up the volume to 1.000 L with distilled water.

Standard phosphate solutions were prepared and analysed with a colourimeter using an accepted method.

The standard calibration graph is shown.



**Question 25 continues on page 19**

Question 25 (continued)

The diluted sample solution was then analysed using the same method as the standard solutions. The absorbance of this solution was found to be 0.64.

Determine the concentration of phosphate ions in the sample of washing machine waste water, in  $\text{mol L}^{-1}$ .

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**End of Question 25**

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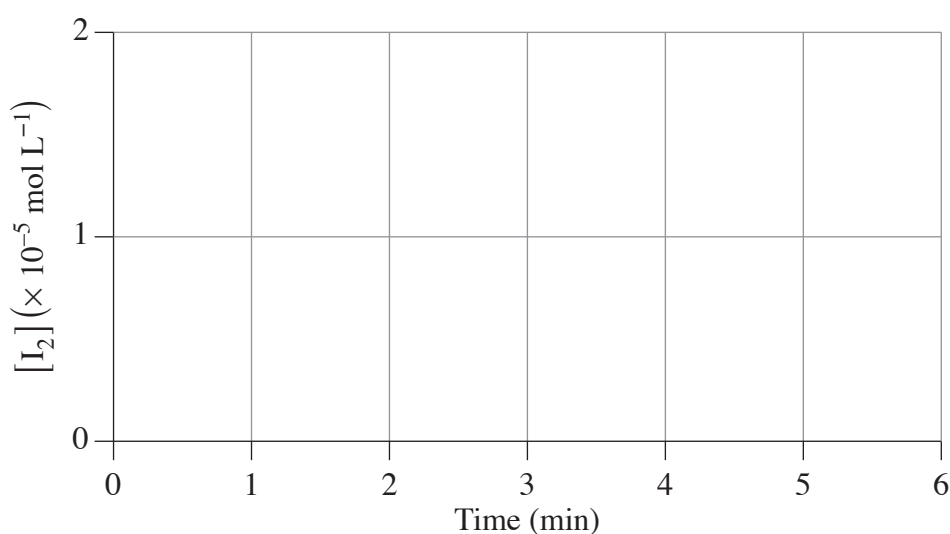
**Question 26** (5 marks)

The equilibrium equation for the reaction of iodine with hydrogen cyanide in aqueous solution is given.



At  $t = 0$  min,  $\text{I}_2$  was added to a mixture of  $\text{HCN}$ ,  $\text{I}^-$  and  $\text{H}^+$ , bringing  $[\text{I}_2]$  to  $2.0 \times 10^{-5} \text{ mol L}^{-1}$ . After 3 minutes, the system was at equilibrium, and an analysis of the mixture found that half of the  $\text{I}_2$  had reacted.

- (a) On the axes provided, sketch a graph to show how  $[\text{I}_2]$  changes in the solution between  $t = 0$  min and  $t = 6$  min. 2



- (b) Using collision theory, explain the rate of reaction between  $t = 0$  min and  $t = 6$  min. Refer to the  $[\text{I}_2]$  in your answer. 3

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**Question 27** (4 marks)

The following procedure is proposed to test for the presence of lead(II) and barium ions in water at concentrations of  $0.1 \text{ mol L}^{-1}$ .

**4**

1. Add excess  $0.1 \text{ mol L}^{-1}$  sodium sulfate solution. If a precipitate is produced, then barium ions are present.
2. Filter any precipitate produced.
3. Add excess  $0.1 \text{ mol L}^{-1}$  sodium bromide solution to the filtrate. If a precipitate is produced, then lead(II) ions are present.

Explain why this procedure gives correct results when only barium ions are present, but not when both barium and lead(II) ions are present. Include ONE balanced chemical equation in your answer.

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**Please turn over**

**Question 28** (3 marks)

Iodic acid and sulfamic acid are monoprotic acids. A  $0.100 \text{ mol L}^{-1}$  solution of iodic acid has a pH of 1.151, as does a  $0.120 \text{ mol L}^{-1}$  solution of sulfamic acid.

**3**

Show that neither iodic acid nor sulfamic acid dissociates completely in water, and determine which is the stronger acid.

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**Question 29** (4 marks)

150 mL of a  $0.20 \text{ mol L}^{-1}$  sodium hydroxide solution is added to 100 mL of a  $0.10 \text{ mol L}^{-1}$  sulfuric acid solution.

**4**

Calculate the pH of the resulting solution, assuming that the volume of the resulting solution is 250 mL and that its temperature is  $25^\circ\text{C}$ .

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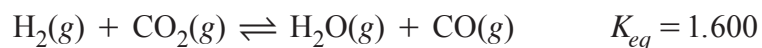
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**Question 30** (4 marks)

An equilibrium mixture of hydrogen, carbon dioxide, water and carbon monoxide is in a closed, 1 L container at a fixed temperature as shown:

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The initial concentrations are  $[\text{H}_2] = 1.000 \text{ mol L}^{-1}$ ,  $[\text{CO}_2] = 0.500 \text{ mol L}^{-1}$ ,  $[\text{H}_2\text{O}] = 0.400 \text{ mol L}^{-1}$  and  $[\text{CO}] = 2.000 \text{ mol L}^{-1}$ .

An unknown amount of  $\text{CO}(\text{g})$  was added to the same container, and the temperature was kept constant. After the new equilibrium had been established, the concentration of  $\text{H}_2\text{O}(\text{g})$  was found to be  $0.200 \text{ mol L}^{-1}$ .

Using this information, calculate the unknown amount (in mol) of  $\text{CO}(\text{g})$  that was added to the container.

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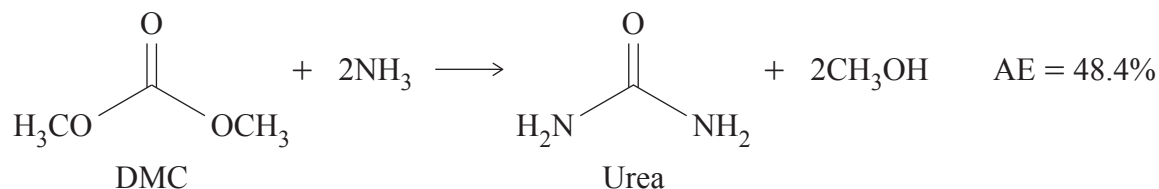
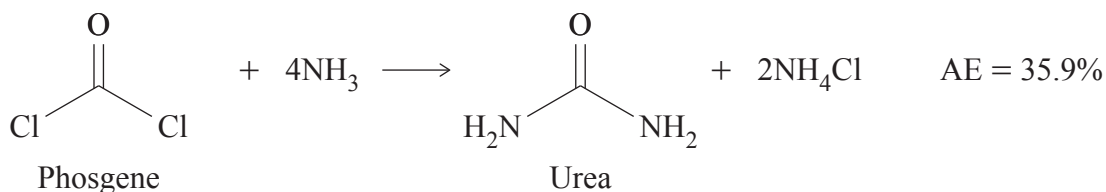


**Question 31** (3 marks)

The atom economy (AE) of a reaction is a measure of the mass of atoms in the starting materials that are incorporated into the desired product. Higher AE means lower mass of waste products.

3

Urea can be produced in a variety of ways. One way is to react ammonia (high toxicity) with phosgene (high toxicity). Another way is to react ammonia with dimethyl carbonate (DMC, low toxicity). The chemical equations and AE for these two processes are provided.



Which of these two processes is preferable for urea production? Justify your answer with reference to the information provided.

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**Question 32 (4 marks)**

Calculate the concentration of cadmium ions in a saturated solution of cadmium(II) phosphate,  $\text{Cd}_3(\text{PO}_4)_2$ ,  $K_{sp} = 2.53 \times 10^{-33}$ .

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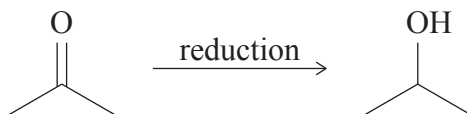
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**Question 33** (5 marks)

Acetone can be reduced, as shown.



- (a) Identify the shape around the central carbon atom in each molecule.

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- (b) Explain how  $^{13}\text{C}$  NMR spectroscopy could be used to monitor the progress of this reaction.

