



CANDIDATE
NAME

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9701/41

May/June 2023

2 hours

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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 **28** pages. Any blank pages are indicated.

- 1 (a) Group 2 nitrates decompose when heated.

Describe how the thermal stability of Group 2 nitrates changes with increasing proton number.
Explain your answer.

.....

 [3]

- (b) Copper(II) nitrate decomposes in a similar manner to Group 2 nitrates.

Write an equation for the decomposition of $\text{Cu}(\text{NO}_3)_2$.

..... [1]

- (c) $\text{Cu}(\text{NO}_3)_2$ is added to water to form solution A.

Fig. 1.1 shows some reactions of solution A.

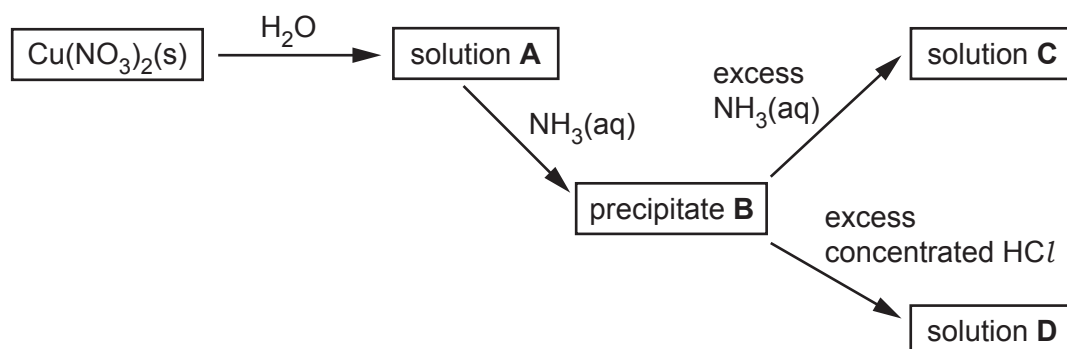


Fig. 1.1

Complete Table 1.1 to show the formula and colour of each of the copper-containing species present in A, B, C and D.

Table 1.1

	formula of copper-containing species formed	colour of copper-containing species formed
A		
B		
C		
D		

[4]

(d) EDTA^{4-} is a polydentate ligand.

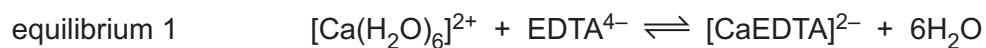
(i) Explain what is meant by a polydentate ligand.

.....

 [2]

(ii) Group 2 metal ions can form complexes similar to those of transition elements.

A solution of EDTA^{4-} is added to water containing $[\text{Ca}(\text{H}_2\text{O})_6]^{2+}$ to form a new complex, $[\text{CaEDTA}]^{2-}$, as shown.



Circle on the structure of EDTA^{4-} in Fig. 1.2 the **six** atoms that form bonds with the metal ion.

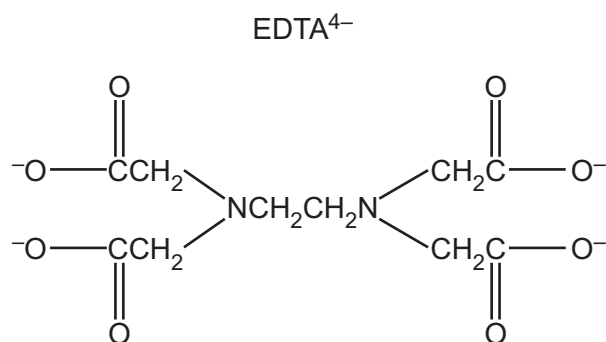


Fig. 1.2

[1]

(iii) The calcium ions in $[\text{Ca}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{CaEDTA}]^{2-}$ have a coordination number of 6.

Explain what is meant by coordination number.

.....
 [1]

- (iv) The complex $[\text{CaEDTA}]^{2-}$ can be used to remove toxic metals from the body.

Table 1.2 shows the numerical values for the stability constants, K_{stab} , for some metal ions with EDTA^{4-} .

Table 1.2

complex	K_{stab}
$[\text{CaEDTA}]^{2-}$	5.0×10^{10}
$[\text{CrEDTA}]^{-}$	2.5×10^{23}
$[\text{FeEDTA}]^{-}$	1.3×10^{25}
$[\text{PbEDTA}]^{2-}$	1.1×10^{18}

An aqueous solution containing $[\text{CaEDTA}]^{2-}$ is added to a solution containing equal concentrations of $\text{Cr}^{3+}(\text{aq})$, $\text{Fe}^{3+}(\text{aq})$ and $\text{Pb}^{2+}(\text{aq})$. The resulting mixture is left to reach a state of equilibrium.

State the type of reaction when $[\text{CaEDTA}]^{2-}$ reacts with $\text{Cr}^{3+}(\text{aq})$, $\text{Fe}^{3+}(\text{aq})$ and $\text{Pb}^{2+}(\text{aq})$.

..... [1]

- (v) Deduce the relative concentrations of $[\text{CrEDTA}]^{-}$, $[\text{FeEDTA}]^{-}$ and $[\text{PbEDTA}]^{2-}$ present in the resulting mixture.

Explain your answer.

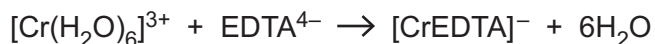
..... > >
highest concentration lowest concentration

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

(e) The number of moles of water of crystallisation in a hydrated ionic salt can be determined by titration using aqueous EDTA^{4-} ions with a suitable indicator.

- 0.255 g of hydrated chromium(III) sulfate, $\text{Cr}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$, is dissolved in water and made up to 100 cm^3 in a volumetric flask.
- 25.0 cm^3 of this solution requires 26.2 cm^3 of $0.00800\text{ mol dm}^{-3}$ aqueous EDTA^{4-} ions to reach the end-point.

The reaction occurs as shown.



Use the data to calculate the value of n in the formula of $\text{Cr}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$.

Show your working.

$n = \dots\dots\dots$ [3]

(f) A solution of $\text{Cr}^{3+}(\text{aq})$ and a solution of $\text{Fe}^{3+}(\text{aq})$ have different colours.

Explain why the two complexes have different colours.

.....

