



# Cambridge International AS & A Level

CANDIDATE  
NAME



CENTRE  
NUMBER

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**CHEMISTRY**

**9701/41**

Paper 4 A Level Structured Questions

**May/June 2025**

**2 hours**

You must answer on the question paper.

No additional materials are needed.

## INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

## INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **24** pages. Any blank pages are indicated.



- 1 Both calcium carbonate,  $\text{CaCO}_3$ , and barium carbonate,  $\text{BaCO}_3$ , decompose when heated to form the metal oxide and a gas.

(a) Write an equation for the thermal decomposition of  $\text{CaCO}_3$ .

..... [1]

(b) State which of  $\text{CaCO}_3$  and  $\text{BaCO}_3$  decomposes at a lower temperature.

Explain your answer.

The compound that decomposes at a lower temperature is .....

explanation .....

.....

.....

.....

..... [2]

(c) Calcium oxide,  $\text{CaO}$ , reacts with water to form compound **A**.

Barium oxide,  $\text{BaO}$ , reacts with water to form compound **B**.

(i) Identify **A**.

..... [1]

(ii) Explain why **A** is less soluble than **B**.

.....

.....

.....

.....

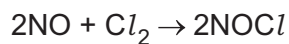
.....

..... [3]

[Total: 7]



- 2 Three experiments are carried out to investigate the reaction of nitrogen oxide, NO, with chlorine.



The rate equation for this reaction is shown.

$$\text{rate} = k[\text{NO}]^2[\text{Cl}_2]$$

- (a) Under the conditions used in experiments 1 and 2, the value of  $k$  is 26.4.

- (i) The rate of the reaction is measured in  $\text{mol dm}^{-3} \text{s}^{-1}$ . State the units of  $k$ .

units of  $k$  = ..... [1]

- (ii) In experiment 1, the initial concentrations of NO and  $\text{Cl}_2$  are equal.

The initial rate of the reaction in experiment 1 is  $2.57 \times 10^{-6} \text{mol dm}^{-3} \text{s}^{-1}$ .

Calculate the initial concentration of NO.

Show your working.

initial concentration of NO = .....  $\text{mol dm}^{-3}$  [2]

- (iii) In experiment 2, the initial concentrations of NO and  $\text{Cl}_2$  are both ten times greater than the initial concentrations used in experiment 1.

Calculate the initial rate of the reaction in experiment 2.

initial rate of reaction in experiment 2 = .....  $\text{mol dm}^{-3} \text{s}^{-1}$  [1]





(b) Experiment 3 uses a large excess of NO.

The initial concentration of  $\text{Cl}_2$  is  $2.00 \times 10^{-4} \text{ mol dm}^{-3}$ .

(i) The graph of  $[\text{Cl}_2]$  against time shows that the reaction has a constant half-life,  $t_{1/2}$ .

Explain this observation.

.....  
 ..... [1]

(ii) Under the conditions used in experiment 3, the value of the rate constant is 105.6.

Show that  $t_{1/2}$  of  $[\text{Cl}_2]$  is  $6.56 \times 10^{-3} \text{ s}$  under these conditions.

[1]

(iii) Calculate the time taken, in s, for  $[\text{Cl}_2]$  to fall to  $1.25 \times 10^{-5} \text{ mol dm}^{-3}$  in experiment 3.

time = ..... s [1]

(c) Sulfur dioxide,  $\text{SO}_2$ , reacts very slowly with oxygen in the atmosphere, forming sulfur trioxide,  $\text{SO}_3$ . This reaction is much faster in the presence of NO.

Explain the role of NO in this process.

Include chemical equations in your answer.

.....  
 .....  
 .....  
 ..... [3]

[Total: 10]





- 3 (a) Chromium(III) hydroxide,  $\text{Cr}(\text{OH})_3$ , is only slightly soluble in water. The value of the solubility product,  $K_{\text{sp}}$ , of  $\text{Cr}(\text{OH})_3$  is  $1.0 \times 10^{-33}$  at 298 K.

(i) Complete the expression for  $K_{\text{sp}}$  of  $\text{Cr}(\text{OH})_3$ . Include the units.

$$K_{\text{sp}} =$$

units = ..... [2]

(ii) Calculate the solubility, in  $\text{g dm}^{-3}$ , of  $\text{Cr}(\text{OH})_3$  in pure water at 298 K.

Show your working.

solubility = .....  $\text{g dm}^{-3}$  [3]

(iii)  $\text{Cr}(\text{OH})_3$  is less soluble in  $0.100 \text{ mol dm}^{-3}$  NaOH than it is in pure water.

Explain this observation.

..... [1]

(b) The value of the acid dissociation constant,  $K_{\text{a}}$ , of butanoic acid,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ , is  $1.51 \times 10^{-5}$  at 298 K.

(i) Calculate the pH of  $0.100 \text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  at 298 K.

Show your working.

pH = ..... [2]

(ii) Calculate the pH of  $0.100 \text{ mol dm}^{-3}$  NaOH at 298 K.

pH = ..... [1]





- (iii)  $5.00 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$  NaOH is added to  $10.00 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ .

Calculate the pH of the resulting solution.

Show your working.

pH = ..... [2]

- (c)  $80.0 \text{ cm}^3$  of an aqueous solution containing  $0.704 \text{ g}$  of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  is shaken with  $100 \text{ cm}^3$  of benzene,  $\text{C}_6\text{H}_6$ .

There is  $0.556 \text{ g}$  of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  in the  $100 \text{ cm}^3$  of  $\text{C}_6\text{H}_6$  at equilibrium.

Calculate the partition coefficient,  $K_{\text{pc}}$ , of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  between  $\text{C}_6\text{H}_6$  and water.

Show your working.

$K_{\text{pc}} = \dots\dots\dots$  [2]

[Total: 13]



- 4 Table 4.1 gives the enthalpy changes of hydration,  $\Delta H_{\text{hyd}}$ , of three ions,  $\text{F}^-$ ,  $\text{K}^+$  and  $\text{Ca}^{2+}$ .

Table 4.1

| ion              | $\Delta H_{\text{hyd}}/\text{kJ mol}^{-1}$ |
|------------------|--------------------------------------------|
| $\text{F}^-$     | –506                                       |
| $\text{K}^+$     | –322                                       |
| $\text{Ca}^{2+}$ | –1650                                      |

- (a) (i) Define enthalpy change of hydration.

.....  
 .....  
 ..... [1]

- (ii) Explain the relative magnitudes of the enthalpy changes of hydration of  $\text{K}^+$  and  $\text{Ca}^{2+}$ .

.....  
 .....  
 .....  
 ..... [2]

- (iii) Define lattice energy.

.....  
 ..... [1]

- (iv) The lattice energy,  $\Delta H_{\text{latt}}$ , of calcium fluoride,  $\text{CaF}_2$ , is  $-2602 \text{ kJ mol}^{-1}$ .

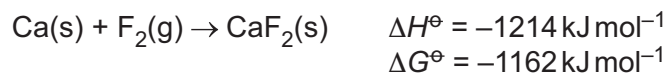
Calculate the enthalpy change of solution,  $\Delta H_{\text{sol}}$ , in  $\text{kJ mol}^{-1}$ , of  $\text{CaF}_2$ .

$\Delta H_{\text{sol}}$  of  $\text{CaF}_2$  = .....  $\text{kJ mol}^{-1}$  [2]





(b) The formation of  $\text{CaF}_2$  at 298 K is shown.



Calculate the entropy change,  $\Delta S^\ominus$ , in  $\text{J K}^{-1} \text{ mol}^{-1}$ , for this reaction.

$$\Delta S^\ominus = \dots\dots\dots \text{J K}^{-1} \text{ mol}^{-1} \quad [2]$$

[Total: 8]





5 Copper is a transition element.

(a) (i) Complete the electronic configurations of a  $\text{Cu}^+$  ion and a  $\text{Cu}^{2+}$  ion.

$\text{Cu}^+$  ion:  $[\text{Ar}]$  .....

$\text{Cu}^{2+}$  ion:  $[\text{Ar}]$  .....

[1]

(ii) Explain why transition elements have variable oxidation states.

.....

..... [1]

(b) Aqueous copper(II) sulfate,  $\text{CuSO}_4$ , contains the  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$  complex ion.

(i) A few drops of  $\text{NH}_3(\text{aq})$  are added to  $\text{CuSO}_4(\text{aq})$ .

Describe any observations made.

..... [1]

(ii) Write an equation for the reaction taking place.

..... [1]

(c) (i) An **excess** of  $\text{NH}_3(\text{aq})$  is added to  $\text{CuSO}_4(\text{aq})$ .

Describe any further observations made.

..... [1]

(ii) Write an equation for the reaction taking place.

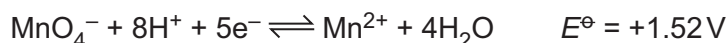
..... [1]

(iii) State the name for the type of reaction taking place.

..... [1]



- (d) Copper metal can be oxidised by acidified  $\text{KMnO}_4$ . The relevant half-equations and their standard electrode potentials,  $E^\ominus$ , are shown.



- (i) A  $\text{MnO}_4^-/\text{Mn}^{2+}$  electrode is constructed using  $0.0020 \text{ mol dm}^{-3} \text{ MnO}_4^-$ ,  $1.0 \text{ mol dm}^{-3} \text{ Mn}^{2+}$  and  $1.0 \text{ mol dm}^{-3} \text{ H}^+$ . The temperature used is  $298 \text{ K}$ .

Use the Nernst equation to show that the  $E$  value for this  $\text{MnO}_4^-/\text{Mn}^{2+}$  electrode is  $+1.49 \text{ V}$ .

[2]

- (ii) An electrochemical cell is constructed using a standard  $\text{Cu}^{2+}/\text{Cu}$  electrode and the  $\text{MnO}_4^-/\text{Mn}^{2+}$  electrode described in (d)(i).

Calculate the value of  $E_{\text{cell}}$ .

$$E_{\text{cell}} = \dots\dots\dots \text{V} \quad [1]$$

- (iii) Write an equation for the reaction taking place in the electrochemical cell described in (d)(ii).

..... [1]

- (iv) Complete the sentences for the electrochemical cell described in (d)(ii).

The ..... electrode is the negative electrode. Electrons flow from the

..... electrode to the ..... electrode when the cell is in use. [1]

- (e) A solution containing  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$  is electrolysed for  $5.00$  hours using a constant electric current.  $0.764 \text{ g}$  of copper metal is formed at the cathode. No other reduction reaction takes place.

Calculate the electric current, in  $\text{A}$ , used. Give your answer to **three** significant figures.

$$\text{current} = \dots\dots\dots \text{A} \quad [3]$$

[Total: 15]

[Turn over]





6 (a) Iron forms complex ions with the monodentate ligand,  $\text{CN}^-$ .

(i) Complex ion **A** contains one  $\text{Fe}^{3+}$  ion and six  $\text{CN}^-$  ligands.

Complex ion **B** contains one  $\text{Fe}^{2+}$  ion and six  $\text{CN}^-$  ligands.

State the formulae of these two complex ions. Include the overall charge of each complex ion.

complex ion **A** .....

complex ion **B** .....

[1]

(ii) Explain why a solution containing complex ion **A** and a solution containing complex ion **B** are different colours.

.....

.....

..... [2]

(iii) In complex ion **A**, the carbon atom of each  $\text{CN}^-$  ligand bonds to the  $\text{Fe}^{3+}$  ion.

State the type of bonding involved.

..... [1]





(b) Complex ions have different geometries.

Complex ion **A** is octahedral.

$\text{Ag}^+$  ions form a linear complex with ammonia.

Ni atoms form a tetrahedral complex with carbon monoxide molecules. The carbon atom in the monodentate carbon monoxide ligand bonds to the nickel atom.

$\text{Pd}^{2+}$  ions form a square planar complex with chloride ions.

Complete Fig. 6.1 to show the geometry of each of these four ions, using three-dimensional bonds where necessary. Label **one** bond angle on each complex ion.

|                                                                                                                                         |                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p style="text-align: center;">complex ion <b>A</b></p><br><br><br><br><br><br><br><br><br><br><p style="text-align: center;">Fe</p>    | <p style="text-align: center;"><math>\text{Ag}^+</math> with ammonia</p><br><br><br><br><br><br><br><br><br><br><p style="text-align: center;">Ag</p>     |
| <p style="text-align: center;">Ni with carbon monoxide</p><br><br><br><br><br><br><br><br><br><br><p style="text-align: center;">Ni</p> | <p style="text-align: center;"><math>\text{Pd}^{2+}</math> with chloride</p><br><br><br><br><br><br><br><br><br><br><p style="text-align: center;">Pd</p> |

Fig. 6.1

[4]

[Total: 8]



- 7 A hydrocarbon is known to be either compound **D** or compound **E**.

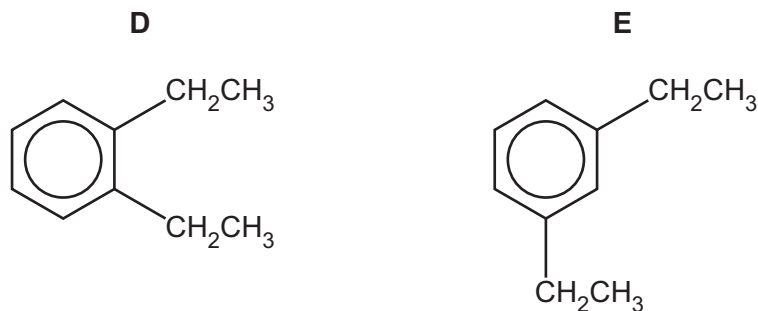


Fig. 7.1

- (a) Give the systematic name of **E**.

..... [1]

- (b) The proton ( $^1\text{H}$ ) NMR spectra of **D** and **E** are compared. They are very similar. The proton ( $^1\text{H}$ ) NMR spectrum of **D** is shown in Fig. 7.2.

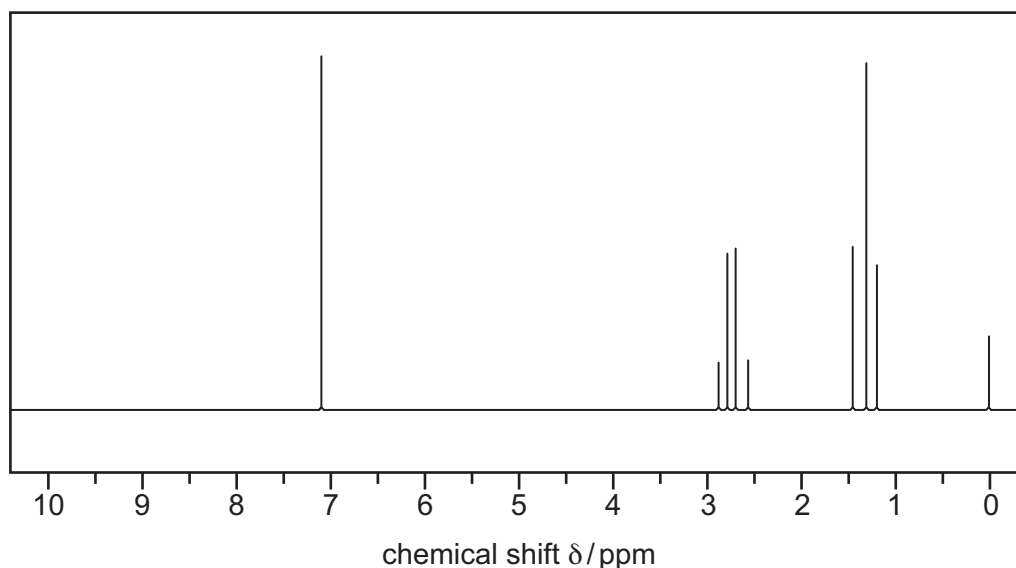


Fig. 7.2

- (i) Suggest a suitable solvent for obtaining the spectrum in Fig. 7.2.

..... [1]

- (ii) The proton ( $^1\text{H}$ ) NMR spectrum of **E** is obtained twice, once before and once after shaking with  $\text{D}_2\text{O}$ .

Describe any differences between these two spectra. Explain your answer.

..... [1]





(iii) Complete Table 7.1 for the proton ( $^1\text{H}$ ) NMR spectrum of **D**.

Table 7.1

| chemical shift<br>$\delta/\text{ppm}$ | number of $^1\text{H}$ atoms<br>responsible for the peak | group responsible<br>for the peak | splitting pattern |
|---------------------------------------|----------------------------------------------------------|-----------------------------------|-------------------|
| 1.3                                   |                                                          |                                   |                   |
| 2.7                                   |                                                          |                                   |                   |
| 7.1                                   |                                                          |                                   |                   |

[3]

Table 7.2

| environment of proton              | example                                                                                             | chemical shift range<br>$\delta/\text{ppm}$ |
|------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------|
| alkane                             | $-\text{CH}_3$ , $-\text{CH}_2-$ , $>\text{CH}-$                                                    | 0.9–1.7                                     |
| alkyl next to $\text{C}=\text{O}$  | $\text{CH}_3-\text{C}=\text{O}$ , $-\text{CH}_2-\text{C}=\text{O}$ , $>\text{CH}-\text{C}=\text{O}$ | 2.2–3.0                                     |
| alkyl next to aromatic ring        | $\text{CH}_3-\text{Ar}$ , $-\text{CH}_2-\text{Ar}$ , $>\text{CH}-\text{Ar}$                         | 2.3–3.0                                     |
| alkyl next to electronegative atom | $\text{CH}_3-\text{O}$ , $-\text{CH}_2-\text{O}$ , $-\text{CH}_2-\text{Cl}$                         | 3.2–4.0                                     |
| attached to alkene                 | $=\text{CHR}$                                                                                       | 4.5–6.0                                     |
| attached to aromatic ring          | $\text{H}-\text{Ar}$                                                                                | 6.0–9.0                                     |
| aldehyde                           | $\text{HCOR}$                                                                                       | 9.3–10.5                                    |
| alcohol                            | $\text{ROH}$                                                                                        | 0.5–6.0                                     |
| phenol                             | $\text{Ar}-\text{OH}$                                                                               | 4.5–7.0                                     |
| carboxylic acid                    | $\text{RCOOH}$                                                                                      | 9.0–13.0                                    |
| alkyl amine                        | $\text{R}-\text{NH}-$                                                                               | 1.0–5.0                                     |
| aryl amine                         | $\text{Ar}-\text{NH}_2$                                                                             | 3.0–6.0                                     |
| amide                              | $\text{RCONHR}$                                                                                     | 5.0–12.0                                    |

(iv) Compounds **D** and **E** can be distinguished by carbon-13 NMR spectroscopy.