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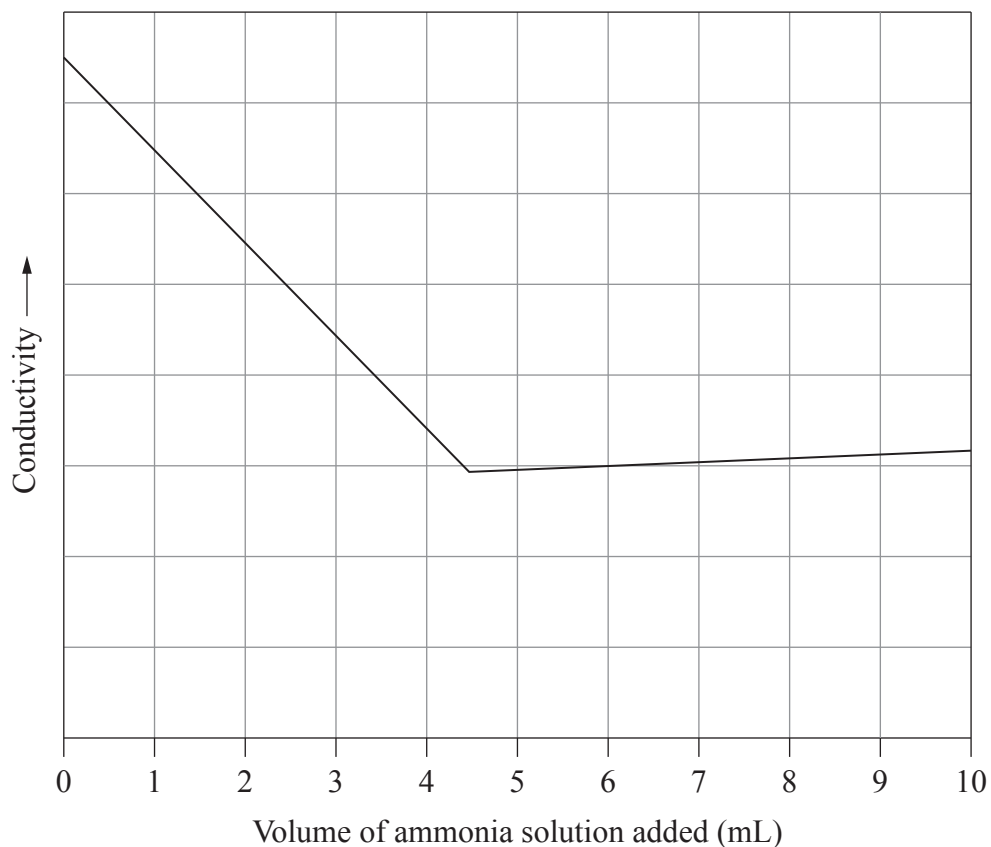
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**Question 34** (4 marks)

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An aqueous solution of ammonia is added to a solution containing hydrochloric acid. A plot of conductivity against volume of ammonia solution added is shown. The temperature of the solution is kept constant throughout and the conductivity of the solution is corrected for dilution.



The relative conductivities of some relevant ions are shown in the table.

| <i>Ion</i>      | <i>Relative conductivity</i> |
|-----------------|------------------------------|
| $\text{H}^+$    | 4.76                         |
| $\text{OH}^-$   | 2.70                         |
| $\text{Cl}^-$   | 1.04                         |
| $\text{NH}_4^+$ | 1.00                         |

**Question 34 continues on page 29**

## Question 34 (continued)

Explain the shape of the graph. Include TWO balanced chemical equations in your answer.

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**End of Question 34**

**Please turn over**

**Question 35** (7 marks)

Unknown samples of three carboxylic acids, labelled X, Y and Z, are analysed to determine their identities.

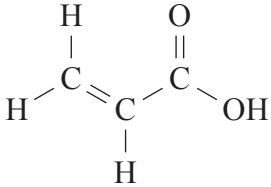
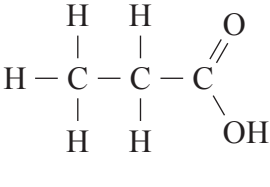
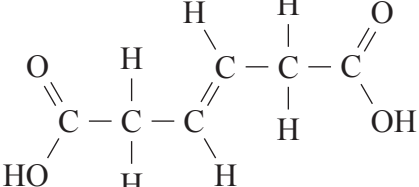
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- Both Y and Z react rapidly with bromine in the absence of UV light, but X does not. A 0.100 g sample of Y reacts with the same amount of bromine as a 0.200 g sample of Z.
- Separate 0.100 g samples of X, Y and Z are titrated with 0.0617 mol L<sup>-1</sup> sodium hydroxide solution. The titre volumes are shown.

| Acid                | X     | Y     | Z     |
|---------------------|-------|-------|-------|
| Volume of NaOH (mL) | 21.88 | 22.49 | 22.49 |

- Both Y and Z can undergo hydration reactions in the presence of a suitable catalyst. Two products are possible for the hydration of Y, but only one product is possible with Z.

Identify which structures 1, 2 and 3 in the table are acids X, Y and Z. Justify your answer with reference to the information provided.

|                                   | Structure 1                                                                         | Structure 2                                                                         | Structure 3                                                                          |
|-----------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|                                   |  |  |  |
| Molar mass (g mol <sup>-1</sup> ) | 72.062 g mol <sup>-1</sup>                                                          | 74.078 g mol <sup>-1</sup>                                                          | 144.124 g mol <sup>-1</sup>                                                          |
| Acid (X, Y or Z)                  |                                                                                     |                                                                                     |                                                                                      |

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**Question 35 continues on page 31**

[illegible]

– 31 –

**Question 36** (5 marks)

14.7 g of solid sodium hydrogen carbonate ( $MM = 84.008 \text{ g mol}^{-1}$ ) was reacted with 120 mL of  $1.50 \text{ mol L}^{-1}$  hydrochloric acid solution (density  $1.02 \text{ g mL}^{-1}$ ) in a calorimeter. The temperature of the solution before and after reaction was recorded.

5

| <i>Initial temperature of<br/>hydrochloric acid solution<br/>(°C)</i> | <i>Final temperature of<br/>reaction solution<br/>(°C)</i> |
|-----------------------------------------------------------------------|------------------------------------------------------------|
| 21.5                                                                  | 11.5                                                       |

Assume that all  $\text{CO}_2$  produced is lost from the reaction solution and that the specific heat capacity of the reaction solution is  $3.80 \text{ J K}^{-1} \text{ g}^{-1}$ .

What is the enthalpy of reaction, in  $\text{kJ mol}^{-1}$ ?

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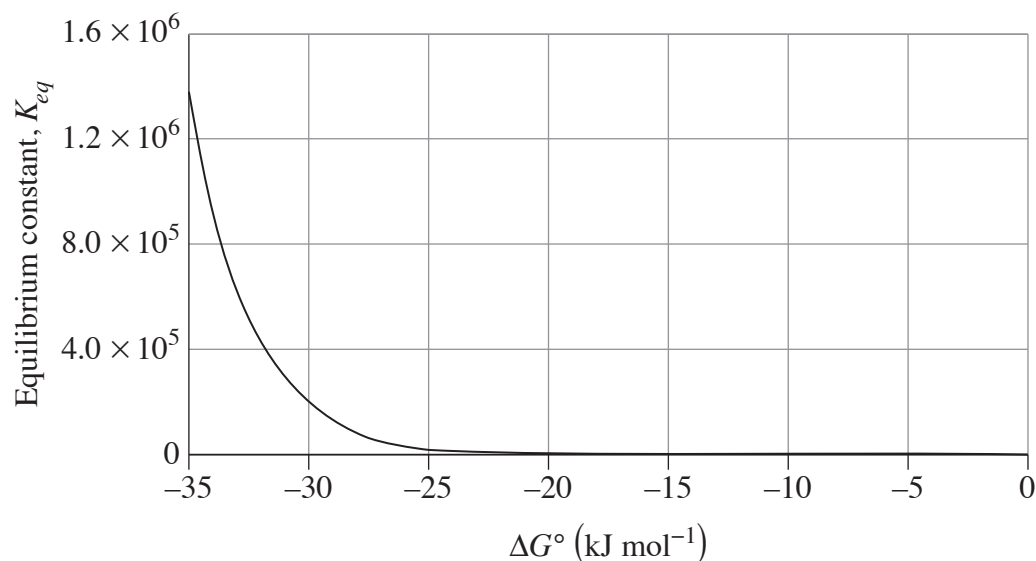
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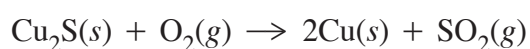


**Question 37** (3 marks)

The relationship between the equilibrium constant,  $K_{eq}$ , and  $\Delta G^\circ$  for any reaction is shown in the graph, for a limited range of  $\Delta G^\circ$  values.