 [2]

[Total: 19]

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- 2 (a) Some transition element complexes can show stereoisomerism.

State **two** types of stereoisomerism shown by transition element complexes.

1

2 [1]

- (b) The complexes $[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$ and $[\text{Pt}(\text{en})_2]^{2+}$ have the same geometry (shape) around the metal ion.

$[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$ exists as two stereoisomers whereas $[\text{Pt}(\text{en})_2]^{2+}$ only has one possible structure.

State the geometry around the metal ion.

..... [1]

- (c) The complex $[\text{Cr}(\text{en})_3]^{2+}$ exists as two stereoisomers whereas the complex $[\text{Cr}(\text{OCH}_2\text{CH}_2\text{NH}_2)_3]^-$ exists as four stereoisomers.

Complete the three-dimensional diagrams in Fig. 2.1 to show the four stereoisomers of $[\text{Cr}(\text{OCH}_2\text{CH}_2\text{NH}_2)_3]^-$.

Represent the ligand $^-\text{OCH}_2\text{CH}_2\text{NH}_2$ by using .

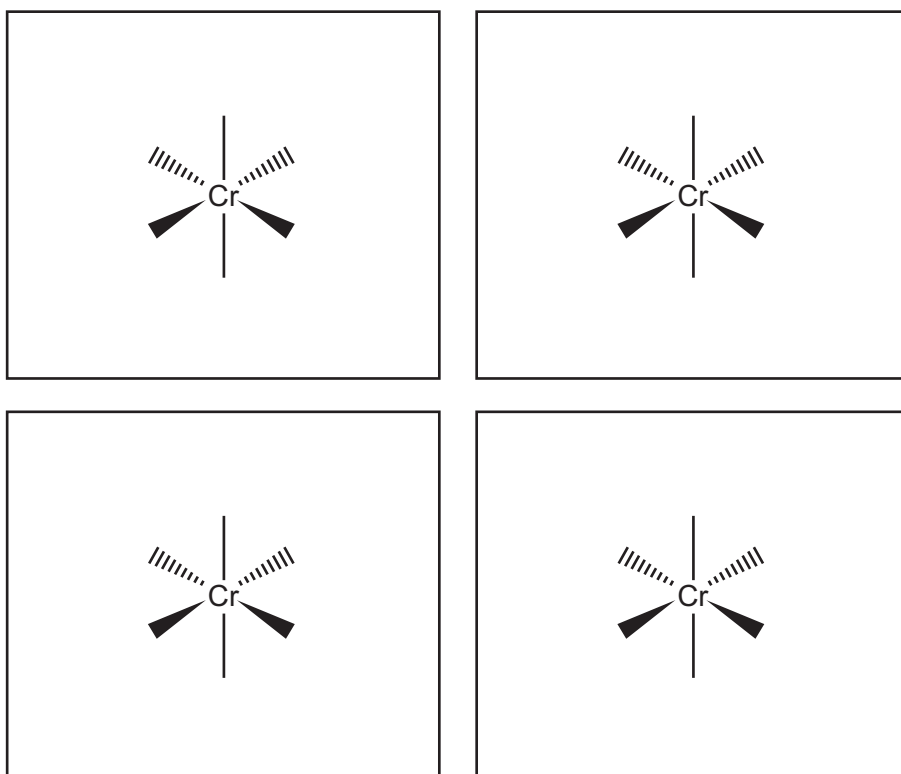


Fig. 2.1

- (d) The complex $[\text{Cr}(\text{OCH}_2\text{CH}_2\text{NH}_2)_3]^-$ is formed by reacting $\text{Cr}^{2+}(\text{aq})$ with the conjugate base of 2-aminoethanol.

A synthesis of 2-aminoethanol is shown in Fig. 2.2.

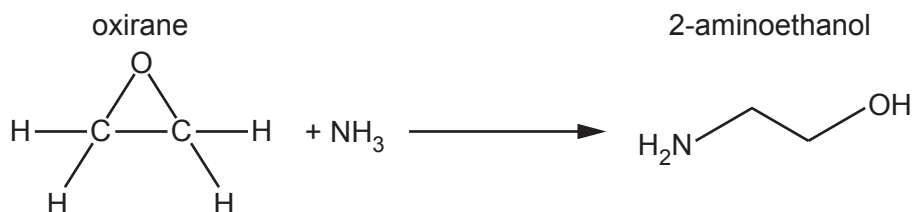


Fig. 2.2

- (i) Suggest the mechanism for step 1 of the reaction of oxirane with ammonia in Fig. 2.3.

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

Draw the structure of the organic intermediate.

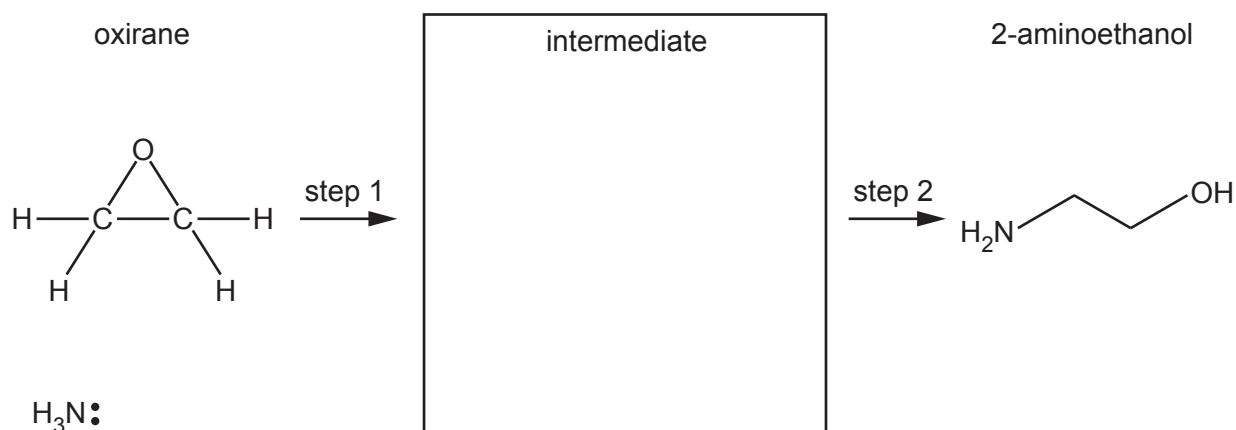


Fig. 2.3

[3]

- (ii) A small amount of by-product **E**, shown in Fig. 2.4, is produced during the reaction shown in Fig. 2.2.