State the number of peaks in each spectrum.

The carbon-13 NMR spectrum of **D** has ..... peaks.

The carbon-13 NMR spectrum of **E** has ..... peaks.

[1]





(c) Compound **D** can be oxidised to compound **F** by alkaline  $\text{KMnO}_4$  followed by dilute acid.

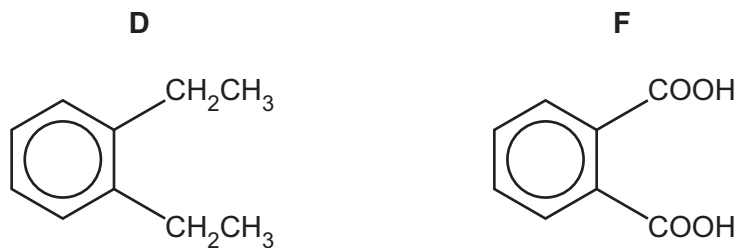


**Fig. 7.3**

- (i) Write an equation for this reaction using molecular formulae for **D** and **F**. The products of this reaction are **F**, water and carbon dioxide.

Use [O] to represent one atom of oxygen from the oxidising agent.

..... [1]



- (ii) **F** reacts with an excess of  $\text{SOCl}_2$  to form compound **G**. The molecular formula of **G** is  $\text{C}_8\text{H}_4\text{Cl}_2\text{O}_2$ .

**G** reacts with ethane-1,2-diol,  $\text{HOCH}_2\text{CH}_2\text{OH}$ , to form a mixture of products that includes compounds **J**, molecular formula  $\text{C}_{10}\text{H}_8\text{O}_4$ , and **K**, molecular formula  $\text{C}_{18}\text{H}_{12}\text{Cl}_2\text{O}_6$ .

Draw the structures of compounds **G**, **J** and **K** in Fig. 7.4.

|                                                              |
|--------------------------------------------------------------|
| <b>G</b> , $\text{C}_8\text{H}_4\text{Cl}_2\text{O}_2$       |
| <b>J</b> , $\text{C}_{10}\text{H}_8\text{O}_4$               |
| <b>K</b> , $\text{C}_{18}\text{H}_{12}\text{Cl}_2\text{O}_6$ |

**Fig. 7.4**

[3]

[Total: 11]





- 8 Bromine reacts with methylbenzene in the dark in the presence of a suitable catalyst to form HBr and compound **L**,  $C_7H_7Br$ . **L** is one of three isomers that can form in this reaction.

- (a) (i) The mechanism for the reaction involves methylbenzene reacting with a  $Br^+$  ion. This ion is produced when bromine reacts with the catalyst.

Complete the equation for the reaction of  $Br_2$  with the catalyst.



- (ii) One of the isomers of **L** forms in much smaller amounts than the other two isomers.

Draw the structure of this isomer and explain why it forms in the smallest amount.

.....  
 .....  
 [2]

- (iii) Complete the mechanism in Fig. 8.1 for the reaction between methylbenzene and the  $Br^+$  ion.

Include all relevant curly arrows and charges.

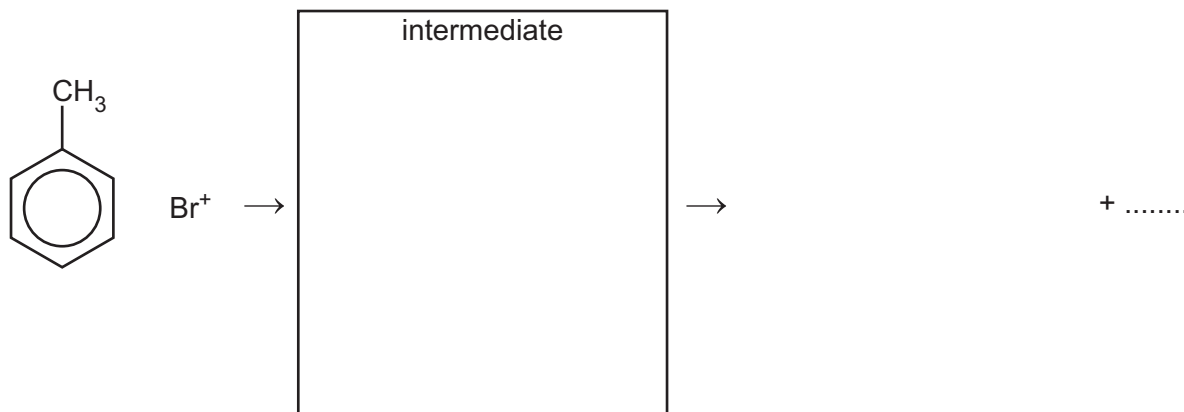


Fig. 8.1

[3]



(b) Chlorobutane and chlorobenzene are added separately to samples of warm aqueous  $\text{AgNO}_3$ .

One of the chloro-compounds reacts slowly and the other does **not** react.

(i) Identify the chloro-compound that reacts and describe any observations.

.....  
..... [1]

(ii) Write **two** equations to explain any observations in (b)(i).

.....  
..... [2]

(iii) Explain the difference in reactivity of chlorobutane and chlorobenzene with warm aqueous  $\text{AgNO}_3$ .

.....  
.....  
.....  
..... [2]

[Total: 11]





- 9 (a) Phenylamine,  $\text{C}_6\text{H}_5\text{NH}_2$ , and propylamine,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ , can be produced by different reduction reactions.

- (i) Identify an organic compound that can be converted into  $\text{C}_6\text{H}_5\text{NH}_2$  by a reduction reaction. State the reagents and conditions for this reaction.

organic compound .....

reagents .....

conditions .....

[2]

- (ii) Identify an organic compound that can be converted into  $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$  by a reduction reaction. State the reagent for this reaction.

organic compound .....

reagent .....

[2]

- (iii) Identify a single test that will distinguish between  $\text{C}_6\text{H}_5\text{NH}_2$  and  $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$  by producing a white precipitate with **only** one of these amines.

Draw the structure of the compound that is precipitated.

testing reagent .....

amine that gives a precipitate .....

structure of the compound that is precipitated:

[2]





Explain your answer.

.....

.....

.....

.....

.....

[4]

[Total: 10]



10 Propanoic acid, methanoic acid and ethanedioic acid are all weak acids.

(a) Draw the displayed formula of ethanedioic acid.

[1]

(b) The three acids, propanoic acid, methanoic acid and ethanedioic acid, can be distinguished using a combination of two chemical tests. Neither testing reagent is an acid–base indicator.

Identify **two** suitable testing reagents and complete Table 10.1 to show the observations from each test.

reagent 1 ..... reagent 2 .....

**Table 10.1**

|                  | observation when treated<br>with reagent 1 | observation when treated<br>with reagent 2 |
|------------------|--------------------------------------------|--------------------------------------------|
| propanoic acid   |                                            |                                            |
| methanoic acid   |                                            |                                            |
| ethanedioic acid |                                            |                                            |

[4]

(c) When propanoic acid is treated with chlorine gas in the presence of ultraviolet light, a mixture of products is formed. One of these products is 2,2-dichloropropanoic acid.

Explain why 2,2-dichloropropanoic acid is stronger than propanoic acid. Refer to the structure of each compound in your answer.

.....  
 .....  
 .....  
 ..... [2]

[Total: 7]





### Important values, constants and standards

|                                 |                                                                                                                                           |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| molar gas constant              | $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$                                                                                              |
| Faraday constant                | $F = 9.65 \times 10^4 \text{ C mol}^{-1}$                                                                                                 |
| Avogadro constant               | $L = 6.02 \times 10^{23} \text{ mol}^{-1}$                                                                                                |
| electronic charge               | $e = -1.60 \times 10^{-19} \text{ C}$                                                                                                     |
| molar volume of gas             | $V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K)<br>$V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions |
| ionic product of water          | $K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))                                                             |
| specific heat capacity of water | $c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g <sup>-1</sup> K <sup>-1</sup> )                                                    |





The Periodic Table of Elements

| Group     |           |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           |           |             |            |           |          |       |    |    |
|-----------|-----------|--------------------------------------------------------------------------------------------------------------|---------------|----------|------------|------------|-----------|------------|--------------|-------------|-------------|----------|-----------|-----------|-------------|------------|-----------|----------|-------|----|----|
| 1         | 2         |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | 13        | 14          | 15         | 16        | 17       | 18    |    |    |
|           |           | <div>1<div>Hhydrogen1.0</div></div>                                                                          |               |          |            |            |           |            |              |             |             |          |           |           |             |            |           |          |       |    |    |
|           |           | <div>Key<div>atomic number</div><div>atomic symbol</div><div>name</div><div>relative atomic mass</div></div> |               |          |            |            |           |            |              |             |             |          |           |           |             |            |           |          |       |    |    |
| 3         | 4         |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | 5         | 6           | 7          | 8         | 9        | 10    | 11 | 12 |
| Li        | Be        |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | B         | C           | N          | O         | F        | Ne    |    |    |
| lithium   | beryllium |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | boron     | carbon      | nitrogen   | oxygen    | fluorine | neon  |    |    |
| 6.9       | 9.0       |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | 10.8      | 12.0        | 14.0       | 16.0      | 19.0     | 20.2  |    |    |
| 11        | 12        |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | 13        | 14          | 15         | 16        | 17       | 18    |    |    |
| Na        | Mg        |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | Al        | Si          | P          | S         | Cl       | Ar    |    |    |
| sodium    | magnesium |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | aluminium | silicon     | phosphorus | sulfur    | chlorine | argon |    |    |
| 23.0      | 24.3      |                                                                                                              |               |          |            |            |           |            |              |             |             |          |           | 27.0      | 28.1        | 31.0       | 32.1      | 35.5     | 39.9  |    |    |
| 19        | 20        | 21                                                                                                           | 22            | 23       | 24         | 25         | 26        | 27         | 28           | 29          | 30          | 31       | 32        | 33        | 34          | 35         | 36        | 37       | 38    |    |    |
| K         | Ca        | Sc                                                                                                           | Ti            | V        | Cr         | Mn         | Fe        | Co         | Ni           | Cu          | Zn          | Ga       | Ge        | As        | Se          | Br         | Kr        | 39       | 40    |    |    |
| potassium | calcium   | scandium                                                                                                     | titanium      | vanadium | chromium   | manganese  | iron      | cobalt     | nickel       | copper      | zinc        | gallium  | germanium | arsenic   | selenium    | bromine    | krypton   | 41       | 42    |    |    |
| 39.1      | 40.1      | 45.0                                                                                                         | 47.9          | 50.9     | 52.0       | 54.9       | 55.8      | 58.9       | 58.7         | 63.5        | 65.4        | 69.7     | 72.6      | 74.9      | 79.0        | 79.9       | 83.8      | 43       | 44    |    |    |
| 37        | 38        | 39                                                                                                           | 40            | 41       | 42         | 43         | 44        | 45         | 46           | 47          | 48          | 49       | 50        | 51        | 52          | 53         | 54        | 45       | 46    |    |    |
| Rb        | Sr        | Y                                                                                                            | Zr            | Nb       | Mo         | Tc         | Ru        | Rh         | Pd           | Ag          | Cd          | In       | Sn        | Sb        | Te          | I          | Xe        | 47       | 48    |    |    |
| rubidium  | strontium | yttrium                                                                                                      | zirconium     | niobium  | molybdenum | technetium | ruthenium | rhodium    | palladium    | silver      | cadmium     | indium   | tin       | antimony  | tellurium   | iodine     | xenon     | 49       | 50    |    |    |
| 85.5      | 87.6      | 88.9                                                                                                         | 91.2          | 92.9     | 95.9       | —          | 101.1     | 102.9      | 106.4        | 107.9       | 112.4       | 114.8    | 118.7     | 121.8     | 127.6       | 126.9      | 131.3     | 51       | 52    |    |    |
| 55        | 56        | 57–71                                                                                                        | 72            | 73       | 74         | 75         | 76        | 77         | 78           | 79          | 80          | 81       | 82        | 83        | 84          | 85         | 86        | 53       | 54    |    |    |
| Cs        | Ba        | lanthanoids                                                                                                  | Hf            | Ta       | W          | Re         | Os        | Ir         | Pt           | Au          | Hg          | Tl       | Pb        | Bi        | Po          | At         | Rn        | 55       | 56    |    |    |
| caesium   | barium    |                                                                                                              | hafnium       | tantalum | tungsten   | rhenium    | osmium    | iridium    | platinum     | gold        | mercury     | thallium | lead      | bismuth   | polonium    | astatine   | radon     | 57       | 58    |    |    |
| 132.9     | 137.3     |                                                                                                              | 178.5         | 180.9    | 183.8      | 186.2      | 190.2     | 192.2      | 195.1        | 197.0       | 200.6       | 204.4    | 207.2     | 209.0     | —           | —          | —         | 59       | 60    |    |    |
| 87        | 88        | 89–103                                                                                                       | 104           | 105      | 106        | 107        | 108       | 109        | 110          | 111         | 112         | 113      | 114       | 115       | 116         | 117        | 118       | 61       | 62    |    |    |
| Fr        | Ra        | actinoids                                                                                                    | Rf            | Db       | Sg         | Bh         | Hs        | Mt         | Ds           | Rg          | Cn          | Nh       | Fl        | Mc        | Lv          | Ts         | Og        | 63       | 64    |    |    |
| francium  | radium    |                                                                                                              | rutherfordium | dubnium  | seaborgium | bohrium    | hassium   | meitnerium | darmstadtium | roentgenium | copernicium | nihonium | flerovium | moscovium | livermorium | tennessine | oganesson | 65       | 66    |    |    |
| —         | —         |                                                                                                              | —             | —        | —          | —          | —         | —          | —            | —           | —           | —        | —         | —         | —           | —          | —         | 67       | 68    |    |    |

lanthanoids

|           |       |         |       |              |       |           |       |            |    |           |       |           |       |            |       |           |       |             |       |             |       |         |       |              |       |          |       |            |       |
|-----------|-------|---------|-------|--------------|-------|-----------|-------|------------|----|-----------|-------|-----------|-------|------------|-------|-----------|-------|-------------|-------|-------------|-------|---------|-------|--------------|-------|----------|-------|------------|-------|
| 57        | La    | 58      | Ce    | 59           | Pr    | 60        | Nd    | 61         | Pm | 62        | Sm    | 63        | Eu    | 64         | Gd    | 65        | Tb    | 66          | Dy    | 67          | Ho    | 68      | Er    | 69           | Tm    | 70       | Yb    | 71         | Lu    |
| lanthanum | 138.9 | cerium  | 140.1 | praseodymium | 140.9 | neodymium | 144.2 | promethium | —  | samarium  | 150.4 | europlum  | 152.0 | gadolinium | 157.3 | terbium   | 158.9 | dysprosium  | 162.5 | holmium     | 164.9 | erbium  | 167.3 | thulium      | 168.9 | yterbium | 173.1 | lutetium   | 175.0 |
| 89        | Ac    | 90      | Th    | 91           | Pa    | 92        | U     | 93         | Np | 94        | Pu    | 95        | Am    | 96         | Cm    | 97        | Bk    | 98          | Cf    | 99          | Es    | 100     | Fm    | 101          | Md    | 102      | No    | 103        | Lr    |
| actinium  | —     | thorium | 232.0 | protactinium | 231.0 | uranium   | 238.0 | neptunium  | —  | plutonium | —     | americium | —     | curium     | —     | berkelium | —     | californium | —     | einsteinium | —     | fermium | —     | mendeleevium | —     | nobelium | —     | lawrencium | —     |

actinoids





# Cambridge International AS & A Level

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**CHEMISTRY**

**9701/42**

Paper 4 A Level Structured Questions

**May/June 2025**

**2 hours**

You must answer on the question paper.

No additional materials are needed.

## INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

## INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **24** pages. Any blank pages are indicated.



- 1 (a) (i) Calcium nitrate,  $\text{Ca}(\text{NO}_3)_2$ , decomposes on heating.

Write an equation for the decomposition of calcium nitrate.

..... [1]

- (ii) Describe the trend in the decomposition temperature of the Group 2 nitrates.

Explain your answer.

.....  
 .....  
 .....  
 .....  
 ..... [3]

- (b) A sample of 0.333g of strontium oxide,  $\text{SrO}$ , is completely dissolved in distilled water to form a solution of strontium hydroxide,  $\text{Sr}(\text{OH})_2$ .

The resulting solution is added to a volumetric flask and made up to  $250.0\text{ cm}^3$  with distilled water.

Calculate the pH of this solution at 298K. Give your answer to **two** decimal places.

pH = ..... [4]

[Total: 8]



- 2 (a) When cobalt(II) sulfate,  $\text{CoSO}_4$ , is dissolved in distilled water, solution **A** is formed.

The reaction scheme in Fig. 2.1 shows some reactions of solution **A**.