**3**

The  $\Delta H^\circ$  and  $T\Delta S^\circ$  values for the reaction between copper(I) sulfide and oxygen are provided.



$$\begin{aligned}\Delta H^\circ &= -217 \text{ kJ mol}^{-1} \\ T\Delta S^\circ &= -3 \text{ kJ mol}^{-1}\end{aligned}$$

Explain, with reference to the information provided, why this reaction proceeds to completion rather than coming to equilibrium.

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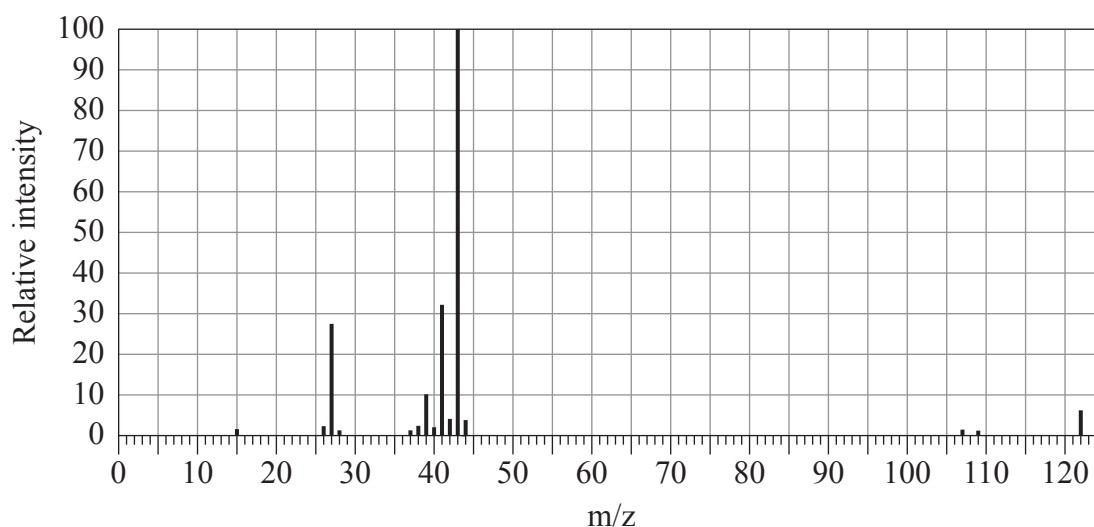
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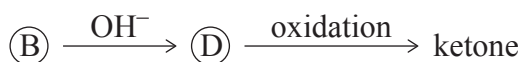
**Question 38** (7 marks)

Compounds A and B are isomers with formula  $C_3H_7X$ , where X is a halogen. The mass spectrum for compound A is shown.

7



Compounds A and B undergo substitution reactions in the presence of hydroxide ions, producing alcohols C and D. Compound D can be oxidised to a ketone; compound C can also be oxidised, but does not produce a ketone.



Compound E can be produced by refluxing 3-methylbutanoic acid, with one of the alcohols C or D, in the presence of a catalyst.

The  $^1\text{H}$  NMR spectrum for compound E contains the following features.

**$^1\text{H}$  NMR spectrum data for compound E**

| Chemical shift (ppm) | Integration | Peak splitting |
|----------------------|-------------|----------------|
| 0.95                 | 3           | Triplet        |
| 0.96                 | 6           | Doublet        |
| 1.7                  | 2           | Multiplet      |
| 2.1                  | 1           | Multiplet      |
| 2.2                  | 2           | Doublet        |
| 4.0                  | 2           | Triplet        |

**Reference  $^1\text{H}$  chemical shift data**

| Type of proton                                                                                                                                                                                 | $\delta/\text{ppm}$ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| $-\text{CH}_3$ , $-\text{CH}_2-$ , $-\text{CH}-$                                                                                                                                               | 0.7–2.1             |
| $\left. \begin{array}{l} \text{H}_3\text{C}-\text{CO}- \\ \text{H}_2\text{C}-\text{CO}- \\ \text{H}_2\text{C}-\text{CO} \end{array} \right\}$ (aldehydes, ketones, carboxylic acids or esters) | 2.2–2.6             |
| $\left. \begin{array}{l} \text{H}_3\text{C}-\text{O}- \\ \text{H}_2\text{C}-\text{O}- \\ \text{HC}-\text{O}- \end{array} \right\}$ (alcohols or esters)                                        | 3.2–5.0             |

**Question 38 continues on page 35**

Question 38 (continued)

Draw the structure of compounds A, B and E. Explain your answer with reference to the information provided.

Compound A

Compound B

Compound E

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Question 38 continues on page 36

Question 38 (continued)

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**End of Question 38**

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**Question 39** (4 marks)

Water and octan-1-ol do not mix. When an aqueous solution of bromoacetic acid ( $\text{BrCH}_2\text{COOH}$ ) is shaken with octan-1-ol, an equilibrium system is established between bromoacetic acid dissolved in the octan-1-ol and in the water.

4



The equilibrium constant expression for this system is

$$K_{eq} = \frac{[\text{BrCH}_2\text{COOH}(\text{octan-1-ol})]}{[\text{BrCH}_2\text{COOH}(aq)]}.$$

An aqueous solution of bromoacetic acid with an initial concentration of  $0.1000 \text{ mol L}^{-1}$  is shaken with an equal volume of octan-1-ol. Bromoacetic acid does not dissociate in octan-1-ol but does dissociate in water, with  $K_a = 1.29 \times 10^{-3}$ . When the system has reached equilibrium, the  $[\text{H}^+]$  is  $9.18 \times 10^{-3} \text{ mol L}^{-1}$ .

Calculate the equilibrium concentration of aqueous bromoacetic acid and hence, or otherwise, calculate the  $K_{eq}$  for the octan-1-ol and water system.

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## Chemistry

## FORMULAE SHEET

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

$$q = mc\Delta T$$

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

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

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

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

$$PV = nRT$$

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

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

Volume of 1 mole ideal gas: at 100 kPa and

at  $0^\circ\text{C}$  (273.15 K) ..... 22.71 L

at  $25^\circ\text{C}$  (298.15 K) ..... 24.79 L

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

Ionisation constant for water at  $25^\circ\text{C}$  (298.15 K),  $K_w$  .....  $1.0 \times 10^{-14}$

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

## DATA SHEET

Solubility constants at  $25^\circ\text{C}$ 

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

### Infrared absorption data

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

### <sup>13</sup>C NMR chemical shift data

| Type of carbon                                                                      | δ/ppm   |
|-------------------------------------------------------------------------------------|---------|
| $\begin{array}{c}   \quad   \\ -C - C- \\   \quad   \end{array}$                    | 5–40    |
| $\begin{array}{c}   \\ R - C - Cl \text{ or } Br \\   \end{array}$                  | 10–70   |
| $\begin{array}{c}   \\ R - C - C - \\    \quad   \\ O \end{array}$                  | 20–50   |
| $\begin{array}{c}   \quad / \\ R - C - N \\   \quad \backslash \end{array}$         | 25–60   |
| $\begin{array}{c}   \\ -C - O - \\   \end{array}$ alcohols,<br>ethers or<br>esters  | 50–90   |
| $\begin{array}{c} \backslash \quad / \\ C = C \\ / \quad \backslash \end{array}$    | 90–150  |
| R — C ≡ N                                                                           | 110–125 |
|  | 110–160 |
| $\begin{array}{c} R - C - \\    \\ O \end{array}$ esters or<br>acids                | 160–185 |
| $\begin{array}{c} R - C - \\    \\ O \end{array}$ aldehydes<br>or ketones           | 190–220 |