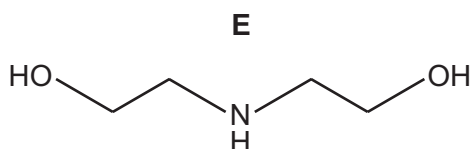


Fig. 2.4

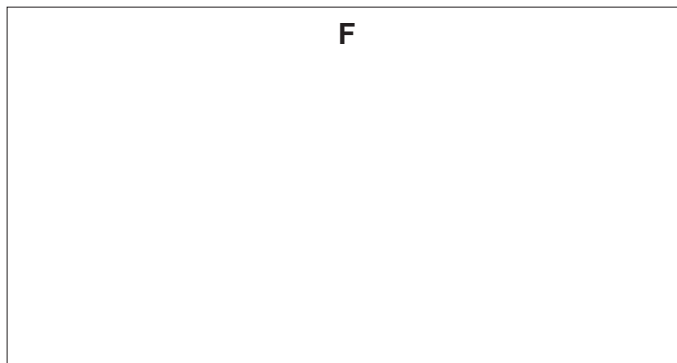
Suggest how the formation of by-product **E** can be minimised.

.....
 [1]

- (iii) Compound **F**, $\text{C}_4\text{H}_9\text{NO}$, can be formed from the reaction of by-product **E**, $\text{C}_4\text{H}_{11}\text{NO}_2$, with concentrated H_2SO_4 .

Compound **F** is a **saturated** and basic organic compound.

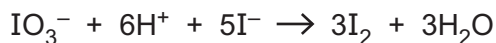
Suggest a structure for compound **F**. State the type of reaction undergone by **E** to form **F**.



type of reaction [2]

[Total: 11]

- 3 (a) Aqueous acidified iodate(V) ions, IO_3^- , react with iodide ions, as shown.



The initial rate of this reaction is investigated. Table 3.1 shows the results obtained.

Table 3.1

experiment	$[\text{IO}_3^-]/\text{mol dm}^{-3}$	$[\text{H}^+]/\text{mol dm}^{-3}$	$[\text{I}^-]/\text{mol dm}^{-3}$	initial rate/ $\text{mol dm}^{-3}\text{min}^{-1}$
1	0.0400	0.0150	0.0250	4.20×10^{-2}
2	0.120	to be calculated	0.0125	7.09×10^{-2}

The rate equation for this reaction is $\text{rate} = k[\text{IO}_3^-][\text{H}^+]^2[\text{I}^-]^2$.

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

.....

 [1]

- (ii) Complete Table 3.2.

Table 3.2

the order of reaction with respect to $[\text{IO}_3^-]$	
the order of reaction with respect to $[\text{H}^+]$	
the order of reaction with respect to $[\text{I}^-]$	
the overall order of reaction	

[1]

- (iii) Use your answer to (a)(ii) to sketch lines in Fig. 3.1 to show the relationship between the initial rates and the concentrations of $[\text{IO}_3^-]$ and $[\text{I}^-]$.

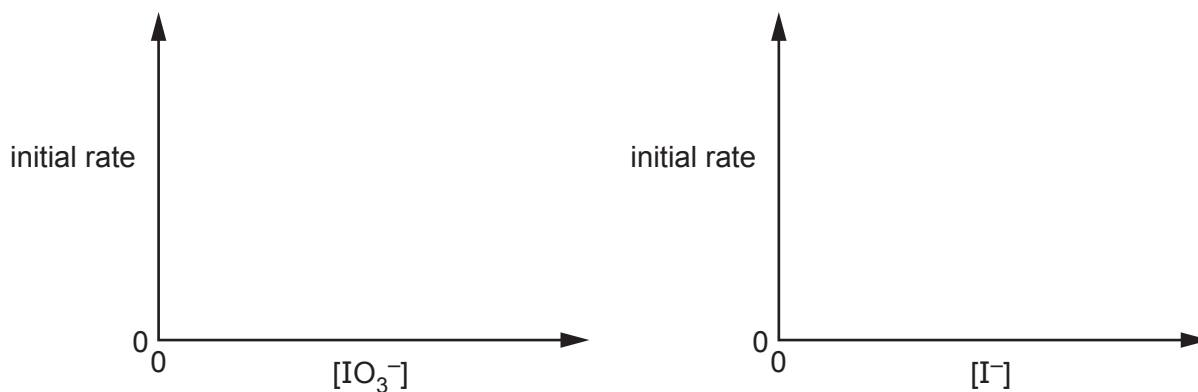


Fig. 3.1

[1]

- (iv) Use data from Table 3.1 to calculate the rate constant, k , for this reaction.

Include the units of k .

$k = \dots\dots\dots$ units $\dots\dots\dots$ [2]

- (v) Use data from Table 3.1 to calculate the concentration of hydrogen ions, $[H^+]$, in experiment 2.

$[H^+] = \dots\dots\dots$ mol dm^{-3} [1]

- (vi) This reaction is repeated in two separate experiments.

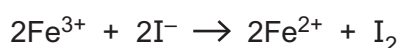
The experiments are carried out at the same temperature and with the same concentrations of I^- and IO_3^- .

One experiment takes place at pH 1.0 and the other experiment takes place at pH 2.0.

Calculate the value of $\frac{\text{rate at pH 1.0}}{\text{rate at pH 2.0}}$.

value of $\frac{\text{rate at pH 1.0}}{\text{rate at pH 2.0}} = \dots\dots\dots$ [1]

- (b) In aqueous solution, iron(III) ions react with iodide ions, as shown.



The initial rate of reaction is first order with respect to Fe^{3+} and second order with respect to I^- .

The mechanism for this reaction has three steps.

Each step involves only **two** ions reacting together.

Suggest equations for the **three** steps of this mechanism. Identify the rate-determining step.

step 1 $\dots\dots\dots$

step 2 $\dots\dots\dots$

step 3 $\dots\dots\dots$

rate-determining step = $\dots\dots\dots$

[3]

- 4 (a) State the hybridisation of the carbon atoms and the C–C–H bond angle in benzene, C_6H_6 . Explain how orbital overlap leads to the formation of σ and π bonds in benzene.