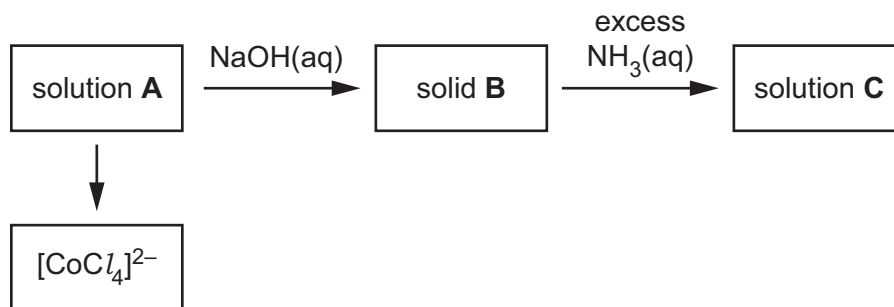


Fig. 2.1

- (i) Complete Table 2.1 to show the formula and colour of each of the cobalt-containing species present in **A**, **B** and **C**. Identify the type of reaction **forming** each of **B** and **C**.

Table 2.1

|          | formula of cobalt-containing species | colour of cobalt-containing species | type of reaction |
|----------|--------------------------------------|-------------------------------------|------------------|
| <b>A</b> |                                      |                                     | X                |
| <b>B</b> |                                      |                                     |                  |
| <b>C</b> |                                      |                                     |                  |

[4]

- (ii) Suggest a suitable reagent for the formation of  $[\text{CoCl}_4]^{2-}$  from solution **A**.

..... [1]

- (b) The complex ion  $[\text{CoCl}_4]^{2-}$  has tetrahedral geometry.

The 3d orbitals in an isolated  $\text{Co}^{2+}$  ion are degenerate.

- (i) Complete Fig. 2.2 to show the relative energies of the 3d orbitals in an isolated  $\text{Co}^{2+}$  ion and in  $\text{Co}^{2+}$  in a tetrahedral complex.

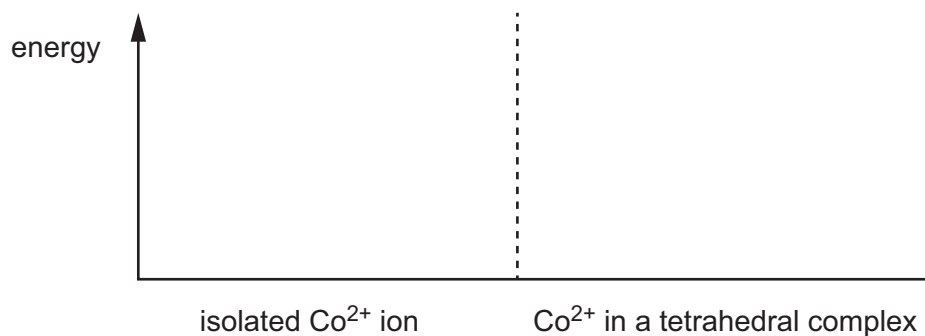


Fig. 2.2

[2]





(ii) Draw a three-dimensional diagram to show the structure of the complex ion  $[\text{CoCl}_4]^{2-}$ .

[1]

(c)  $\text{H}_2\text{O}_2$  can act as an oxidising agent or a reducing agent when reacting with species that contain manganese.

Table 2.2 shows electrode potentials,  $E^\ominus$ , for some electrode reactions.

Table 2.2

| electrode reaction                                                                                          | $E^\ominus/\text{V}$ |
|-------------------------------------------------------------------------------------------------------------|----------------------|
| $\text{MnO}_2 + 2\text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{Mn}(\text{OH})_2 + 2\text{OH}^-$ | -0.04                |
| $\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O}$          | +1.22                |
| $\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$                   | +1.78                |
| $\text{H}_2\text{O}_2 + \text{OH}^- + 2\text{e}^- \rightleftharpoons 3\text{OH}^-$                          | +0.88                |
| $\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2$                            | +0.68                |

Use **only** the species listed in Table 2.2 to suggest:

- one reaction in which  $\text{H}_2\text{O}_2$  acts as an oxidising agent and
- one reaction in which  $\text{H}_2\text{O}_2$  acts as a reducing agent.

Include the value of the standard cell potential,  $E^\ominus_{\text{cell}}$ , and an overall equation for each reaction.

$\text{H}_2\text{O}_2$  acting as an oxidising agent .....

.....  
 .....  
 .....

$\text{H}_2\text{O}_2$  acting as a reducing agent .....

.....  
 .....  
 .....

[4]



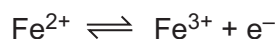
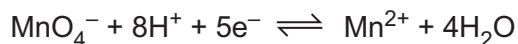
- (d) Acidified manganate(VII) ions,  $\text{MnO}_4^-$ , can be used to analyse the content of iron tablets by titration.

**Two** identical iron tablets are crushed and dissolved in distilled water.

The resulting solution is made up to  $150.0 \text{ cm}^3$  with distilled water.

$25.0 \text{ cm}^3$  of this solution requires  $18.60 \text{ cm}^3$  of  $0.0500 \text{ mol dm}^{-3}$  acidified  $\text{MnO}_4^-$  to reach the end-point. All the  $\text{Fe}^{2+}$  ions are oxidised.

The relevant half-equations are shown.



- (i) Describe the colour change observed at the end-point of this titration.

from ..... to ..... [1]

- (ii) Calculate the mass, in mg, of iron in **one** tablet.

Assume that all the iron in the tablets is  $\text{Fe}^{2+}$ .

Show your working.

mass of iron in one tablet = ..... mg [4]

[Total: 17]





3 (a) Define entropy.

.....

..... [1]

(b) Fig. 3.1 shows how the entropy,  $S$ , of a pure substance changes with temperature,  $T$ .

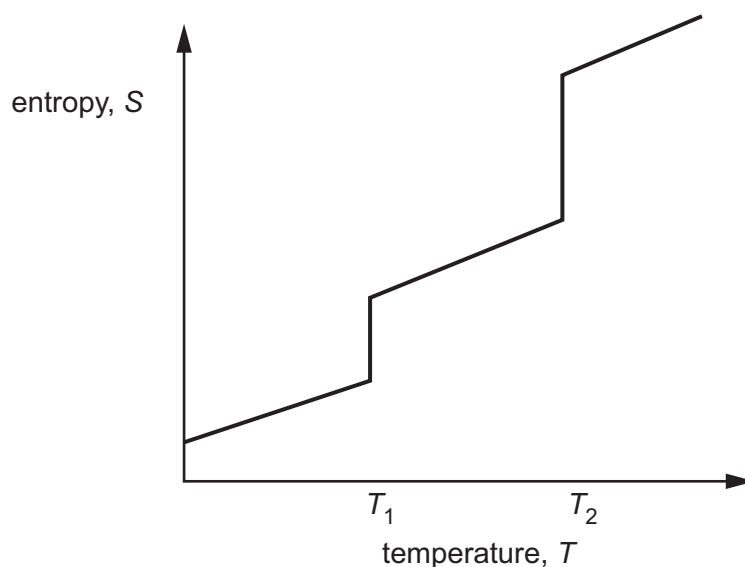


Fig. 3.1

(i) Identify the process occurring at each of the temperatures  $T_1$  and  $T_2$ .

$T_1$  .....  $T_2$  ..... [1]

(ii) Explain why the entropy change,  $\Delta S$ , at  $T_2$  is bigger than the entropy change at  $T_1$ .

.....

.....

..... [1]



(c) The equation for the reduction of iron(III) oxide by carbon monoxide at 450 °C is shown.

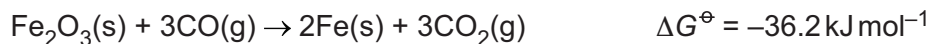


Table 3.1 shows the enthalpy of formation,  $\Delta H_f^\ominus$ , and the entropy,  $S^\ominus$ , for some substances.

**Table 3.1**

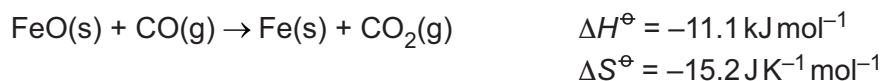
|                                               | $\text{Fe}_2\text{O}_3(\text{s})$ | $\text{CO}(\text{g})$ | $\text{Fe}(\text{s})$ | $\text{CO}_2(\text{g})$ |
|-----------------------------------------------|-----------------------------------|-----------------------|-----------------------|-------------------------|
| $\Delta H_f^\ominus / \text{kJ mol}^{-1}$     | -824.2                            | -110.5                | 0.0                   | -393.5                  |
| $S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$ | 87.4                              | to be calculated      | 27.3                  | 213.8                   |

Use the data in Table 3.1 to calculate the entropy,  $S^\ominus$ , of carbon monoxide at 450 °C.

Show your working.

$$S^\ominus \text{ of CO(g)} = \dots\dots\dots \text{J K}^{-1} \text{mol}^{-1} \quad [3]$$

(d) Iron(II) oxide can also be reduced to iron by carbon monoxide, as shown.



State the effect of increasing temperature on the feasibility of this reaction.

Explain your answer.

.....

.....

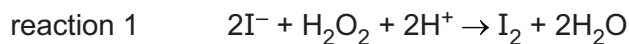
.....

..... [2]

[Total: 8]



- 4 (a) In aqueous solution, iodide ions react with acidified hydrogen peroxide, as shown in reaction 1.



The rate equation for reaction 1 is shown.

$$\text{rate} = k [\text{I}^-][\text{H}_2\text{O}_2]$$

- (i) Explain what is meant by order of reaction.

.....  
 .....  
 ..... [1]

- (ii) Complete Table 4.1.

**Table 4.1**

|                                                                |  |
|----------------------------------------------------------------|--|
| the order of reaction with respect to $[\text{H}^+]$           |  |
| the order of reaction with respect to $[\text{I}^-]$           |  |
| the order of reaction with respect to $[\text{H}_2\text{O}_2]$ |  |
| overall order of the reaction                                  |  |

[2]

- (iii) Sketch a line on Fig. 4.1 to show the relationship between  $[\text{I}^-]$  and time.

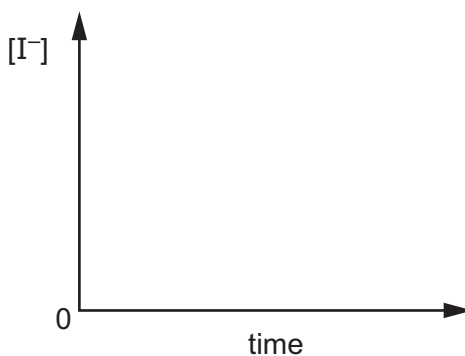


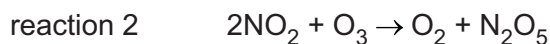
**Fig. 4.1**

[1]





(b) Nitrogen dioxide,  $\text{NO}_2$ , reacts with ozone,  $\text{O}_3$ , as shown in reaction 2.



The rate equation for reaction 2 is shown.

$$\text{rate} = k [\text{NO}_2][\text{O}_3]$$

(i) Two experiments are carried out to measure the rate of reaction 2.

In the first experiment, the initial rate is measured starting with known concentrations of  $\text{NO}_2$  and  $\text{O}_3$ . In the second experiment, the concentrations of  $\text{NO}_2$  and  $\text{O}_3$  are **both** increased by a factor of four.

Predict how the initial rate for reaction 2 would change.

..... [1]

(ii) The reaction mechanism for reaction 2 has two steps.

Define rate-determining step.

..... [1]

(iii) Suggest equations for the **two** steps of the reaction mechanism for reaction 2.

step 1 .....

step 2 ..... [2]





(c) Dinitrogen pentoxide,  $\text{N}_2\text{O}_5$ , can decompose to  $\text{NO}_2$  and  $\text{O}_2$ .

The rate equation for this decomposition is shown.

$$\text{rate} = k [\text{N}_2\text{O}_5]$$

Fig. 4.2 shows the graph of rate against  $[\text{N}_2\text{O}_5]$  for this decomposition.

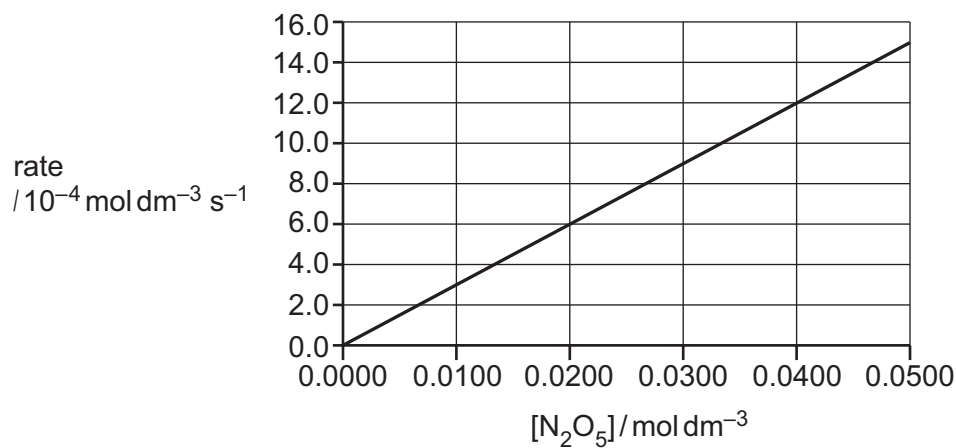


Fig. 4.2

(i) Use Fig. 4.2 to calculate a value for the rate constant,  $k$ , for this decomposition.

$$k = \dots\dots\dots [1]$$

(ii) Use your answer to (c)(i) to calculate the half-life,  $t_{\frac{1}{2}}$ , in seconds, for this decomposition.

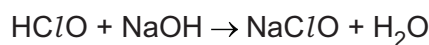
$$t_{\frac{1}{2}} = \dots\dots\dots \text{ s } [1]$$

[Total: 10]



- 5 (a) Chloric(I) acid,  $\text{HClO}$ , is a weak Brønsted–Lowry acid.

When chloric(I) acid is added to aqueous sodium hydroxide, an acid–base reaction takes place, as shown.



- (i) Identify the **two** conjugate acid–base pairs in this reaction.

acid I     $\text{HClO}$                       conjugate base of acid I    .....

acid II    .....                      conjugate base of acid II    .....

[1]

- (ii) The value for the acid dissociation constant,  $K_a$ , of  $\text{HClO}(\text{aq})$  is  $3.70 \times 10^{-8}$ .

Calculate the concentration, in  $\text{mol dm}^{-3}$ , of  $\text{HClO}(\text{aq})$  at a pH of 4.51.

concentration of  $\text{HClO} = \dots\dots\dots \text{mol dm}^{-3}$  [2]

- (iii) When a solution of  $\text{HClO}(\text{aq})$  is heated, chloric(V) acid and a strong acid **not** containing oxygen are formed as the only products.

Write an equation for this reaction.

..... [1]

- (b) (i) Define a buffer solution.

.....

..... [1]

- (ii) Suggest a substance that could be added to aqueous ethanoic acid to form a buffer solution.

Explain your answer.

.....

.....

..... [1]





- (c) Some fertilisers contain calcium dihydrogenphosphate,  $\text{Ca}(\text{H}_2\text{PO}_4)_2$ .

An aqueous solution containing dihydrogenphosphate ions,  $\text{H}_2\text{PO}_4^-$ , can act as a buffer solution.

Write **two** equations to show how  $\text{H}_2\text{PO}_4^-$  ions can act as a buffer.

equation 1 .....

equation 2 ..... [2]

- (d) The solubility of calcium phosphate,  $\text{Ca}_3(\text{PO}_4)_2$ , is  $1.14 \times 10^{-7} \text{ mol dm}^{-3}$  at  $25^\circ\text{C}$ .

- (i) The expression for the solubility product,  $K_{\text{sp}}$ , of  $\text{Ca}_3(\text{PO}_4)_2$  is shown.

$$K_{\text{sp}} = [\text{Ca}^{2+}]^3[\text{PO}_4^{3-}]^2$$

Calculate the value of  $K_{\text{sp}}$  for  $\text{Ca}_3(\text{PO}_4)_2$ . Include units.

$$K_{\text{sp}} = \dots \text{ units} \dots [3]$$

- (ii) Some solid sodium phosphate is added to a saturated solution of  $\text{Ca}_3(\text{PO}_4)_2$ .

Predict the effect, if any, on the solubility of  $\text{Ca}_3(\text{PO}_4)_2$ .

Explain your answer.

..... [1]  
 .....  
 .....

[Total: 12]



- 6 (a) Methylbenzene reacts readily with nitronium ions,  $\text{NO}_2^+$ .

$\text{NO}_2^+$  ions are generated by the reaction between concentrated nitric acid and concentrated sulfuric acid.

- (i) Write an equation for the formation of the  $\text{NO}_2^+$  ion.

..... [1]

- (ii) Complete the mechanism in Fig. 6.1 for the nitration of methylbenzene to form 1-methyl-2-nitrobenzene.

Include all relevant curly arrows and charges.

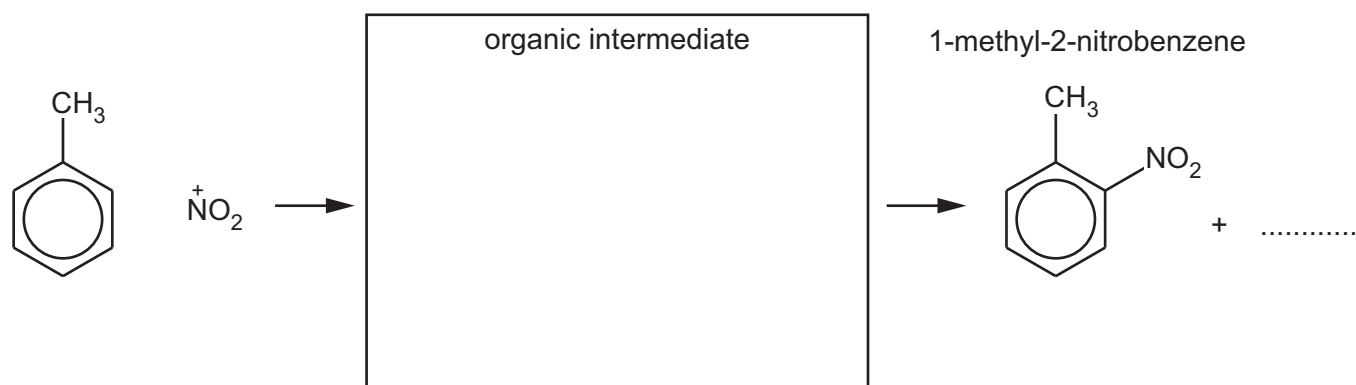


Fig. 6.1

[3]

- (b) Phenol can be nitrated with dilute nitric acid.