### UV absorption

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

| Chromophore | λ <sub>max</sub> (nm) |
|-------------|-----------------------|
| C—H         | 122                   |
| C=C         | 135                   |
| C=C         | 162                   |

| Chromophore | λ <sub>max</sub> (nm) |
|-------------|-----------------------|
| C≡C         | 173 178<br>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  |
| $\frac{1}{2}\text{O}_2(g) + \text{H}_2\text{O} + 2\text{e}^-$       | $\rightleftharpoons$ | $2\text{OH}^-$                                   | 0.40 V  |
| $\text{Cu}^+ + \text{e}^-$                                          | $\rightleftharpoons$ | $\text{Cu}(s)$                                   | 0.52 V  |
| $\frac{1}{2}\text{I}_2(s) + \text{e}^-$                             | $\rightleftharpoons$ | $\text{I}^-$                                     | 0.54 V  |
| $\frac{1}{2}\text{I}_2(aq) + \text{e}^-$                            | $\rightleftharpoons$ | $\text{I}^-$                                     | 0.62 V  |
| $\text{Fe}^{3+} + \text{e}^-$                                       | $\rightleftharpoons$ | $\text{Fe}^{2+}$                                 | 0.77 V  |
| $\text{Ag}^+ + \text{e}^-$                                          | $\rightleftharpoons$ | $\text{Ag}(s)$                                   | 0.80 V  |
| $\frac{1}{2}\text{Br}_2(l) + \text{e}^-$                            | $\rightleftharpoons$ | $\text{Br}^-$                                    | 1.08 V  |
| $\frac{1}{2}\text{Br}_2(aq) + \text{e}^-$                           | $\rightleftharpoons$ | $\text{Br}^-$                                    | 1.10 V  |
| $\frac{1}{2}\text{O}_2(g) + 2\text{H}^+ + 2\text{e}^-$              | $\rightleftharpoons$ | $\text{H}_2\text{O}$                             | 1.23 V  |
| $\frac{1}{2}\text{Cl}_2(g) + \text{e}^-$                            | $\rightleftharpoons$ | $\text{Cl}^-$                                    | 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  |
| $\frac{1}{2}\text{Cl}_2(aq) + \text{e}^-$                           | $\rightleftharpoons$ | $\text{Cl}^-$                                    | 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  |
| $\frac{1}{2}\text{F}_2(g) + \text{e}^-$                             | $\rightleftharpoons$ | $\text{F}^-$                                     | 2.89 V  |

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

PERIODIC TABLE OF THE ELEMENTS

|                               |                                 |                               |                                |                               |                                 |                                |                                |                              |                                |                             |                              |                               |
|-------------------------------|---------------------------------|-------------------------------|--------------------------------|-------------------------------|---------------------------------|--------------------------------|--------------------------------|------------------------------|--------------------------------|-----------------------------|------------------------------|-------------------------------|
| 1<br>H<br>1.008<br>Hydrogen   | KEY                             |                               |                                |                               |                                 |                                |                                |                              |                                |                             | 2<br>He<br>4.003<br>Helium   |                               |
|                               | Atomic Number<br>Symbol<br>Name |                               |                                |                               |                                 |                                |                                |                              |                                |                             |                              |                               |
| 3<br>Li<br>6.941<br>Lithium   | 4<br>Be<br>9.012<br>Beryllium   | Standard Atomic Weight        |                                |                               |                                 |                                |                                |                              |                                |                             |                              | 5<br>B<br>10.81<br>Boron      |
| 11<br>Na<br>22.99<br>Sodium   | 12<br>Mg<br>24.31<br>Magnesium  | Name                          |                                |                               |                                 |                                |                                |                              |                                |                             |                              | 6<br>C<br>12.01<br>Carbon     |
| 19<br>K<br>39.10<br>Potassium | 20<br>Ca<br>40.08<br>Calcium    | 21<br>Sc<br>44.96<br>Scandium | 22<br>Ti<br>47.87<br>Titanium  | 23<br>V<br>50.94<br>Vanadium  | 24<br>Cr<br>52.00<br>Chromium   | 25<br>Mn<br>54.94<br>Manganese | 26<br>Fe<br>55.85<br>Iron      | 27<br>Co<br>58.93<br>Cobalt  | 28<br>Ni<br>58.69<br>Nickel    | 29<br>Cu<br>63.55<br>Copper | 30<br>Zn<br>65.38<br>Zinc    | 31<br>Ga<br>69.72<br>Gallium  |
| 37<br>Rb<br>85.47<br>Rubidium | 38<br>Sr<br>87.61<br>Strontium  | 39<br>Y<br>88.91<br>Yttrium   | 40<br>Zr<br>91.22<br>Zirconium | 41<br>Nb<br>92.91<br>Niobium  | 42<br>Mo<br>95.96<br>Molybdenum | 43<br>Tc<br>Technetium         | 44<br>Ru<br>101.1<br>Ruthenium | 45<br>Rh<br>102.9<br>Rhodium | 46<br>Pd<br>106.4<br>Palladium | 47<br>Ag<br>107.9<br>Silver | 48<br>Cd<br>112.4<br>Cadmium | 49<br>In<br>114.8<br>Indium   |
| 55<br>Cs<br>132.9<br>Caesium  | 56<br>Ba<br>137.3<br>Barium     | 57–71<br>Lanthanoids          | 72<br>Hf<br>178.5<br>Hafnium   | 73<br>Ta<br>180.9<br>Tantalum | 74<br>W<br>183.9<br>Tungsten    | 75<br>Re<br>186.2<br>Rhenium   | 76<br>Os<br>190.2<br>Osmium    | 77<br>Ir<br>192.2<br>Iridium | 78<br>Pt<br>195.1<br>Platinum  | 79<br>Au<br>197.0<br>Gold   | 80<br>Hg<br>200.6<br>Mercury | 81<br>Tl<br>204.4<br>Thallium |
| 87<br>Fr<br>Francium          | 88<br>Ra<br>Radium              | Actinoids                     | 104<br>Rf<br>Rutherfordium     | 105<br>Db<br>Dubnium          | 106<br>Sg<br>Seaborgium         | 107<br>Bh<br>Bohrium           | 108<br>Hs<br>Hassium           | 109<br>Mt<br>Meitnerium      | 110<br>Ds<br>Darmstadtium      | 111<br>Rg<br>Roentgenium    | 112<br>Cn<br>Copernicium     | 113<br>Nh<br>Nihonium         |
|                               |                                 |                               |                                |                               |                                 |                                |                                |                              |                                |                             |                              | 114<br>Fl<br>Flerovium        |
|                               |                                 |                               |                                |                               |                                 |                                |                                |                              |                                |                             |                              | 115<br>Mc<br>Moscovium        |
|                               |                                 |                               |                                |                               |                                 |                                |                                |                              |                                |                             |                              | 116<br>Lv<br>Livermorium      |
|                               |                                 |                               |                                |                               |                                 |                                |                                |                              |                                |                             |                              | 117<br>Ts<br>Tennessine       |
|                               |                                 |                               |                                |                               |                                 |                                |                                |                              |                                |                             |                              | Oganesson                     |

Lanthanoids

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

Actinoids

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

# 2024 HSC Chemistry Marking Guidelines

## Section I

### Multiple-choice Answer Key

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

## Section II

### Question 21

| Criteria                             | Marks |
|--------------------------------------|-------|
| • Identifies both products           | 2     |
| • Provides some relevant information | 1     |

**Sample answer:**

Hydrogen and magnesium acetate/ethanoate

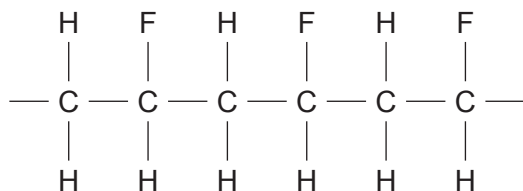
**Answers could include:**

$\text{H}_2$  and  $\text{Mg}(\text{CH}_3\text{COO})_2$

### Question 22

| Criteria                                | Marks |
|-----------------------------------------|-------|
| • Provides a correct structural formula | 2     |
| • Provides some relevant information    | 1     |

**Sample answer:**



**Question 23**

| Criteria                                                                                | Marks |
|-----------------------------------------------------------------------------------------|-------|
| • Provides a sound relationship between the observed colour change and $K_{eq}$         | 3     |
| • Provides some information about changes in concentration of reactants and/or products | 2     |
| • Provides some relevant information                                                    | 1     |