.....

 [3]

- (b) Compound **Z** can be synthesised from benzene in three steps by the route shown in Fig. 4.1.

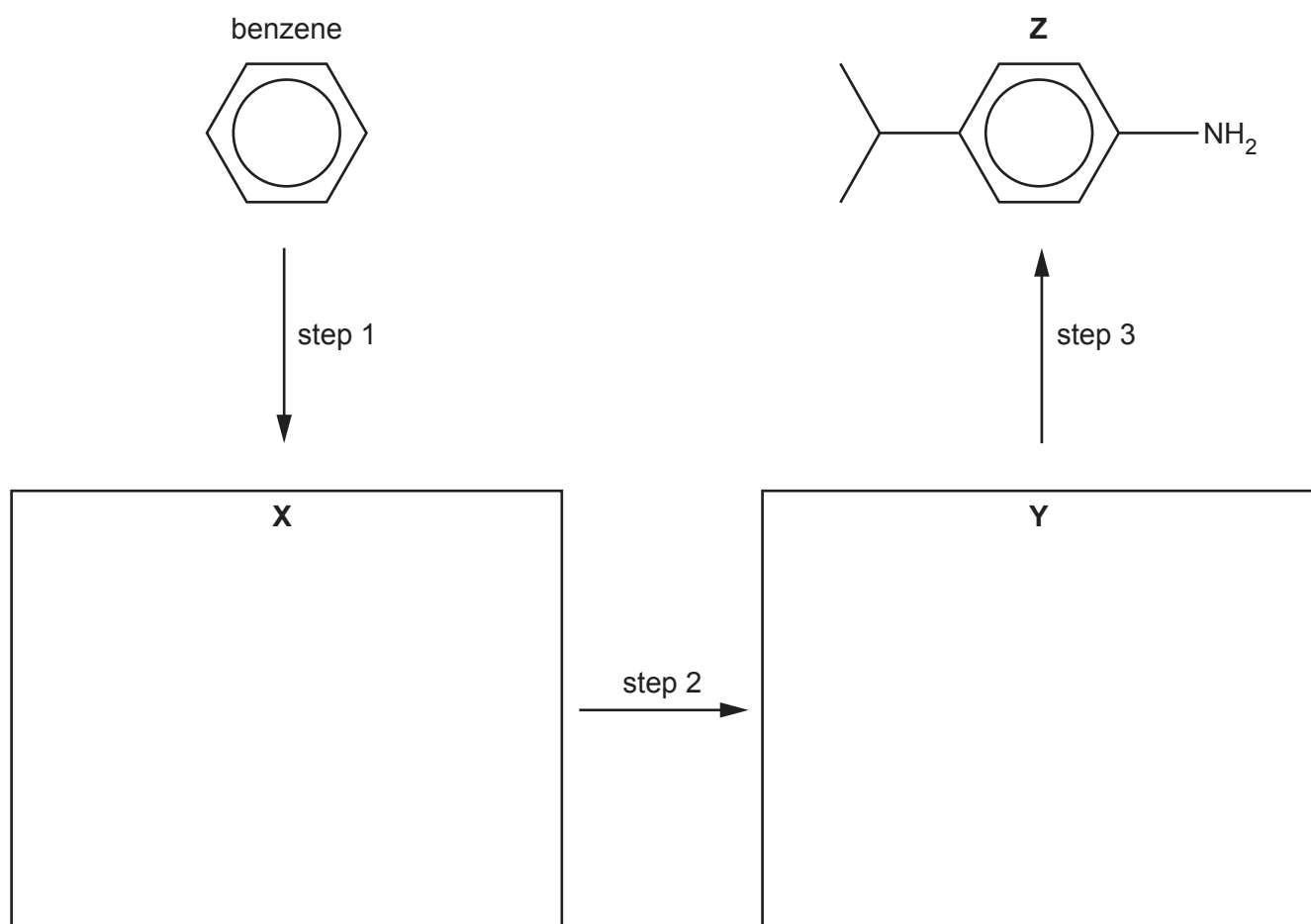


Fig. 4.1

- (i) Draw structures for **X** and **Y** in Fig. 4.1. [2]
- (ii) Give the reagents and conditions for steps 1, 2 and 3.

step 1
 step 2
 step 3 [3]

- (c) Compound **W** is an isomer of **Z**.

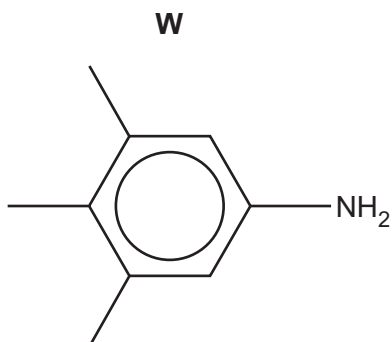


Fig. 4.2

Give the systematic name of **W**.

..... [1]

- (d) Complete Table 4.1 to show the number of peaks observed in the carbon-13 NMR spectrum for **W** and **Z**.

Table 4.1

compound	number of peaks observed
W	
Z	

[1]

[Total: 10]

- 5 (a) The exhaust systems of most modern gasoline-fuelled cars contain a catalytic converter with three metal catalysts.

These metals act as heterogeneous catalysts.

- (i) Name **three** metal catalysts used in catalytic converters.

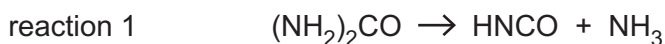
1 2 3 [1]

- (ii) Explain what is meant by a heterogeneous catalyst.

.....
 [1]

- (b) The exhaust systems of many diesel-fuelled cars contain an additional system to reduce vehicle emissions. This uses a liquid that is added to the exhaust system.

This liquid contains urea, $(\text{NH}_2)_2\text{CO}$, which decomposes on heating to isocyanic acid, HNCO , and ammonia.



Isocyanic acid reacts with water vapour to form ammonia and carbon dioxide.



Some values for standard enthalpy changes of formation, $\Delta H_f^\ominus$, and standard entropies, $S^\ominus$, are given in Table 5.1.