Explain why the nitration of phenol occurs under **milder** conditions than the nitration of benzene.

.....  
 .....  
 .....  
 .....  
 ..... [2]

- (c) A sample of 2-nitrophenol is reacted with sodium.

Complete the equation in Fig. 6.2 for the reaction of 2-nitrophenol with sodium.

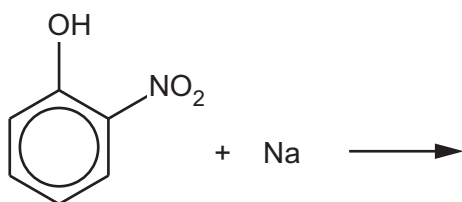


Fig. 6.2

[1]





(d) 2-nitrophenol can undergo different reactions as shown in Fig. 6.3.

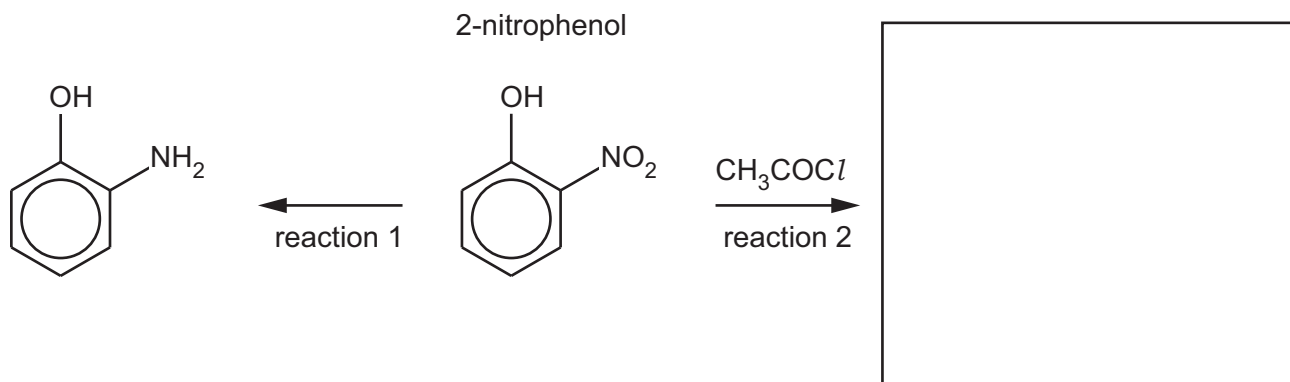


Fig. 6.3

(i) Suggest reagents and conditions for reaction 1.

..... [1]

(ii) Name the type of reaction for reaction 1.

..... [1]

(iii) Reaction 2 is carried out at room temperature.

Draw the structure of the organic product from reaction 2 in Fig. 6.3. [1]

(iv) Name the mechanism for reaction 2.

..... [1]

(e) The  $\text{NO}_2$  group in 2-nitrophenol is electron withdrawing.

Suggest the relative acidities of ethanol, 2-nitrophenol, phenol and water.

Explain your answer.

.....

most acidic least acidic

.....

.....

.....

.....

.....

.....

[4]



- (f) Salbutamol is a pharmaceutical drug that contains a phenol functional group.

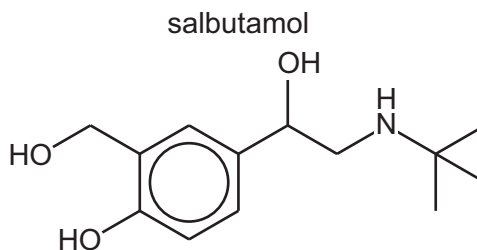


Fig. 6.4

- (i) Name and classify the **three** other functional groups in salbutamol in Table 6.1.

Table 6.1

| name of functional group | classification of functional group |
|--------------------------|------------------------------------|
|                          |                                    |
|                          |                                    |
|                          |                                    |

[2]

- (ii) Salbutamol reacts with  $\text{Br}_2(\text{aq})$  to form organic product **X**.

Draw the structure of **X**.

[1]

- (iii) Salbutamol reacts with an excess of  $\text{SOCl}_2$  to form organic product **Y**.

The molecular formula of **Y** is  $\text{C}_{13}\text{H}_{19}\text{Cl}_2\text{NO}$ .

Draw the structure of **Y**.

[1]





- 7 (a) 2-aminobutane,  $\text{CH}_3\text{CH}(\text{NH}_2)\text{CH}_2\text{CH}_3$ , exists as a mixture of two enantiomers.

Define enantiomers.

.....  
 ..... [1]

- (b) (i) Explain why an aqueous solution of 2-aminobutane has a pH greater than 7.

Include an equation in your answer.

.....  
 .....  
 ..... [2]

- (ii) A  $0.10 \text{ mol dm}^{-3}$  solution of diethylamine,  $(\text{CH}_3\text{CH}_2)_2\text{NH}$ , has a higher pH than a  $0.10 \text{ mol dm}^{-3}$  solution of 2-aminobutane,  $\text{CH}_3\text{CH}(\text{NH}_2)\text{CH}_2\text{CH}_3$ .

Suggest why.

.....  
 .....  
 .....  
 ..... [2]

- (iii)  $(\text{CH}_3\text{CH}_2)_2\text{NH}$  reacts with ethanoic acid,  $\text{CH}_3\text{COOH}$ .

Complete the equation for this reaction.



- (iv)  $(\text{CH}_3\text{CH}_2)_2\text{NH}$  reacts with ethanoyl chloride,  $\text{CH}_3\text{COCl}$ .

Complete the equation for this reaction.

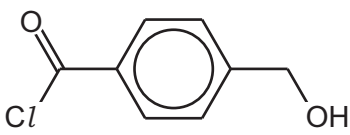




(c) Table 7.1 shows monomers that can undergo polymerisation.

(i) Complete Table 7.1.

Table 7.1

| monomer                                                                           | type of polymerisation |
|-----------------------------------------------------------------------------------|------------------------|
| $\text{CH}_2\text{C}(\text{CH}_3)\text{COOH}$                                     |                        |
|  |                        |
| $\text{CH}_3\text{CH}(\text{NH}_2)\text{COOH}$                                    |                        |

[1]

(ii) Ethanedioic acid,  $\text{HOOC}\text{COOH}$ , can react with propane-1,3-diamine,  $\text{H}_2\text{NCH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ , to form polymer **W**.

Draw a section of polymer **W** showing only **one** repeat unit.

The new functional group formed should be displayed.

[2]

(iii) Poly(alkenes) biodegrade very slowly. Explain why.

.....  
 ..... [1]

[Total: 11]



- 8 (a) Compound **A** is analysed by carbon-13 NMR and proton ( $^1\text{H}$ ) NMR spectroscopy.

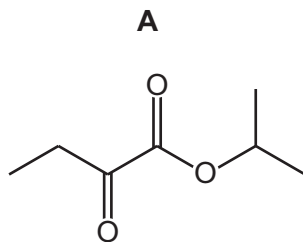


**Fig. 8.1**

State the reference substance and a solvent that can be used in NMR spectroscopy.

reference .....

solvent ..... [1]

- (b) Predict the number of peaks in the carbon-13 NMR spectrum of **A**.

..... [1]

- (c) The proton ( $^1\text{H}$ ) NMR spectrum of **A** shows peaks in four different chemical environments.

Complete Table 8.1 for the proton ( $^1\text{H}$ ) NMR spectrum of **A**.

**Table 8.1**

| chemical shift<br>$\delta/\text{ppm}$ | splitting pattern | number of protons on<br>adjacent carbon atoms | number of $^1\text{H}$ atoms<br>responsible for the peak |
|---------------------------------------|-------------------|-----------------------------------------------|----------------------------------------------------------|
| 1.10                                  |                   |                                               |                                                          |
| 1.50                                  |                   |                                               | 6                                                        |
| 2.85                                  |                   |                                               |                                                          |
| 3.75                                  |                   |                                               |                                                          |

[4]

[Total: 6]





Table 8.2

| environment of proton              | example                                                                                             | chemical shift range<br>$\delta$ /ppm |
|------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------|
| alkane                             | $-\text{CH}_3$ , $-\text{CH}_2-$ , $>\text{CH}-$                                                    | 0.9–1.7                               |
| alkyl next to $\text{C}=\text{O}$  | $\text{CH}_3-\text{C}=\text{O}$ , $-\text{CH}_2-\text{C}=\text{O}$ , $>\text{CH}-\text{C}=\text{O}$ | 2.2–3.0                               |
| alkyl next to aromatic ring        | $\text{CH}_3-\text{Ar}$ , $-\text{CH}_2-\text{Ar}$ , $>\text{CH}-\text{Ar}$                         | 2.3–3.0                               |
| alkyl next to electronegative atom | $\text{CH}_3-\text{O}$ , $-\text{CH}_2-\text{O}$ , $-\text{CH}_2-\text{Cl}$                         | 3.2–4.0                               |
| attached to alkene                 | $=\text{CHR}$                                                                                       | 4.5–6.0                               |
| attached to aromatic ring          | $\text{H}-\text{Ar}$                                                                                | 6.0–9.0                               |
| aldehyde                           | $\text{HCOR}$                                                                                       | 9.3–10.5                              |
| alcohol                            | $\text{ROH}$                                                                                        | 0.5–6.0                               |
| phenol                             | $\text{Ar}-\text{OH}$                                                                               | 4.5–7.0                               |
| carboxylic acid                    | $\text{RCOOH}$                                                                                      | 9.0–13.0                              |
| alkyl amine                        | $\text{R}-\text{NH}-$                                                                               | 1.0–5.0                               |
| aryl amine                         | $\text{Ar}-\text{NH}_2$                                                                             | 3.0–6.0                               |
| amide                              | $\text{RCONHR}$                                                                                     | 5.0–12.0                              |



- 9 (a) The structures of the amino acids serine and lysine are shown in Fig. 9.1.

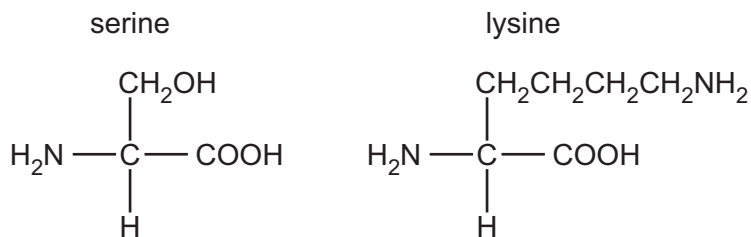


Fig. 9.1

Draw the structure for the dipeptide, ser-lys, with molecular formula  $\text{C}_9\text{H}_{19}\text{N}_3\text{O}_4$ . The peptide functional group formed should be displayed.

[2]

- (b) The isoelectric point of serine is 5.7 and of lysine is 9.7.

- (i) State what is meant by isoelectric point.

.....  
 ..... [1]

- (ii) A mixture of serine, lysine and ser-lys is analysed by electrophoresis using a buffer at pH 5.7.

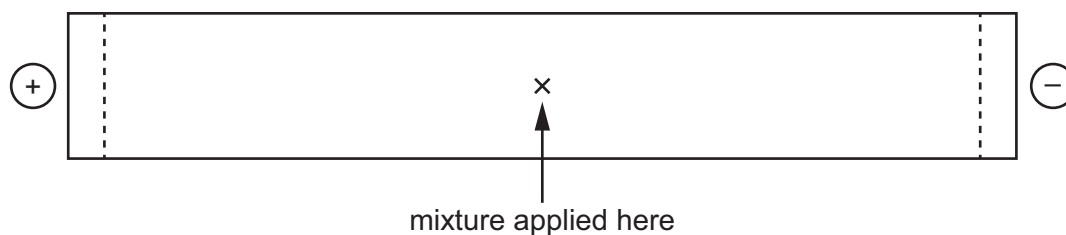


Fig. 9.2

Draw and label **three** spots on Fig. 9.2 to indicate the predicted position of each of these three species, serine, lysine and ser-lys, after electrophoresis.

Explain your answer.

.....  
 .....  
 .....  
 ..... [3]



(c) Fig. 9.3 shows the synthesis of compound **R** from compound **P**.

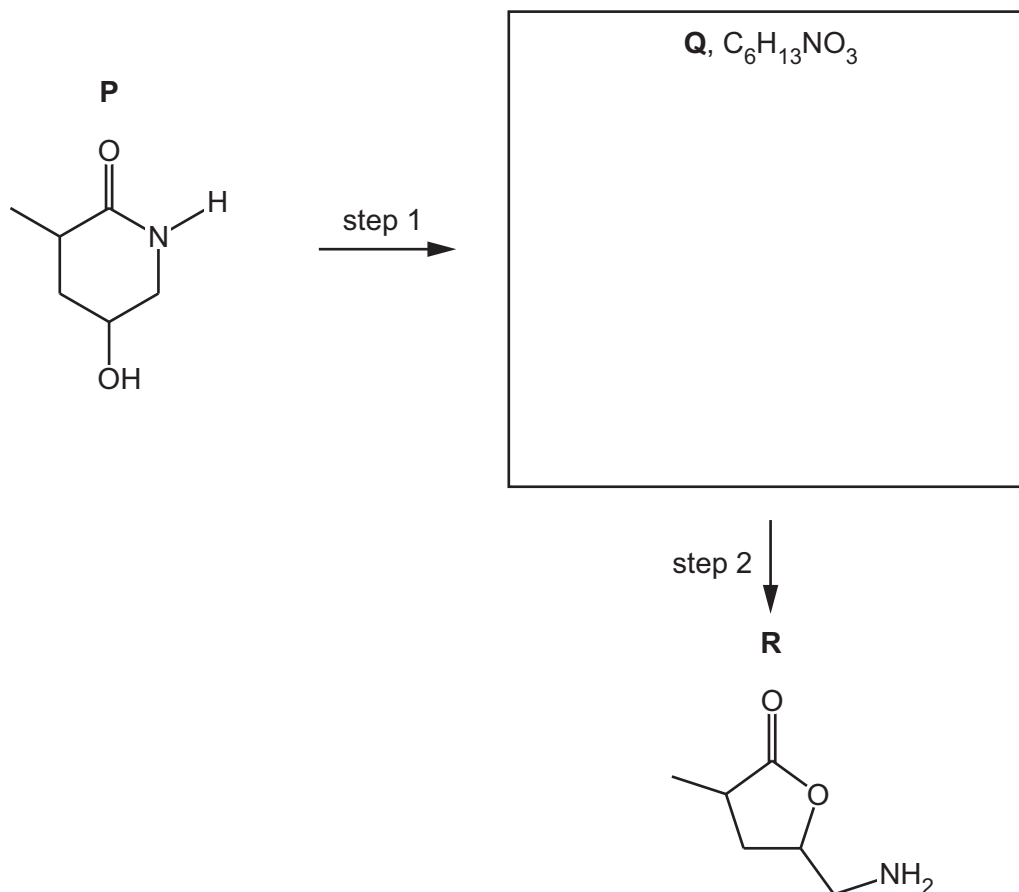


Fig. 9.3

(i) Draw the structure of **Q** in Fig. 9.3. [1]

(ii) State the reagents and conditions for steps 1 and 2 in Fig. 9.3.

step 1 .....

step 2 .....