**Sample answer:**

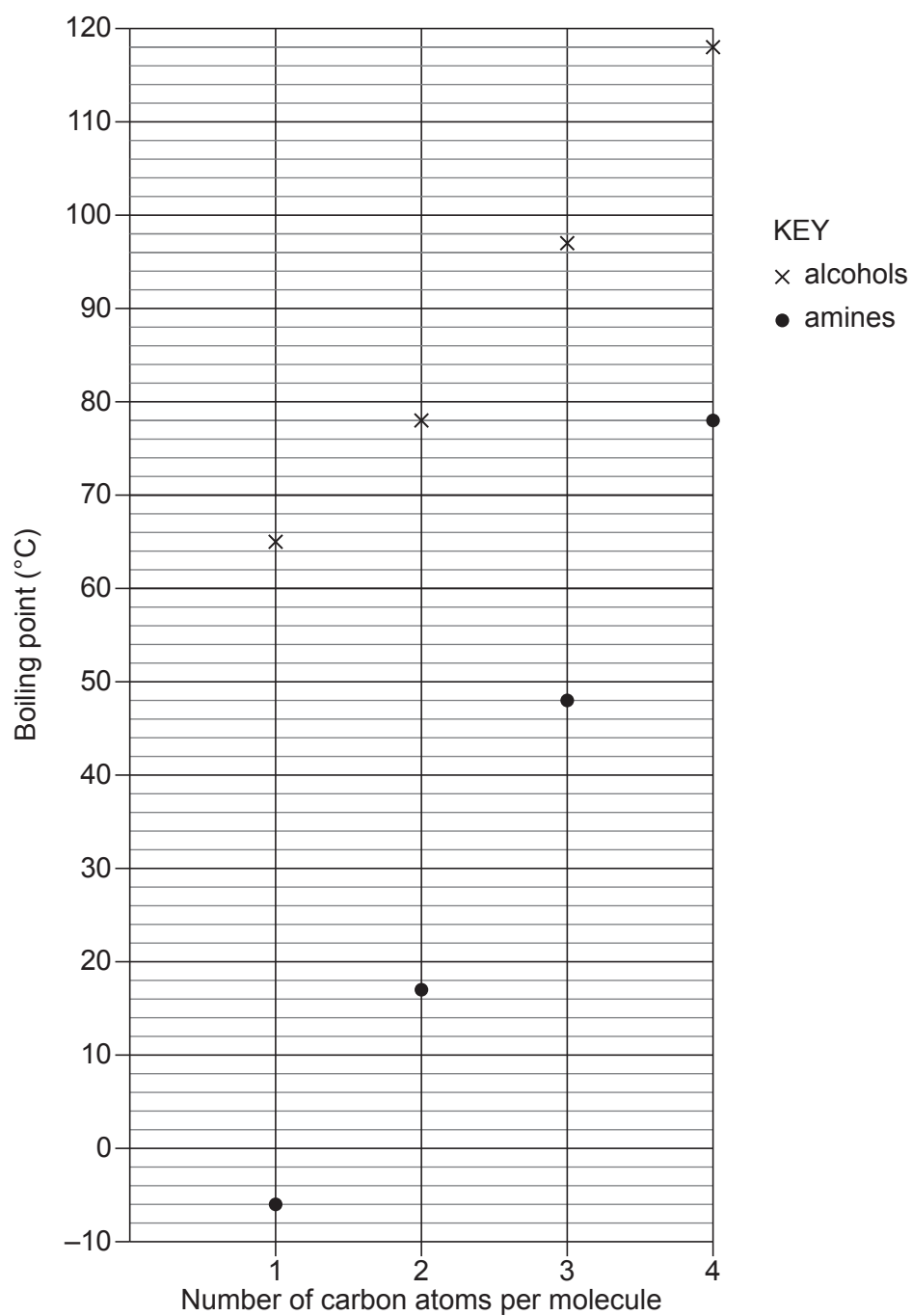
The mixture becomes more blue as temperature is increased, which suggests that the concentration of  $[\text{CoCl}_4]^{2-}$  is increasing. This means that an increase in temperature favours the forward reaction. This response will result in a larger value of  $K_{eq}$  as

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

### Question 24 (a)

| Criteria                                                                                                                                                | Marks |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>All correct points plotted</li> <li>Correct scale and label on y-axis</li> <li>Each series identified</li> </ul> | 3     |
| <ul style="list-style-type: none"> <li>Two of three features included (correct points, label/scale y-axis, each series identified)</li> </ul>           | 2     |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                                    | 1     |

**Sample answer:**





**Question 24 (b)**

| Criteria                                                                                                                                                                                                                                                                         | Marks |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Explains increase in boiling point with increasing carbon number due to increasing dispersion forces</li> <li>Explains difference in boiling point between series with reference to difference in strength of hydrogen bonding</li> </ul> | 4     |
| <ul style="list-style-type: none"> <li>Explains ONE trend</li> </ul> OR <ul style="list-style-type: none"> <li>Describes trends</li> </ul>                                                                                                                                       | 3     |
| <ul style="list-style-type: none"> <li>Makes a relevant comparison to a data series</li> </ul>                                                                                                                                                                                   | 2     |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                                                                                                                                                             | 1     |

**Sample answer:**

For both the alcohols and the amines, dispersion forces will increase with increasing carbon number, due to increased number of electrons present, leading to increased boiling points.

However, for any given carbon number, the alcohol has stronger hydrogen bonding than the corresponding amine, as oxygen has a higher electronegativity than nitrogen, so the alcohols all have higher boiling points than the corresponding amines.

**Question 25**

| Criteria                                                                                                                                    | Marks |
|---------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Calculates the correct concentration of phosphate ions, in <math>\text{mol L}^{-1}</math></li> </ul> | 4     |
| <ul style="list-style-type: none"> <li>Provides the main steps of the calculation</li> </ul>                                                | 3     |
| <ul style="list-style-type: none"> <li>Provides some steps of the calculation</li> </ul>                                                    | 2     |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                        | 1     |

**Sample answer:**

Concentration of diluted sample =  $0.78 \text{ mg L}^{-1}$

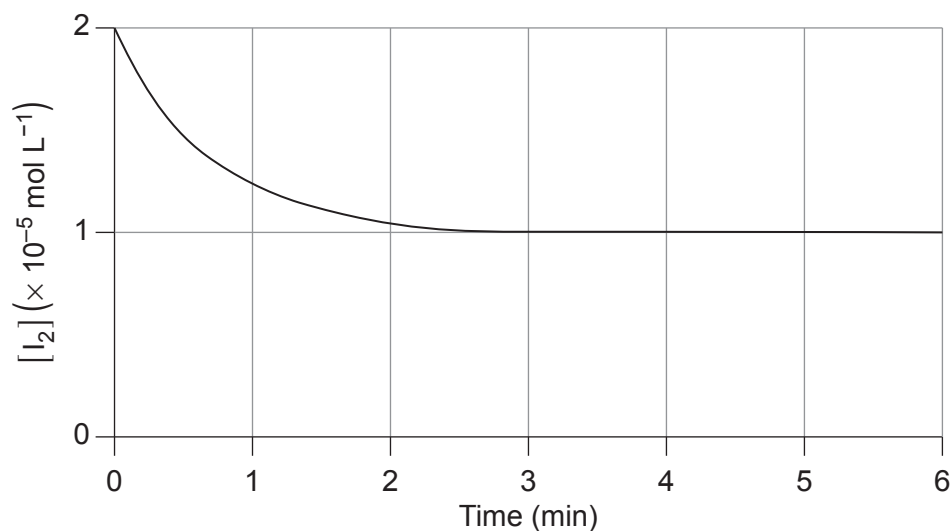
Concentration of phosphate ions in original sample in  $\text{mg L}^{-1}$  =  $1000 \times 0.78 \text{ mg L}^{-1} = 780 \text{ mg L}^{-1} = 0.78 \text{ g L}^{-1}$

Molar mass of  $\text{PO}_4^{3-}$  =  $(30.97 + 4 \times 16.00) = 94.97 \text{ g mol}^{-1}$

Concentration of phosphate ions in  $\text{mol L}^{-1}$  =  $\frac{0.78}{94.97} = 0.0082 \text{ mol L}^{-1}$

**Question 26 (a)**

| Criteria                       | Marks |
|--------------------------------|-------|
| • Provides a correct graph     | 2     |
| • Provides one correct feature | 1     |

**Sample answer:****Question 26 (b)**

| Criteria                                                                                          | Marks |
|---------------------------------------------------------------------------------------------------|-------|
| • Provides an explanation of the rate of reaction with clear link to $[I_2]$ and collision theory | 3     |
| • Provides some description of the rate of reaction with link to $[I_2]$ and/or collision theory  | 2     |
| • Provides some relevant information                                                              | 1     |

**Sample answer:**

The initial high  $[I_2]$  results in more frequent successful collisions and a high rate of forward reaction. As the reaction proceeds,  $I_2$  is consumed, so  $[I_2]$  decreases, so the reaction rate decreases. After  $t = 3 \text{ min}$ , the system is at equilibrium so the rates of the forward and reverse reactions are the same, so  $[I_2]$  is constant.