Table 5.1

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
$\text{HNCO}(\text{g})$	-101.7	+238.2
$\text{H}_2\text{O}(\text{g})$	-241.8	+188.8
$\text{NH}_3(\text{g})$	-45.9	+192.8
$\text{CO}_2(\text{g})$	-393.5	+213.8

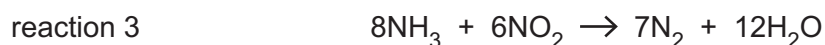
- (i) Explain what is meant by the term entropy of a system.

.....
 [1]

- (ii) Use the data in Table 5.1 to calculate $\Delta G^\ominus$ for **reaction 2** at 25 °C.
Show your working.

$$\Delta G^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [4]$$

- (c) The ammonia formed in reactions 1 and 2 can be used to remove nitrogen dioxide from exhaust emissions, as shown.



Use the equations for reactions 1, 2 and 3 to construct an overall equation for the reduction of NO_2 by $(\text{NH}_2)_2\text{CO}$.

..... [1]

- (d) Isocyanic acid, HNCO , can form cyanuric acid, $\text{C}_3\text{H}_3\text{N}_3\text{O}_3$, under certain conditions.

$\text{C}_3\text{H}_3\text{N}_3\text{O}_3$ has a cyclic structure containing alternating carbon and nitrogen atoms in the ring system.

Suggest a structure for cyanuric acid.

[1]

(e) Isocyanic acid, HNCO, is a weak acid.



(i) Write the mathematical expressions for $\text{p}K_{\text{a}}$ and pH.

$\text{p}K_{\text{a}} = \dots\dots\dots$

$\text{pH} = \dots\dots\dots$

[1]

(ii) Calculate the pH of $0.120 \text{ mol dm}^{-3}$ HNCO(aq).
Give your answer to **three** significant figures.

$\text{pH} = \dots\dots\dots$ [2]

(iii) Calculate the percentage of HNCO molecules that are ionised in $0.120 \text{ mol dm}^{-3}$ HNCO.

percentage ionisation of HNCO = $\dots\dots\dots$ [1]

[Total: 13]

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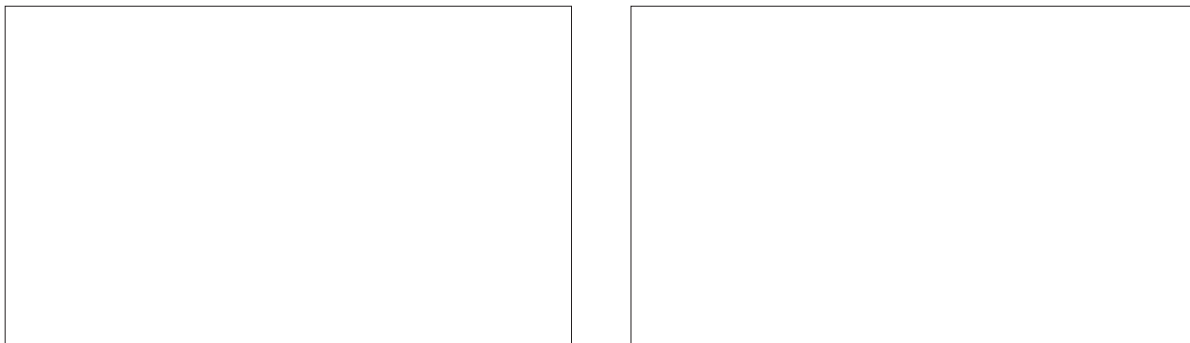
6 (a) Compound **H** has the structural formula $\text{CH}_2=\text{CHCH}(\text{NH}_2)\text{COOH}$.

(i) Name all the functional groups in **H**.

.....
 [2]

(ii) Compound **H** exhibits stereoisomerism.

Draw three-dimensional structures for the two stereoisomers of **H**.
 Name this type of stereoisomerism.



[2]

(b) Compound **H** can be prepared from the reaction of **J** with an excess of hot aqueous acid.

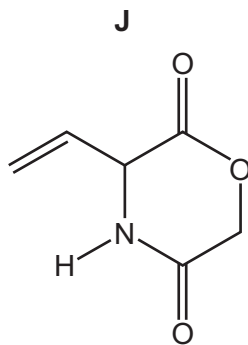


Fig. 6.1

(i) Complete Fig. 6.2 to show the equation for this reaction.

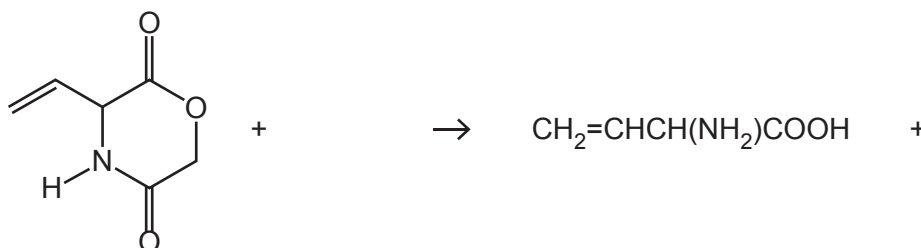


Fig. 6.2

[1]

(ii) Name the type of reaction in (b)(i).

..... [1]

(c) Polymers consist of monomers joined together by undergoing either addition or condensation polymerisation.

Compound **H** can react to form an addition polymer, **K**, or a condensation polymer, **L**, depending on the conditions.

(i) Draw **one** repeat unit of addition polymer **K**.

[1]

(ii) Draw **two** repeat units of condensation polymer **L**.

The new functional group formed should be displayed.

[2]

(iii) Explain why condensation polymers can normally biodegrade more readily than addition polymers.

.....

..... [1]

[Total: 10]

- 7 (a) State the relative basicities of ethanamide, diethylamine and ethylamine in aqueous solution. Explain your answer.

..... > >
 most basic least basic

.....

.....

.....

.....

.....

[4]

- (b) The amino acid alanine, $\text{H}_2\text{NCH}(\text{CH}_3)\text{COOH}$, can act as a buffer.

- (i) Define a buffer solution.

.....

.....

..... [2]

- (ii) Write **two** equations to show how an aqueous solution of alanine can act as a buffer solution.

.....

..... [2]

- (c) Glutamic acid is another amino acid that acts as a buffer.