[2]

[Total: 9]







### Important values, constants and standards

|                                 |                                                                                                                                           |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| molar gas constant              | $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$                                                                                              |
| Faraday constant                | $F = 9.65 \times 10^4 \text{ C mol}^{-1}$                                                                                                 |
| Avogadro constant               | $L = 6.02 \times 10^{23} \text{ mol}^{-1}$                                                                                                |
| electronic charge               | $e = -1.60 \times 10^{-19} \text{ C}$                                                                                                     |
| molar volume of gas             | $V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K)<br>$V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions |
| ionic product of water          | $K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25°C))                                                              |
| specific heat capacity of water | $c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g <sup>-1</sup> K <sup>-1</sup> )                                                    |





The Periodic Table of Elements

| Group                  |                         |                                                                                                           |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  |    |    |  |  |
|------------------------|-------------------------|-----------------------------------------------------------------------------------------------------------|-------------------------|--------------------------|--------------------------|-------------------------|--------------------------|------------------------|--------------------------|-------------------------|------------------------|------------------------|--|--|--|----|----|--|--|
| 1                      | 2                       | Key                                                                                                       |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  | 17 | 18 |  |  |
|                        |                         | <div><div>1</div><div>H</div><div>hydrogen</div><div>1.0</div></div>                                      |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  |    |    |  |  |
|                        |                         | <div><div>2</div><div>He</div><div>helium</div><div>4.0</div></div>                                       |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  |    |    |  |  |
| 3                      | 4                       | <div><div>atomic number</div><div>atomic symbol</div><div>name</div><div>relative atomic mass</div></div> |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  |    |    |  |  |
| Li<br>lithium<br>6.9   | Be<br>beryllium<br>9.0  |                                                                                                           |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  |    |    |  |  |
| 11                     | 12                      |                                                                                                           |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  |    |    |  |  |
| Na<br>sodium<br>23.0   | Mg<br>magnesium<br>24.3 |                                                                                                           |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  |    |    |  |  |
|                        |                         | 3                                                                                                         | 4                       | 5                        | 6                        | 7                       | 8                        | 9                      | 10                       | 11                      | 12                     |                        |  |  |  |    |    |  |  |
| 19                     | 20                      | 21                                                                                                        | 22                      | 23                       | 24                       | 25                      | 26                       | 27                     | 28                       | 29                      | 30                     |                        |  |  |  |    |    |  |  |
| K<br>potassium<br>39.1 | Ca<br>calcium<br>40.1   | Sc<br>scandium<br>45.0                                                                                    | Ti<br>titanium<br>47.9  | V<br>vanadium<br>50.9    | Cr<br>chromium<br>52.0   | Mn<br>manganese<br>54.9 | Fe<br>iron<br>55.8       | Co<br>cobalt<br>58.9   | Ni<br>nickel<br>58.7     | Cu<br>copper<br>63.5    | Zn<br>zinc<br>65.4     |                        |  |  |  |    |    |  |  |
| 37                     | 38                      | 39                                                                                                        | 40                      | 41                       | 42                       | 43                      | 44                       | 45                     | 46                       | 47                      | 48                     |                        |  |  |  |    |    |  |  |
| Rb<br>rubidium<br>85.5 | Sr<br>strontium<br>87.6 | Y<br>yttrium<br>88.9                                                                                      | Zr<br>zirconium<br>91.2 | Nb<br>niobium<br>92.9    | Mo<br>molybdenum<br>95.9 | Tc<br>technetium<br>—   | Ru<br>ruthenium<br>101.1 | Rh<br>rhodium<br>102.9 | Pd<br>palladium<br>106.4 | Ag<br>silver<br>107.9   | Cd<br>cadmium<br>112.4 |                        |  |  |  |    |    |  |  |
| 55                     | 56                      | 57–71<br>lanthanoids                                                                                      |                         | 72                       | 73                       | 74                      | 75                       | 76                     | 77                       | 78                      | 79                     | 80                     |  |  |  |    |    |  |  |
| Cs<br>caesium<br>132.9 | Ba<br>barium<br>137.3   |                                                                                                           |                         | Hf<br>hafnium<br>178.5   | Ta<br>tantalum<br>180.9  | W<br>tungsten<br>183.8  | Re<br>rhenium<br>186.2   | Os<br>osmium<br>190.2  | Ir<br>iridium<br>192.2   | Pt<br>platinum<br>195.1 | Au<br>gold<br>197.0    | Hg<br>mercury<br>200.6 |  |  |  |    |    |  |  |
| 87                     | 88                      | 89–103<br>actinoids                                                                                       |                         | 104                      | 105                      | 106                     | 107                      | 108                    | 109                      | 110                     | 111                    | 112                    |  |  |  |    |    |  |  |
| Fr<br>francium<br>—    | Ra<br>radium<br>—       |                                                                                                           |                         | Rf<br>rutherfordium<br>— | Db<br>dubnium<br>—       | Sg<br>seaborgium<br>—   | Bh<br>bohrium<br>—       | Hs<br>hassium<br>—     | Mt<br>meitnerium<br>—    | Ds<br>darmstadtium<br>— | Rg<br>roentgenium<br>— | Cn<br>copernicium<br>— |  |  |  |    |    |  |  |
|                        |                         |                                                                                                           |                         |                          |                          |                         |                          |                        |                          |                         |                        |                        |  |  |  |    |    |  |  |



# Cambridge International AS & A Level

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## CHEMISTRY

9701/43

Paper 4 A Level Structured Questions

May/June 2025

2 hours

You must answer on the question paper.

No additional materials are needed.

### INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

### INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **24** pages. Any blank pages are indicated.



- 1 Both calcium carbonate,  $\text{CaCO}_3$ , and barium carbonate,  $\text{BaCO}_3$ , decompose when heated to form the metal oxide and a gas.

(a) Write an equation for the thermal decomposition of  $\text{CaCO}_3$ .

..... [1]

(b) State which of  $\text{CaCO}_3$  and  $\text{BaCO}_3$  decomposes at a lower temperature.

Explain your answer.

The compound that decomposes at a lower temperature is .....

explanation .....

.....

.....

.....

.....

[2]

(c) Calcium oxide,  $\text{CaO}$ , reacts with water to form compound **A**.

Barium oxide,  $\text{BaO}$ , reacts with water to form compound **B**.

(i) Identify **A**.

..... [1]

(ii) Explain why **A** is less soluble than **B**.

.....

.....

.....

.....

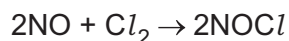
.....

..... [3]

[Total: 7]



- 2 Three experiments are carried out to investigate the reaction of nitrogen oxide, NO, with chlorine.



The rate equation for this reaction is shown.

$$\text{rate} = k[\text{NO}]^2[\text{Cl}_2]$$

- (a) Under the conditions used in experiments 1 and 2, the value of  $k$  is 26.4.

- (i) The rate of the reaction is measured in  $\text{mol dm}^{-3} \text{s}^{-1}$ . State the units of  $k$ .

units of  $k$  = ..... [1]

- (ii) In experiment 1, the initial concentrations of NO and  $\text{Cl}_2$  are equal.

The initial rate of the reaction in experiment 1 is  $2.57 \times 10^{-6} \text{mol dm}^{-3} \text{s}^{-1}$ .

Calculate the initial concentration of NO.

Show your working.

initial concentration of NO = .....  $\text{mol dm}^{-3}$  [2]

- (iii) In experiment 2, the initial concentrations of NO and  $\text{Cl}_2$  are both ten times greater than the initial concentrations used in experiment 1.

Calculate the initial rate of the reaction in experiment 2.

initial rate of reaction in experiment 2 = .....  $\text{mol dm}^{-3} \text{s}^{-1}$  [1]





(b) Experiment 3 uses a large excess of NO.

The initial concentration of  $\text{Cl}_2$  is  $2.00 \times 10^{-4} \text{ mol dm}^{-3}$ .

(i) The graph of  $[\text{Cl}_2]$  against time shows that the reaction has a constant half-life,  $t_{1/2}$ .

Explain this observation.

.....  
 ..... [1]

(ii) Under the conditions used in experiment 3, the value of the rate constant is 105.6.

Show that  $t_{1/2}$  of  $[\text{Cl}_2]$  is  $6.56 \times 10^{-3} \text{ s}$  under these conditions.

[1]

(iii) Calculate the time taken, in s, for  $[\text{Cl}_2]$  to fall to  $1.25 \times 10^{-5} \text{ mol dm}^{-3}$  in experiment 3.

time = ..... s [1]

(c) Sulfur dioxide,  $\text{SO}_2$ , reacts very slowly with oxygen in the atmosphere, forming sulfur trioxide,  $\text{SO}_3$ . This reaction is much faster in the presence of NO.

Explain the role of NO in this process.

Include chemical equations in your answer.

.....  
 .....  
 .....  
 ..... [3]

[Total: 10]





- 3 (a) Chromium(III) hydroxide,  $\text{Cr}(\text{OH})_3$ , is only slightly soluble in water. The value of the solubility product,  $K_{\text{sp}}$ , of  $\text{Cr}(\text{OH})_3$  is  $1.0 \times 10^{-33}$  at 298 K.

(i) Complete the expression for  $K_{\text{sp}}$  of  $\text{Cr}(\text{OH})_3$ . Include the units.

$$K_{\text{sp}} =$$

units = ..... [2]

(ii) Calculate the solubility, in  $\text{g dm}^{-3}$ , of  $\text{Cr}(\text{OH})_3$  in pure water at 298 K.

Show your working.

solubility = .....  $\text{g dm}^{-3}$  [3]

(iii)  $\text{Cr}(\text{OH})_3$  is less soluble in  $0.100 \text{ mol dm}^{-3}$  NaOH than it is in pure water.

Explain this observation.

..... [1]

(b) The value of the acid dissociation constant,  $K_{\text{a}}$ , of butanoic acid,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ , is  $1.51 \times 10^{-5}$  at 298 K.

(i) Calculate the pH of  $0.100 \text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  at 298 K.

Show your working.

pH = ..... [2]

(ii) Calculate the pH of  $0.100 \text{ mol dm}^{-3}$  NaOH at 298 K.

pH = ..... [1]





- (iii)  $5.00 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$  NaOH is added to  $10.00 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ .

Calculate the pH of the resulting solution.

Show your working.

pH = ..... [2]

- (c)  $80.0 \text{ cm}^3$  of an aqueous solution containing  $0.704 \text{ g}$  of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  is shaken with  $100 \text{ cm}^3$  of benzene,  $\text{C}_6\text{H}_6$ .

There is  $0.556 \text{ g}$  of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  in the  $100 \text{ cm}^3$  of  $\text{C}_6\text{H}_6$  at equilibrium.

Calculate the partition coefficient,  $K_{\text{pc}}$ , of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  between  $\text{C}_6\text{H}_6$  and water.

Show your working.

$K_{\text{pc}} = \dots\dots\dots$  [2]

[Total: 13]



- 4 Table 4.1 gives the enthalpy changes of hydration,  $\Delta H_{\text{hyd}}$ , of three ions,  $\text{F}^-$ ,  $\text{K}^+$  and  $\text{Ca}^{2+}$ .

Table 4.1

| ion              | $\Delta H_{\text{hyd}}/\text{kJ mol}^{-1}$ |
|------------------|--------------------------------------------|
| $\text{F}^-$     | –506                                       |
| $\text{K}^+$     | –322                                       |
| $\text{Ca}^{2+}$ | –1650                                      |

- (a) (i) Define enthalpy change of hydration.

.....  
 .....  
 ..... [1]

- (ii) Explain the relative magnitudes of the enthalpy changes of hydration of  $\text{K}^+$  and  $\text{Ca}^{2+}$ .

.....  
 .....  
 .....  
 ..... [2]

- (iii) Define lattice energy.

.....  
 ..... [1]

- (iv) The lattice energy,  $\Delta H_{\text{latt}}$ , of calcium fluoride,  $\text{CaF}_2$ , is  $-2602 \text{ kJ mol}^{-1}$ .

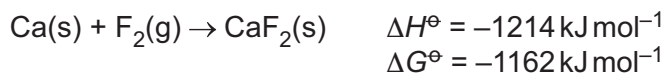
Calculate the enthalpy change of solution,  $\Delta H_{\text{sol}}$ , in  $\text{kJ mol}^{-1}$ , of  $\text{CaF}_2$ .

$\Delta H_{\text{sol}}$  of  $\text{CaF}_2 = \dots\dots\dots \text{kJ mol}^{-1}$  [2]





(b) The formation of  $\text{CaF}_2$  at 298 K is shown.



Calculate the entropy change,  $\Delta S^\ominus$ , in  $\text{J K}^{-1} \text{ mol}^{-1}$ , for this reaction.

$$\Delta S^\ominus = \dots\dots\dots \text{J K}^{-1} \text{ mol}^{-1} \quad [2]$$

[Total: 8]





5 Copper is a transition element.

(a) (i) Complete the electronic configurations of a  $\text{Cu}^+$  ion and a  $\text{Cu}^{2+}$  ion.

$\text{Cu}^+$  ion:  $[\text{Ar}]$  .....

$\text{Cu}^{2+}$  ion:  $[\text{Ar}]$  .....

[1]

(ii) Explain why transition elements have variable oxidation states.

.....

..... [1]

(b) Aqueous copper(II) sulfate,  $\text{CuSO}_4$ , contains the  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$  complex ion.

(i) A few drops of  $\text{NH}_3(\text{aq})$  are added to  $\text{CuSO}_4(\text{aq})$ .

Describe any observations made.

..... [1]

(ii) Write an equation for the reaction taking place.

..... [1]

(c) (i) An **excess** of  $\text{NH}_3(\text{aq})$  is added to  $\text{CuSO}_4(\text{aq})$ .

Describe any further observations made.

..... [1]

(ii) Write an equation for the reaction taking place.

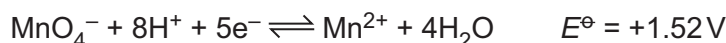
..... [1]

(iii) State the name for the type of reaction taking place.

..... [1]



- (d) Copper metal can be oxidised by acidified  $\text{KMnO}_4$ . The relevant half-equations and their standard electrode potentials,  $E^\ominus$ , are shown.



- (i) A  $\text{MnO}_4^-/\text{Mn}^{2+}$  electrode is constructed using  $0.0020 \text{ mol dm}^{-3} \text{ MnO}_4^-$ ,  $1.0 \text{ mol dm}^{-3} \text{ Mn}^{2+}$  and  $1.0 \text{ mol dm}^{-3} \text{ H}^+$ . The temperature used is  $298 \text{ K}$ .

Use the Nernst equation to show that the  $E$  value for this  $\text{MnO}_4^-/\text{Mn}^{2+}$  electrode is  $+1.49 \text{ V}$ .

[2]

- (ii) An electrochemical cell is constructed using a standard  $\text{Cu}^{2+}/\text{Cu}$  electrode and the  $\text{MnO}_4^-/\text{Mn}^{2+}$  electrode described in (d)(i).

Calculate the value of  $E_{\text{cell}}$ .

$$E_{\text{cell}} = \dots\dots\dots \text{V} \quad [1]$$

- (iii) Write an equation for the reaction taking place in the electrochemical cell described in (d)(ii).

..... [1]

- (iv) Complete the sentences for the electrochemical cell described in (d)(ii).

The ..... electrode is the negative electrode. Electrons flow from the

..... electrode to the ..... electrode when the cell is in use. [1]

- (e) A solution containing  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$  is electrolysed for  $5.00 \text{ hours}$  using a constant electric current.  $0.764 \text{ g}$  of copper metal is formed at the cathode. No other reduction reaction takes place.

Calculate the electric current, in  $\text{A}$ , used. Give your answer to **three** significant figures.

$$\text{current} = \dots\dots\dots \text{A} \quad [3]$$

[Total: 15]

[Turn over]



6 (a) Iron forms complex ions with the monodentate ligand,  $\text{CN}^-$ .

(i) Complex ion **A** contains one  $\text{Fe}^{3+}$  ion and six  $\text{CN}^-$  ligands.

Complex ion **B** contains one  $\text{Fe}^{2+}$  ion and six  $\text{CN}^-$  ligands.

State the formulae of these two complex ions. Include the overall charge of each complex ion.

complex ion **A** .....

complex ion **B** .....

[1]

(ii) Explain why a solution containing complex ion **A** and a solution containing complex ion **B** are different colours.

.....

.....

..... [2]

(iii) In complex ion **A**, the carbon atom of each  $\text{CN}^-$  ligand bonds to the  $\text{Fe}^{3+}$  ion.

State the type of bonding involved.

..... [1]





(b) Complex ions have different geometries.

Complex ion **A** is octahedral.

$\text{Ag}^+$  ions form a linear complex with ammonia.

Ni atoms form a tetrahedral complex with carbon monoxide molecules. The carbon atom in the monodentate carbon monoxide ligand bonds to the nickel atom.

$\text{Pd}^{2+}$  ions form a square planar complex with chloride ions.

Complete Fig. 6.1 to show the geometry of each of these four ions, using three-dimensional bonds where necessary. Label **one** bond angle on each complex ion.

|                                                                                                  |                                                                                                                    |
|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| <p style="text-align: center;">complex ion <b>A</b></p> <p style="text-align: center;">Fe</p>    | <p style="text-align: center;"><math>\text{Ag}^+</math> with ammonia</p> <p style="text-align: center;">Ag</p>     |
| <p style="text-align: center;">Ni with carbon monoxide</p> <p style="text-align: center;">Ni</p> | <p style="text-align: center;"><math>\text{Pd}^{2+}</math> with chloride</p> <p style="text-align: center;">Pd</p> |

Fig. 6.1

[4]

[Total: 8]



- 7 A hydrocarbon is known to be either compound **D** or compound **E**.

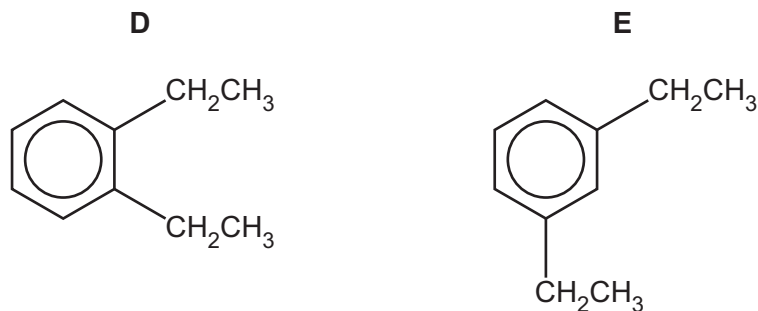


Fig. 7.1

- (a) Give the systematic name of **E**.

..... [1]

- (b) The proton ( $^1\text{H}$ ) NMR spectra of **D** and **E** are compared. They are very similar. The proton ( $^1\text{H}$ ) NMR spectrum of **D** is shown in Fig. 7.2.

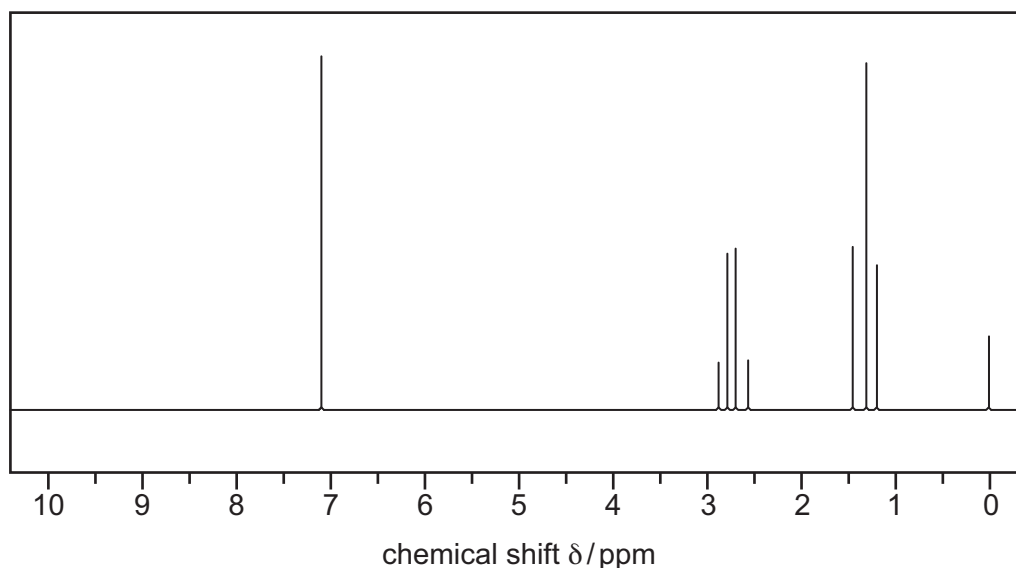


Fig. 7.2

- (i) Suggest a suitable solvent for obtaining the spectrum in Fig. 7.2.