## Question 27

| Criteria                                                                                                                                                                                              | Marks |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Demonstrates a thorough understanding of the procedure and qualitative ion testing</li> <li>Includes a balanced chemical equation, including states</li> </ul> | 4     |
| <ul style="list-style-type: none"> <li>Demonstrates a sound understanding of the procedure and qualitative ion testing</li> </ul>                                                                     | 3     |
| <ul style="list-style-type: none"> <li>Demonstrates some understanding of the procedure and qualitative ion testing</li> </ul>                                                                        | 2     |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                                                                                  | 1     |

### Sample answer:

If only barium ions are present, they will give a precipitate in step 1 of this procedure ( $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$ ), so the conclusion that only barium ions are present will be correct.

If lead(II) ions are present, they will also precipitate at step 1 of this procedure. This will leave insufficient lead(II) ions in solution to give a precipitate in step 3. The conclusion reached will be that only barium ions are present, which is incorrect.

## Question 28

| Criteria                                                                                                                                      | Marks |
|-----------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Shows that both acids do not dissociate completely in water and that iodic acid is stronger</li> </ul> | 3     |
| <ul style="list-style-type: none"> <li>Provides some information relating to of the dissociation of one or both acids</li> </ul>              | 2     |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                          | 1     |

### Sample answer:

For both acids,  $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-1.151} = 0.0706 \text{ mol L}^{-1}$ , which is less than the acid concentration. Accordingly, both acids do not dissociate completely in water and are weak.

Since a smaller concentration of iodic acid is required to give a pH of 1.151 compared to sulfamic acid, iodic acid must ionise to a greater extent than sulfamic acid, ie iodic acid must be a stronger acid than sulfamic acid.

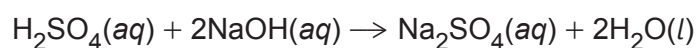
## Question 29

| Criteria                                          | Marks |
|---------------------------------------------------|-------|
| • Calculates the pH of the resulting solution     | 4     |
| • Provides most relevant steps of the calculation | 3     |
| • Provides some relevant steps of the calculation | 2     |
| • Provides some relevant information              | 1     |

### Sample answer:

$$n(\text{NaOH}) = 0.150 \text{ L} \times 0.20 \text{ mol L}^{-1} = 0.030 \text{ mol}$$

$$n(\text{H}_2\text{SO}_4) = 0.100 \text{ L} \times 0.10 \text{ mol L}^{-1} = 0.010 \text{ mol}$$



$$n(\text{NaOH required for reaction with H}_2\text{SO}_4) = 2 \times 0.010 \text{ mol} = 0.020 \text{ mol}$$

$$n(\text{NaOH in excess}) = 0.030 \text{ mol} - 0.020 \text{ mol} = 0.010 \text{ mol}$$

$$[\text{NaOH}] = \frac{0.010 \text{ mol}}{0.250 \text{ L}} = 0.040 \text{ mol L}^{-1}$$

$$\text{p}(\text{OH}) = -\log_{10}(0.040) = 1.40$$

$$\text{pH} = 14.00 - 1.40 = 12.60$$

### Question 30

| Criteria                                     | Marks |
|----------------------------------------------|-------|
| • Calculates correct amount of CO(g) added   | 4     |
| • Provides the main steps of the calculation | 3     |
| • Provides some steps of the calculation     | 2     |
| • Provides some relevant information         | 1     |

**Sample answer:**

Changes in  $[\text{H}_2\text{O}] = (0.400 - 0.200) = 0.200 \text{ mol L}^{-1} = 0.200 \text{ mol in 1 L}$

ICE table:

|         | $n(\text{H}_2)$ in 1 L<br>(mol) | $n(\text{CO}_2)$ in 1 L<br>(mol) | $n(\text{H}_2\text{O})$ in 1 L<br>(mol) | $n(\text{CO})$ in 1 L<br>(mol) |
|---------|---------------------------------|----------------------------------|-----------------------------------------|--------------------------------|
| Initial | 1.000                           | 0.500                            | 0.400                                   | $2.000 + x$                    |
| Change  | +0.200                          | +0.200                           | -0.200                                  | -0.200                         |
| Equib   | 1.200                           | 0.700                            | 0.200                                   | $1.800 + x$                    |

$$K_{eq} = \frac{[\text{H}_2\text{O}][\text{CO}]}{[\text{H}_2][\text{CO}_2]}$$

$$1.600 = \frac{[0.200][1.800 + x]}{[1.200][0.700]}$$

$$x = \frac{1.600 \times 1.200 \times 0.700}{0.200} - 1.800$$

$$x = 4.92 \text{ mol in 1 L}$$

## Question 31

| Criteria                                                            | Marks |
|---------------------------------------------------------------------|-------|
| • Correctly compares the processes and justifies preferred approach | 3     |
| • Compares one aspect of the processes                              | 2     |
| • Provides some relevant information                                | 1     |

### Sample answer:

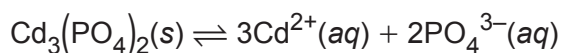
The atom economy for the reaction with DMC is 48.4% compared to the phosgene reaction at 35.9%. As a result, there is less waste in the process involving the less harmful DMC. Less ammonia is also required (2 moles, in place of 4 for phosgene).

This comparison identifies the production of urea from DMC as the preferred approach in terms of atom economy, toxicity of starting materials and quantities of harmful reactants required.

## Question 32

| Criteria                                                                         | Marks |
|----------------------------------------------------------------------------------|-------|
| • Calculates the concentration of $\text{Cd}^{2+}$ ions to 3 significant figures | 4     |
| • Provides most relevant steps of the calculation                                | 3     |
| • Provides some relevant steps of the calculation                                | 2     |
| • Provides some relevant information                                             | 1     |

### Sample answer:



Let  $s$  mol  $\text{Cd}_3(\text{PO}_4)_2(s)$  dissolve per litre

$$K_{sp} = [\text{Cd}^{2+}]^3 [\text{PO}_4^{3-}]^2 = (3s)^3 (2s)^2 = 108s^5$$

$$s = \sqrt[5]{\frac{2.53 \times 10^{-33}}{108}} = 1.19 \times 10^{-7}$$

$$[\text{Cd}^{2+}] = 3s = 3.56 \times 10^{-7} \text{ mol L}^{-1}$$

**Question 33 (a)**

| Criteria                                                                                                                                          | Marks |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Identifies correct shape around both central carbon atoms in the reactant and product molecules</li> </ul> | 2     |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                              | 1     |

**Sample answer:**

The shape around the central carbon in the reactant molecule is trigonal planar, whereas the shape around the central carbon atom in the product is tetrahedral.

**Question 33 (b)**

| Criteria                                                                                                                                                                       | Marks |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Provides a sound explanation of how key <math>^{13}\text{C}</math> NMR spectral features can be used to monitor the reaction</li> </ul> | 3     |
| <ul style="list-style-type: none"> <li>Provides some explanation of how key <math>^{13}\text{C}</math> NMR spectral features can be used to monitor the reaction</li> </ul>    | 2     |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                                                           | 1     |

**Sample answer:**

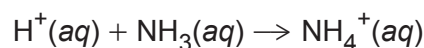
In the  $^{13}\text{C}$  NMR spectrum of the reaction mixture at the start of the reaction, there will be two (2) signals, due to the 2 different carbons ( $\text{C}=\text{O}$  and  $\text{CH}_3$ ) in the reactant molecule. However, as the reaction proceeds, the  $\text{C}=\text{O}$  bond is transformed to  $\text{H}-\text{C}-\text{OH}$ . Therefore, a new signal will appear in the  $^{13}\text{C}$  NMR spectrum of the reaction mixture that corresponds to the different carbon environment in the product. This peak will appear as the reaction proceeds, while the original peak for  $\text{C}=\text{O}$  will disappear.