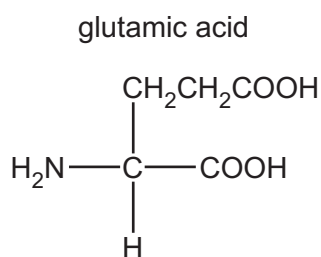


Fig. 7.1

- (i) Draw the **skeletal** formula for glutamic acid.

- (ii) Draw the structure for the dipeptide, ala-glu, formed from one molecule of alanine and one molecule of glutamic acid.

The peptide bond formed should be displayed.

[2]

- (d) The isoelectric point of alanine is 6.0 and of glutamic acid is 3.2.

A mixture of the dipeptide, ala-glu, and its two constituent amino acids, alanine and glutamic acid, is analysed by electrophoresis using a buffer at pH 6.0.

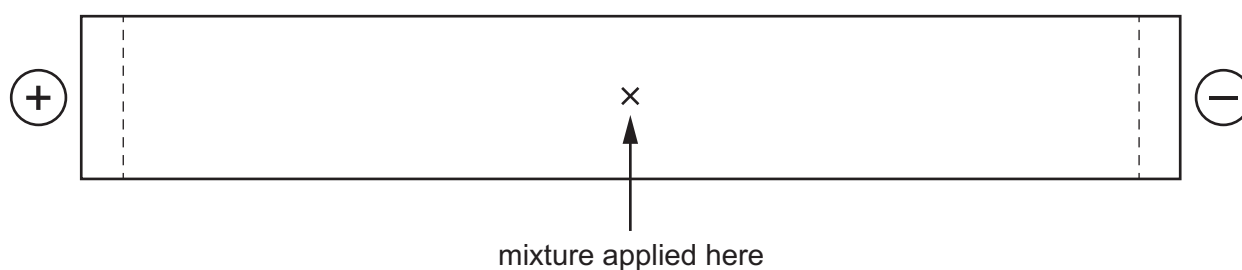


Fig. 7.2

Draw and label **three** spots on Fig. 7.2 to indicate the predicted position of each of these three species after electrophoresis.

Explain your answer.

.....

.....

.....

.....

..... [3]

- (e) Alanine, $\text{H}_2\text{NCH}(\text{CH}_3)\text{COOH}$, reacts with methanol to form the ester **G** under certain conditions.

The proton (^1H) NMR spectrum of **G** dissolved in D_2O is shown in Fig. 7.3.

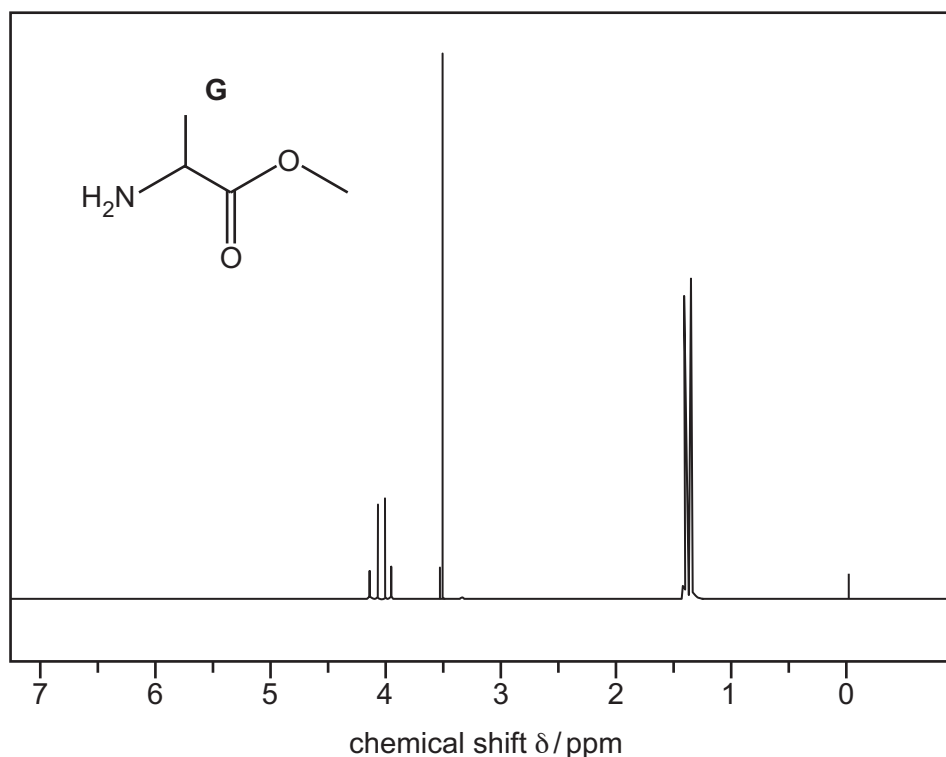


Fig. 7.3

Table 7.1

environment of proton	example	chemical shift range, δ/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	CH_3-Ar , $-\text{CH}_2-\text{Ar}$, $>\text{CH}-\text{Ar}$	2.3–3.0
alkyl next to electronegative atom	CH_3-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	HCOR	9.3–10.5
alcohol	ROH	0.5–6.0
phenol	$\text{Ar}-\text{OH}$	4.5–7.0
carboxylic acid	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	RCONHR	5.0–12.0

- (i) Complete Table 7.2 for the proton (^1H) NMR spectrum of **G**.

Table 7.2

chemical shift (δ)	splitting pattern	number of ^1H atoms responsible for the peak	number of protons on adjacent carbon atoms
1.4			
3.5			
4.0			

[3]

- (ii) The proton (^1H) NMR spectrum of **G** dissolved in CDCl_3 is obtained.

Describe the difference observed between this spectrum and the proton NMR spectrum in D_2O shown in Fig 7.3.

Explain your answer.

.....

 [1]

[Total: 18]

- 8 (a) Complete Table 8.1 by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

Table 8.1

energy change	always positive	always negative	can be either negative or positive
lattice energy			
enthalpy change of hydration			
enthalpy change of solution			

[1]

- (b) Define enthalpy change of hydration.

.....

.....

..... [1]

- (c) Table 8.2 shows various energy changes which can be used in the following questions.