..... [1]

- (ii) The proton ( $^1\text{H}$ ) NMR spectrum of **E** is obtained twice, once before and once after shaking with  $\text{D}_2\text{O}$ .

Describe any differences between these two spectra. Explain your answer.

..... [1]





(iii) Complete Table 7.1 for the proton ( $^1\text{H}$ ) NMR spectrum of **D**.

Table 7.1

| chemical shift<br>$\delta/\text{ppm}$ | number of $^1\text{H}$ atoms<br>responsible for the peak | group responsible<br>for the peak | splitting pattern |
|---------------------------------------|----------------------------------------------------------|-----------------------------------|-------------------|
| 1.3                                   |                                                          |                                   |                   |
| 2.7                                   |                                                          |                                   |                   |
| 7.1                                   |                                                          |                                   |                   |

[3]

Table 7.2

| environment of proton              | example                                                                                             | chemical shift range<br>$\delta/\text{ppm}$ |
|------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------|
| alkane                             | $-\text{CH}_3$ , $-\text{CH}_2-$ , $>\text{CH}-$                                                    | 0.9–1.7                                     |
| alkyl next to $\text{C}=\text{O}$  | $\text{CH}_3-\text{C}=\text{O}$ , $-\text{CH}_2-\text{C}=\text{O}$ , $>\text{CH}-\text{C}=\text{O}$ | 2.2–3.0                                     |
| alkyl next to aromatic ring        | $\text{CH}_3-\text{Ar}$ , $-\text{CH}_2-\text{Ar}$ , $>\text{CH}-\text{Ar}$                         | 2.3–3.0                                     |
| alkyl next to electronegative atom | $\text{CH}_3-\text{O}$ , $-\text{CH}_2-\text{O}$ , $-\text{CH}_2-\text{Cl}$                         | 3.2–4.0                                     |
| attached to alkene                 | $=\text{CHR}$                                                                                       | 4.5–6.0                                     |
| attached to aromatic ring          | $\text{H}-\text{Ar}$                                                                                | 6.0–9.0                                     |
| aldehyde                           | $\text{HCOR}$                                                                                       | 9.3–10.5                                    |
| alcohol                            | $\text{ROH}$                                                                                        | 0.5–6.0                                     |
| phenol                             | $\text{Ar}-\text{OH}$                                                                               | 4.5–7.0                                     |
| carboxylic acid                    | $\text{RCOOH}$                                                                                      | 9.0–13.0                                    |
| alkyl amine                        | $\text{R}-\text{NH}-$                                                                               | 1.0–5.0                                     |
| aryl amine                         | $\text{Ar}-\text{NH}_2$                                                                             | 3.0–6.0                                     |
| amide                              | $\text{RCONHR}$                                                                                     | 5.0–12.0                                    |

(iv) Compounds **D** and **E** can be distinguished by carbon-13 NMR spectroscopy.

State the number of peaks in each spectrum.

The carbon-13 NMR spectrum of **D** has ..... peaks.

The carbon-13 NMR spectrum of **E** has ..... peaks.

[1]



(c) Compound **D** can be oxidised to compound **F** by alkaline  $\text{KMnO}_4$  followed by dilute acid.

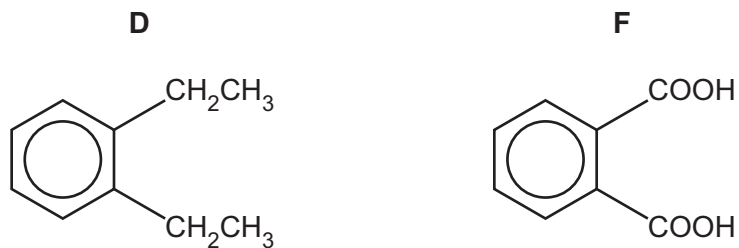


**Fig. 7.3**

- (i) Write an equation for this reaction using molecular formulae for **D** and **F**. The products of this reaction are **F**, water and carbon dioxide.

Use [O] to represent one atom of oxygen from the oxidising agent.

..... [1]





- (ii) **F** reacts with an excess of  $\text{SOCl}_2$  to form compound **G**. The molecular formula of **G** is  $\text{C}_8\text{H}_4\text{Cl}_2\text{O}_2$ .

**G** reacts with ethane-1,2-diol,  $\text{HOCH}_2\text{CH}_2\text{OH}$ , to form a mixture of products that includes compounds **J**, molecular formula  $\text{C}_{10}\text{H}_8\text{O}_4$ , and **K**, molecular formula  $\text{C}_{18}\text{H}_{12}\text{Cl}_2\text{O}_6$ .

Draw the structures of compounds **G**, **J** and **K** in Fig. 7.4.

|                                                              |
|--------------------------------------------------------------|
| <b>G</b> , $\text{C}_8\text{H}_4\text{Cl}_2\text{O}_2$       |
| <b>J</b> , $\text{C}_{10}\text{H}_8\text{O}_4$               |
| <b>K</b> , $\text{C}_{18}\text{H}_{12}\text{Cl}_2\text{O}_6$ |

**Fig. 7.4**

[3]

[Total: 11]



- 8 Bromine reacts with methylbenzene in the dark in the presence of a suitable catalyst to form HBr and compound **L**,  $C_7H_7Br$ . **L** is one of three isomers that can form in this reaction.

- (a) (i) The mechanism for the reaction involves methylbenzene reacting with a  $Br^+$  ion. This ion is produced when bromine reacts with the catalyst.

Complete the equation for the reaction of  $Br_2$  with the catalyst.



- (ii) One of the isomers of **L** forms in much smaller amounts than the other two isomers.

Draw the structure of this isomer and explain why it forms in the smallest amount.

.....  
 .....  
 [2]

- (iii) Complete the mechanism in Fig. 8.1 for the reaction between methylbenzene and the  $Br^+$  ion.

Include all relevant curly arrows and charges.

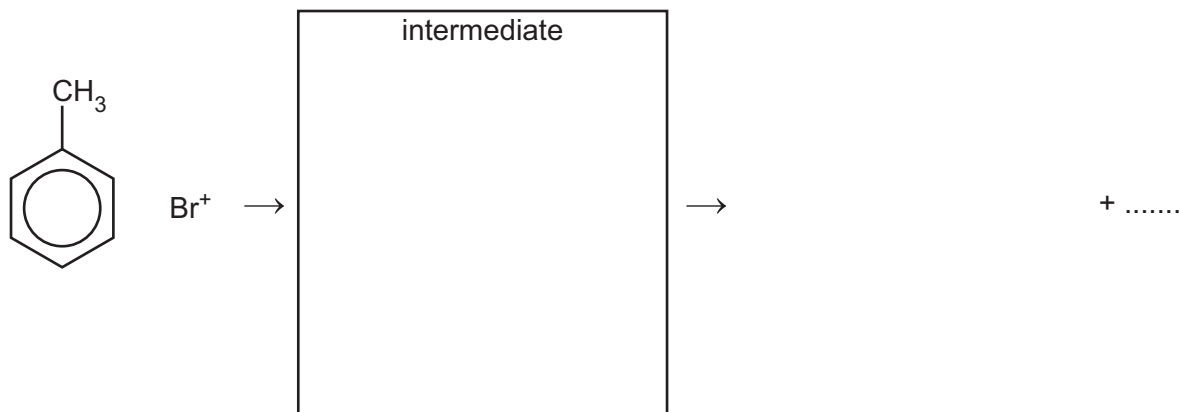


Fig. 8.1

[3]



(b) Chlorobutane and chlorobenzene are added separately to samples of warm aqueous  $\text{AgNO}_3$ .

One of the chloro-compounds reacts slowly and the other does **not** react.

(i) Identify the chloro-compound that reacts and describe any observations.

.....  
..... [1]

(ii) Write **two** equations to explain any observations in (b)(i).

.....  
..... [2]

(iii) Explain the difference in reactivity of chlorobutane and chlorobenzene with warm aqueous  $\text{AgNO}_3$ .

.....  
.....  
.....  
..... [2]

[Total: 11]





- 9 (a) Phenylamine,  $\text{C}_6\text{H}_5\text{NH}_2$ , and propylamine,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ , can be produced by different reduction reactions.

- (i) Identify an organic compound that can be converted into  $\text{C}_6\text{H}_5\text{NH}_2$  by a reduction reaction. State the reagents and conditions for this reaction.

organic compound .....

reagents .....

conditions .....

[2]

- (ii) Identify an organic compound that can be converted into  $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$  by a reduction reaction. State the reagent for this reaction.

organic compound .....

reagent .....

[2]

- (iii) Identify a single test that will distinguish between  $\text{C}_6\text{H}_5\text{NH}_2$  and  $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$  by producing a white precipitate with **only** one of these amines.

Draw the structure of the compound that is precipitated.

testing reagent .....

amine that gives a precipitate .....

structure of the compound that is precipitated:

[2]





Explain your answer.

[illegible]

[4]

[Total: 10]



10 Propanoic acid, methanoic acid and ethanedioic acid are all weak acids.

(a) Draw the displayed formula of ethanedioic acid.

[1]

(b) The three acids, propanoic acid, methanoic acid and ethanedioic acid, can be distinguished using a combination of two chemical tests. Neither testing reagent is an acid–base indicator.

Identify **two** suitable testing reagents and complete Table 10.1 to show the observations from each test.

reagent 1 ..... reagent 2 .....

**Table 10.1**

|                  | observation when treated<br>with reagent 1 | observation when treated<br>with reagent 2 |
|------------------|--------------------------------------------|--------------------------------------------|
| propanoic acid   |                                            |                                            |
| methanoic acid   |                                            |                                            |
| ethanedioic acid |                                            |                                            |

[4]

(c) When propanoic acid is treated with chlorine gas in the presence of ultraviolet light, a mixture of products is formed. One of these products is 2,2-dichloropropanoic acid.

Explain why 2,2-dichloropropanoic acid is stronger than propanoic acid. Refer to the structure of each compound in your answer.

.....  
 .....  
 .....  
 ..... [2]

[Total: 7]





### Important values, constants and standards

|                                 |                                                                                                                                           |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| molar gas constant              | $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$                                                                                              |
| Faraday constant                | $F = 9.65 \times 10^4 \text{ C mol}^{-1}$                                                                                                 |
| Avogadro constant               | $L = 6.02 \times 10^{23} \text{ mol}^{-1}$                                                                                                |
| electronic charge               | $e = -1.60 \times 10^{-19} \text{ C}$                                                                                                     |
| molar volume of gas             | $V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K)<br>$V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions |
| ionic product of water          | $K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))                                                             |
| specific heat capacity of water | $c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g <sup>-1</sup> K <sup>-1</sup> )                                                    |





The Periodic Table of Elements

| Group                  |                         |                                                                |                         |                       |                          |                         |                          |                        |                          |                       |                        |                         |                         |                         |                          |                        |                       |    |    |
|------------------------|-------------------------|----------------------------------------------------------------|-------------------------|-----------------------|--------------------------|-------------------------|--------------------------|------------------------|--------------------------|-----------------------|------------------------|-------------------------|-------------------------|-------------------------|--------------------------|------------------------|-----------------------|----|----|
| 1                      | 2                       | Key                                                            |                         |                       |                          |                         |                          |                        |                          |                       |                        | 13                      | 14                      | 15                      | 16                       | 17                     | 18                    |    |    |
|                        |                         | <div>1<br/>H<br/>hydrogen<br/>1.0</div>                        |                         |                       |                          |                         |                          |                        |                          |                       |                        |                         |                         |                         |                          |                        |                       |    |    |
| 3                      | 4                       | atomic number<br>atomic symbol<br>name<br>relative atomic mass |                         |                       |                          |                         |                          |                        |                          |                       |                        | 5                       | 6                       | 7                       | 8                        | 9                      | 10                    | 11 | 12 |
| Li<br>lithium<br>6.9   | Be<br>beryllium<br>9.0  |                                                                |                         |                       |                          |                         |                          |                        |                          |                       |                        | B<br>boron<br>10.8      | C<br>carbon<br>12.0     | N<br>nitrogen<br>14.0   | O<br>oxygen<br>16.0      | F<br>fluorine<br>19.0  | Ne<br>neon<br>20.2    |    |    |
| 11                     | 12                      |                                                                |                         |                       |                          |                         |                          |                        |                          |                       |                        | 13                      | 14                      | 15                      | 16                       | 17                     | 18                    |    |    |
| Na<br>sodium<br>23.0   | Mg<br>magnesium<br>24.3 |                                                                |                         |                       |                          |                         |                          |                        |                          |                       |                        | Al<br>aluminium<br>27.0 | Si<br>silicon<br>28.1   | P<br>phosphorus<br>31.0 | S<br>sulfur<br>32.1      | Cl<br>chlorine<br>35.5 | Ar<br>argon<br>39.9   |    |    |
| 19                     | 20                      | 21                                                             | 22                      | 23                    | 24                       | 25                      | 26                       | 27                     | 28                       | 29                    | 30                     | 31                      | 32                      | 33                      | 34                       | 35                     | 36                    |    |    |
| K<br>potassium<br>39.1 | Ca<br>calcium<br>40.1   | Sc<br>scandium<br>45.0                                         | Ti<br>titanium<br>47.9  | V<br>vanadium<br>50.9 | Cr<br>chromium<br>52.0   | Mn<br>manganese<br>54.9 | Fe<br>iron<br>55.8       | Co<br>cobalt<br>58.9   | Ni<br>nickel<br>58.7     | Cu<br>copper<br>63.5  | Zn<br>zinc<br>65.4     | Ga<br>gallium<br>69.7   | Ge<br>germanium<br>72.6 | As<br>arsenic<br>74.9   | Se<br>selenium<br>79.0   | Br<br>bromine<br>79.9  | Kr<br>krypton<br>83.8 |    |    |
| 37                     | 38                      | 39                                                             | 40                      | 41                    | 42                       | 43                      | 44                       | 45                     | 46                       | 47                    | 48                     | 49                      | 50                      | 51                      | 52                       | 53                     | 54                    |    |    |
| Rb<br>rubidium<br>85.5 | Sr<br>strontium<br>87.6 | Y<br>yttrium<br>88.9                                           | Zr<br>zirconium<br>91.2 | Nb<br>niobium<br>92.9 | Mo<br>molybdenum<br>95.9 | Tc<br>technetium<br>—   | Ru<br>ruthenium<br>101.1 | Rh<br>rhodium<br>102.9 | Pd<br>palladium<br>106.4 | Ag<br>silver<br>107.9 | Cd<br>cadmium<br>112.4 | In<br>indium<br>114.8   | Sn<br>tin<br>118.7      | Sb<br>antimony<br>121.8 | Te<br>tellurium<br>127.6 | I<br>iodine<br>126.9   | Xe<br>xenon<br>131.3  |    |    |
| 55                     | 56                      | 57–71<br>lanthanoids                                           | 72                      | 73                    | 74                       | 75                      | 76                       | 77                     | 78                       | 79                    | 80                     | 81                      | 82                      | 83                      | 84                       | 85                     | 86                    |    |    |
| Cs<br>caesium<br>132.9 | Ba<br>barium<br>137.3   |                                                                |                         |                       |                          |                         |                          |                        |                          |                       |                        | Tl<br>thallium<br>204.4 | Pb<br>lead<br>207.2     | Bi<br>bismuth<br>209.0  | Po<br>polonium<br>—      | At<br>astatine<br>—    | Rn<br>radon<br>—      |    |    |
| 87                     | 88                      | 89–103<br>actinoids                                            | 104                     | 105                   | 106                      | 107                     | 108                      | 109                    | 110                      | 111                   | 112                    | 113                     | 114                     | 115                     | 116                      | 117                    | 118                   |    |    |
| Fr<br>francium<br>—    | Ra<br>radium<br>—       |                                                                |                         |                       |                          |                         |                          |                        |                          |                       |                        | Nh<br>nihonium<br>—     | Fl<br>flerovium<br>—    | Mc<br>moscovium<br>—    | Lv<br>livermorium<br>—   | Ts<br>tennessine<br>—  | Og<br>oganesson<br>—  |    |    |

lanthanoids

actinoids

|           |         |              |           |            |           |           |            |           |             |             |         |              |           |            |
|-----------|---------|--------------|-----------|------------|-----------|-----------|------------|-----------|-------------|-------------|---------|--------------|-----------|------------|
| 57        | 58      | 59           | 60        | 61         | 62        | 63        | 64         | 65        | 66          | 67          | 68      | 69           | 70        | 71         |
| La        | Ce      | Pr           | Nd        | Pm         | Sm        | Eu        | Gd         | Tb        | Dy          | Ho          | Er      | Tm           | Yb        | Lu         |
| lanthanum | cerium  | praseodymium | neodymium | promethium | samarium  | europlum  | gadolinium | terbium   | dysprosium  | holmium     | erbium  | thulium      | ytterbium | lutetium   |
| 138.9     | 140.1   | 140.9        | 144.2     | —          | 150.4     | 152.0     | 157.3      | 158.9     | 162.5       | 164.9       | 167.3   | 168.9        | 173.1     | 175.0      |
| 89        | 90      | 91           | 92        | 93         | 94        | 95        | 96         | 97        | 98          | 99          | 100     | 101          | 102       | 103        |
| Ac        | Th      | Pa           | U         | Np         | Pu        | Am        | Cm         | Bk        | Cf          | Es          | Fm      | Md           | No        | Lr         |
| actinium  | thorium | protactinium | uranium   | neptunium  | plutonium | americium | curium     | berkelium | californium | einsteinium | fermium | mendeleevium | nobelium  | lawrencium |
| —         | 232.0   | 231.0        | 238.0     | —          | —         | —         | —          | —         | —           | —           | —       | —            | —         | —          |

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# Cambridge International AS & A Level

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**CHEMISTRY**

**9701/44**

Paper 4 A Level Structured Questions

**May/June 2025**

**2 hours**

You must answer on the question paper.