## Question 34

| Criteria                                                                                                                                                      | Marks |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Provides a thorough explanation of the shape of the graph</li> <li>Includes TWO balanced chemical equations</li> </ul> | 4     |
| <ul style="list-style-type: none"> <li>Provides a sound explanation of the shape of the graph</li> <li>Includes a balanced chemical equation</li> </ul>       | 3     |
| <ul style="list-style-type: none"> <li>Demonstrates some understanding of the shape of the graph</li> </ul>                                                   | 2     |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                                          | 1     |

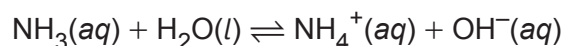
### Sample answer:

Before the equivalence point (below 4.5 mL), hydrochloric acid is being neutralised by the added ammonia:



This has the effect of replacing  $\text{H}^+$  ions (high conductivity) with  $\text{NH}_4^+$  ions (low conductivity), so the conductivity decreases.

After the equivalence point, the excess ammonia added will produce some  $\text{NH}_4^+$  and  $\text{OH}^-$  ions, both of which have greater conductivity than the reactant molecules:



This reaction only occurs to a small extent, however, as the  $\text{NH}_4^+$  already present in the solution will suppress this ionisation, in accordance with Le Châtelier's Principle. Accordingly, the conductivity only increases slightly after the equivalence point.



## Question 35

| Criteria                                                                                                                                                                                                                                                                                                      | Marks |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Correctly identifies the structure of compounds X, Y and Z</li> <li>Justifies the correct structures showing an extensive understanding of the interpretation of titration and reaction data</li> <li>Makes extensive reference to the information provided</li> </ul> | 7     |
| <ul style="list-style-type: none"> <li>Correctly identifies the structure of compounds X, Y and Z</li> <li>Justifies the correct structures showing a thorough understanding of the interpretation of titration and reaction data</li> <li>Makes reference to the information provided</li> </ul>             | 6     |
| <ul style="list-style-type: none"> <li>Demonstrates a sound understanding of the interpretation of titration and/or reaction data</li> <li>Uses relevant information presented in the question to explain structures</li> </ul>                                                                               | 4–5   |
| <ul style="list-style-type: none"> <li>Demonstrates some understanding of the interpretation of titration and/or reaction data</li> </ul>                                                                                                                                                                     | 2–3   |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                                                                                                                                                                                          | 1     |

### Sample answer:

X does not undergo an addition reaction with  $\text{Br}_2$  or a hydration reaction so does not possess a double bond. Thus, the only structure that can be X is Structure 2.

Y and Z do contain at least one double bond because of the addition and hydration reactions. As 0.100 g of Y reacts with the same amount of  $\text{Br}_2$  as 0.200 g of Z, Z must have a molar mass that is double the molar mass of Y.

Only one product is formed from the hydration of Z so Z must be symmetrical around the double bond and Y is not symmetrical.

The equal volumes of Y and Z in the titration is a result of Z having double the molar mass of Y AND being a diprotic acid. Thus, Structure 1 is Y and Structure 3 is Z.

## Question 36

| Criteria                                          | Marks |
|---------------------------------------------------|-------|
| • Calculates the enthalpy of reaction             | 5     |
| • Provides a substantially correct calculation    | 4     |
| • Provides the main steps in the calculation      | 3     |
| • Provides some relevant steps in the calculation | 2     |
| • Provides some relevant information              | 1     |

### Sample answer:



$$n(\text{NaHCO}_3) \text{ added} = \frac{14.7 \text{ g}}{84.008 \text{ mol L}^{-1}} = 0.175 \text{ mol}$$

$$n(\text{HCl}) \text{ added} = 1.50 \text{ mol} \times 0.120 \text{ L} = 0.180 \text{ mol}$$

1 : 1 reaction therefore HCl is in excess and NaHCO<sub>3</sub> is the limiting reagent

$$m(\text{CO}_2 \text{ lost}) = 0.175 \text{ mol} \times (12.01 + 16.00 \times 2) \text{ g mol}^{-1} = 7.70 \text{ g}$$

$$\text{Therefore, total mass of reaction solution} = (14.7 - 7.70) \text{ g} + (1.02 \times 120) \text{ g} = 129 \text{ g}$$

$$q = mc\Delta T$$

$$q = 129 \text{ g} \times 3.80 \text{ J K}^{-1} \text{ g}^{-1} \times (11.5 - 21.5)^\circ\text{C}$$

$$q = -4917 \text{ J} = -4.92 \text{ kJ}$$

$$\Delta H = \frac{4.92 \text{ kJ}}{0.175 \text{ mol}} = +28.1 \text{ kJ mol}^{-1}$$

### Answers could include:



$$n(\text{NaHCO}_3) \text{ added} = \frac{14.7 \text{ g}}{84.008 \text{ mol L}^{-1}} = 0.175 \text{ mol}$$

$$n(\text{HCl}) \text{ added} = 1.50 \text{ mol} \times 0.120 \text{ L} = 0.180 \text{ mol}$$

1 : 1 reaction therefore HCl is in excess and NaHCO<sub>3</sub> is the limiting reagent

$$\text{Therefore, total mass of reaction solution} = 14.7 \text{ g} + (1.02 \times 120 \text{ g}) = 137.1 \text{ g}$$

$$q = mc\Delta T$$

$$q = 137.1 \text{ g} \times 3.80 \text{ J K}^{-1} \text{ g}^{-1} \times (11.5 - 21.5)^\circ\text{C}$$

$$q = -5209.8 \text{ J} = -5.209 \text{ kJ}$$

$$\Delta H = \frac{5.209 \text{ kJ}}{0.175 \text{ mol}} = +29.8 \text{ kJ mol}^{-1}$$

**Question 37**

| Criteria                                                                                                                 | Marks |
|--------------------------------------------------------------------------------------------------------------------------|-------|
| • Provides an explanation of why the reaction proceeds to completion with reference to the data provided                 | 3     |
| • Demonstrates some understanding of why the reaction proceeds to completion with reference to some of the data provided | 2     |
| • Provides some relevant information                                                                                     | 1     |

**Sample answer:**

The graph shows that reactions with large negative  $\Delta G^\circ$  values will have extremely large equilibrium constants, ie they effectively proceed to completion.

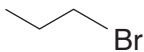
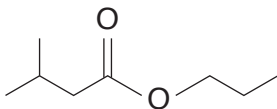
For this reaction,  $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = -217 \text{ kJ mol}^{-1} - (-3 \text{ kJ mol}^{-1}) = -214 \text{ kJ mol}^{-1}$

This  $\Delta G^\circ$  value is large and negative, which means that the reaction will effectively proceed to completion. Accordingly, this reaction proceeds to completion mostly due to its large, negative  $\Delta H^\circ$  value; the  $T\Delta S^\circ$  term is small and has little effect.

## Question 38

| Criteria                                                                                                                                                                                                                                                                                                                                                                                                         | Marks |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| <ul style="list-style-type: none"> <li>Draws the correct structure of compounds A, B and E</li> <li>Explains the correct structures showing an extensive understanding of the interpretation of spectroscopic data and reaction pathways</li> <li>Refers to relevant spectroscopic data</li> </ul>                                                                                                               | 7     |
| <ul style="list-style-type: none"> <li>Draws the correct structure of compounds A, B and E</li> <li>Explains the correct structures showing a thorough understanding of the interpretation of spectroscopic data and reaction pathways</li> <li>Refers to most relevant spectroscopic data</li> </ul>                                                                                                            | 6     |
| <ul style="list-style-type: none"> <li>Shows a sound understanding of the interpretation of spectroscopic data and reaction pathways</li> <li>Uses relevant information presented in the question to explain structures</li> <li>Draws structures for compounds A and B with halogen location correct</li> </ul> AND/OR <ul style="list-style-type: none"> <li>Draws correct structure for compound E</li> </ul> | 4–5   |
| <ul style="list-style-type: none"> <li>Demonstrates some understanding of the different reactions</li> </ul> AND/OR <ul style="list-style-type: none"> <li>Demonstrates some understanding of the interpretation of spectroscopic data</li> </ul>                                                                                                                                                                | 2–3   |
| <ul style="list-style-type: none"> <li>Provides some relevant information</li> </ul>                                                                                                                                                                                                                                                                                                                             | 1     |

### Sample answer:

|                                                                                                   |
|---------------------------------------------------------------------------------------------------|
| Compound A<br> |
| Compound B<br> |
| Compound E<br> |

From the mass spectrum of A, the two peaks at  $m/z$  122/124 indicate the presence of a Br atom (two isotopes of approximately equal abundance) – halogen X in  $C_3H_7X$  is Br. The peak at  $m/z$  43 is due to the loss of Br.