Table 8.2

energy change	value / kJ mol ⁻¹
standard enthalpy change of atomisation of calcium	+178.2
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1145
standard enthalpy change of atomisation of bromine	+111.9
Br–Br bond energy	+192.9
standard enthalpy change of solution of calcium bromide, CaBr ₂ (s)	–103.1
standard enthalpy change of formation of calcium bromide, CaBr ₂ (s)	–682.8
standard enthalpy change of hydration of Ca ²⁺	–1579
first electron affinity of bromine	–324.6
first ionisation energy of bromine	+1140

- (i) Select and use relevant data from Table 8.2 to calculate the lattice energy, $\Delta H_{\text{latt}}^{\ominus}$, of $\text{CaBr}_2(\text{s})$.

It may be helpful to draw a labelled energy cycle.

Show your working.

$$\Delta H_{\text{latt}}^{\ominus} \text{ of } \text{CaBr}_2(\text{s}) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [3]$$

- (ii) Select and use relevant data from Table 8.2 and your answer to (c)(i) to calculate the standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$, of Br^- .

It may be helpful to draw a labelled energy cycle.

If you were not able to answer (c)(i), use $-2500 \text{ kJ mol}^{-1}$ as your value for $\Delta H_{\text{latt}}^{\ominus}$ of $\text{CaBr}_2(\text{s})$. This is **not** the correct value.

Show your working.

$$\Delta H_{\text{hyd}}^{\ominus} \text{ of } \text{Br}^- = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

- (iii) The enthalpy change of hydration of the Br^- ion is more negative than the enthalpy change of hydration of the I^- ion. Explain why.

.....

 [2]

[Total: 9]

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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	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
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) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ 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 ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group																					
1	2													13	14	15	16	17	18		
		1 Hhydrogen1.0																		2 Hehelium4.0	
		Key atomic number atomic symbol name relative atomic mass																			
3 Li lithium 6.9	4 Be beryllium 9.0													5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2		
11 Na sodium 23.0	12 Mg magnesium 24.3													13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9		
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8				
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3				
55 Cs caesium 132.9	56 Ba barium 137.3	lanthanoids		72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —	86 Rn radon —			
87 Fr francium —	88 Ra radium —	actinoids		104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganesson —			
lanthanoids		57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	61 Pm promethium —	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0					
actinoids		89 Ac actinium —	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —					

lanthanoids

actinoids

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La lanthanum 138.9	Ce cerium 140.1	Pr praseodymium 140.9	Nd neodymium 144.4	Pm promethium —	Sm samarium 150.4	Eu europium 152.0	Gd gadolinium 157.3	Tb terbium 158.9	Dy dysprosium 162.5	Ho holmium 164.9	Er erbium 167.3	Tm thulium 168.9	Yb ytterbium 173.1	Lu lutetium 175.0
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac actinium —	Th thorium 232.0	Pa protactinium 231.0	U uranium 238.0	Np neptunium —	Pu plutonium —	Am americium —	Cm curium —	Bk berkelium —	Cf californium —	Es einsteinium —	Fm fermium —	Md mendelevium —	No nobelium —	Lr lawrencium —



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9701/42

May/June 2023

2 hours

No additional materials are needed.

- 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.

- 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.

[Turn over

1 (a) Group 2 carbonates decompose when heated to form the metal oxide and carbon dioxide.

- (i) Suggest a mechanism for the decomposition of the carbonate ion by adding **two** curly arrows in Fig. 1.1.

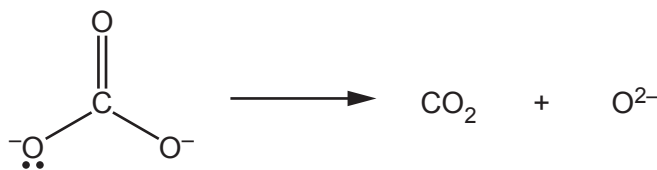


Fig. 1.1

[1]

- (ii) Describe the variation in the thermal stability of Group 2 carbonates. Explain your answer.

.....

 [3]

- (b) (i) Define lattice energy.

.....

 [2]

- (ii) The lattice energy of the Group 2 carbonates, $\Delta H_{\text{latt}}^{\ominus}(\text{MCO}_3)$, becomes less exothermic down the group.

The lattice energy of the Group 2 oxides, $\Delta H_{\text{latt}}^{\ominus}(\text{MO})$, also becomes less exothermic down the group.

$\Delta H_{\text{latt}}^{\ominus}(\text{MCO}_3)$ and $\Delta H_{\text{latt}}^{\ominus}(\text{MO})$ change by **different** amounts going down the group.

Suggest how the standard enthalpy change of the decomposition reaction for Group 2 carbonates changes down the group.

Explain your reasoning in terms of the relative sizes of the anions and the relative changes in lattice energy down the group.

.....

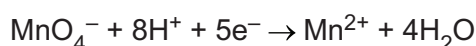
 [2]

(c) Potassium sulfite, K_2SO_3 , is used as a food additive.

The concentration of sulfite ions, SO_3^{2-} , can be determined by titration using aqueous acidified manganate(VII) ions, MnO_4^- .

- A 250 cm^3 solution contains 3.40 g of impure K_2SO_3 .
- 25.0 cm^3 of this solution requires 22.40 cm^3 of $0.0250\text{ mol dm}^{-3}$ acidified MnO_4^- to reach the end-point. All the SO_3^{2-} ions are oxidised. None of the other species in the impure K_2SO_3 are oxidised.

The reaction occurs as shown by the two half-equations.



(i) Give the ionic equation for the reaction between SO_3^{2-} and acidified MnO_4^- .

..... [1]

(ii) Calculate the percentage purity of the sample of K_2SO_3 .
Show your working.

percentage purity of $\text{K}_2\text{SO}_3 = \dots\dots\dots$ [3]

(d) Potassium disulfite, $\text{K}_2\text{S}_2\text{O}_5$, is another food additive. The disulfite ion, $\text{S}_2\text{O}_5^{2-}$, has the displayed formula shown in Fig. 1.2.

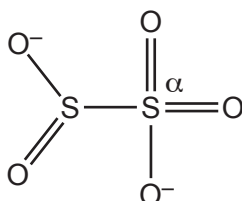


Fig. 1.2

Deduce the geometry (shape) around the $\text{S}(\alpha)$ atom in $\text{S}_2\text{O}_5^{2-}$.

geometry around $\text{S}(\alpha) \dots\dots\dots$ [1]

2 (a) State **two** typical chemical properties of a transition element.