No additional materials are needed.

## INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

## INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **24** pages. Any blank pages are indicated.



- 1 (a) (i) Describe the trend in the thermal stabilities of the carbonates of the Group 2 elements.

Explain your answer.

.....  
 .....  
 .....  
 ..... [3]

- (ii) Copper(II) carbonate decomposes on heating in a similar way to the carbonates of Group 2.

Write an equation for the decomposition of copper(II) carbonate.

..... [1]

- (b) (i) Complete the electrons in boxes diagram in Fig. 1.1 to show the electronic configuration of a copper(II) ion.



Fig. 1.1

[1]

- (ii) There are five different 3d orbitals.

Sketch the shape of a  $3d_{z^2}$  orbital in Fig. 1.2.

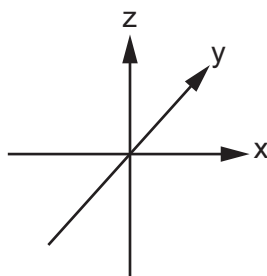


Fig. 1.2

[1]

- (iii) Copper can form stable complexes in the +1 and +2 oxidation states.

Explain why transition elements have variable oxidation states.

.....  
 ..... [1]





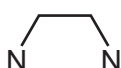
- (c) (i) 1,2-diaminoethane,  $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ , *en*, can act as a bidentate ligand.

Explain what is meant by a bidentate ligand.

.....  
 .....  
 ..... [2]

- (ii) The complex  $[\text{Cu}(\text{H}_2\text{O})_2(\text{en})_2]^{2+}$  exists as stereoisomers.

Complete the three-dimensional diagrams in Fig. 1.3 to show the **three** different stereoisomers of  $[\text{Cu}(\text{H}_2\text{O})_2(\text{en})_2]^{2+}$ .

The *en* ligand can be represented using  .

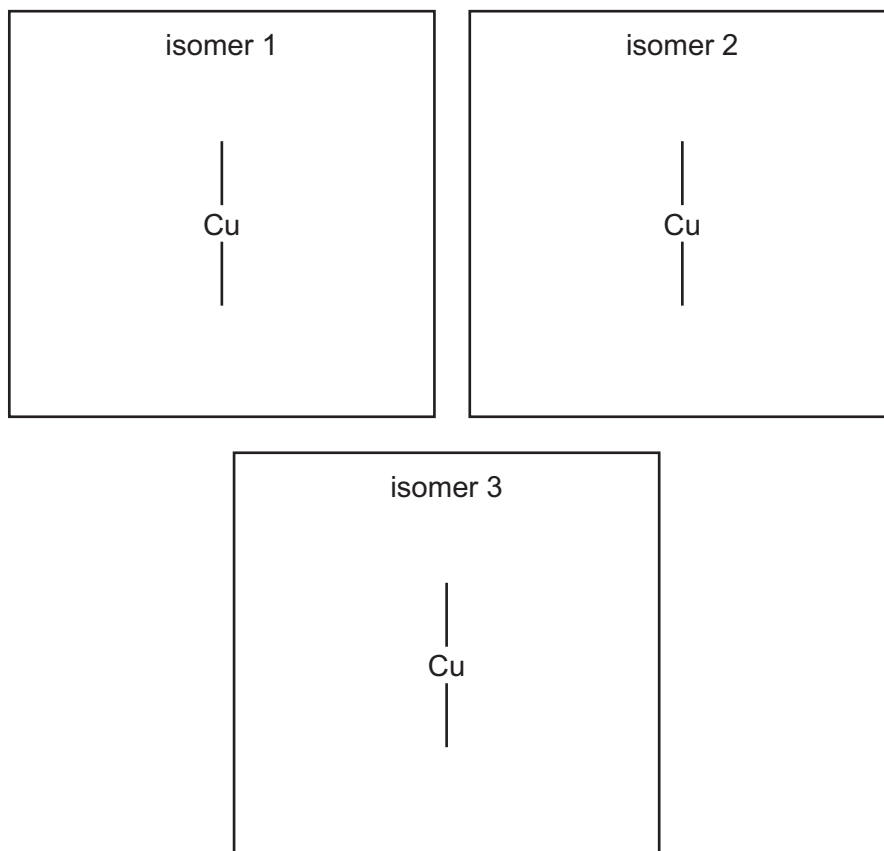


Fig. 1.3

- (iii) State the different types of stereoisomerism shown by  $[\text{Cu}(\text{H}_2\text{O})_2(\text{en})_2]^{2+}$ .

..... [1]





(iv) Identify **one** isomer in (c)(ii) that is **polar**. Explain your answer.

isomer .....

.....  
 ..... [1]

(d) (i) The mineral ore cryolite,  $\text{Na}_3\text{AlF}_6$ , contains a single anion which is a complex ion.

Complete Table 1.1 to suggest the formula of the complex ion and to identify the ligand present in  $\text{Na}_3\text{AlF}_6$ .

Table 1.1

|                                          |  |
|------------------------------------------|--|
| complex ion in $\text{Na}_3\text{AlF}_6$ |  |
| ligand in $\text{Na}_3\text{AlF}_6$      |  |

[1]

(ii) When a solution of  $\text{Al}_2\text{O}_3$  in molten cryolite is electrolysed, aluminium metal is formed at the cathode. The equation is shown.



Calculate the maximum mass of aluminium produced when a current of 1.5A is passed through this solution for 30 minutes.

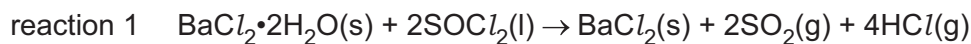
Give your answer to **two** significant figures.

mass of aluminium = ..... g [4]

[Total: 19]



- 2 (a) Anhydrous barium chloride can be obtained from the hydrated salt, as shown in reaction 1.



- (i) Describe **one** observation when reaction 1 is carried out.

.....  
 ..... [1]

- (ii) Define the term entropy,  $S$ .

.....  
 ..... [1]

- (iii) The entropy change,  $\Delta S^\ominus$ , for reaction 1 at  $25^\circ\text{C}$  is  $+768 \text{ J K}^{-1} \text{ mol}^{-1}$ .

Explain why  $\Delta S^\ominus$  has a large positive value.

.....  
 ..... [1]

- (iv) Table 2.1 shows the enthalpy changes of formation,  $\Delta H_f^\ominus$ , for the compounds in reaction 1.

Table 2.1

| compound                                            | $\Delta H_f^\ominus / \text{kJ mol}^{-1}$ |
|-----------------------------------------------------|-------------------------------------------|
| $\text{BaCl}_2(\text{s})$                           | −859                                      |
| $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}(\text{s})$ | −1460                                     |
| $\text{SOCl}_2(\text{l})$                           | −246                                      |
| $\text{SO}_2(\text{g})$                             | −297                                      |
| $\text{HCl}(\text{g})$                              | −92                                       |

Calculate the standard Gibbs free energy change,  $\Delta G^\ominus$ , in  $\text{kJ mol}^{-1}$ , for reaction 1 at  $25^\circ\text{C}$ .

$\Delta G^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$  [3]





(b) When aqueous solutions of  $\text{BaCl}_2$  and  $\text{Na}_2\text{Cr}_2\text{O}_7$  are mixed, a yellow precipitate of  $\text{BaCrO}_4(\text{s})$  is produced and an acidic solution remains.

(i) Write the ionic equation for this reaction.

..... [1]

(ii) Explain why  $\text{BaCrO}_4(\text{s})$  is coloured.

.....  
 .....  
 .....  
 .....  
 .....  
 ..... [3]

(c) Barium sulfate is the least soluble of the Group 2 sulfates.

Explain the trend in the solubilities of the Group 2 sulfates.

.....  
 .....  
 .....  
 .....  
 .....  
 ..... [3]

[Total: 13]



- 3 (a) Nickel(II) iodate(V),  $\text{Ni}(\text{IO}_3)_2$ , is sparingly soluble in water. The concentration of its saturated solution is  $2.30 \times 10^{-2} \text{ mol dm}^{-3}$  at 298 K.

(i) Complete the expression for the solubility product,  $K_{\text{sp}}$ , of  $\text{Ni}(\text{IO}_3)_2$ . Include the units.

$$K_{\text{sp}} =$$

units = .....

[2]

(ii) Calculate the numerical value for  $K_{\text{sp}}$  of  $\text{Ni}(\text{IO}_3)_2$  at 298 K.

$$K_{\text{sp}} = \dots\dots\dots [1]$$

(b) An electrochemical cell is set up as shown in Fig. 3.1.

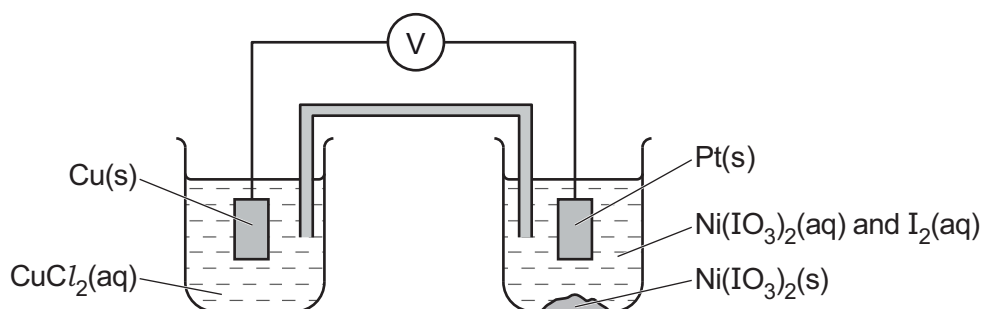
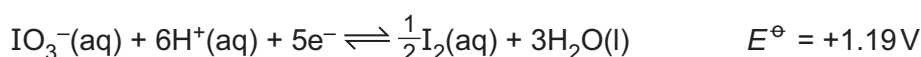


Fig. 3.1

The relevant standard electrode potentials,  $E^\ominus$ , for this electrochemical cell are shown.



(i) Use this information to calculate the value of  $E_{\text{cell}}^\ominus$ . State which electrode is positive.

$$E_{\text{cell}}^\ominus = \dots\dots\dots \text{positive electrode is } \dots\dots\dots [1]$$

(ii) Suggest how the measured  $E_{\text{cell}}$  of this cell compares to the  $E_{\text{cell}}^\ominus$  under standard conditions.

Explain your answer.

.....  
 ..... [1]



- (iii) Complete Table 3.1 by placing **one** tick (✓) to indicate how the  $E_{\text{cell}}$  of this cell changes when a small amount of  $\text{NiSO}_4(\text{aq})$  is added to the beaker containing  $\text{Ni}(\text{IO}_3)_2(\text{aq})$  and  $\text{I}_2(\text{aq})$  in Fig. 3.1.

Explain your answer.

**Table 3.1**

| change in $E_{\text{cell}}$ |           |               |
|-----------------------------|-----------|---------------|
| less positive               | no change | more positive |
|                             |           |               |

.....  
 .....  
 ..... [2]

- (c) In solution, iodic(V) acid,  $\text{HIO}_3$ , ionises as shown.



The pH of a  $1.0 \text{ mol dm}^{-3}$  solution of  $\text{HIO}_3$  is 0.47.

- (i) Calculate  $[\text{H}^+(\text{aq})]$ , in  $\text{mol dm}^{-3}$ , in a  $1.0 \text{ mol dm}^{-3}$  solution of  $\text{HIO}_3$ .

$$[\text{H}^+(\text{aq})] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

- (ii) Use your answer from (c)(i) to calculate the equilibrium concentrations of  $\text{HIO}_3(\text{aq})$  and  $\text{IO}_3^-(\text{aq})$ , in  $\text{mol dm}^{-3}$ , in a  $1.0 \text{ mol dm}^{-3}$  solution of  $\text{HIO}_3$ .

$$[\text{HIO}_3(\text{aq})] = \dots\dots\dots \text{mol dm}^{-3}$$

$$[\text{IO}_3^-(\text{aq})] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

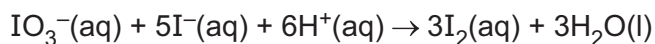
- (iii) Use your answers from (c)(i) and (c)(ii) to calculate the  $K_a$ , in  $\text{mol dm}^{-3}$ , of  $\text{HIO}_3$ .

$$K_a = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$





(d) The *Dushman reaction* is the reaction between iodate(V) ions and iodide ions in acid solution.



The rate equation for this reaction is shown.

$$\text{rate} = k [\text{IO}_3^-][\text{I}^-]^2[\text{H}^+]^2$$

The rate of this reaction is investigated in a buffer solution.

The initial concentrations are shown.

$$[\text{IO}_3^-] = 0.500 \text{ mol dm}^{-3} \quad [\text{I}^-] = 1.00 \times 10^{-3} \text{ mol dm}^{-3} \quad [\text{H}^+] = 1.00 \times 10^{-2} \text{ mol dm}^{-3}$$

Under these conditions the initial rate of the reaction is  $2.10 \times 10^{-2} \text{ mol dm}^{-3} \text{ s}^{-1}$ .

(i) Define buffer solution.

.....  
 .....  
 ..... [2]

(ii) Use the information to calculate the rate constant,  $k$ . State its units.

$$k = \dots\dots\dots \text{units} = \dots\dots\dots [2]$$

(iii) This reaction is repeated at the same temperature and with the same initial values of  $[\text{IO}_3^-]$  and  $[\text{I}^-]$ . The  $[\text{H}^+]$  is increased to  $3.00 \times 10^{-2} \text{ mol dm}^{-3}$ .

Calculate the initial rate of this reaction.

$$\text{rate} = \dots\dots\dots \text{mol dm}^{-3} \text{ s}^{-1} [1]$$

[Total: 15]



\* 0000800000011 \*



11

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- 4 Table 4.1 shows the structures of sections of three polymers, **X**, **Y** and **Z**.

Each polymer is made from only **one** type of monomer.

**Table 4.1**

| polymer  | structure of section of polymer |
|----------|---------------------------------|
| <b>X</b> |                                 |
| <b>Y</b> |                                 |
| <b>Z</b> |                                 |

- (a) Complete Table 4.2 to state the type of polymerisation and draw the structure of the monomer for each polymer, **X**, **Y** and **Z**.

**Table 4.2**

| polymer  | type of polymerisation | structure of monomer |
|----------|------------------------|----------------------|
| <b>X</b> |                        |                      |
| <b>Y</b> |                        |                      |
| <b>Z</b> |                        |                      |

[4]



- (b) Amino acids can act as monomers.

State what is meant by the isoelectric point of an amino acid.

.....  
 ..... [1]

- (c) Electrophoresis can be used to separate and identify amino acids.

Table 4.3 shows information about the three amino acids glycine, lysine and glutamic acid.

**Table 4.3**

| amino acid          | structural formula of amino acid                                                           | isoelectric point |
|---------------------|--------------------------------------------------------------------------------------------|-------------------|
| glycine (gly)       | $\text{H}_2\text{NCH}_2\text{COOH}$                                                        | 6.0               |
| lysine (lys)        | $\text{H}_2\text{NCH}(\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2)\text{COOH}$ | 9.7               |
| glutamic acid (glu) | $\text{H}_2\text{NCH}(\text{CH}_2\text{CH}_2\text{COOH})\text{COOH}$                       | 3.2               |

- (i) A mixture containing these three amino acids is analysed in a buffer solution of pH 6.0.

Draw and label **three** spots on Fig. 4.1 to indicate the predicted position of each of these amino acids, gly, lys and glu, after electrophoresis.

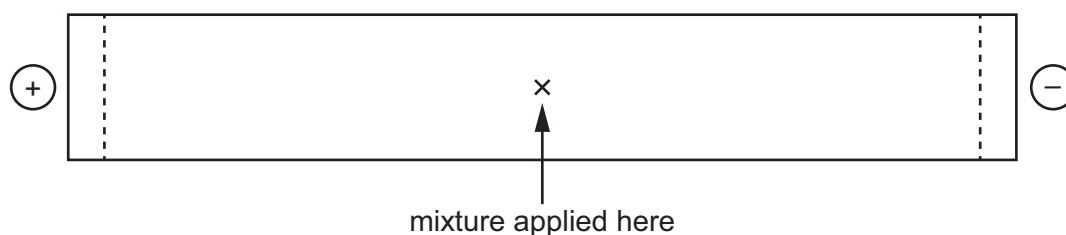


**Fig. 4.1**

[2]

- (ii) Electrophoresis is repeated using a buffer solution of pH 11.

Predict how the position of glycine will change, if at all, after electrophoresis.