There are two isomers of  $C_3H_7Br$ : 1-bromopropane and 2-bromopropane. These will produce propan-1-ol and propan-2-ol respectively after substitution with hydroxide. Only propan-2-ol will produce a ketone upon oxidation, so B must be 2-bromopropane and A must be 1-bromopropane.

E is an ester formed from the reaction of 3-methylbutanoic acid with either C (propan-1-ol) or D (propan-2-ol).

The  $^1\text{H}$  NMR data gives the following information:

- The peak at  $\delta$  4.0 ppm is a  $\text{CH}_2$  group bonded to an oxygen atom (hence the high chemical shift). This tells us that E is a propyl ester,  $-\text{OCH}_2\text{CH}_2\text{CH}_3$ .
- The rest of the propyl group gives rise to a  $\text{CH}_2$  multiplet (present at  $\delta$  1.7 ppm) and a  $\text{CH}_3$  triplet (present at  $\delta$  0.95 ppm).
- The peak at  $\delta$  2.2 ppm is a  $\text{CH}_2$  group attached to a carbonyl ( $\text{C}=\text{O}$ ) group.
- The remaining peaks integrate for 6 ( $\delta$  0.95 ppm doublet) and 1 ( $\delta$  2.1 ppm multiplet), which indicates an isopropyl group attached to the  $\text{CH}_2$  group, giving the structure for E.

### Question 39

| Criteria                                 | Marks |
|------------------------------------------|-------|
| • Calculates the $K_{eq}$                | 4     |
| • Provides most steps of the calculation | 3     |
| • Provides some steps of the calculation | 2     |
| • Provides some relevant information     | 1     |

**Sample answer:**

$$K_a = \frac{[\text{H}^+][\text{BrCH}_2\text{COO}^-]}{[\text{BrCH}_2\text{COOH}]}$$

$$\begin{aligned} [\text{BrCH}_2\text{COOH}](aq) &= \frac{[\text{H}^+][\text{BrCH}_2\text{COO}^-]}{K_a} \\ &= \frac{[9.18 \times 10^{-3}][9.18 \times 10^{-3}]}{1.29 \times 10^{-3}} \\ &= 0.0654 \text{ mol L}^{-1} \end{aligned}$$

$$[\text{BrCH}_2\text{COOH}](\text{octan-1-ol}) = 0.1000 - 0.0654 - 9.18 \times 10^{-3} = 0.0254 \text{ mol L}^{-1}$$

$$K_{eq} = \frac{[\text{BrCH}_2\text{COOH}(\text{octan-1-ol})]}{[\text{BrCH}_2\text{COOH}(aq)]} = \frac{0.0254 \text{ mol L}^{-1}}{0.0654 \text{ mol L}^{-1}} = 0.390$$

# 2024 HSC Chemistry

## Mapping Grid

### Section I

| Question | Marks | Content                                    | Syllabus outcomes |
|----------|-------|--------------------------------------------|-------------------|
| 1        | 1     | Mod 7 Hydrocarbons                         | 12-14             |
| 2        | 1     | Mod 5 Solution Equilibria                  | 12-12             |
| 3        | 1     | Mod 6 Properties of Acids and Bases        | 12-13             |
| 4        | 1     | Mod 8 Analysis of Organic Substances       | 12-5, 12-15       |
| 5        | 1     | Mod 7 Alcohols                             | 12-2, 12-14       |
| 6        | 1     | Mod 6 Using Brønsted–Lowry Theory          | 12-4, 12-13       |
| 7        | 1     | Mod 5 Factors that Affect Equilibrium      | 12-6, 12-12       |
| 8        | 1     | Mod 8 Analysis of Inorganic Substances     | 12-6, 12-15       |
| 9        | 1     | Mod 8 Analysis of Organic Substances       | 12-5, 12-15       |
| 10       | 1     | Mod 5 Factors that Affect Equilibrium      | 12-12             |
| 11       | 1     | Mod 5 Solution Equilibria                  | 12-4, 12-12       |
| 12       | 1     | Mod 7 Nomenclature                         | 12-14             |
| 13       | 1     | Mod 7 Alcohols                             | 12-4, 12-14       |
| 14       | 1     | Mod 7 Polymers                             | 12-6, 12-14       |
| 15       | 1     | Mod 5 Factors that Affect Equilibrium      | 12-6, 12-12       |
| 16       | 1     | Mod 6 Quantitative Analysis                | 12-7, 12-13       |
| 17       | 1     | Mod 6 Quantitative Analysis                | 12-5, 12-13       |
| 18       | 1     | Mod 5 Calculating the Equilibrium Constant | 12-6, 12-12       |
| 19       | 1     | Mod 8 Analysis of Organic Substances       | 12-5, 12-15       |
| 20       | 1     | Mod 6 Quantitative Analysis                | 12-4, 12-6, 12-13 |

### Section II

| Question | Marks | Content                                    | Syllabus outcomes |
|----------|-------|--------------------------------------------|-------------------|
| 21       | 2     | Mod 6 Properties of Acids and Bases        | 12-13             |
| 22       | 2     | Mod 7 Polymers                             | 12-7, 12-14       |
| 23       | 3     | Mod 5 Calculating the Equilibrium Constant | 12-12             |
| 24 (a)   | 3     | Mod 7 Reactions of Organic Acids and Bases | 12-4, 12-7, 12-14 |
| 24 (b)   | 4     | Mod 7 Reactions of Organic Acids and Bases | 12-5, 12-14       |
| 25       | 4     | Mod 8 Analysis of Inorganic Substances     | 12-4, 12-5, 12-15 |
| 26 (a)   | 2     | Mod 5 Factors that Affect Equilibrium      | 12-4, 12-12       |
| 26 (b)   | 3     | Mod 5 Factors that Affect Equilibrium      | 12-12             |
| 27       | 4     | Mod 8 Analysis of Inorganic Substances     | 12-2, 12-6, 12-15 |
| 28       | 3     | Mod 6 Using Brønsted–Lowry Theory          | 12-13             |
| 29       | 4     | Mod 6 Using Brønsted–Lowry Theory          | 12-13             |

| Question | Marks | Content                                                                            | Syllabus outcomes  |
|----------|-------|------------------------------------------------------------------------------------|--------------------|
| 30       | 4     | Mod 5 Calculating the Equilibrium Constant                                         | 12-12              |
| 31       | 3     | Mod 8 Chemical Synthesis and Design                                                | 12-4, 12-6, 12-15  |
| 32       | 4     | Mod 5 Solution Equilibria                                                          | 12-12              |
| 33 (a)   | 2     | Mod 7 Hydrocarbons                                                                 | 12-1, 12-14        |
| 33 (b)   | 3     | Mod 8 Analysis of Organic Substances                                               | 12-15              |
| 34       | 4     | Mod 6 Quantitative Analysis                                                        | 12-5, 12-13        |
| 35       | 7     | Mod 6 Quantitative Analysis<br>Mod 7 Hydrocarbons                                  | 12-7, 12-13, 12-14 |
| 36       | 5     | Mod 6 Properties of Acids and Bases                                                | 12-13              |
| 37       | 3     | Mod 5 Static and Dynamic Equilibrium                                               | 12-12              |
| 38       | 7     | Mod 7 Reactions of Organic Acids and Bases<br>Mod 8 Analysis of Organic Substances | 12-7, 12-14, 12-15 |
| 39       | 4     | Mod 5 Calculating the Equilibrium Constant<br>Mod 6 Quantitative Analysis          | 12-12, 12-13       |