.....  
 ..... [1]

[Total: 8]



- 5 A group of drugs known as statins are used to lower cholesterol in blood. A commonly used statin is atorvastatin.

atorvastatin

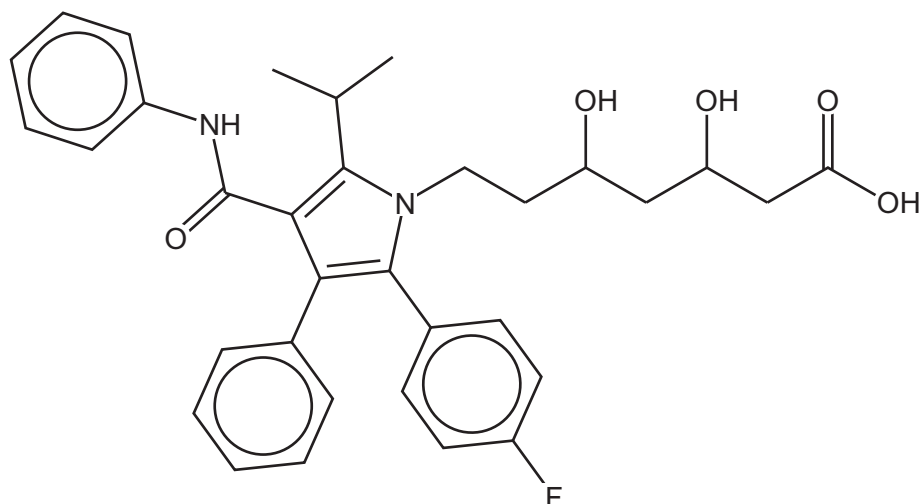


Fig. 5.1

- (a) Statins can break down in the acid found in the stomach.
- (i) Draw a line through the bond in the atorvastatin structure in Fig. 5.1 that could be broken under acid conditions. [1]

- (ii) By referring to the structure, explain why atorvastatin dissolves in water.

.....  
 ..... [1]

- (iii) Complete the molecular formula of atorvastatin.

C H<sub>35</sub> N O F [1]

- (iv) Atorvastatin contains chiral carbon atoms.

Circle **all** chiral carbon atoms in Fig. 5.1. [1]

- (v) The synthetic preparation of atorvastatin requires the production of a single optical isomer.

Suggest why.

.....  
 ..... [1]





- (b) (i) The proton ( $^1\text{H}$ ) NMR spectrum of atorvastatin dissolved in  $\text{CDCl}_3$  is recorded.

Use Table 5.1 to deduce the number of hydrogen atoms that could produce peaks in the region  $\delta = 6.5\text{--}13.0\text{ ppm}$ .

..... [1]

- (ii) The proton ( $^1\text{H}$ ) NMR spectrum of atorvastatin dissolved in  $\text{D}_2\text{O}$  is recorded.

Predict the number of hydrogen atoms that would **not** show a peak in this spectrum.

Explain your answer.

.....  
 .....  
 ..... [2]

Table 5.1

| environment of proton              | example                                                                                             | chemical shift range<br>$\delta/\text{ppm}$ |
|------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------|
| alkane                             | $-\text{CH}_3$ , $-\text{CH}_2-$ , $>\text{CH}-$                                                    | 0.9–1.7                                     |
| alkyl next to $\text{C}=\text{O}$  | $\text{CH}_3-\text{C}=\text{O}$ , $-\text{CH}_2-\text{C}=\text{O}$ , $>\text{CH}-\text{C}=\text{O}$ | 2.2–3.0                                     |
| alkyl next to aromatic ring        | $\text{CH}_3-\text{Ar}$ , $-\text{CH}_2-\text{Ar}$ , $>\text{CH}-\text{Ar}$                         | 2.3–3.0                                     |
| alkyl next to electronegative atom | $\text{CH}_3-\text{O}$ , $-\text{CH}_2-\text{O}$ , $-\text{CH}_2-\text{Cl}$                         | 3.2–4.0                                     |
| attached to alkene                 | $=\text{CHR}$                                                                                       | 4.5–6.0                                     |
| attached to aromatic ring          | $\text{H}-\text{Ar}$                                                                                | 6.0–9.0                                     |
| aldehyde                           | $\text{HCOR}$                                                                                       | 9.3–10.5                                    |
| alcohol                            | $\text{ROH}$                                                                                        | 0.5–6.0                                     |
| phenol                             | $\text{Ar}-\text{OH}$                                                                               | 4.5–7.0                                     |
| carboxylic acid                    | $\text{RCOOH}$                                                                                      | 9.0–13.0                                    |
| alkyl amine                        | $\text{R}-\text{NH}-$                                                                               | 1.0–5.0                                     |
| aryl amine                         | $\text{Ar}-\text{NH}_2$                                                                             | 3.0–6.0                                     |
| amide                              | $\text{RCONHR}$                                                                                     | 5.0–12.0                                    |

- (c) Atorvastatin reacts with an excess of  $\text{LiAlH}_4$ .

Name all the functional groups in atorvastatin that react with  $\text{LiAlH}_4$ .

Name the new functional group that would be formed in each case.

names of functional groups in atorvastatin that react

.....

names of the new functional groups formed

..... [2]







- 6 (a) A list of tests for different organic groups is given in Table 6.1.

Complete Table 6.1 to identify an organic functional group, in aliphatic compounds, that produces a positive result in each test.

**Table 6.1**

| test         |                                     |          |                                                          |                             |                          |
|--------------|-------------------------------------|----------|----------------------------------------------------------|-----------------------------|--------------------------|
| sodium metal | $\text{Na}_2\text{CO}_3(\text{aq})$ | 2,4-DNPH | $\text{I}_2(\text{aq})$<br>+<br>$\text{OH}^-(\text{aq})$ | warm with Fehling's reagent | $\text{Br}_2(\text{aq})$ |
|              |                                     |          |                                                          |                             |                          |

[4]



- (b) Lavandulol is an aliphatic organic compound and the major component of lavender oil. Fig. 6.1 shows a reaction scheme involving lavandulol, **A**.

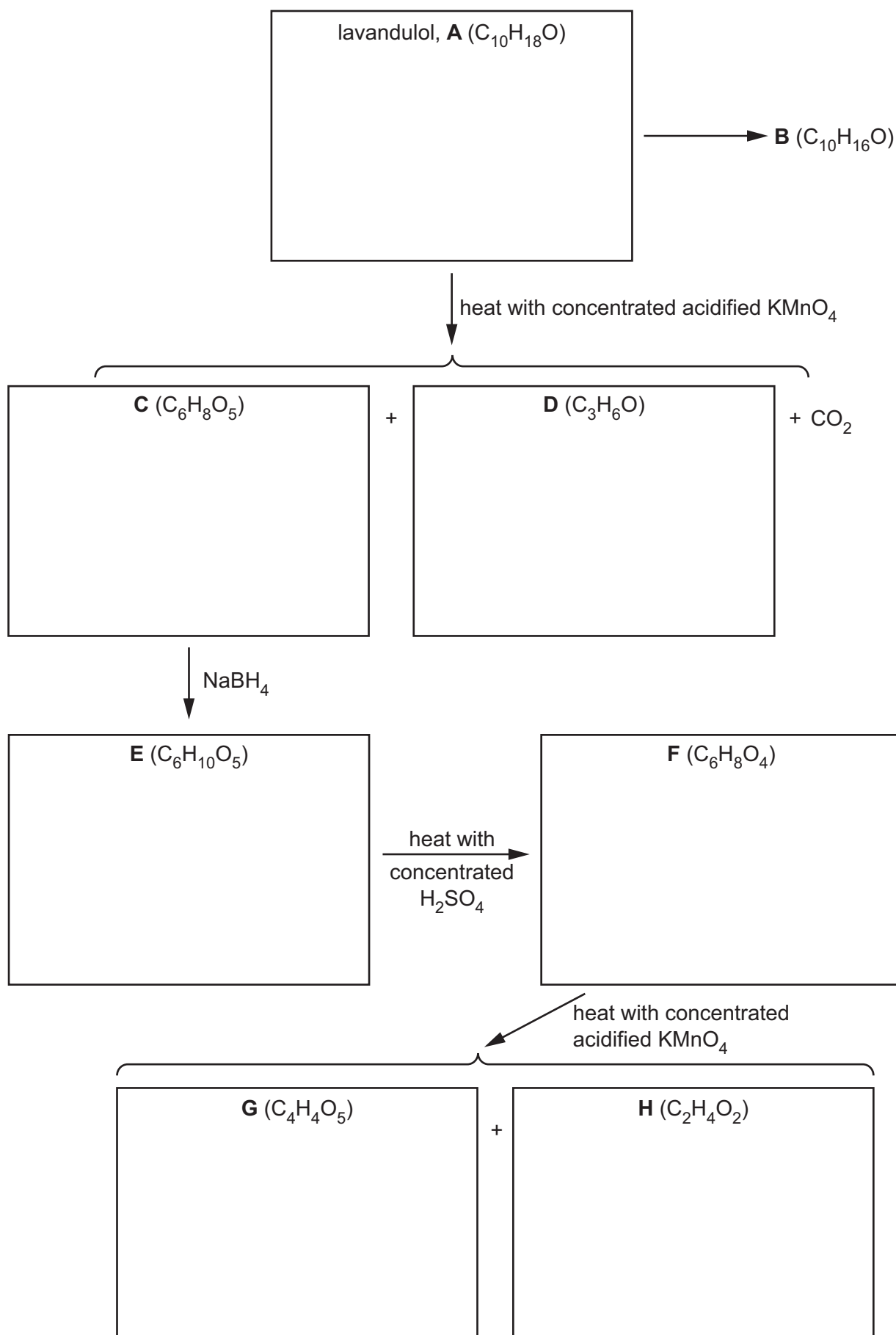


Fig. 6.1





Table 6.2 shows the results obtained when the tests in Table 6.1 are carried out on the eight organic compounds, **A–H**, in the reaction scheme in Fig. 6.1.

Table 6.2

| letter of compound | test         |                                      |          |                                            |                             |                      |
|--------------------|--------------|--------------------------------------|----------|--------------------------------------------|-----------------------------|----------------------|
|                    | sodium metal | Na <sub>2</sub> CO <sub>3</sub> (aq) | 2,4-DNPH | I <sub>2</sub> (aq) + OH <sup>–</sup> (aq) | warm with Fehling's reagent | Br <sub>2</sub> (aq) |
| <b>A</b>           | ✓            | ✗                                    | ✗        | ✗                                          | ✗                           | ✓                    |
| <b>B</b>           | ✗            | ✗                                    | ✓        | ✗                                          | ✓                           | ✓                    |
| <b>C</b>           | ✓            | ✓                                    | ✓        | ✓                                          | ✗                           | ✗                    |
| <b>D</b>           | ✗            | ✗                                    | ✓        | ✓                                          | ✗                           | ✗                    |
| <b>E</b>           | ✓            | ✓                                    | ✗        | ✓                                          | ✗                           | ✗                    |
| <b>F</b>           | ✓            | ✓                                    | ✗        | ✗                                          | ✗                           | ✓                    |
| <b>G</b>           | ✓            | ✓                                    | ✓        | ✗                                          | ✗                           | ✗                    |
| <b>H</b>           | ✓            | ✓                                    | ✗        | ✗                                          | ✗                           | ✗                    |

- (i) Deduce the functional group present in compound **A** using both the molecular formulae of **A** and **B** and the reaction of **B** with Fehling's reagent.

..... [1]

- (ii) Name the type of reaction that occurs in each of the following conversions.

• **A** → **B** .....

• **C** → **E** .....

• **E** → **F** .....

[3]

- (iii) Use the information in Table 6.2 and the molecular formulae to deduce structures for **G** and **H**. Draw your structures in Fig. 6.1. [2]

- (iv) Use the information in Table 6.2, the molecular formulae and your answer to (b)(iii) to deduce structures for **A**, **C**, **D**, **E** and **F**. Draw your structures in Fig. 6.1. [5]

[Total: 15]



- DO NOT WRITE IN THIS MARGIN

[3]

- DO NOT WRITE IN THIS MARGIN

[2]

DO NOT WRITE IN THIS MARGIN

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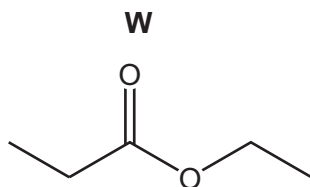


**Fig. 7.2**

- [1]

(ii) Complete the mechanism in Fig. 7.3 for the reaction between  $\text{C}_2\text{H}_5\text{COCl}$  and ethanol.

$\text{R-OH}$  represents ethanol.

Include all relevant lone pairs of electrons, curly arrows, charges and partial charges.

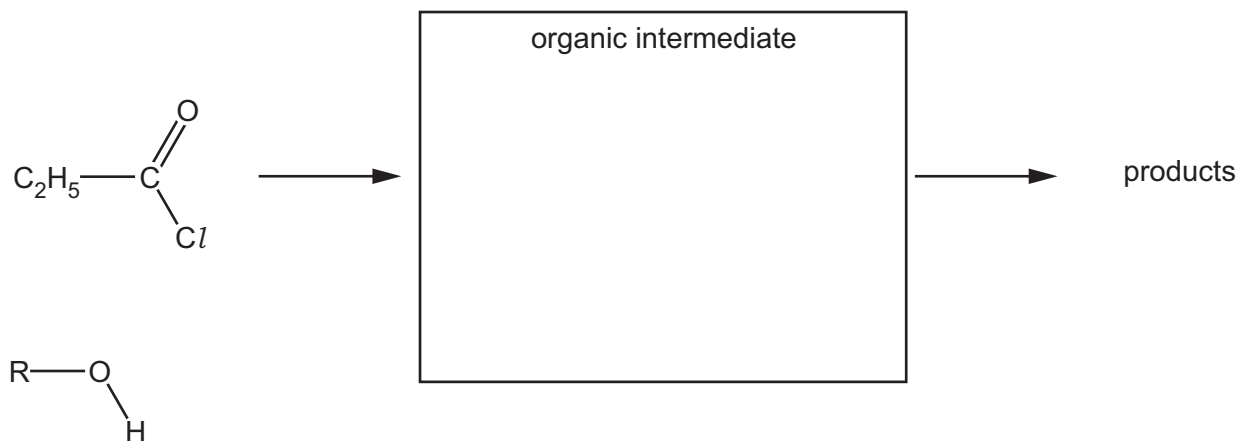


Fig. 7.3

[4]

(iii) Name the mechanism for the reaction shown in Fig. 7.3.

..... [1]

[Total: 11]

8 (a) (i) Define lattice energy,  $\Delta H_{\text{latt}}$ .

.....  
 ..... [2]

(ii) Define enthalpy change of solution,  $\Delta H_{\text{sol}}$ .

.....  
 ..... [1]

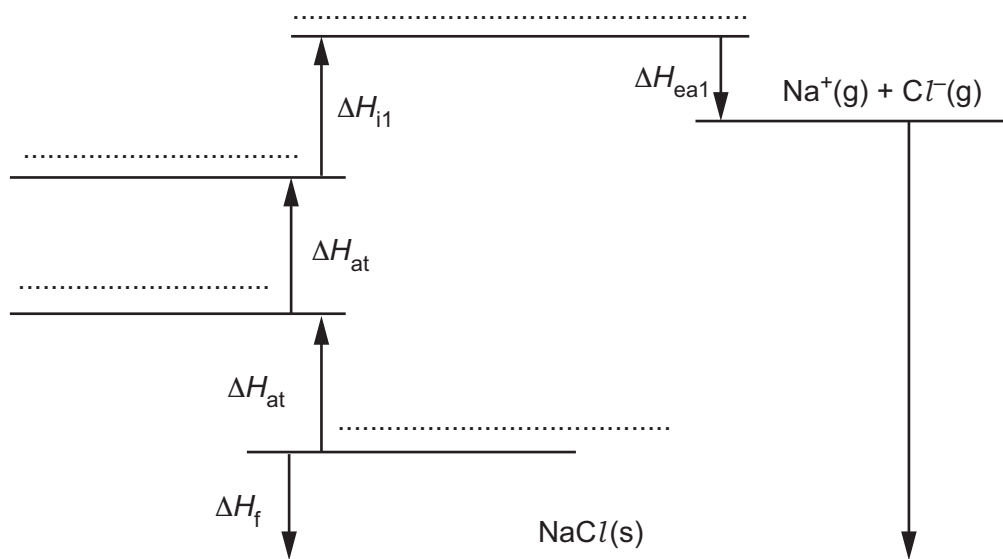
(b) The enthalpy change of hydration can be represented by  $\Delta H_{\text{hyd}}$ .

Write the mathematical expression for the  $\Delta H_{\text{sol}}$  of NaCl in terms of  $\Delta H_{\text{latt}}(\text{NaCl})$ ,  $\Delta H_{\text{hyd}}(\text{Na}^+)$  and  $\Delta H_{\text{hyd}}(\text{Cl}^-)$ .

$\Delta H_{\text{sol}}(\text{NaCl}) = \dots\dots\dots$  [1]

(c) Complete the Born–Haber cycle in Fig. 8.1 for the ionic solid NaCl.

Include state symbols of relevant species.



**Key**

$\Delta H_{\text{i1}}$  first ionisation energy

$\Delta H_{\text{ea1}}$  first electron affinity

**Fig. 8.1**

[3]



(d) Predict which of the ions,  $\text{Cl}^-$  or  $\text{NO}_3^-$ , has the more negative enthalpy change of hydration.

Explain your answer.

.....

.....

.....

.....

..... [2]

[Total: 9]

### Important values, constants and standards

|                                 |                                                                                                                                           |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| molar gas constant              | $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$                                                                                              |
| Faraday constant                | $F = 9.65 \times 10^4 \text{ C mol}^{-1}$                                                                                                 |
| Avogadro constant               | $L = 6.02 \times 10^{23} \text{ mol}^{-1}$                                                                                                |
| electronic charge               | $e = -1.60 \times 10^{-19} \text{ C}$                                                                                                     |
| molar volume of gas             | $V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K)<br>$V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions |
| ionic product of water          | $K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))                                                             |
| specific heat capacity of water | $c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ ( $4.18 \text{ J g}^{-1} \text{ K}^{-1}$ )                                                   |





The Periodic Table of Elements

| Group |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|-------|---|------------------------------------------------|--|--|--|--|--|--|--|--|--|--|--|----|----|----|----|----|----|
| 1     | 2 |                                                |  |  |  |  |  |  |  |  |  |  |  | 13 | 14 | 15 | 16 | 17 | 18 |
|       |   | <div>Key</div>                                 |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   | <div>1<div>H</div>hydrogen<div>1.0</div></div> |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
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|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
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|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
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|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
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|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
|       |   |                                                |  |  |  |  |  |  |  |  |  |  |  |    |    |    |    |    |    |
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