1

2 [1]

(b) Aqueous solutions of cobalt(II) salts contain the complex ion $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.

(i) Define complex ion.

.....

..... [1]

(ii) Samples of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ are reacted separately with an excess of aqueous ammonia, with an excess of concentrated HCl and with an excess of aqueous sodium hydroxide, as shown in Fig. 2.1.

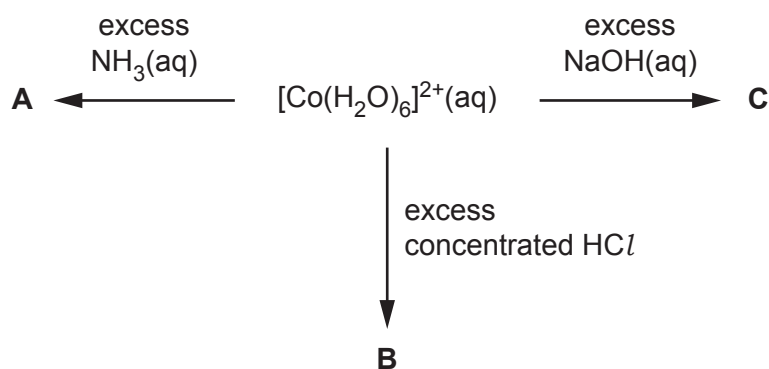


Fig. 2.1

Complete Table 2.1 about the reactions shown by $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.

Table 2.1

reagent added to $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$	formula of cobalt species formed	colour and state of cobalt species formed	type of reaction
an excess of $\text{NH}_3(\text{aq})$	A =		
an excess of concentrated HCl	B =		
an excess of $\text{NaOH}(\text{aq})$	C =		

[4]

(c) The ethanedioate ion, $\text{C}_2\text{O}_4^{2-}$, can act as a bidentate ligand.

(i) Explain what is meant by a bidentate ligand.

.....

 [2]

(ii) The complex $[\text{Co}(\text{H}_2\text{O})_2(\text{C}_2\text{O}_4)\text{BrCl}]^-$ exists as stereoisomers.

Complete the three-dimensional diagrams in Fig. 2.2 to show **four** stereoisomers of $[\text{Co}(\text{H}_2\text{O})_2(\text{C}_2\text{O}_4)\text{BrCl}]^-$.

The $\text{C}_2\text{O}_4^{2-}$ ligand is represented using $\text{O} \text{---} \text{O}$.

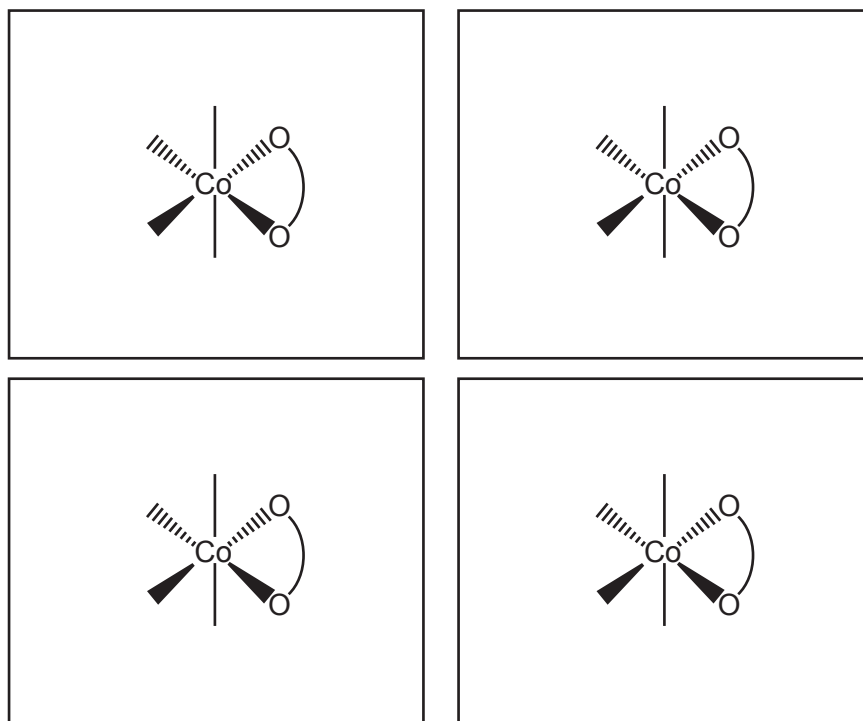


Fig. 2.2

[3]

(iii) State the oxidation state of cobalt in this complex and a type of stereoisomerism shown.

oxidation state of cobalt

type of stereoisomerism

[1]

[Total: 12]

- 3 (a) Complete Table 3.1 by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

Table 3.1

energy change	always positive	always negative	can be either negative or positive
bond energy			
enthalpy change of atomisation			
enthalpy change of formation			

[1]

- (b) Define standard enthalpy change of atomisation.

.....

.....

..... [2]

- (c) Table 3.2 shows some energy changes.

Table 3.2

energy change	value / kJ mol ⁻¹
standard enthalpy change of atomisation of silver	+285
first ionisation energy of silver	+731
second ionisation energy of silver	+2074
bond energy of O=O	+496
bond energy of O–O	+150
first electron affinity of oxygen	–141
second electron affinity of oxygen	+798
first ionisation energy of oxygen	+1314
standard enthalpy change of formation of silver oxide, Ag ₂ O(s)	–31

Calculate the lattice energy, $\Delta H_{\text{latt}}^{\ominus}$, of $\text{Ag}_2\text{O}(\text{s})$ using relevant data from Table 3.2.

It may be helpful to draw a labelled energy cycle.

Show your working.

$\Delta H_{\text{latt}}^{\ominus}$ of $\text{Ag}_2\text{O}(\text{s}) = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

- (d) Suggest the trend in the magnitude of the lattice energies of the silver compounds Ag_2S , Ag_2O and Ag_2Se .

Explain your answer.

.....
least exothermic most exothermic
.....
.....
..... [2]

(e) Silver sulfite, $\text{Ag}_2\text{SO}_3(\text{s})$, is sparingly soluble in water.

(i) Give an expression for the solubility product, K_{sp} , of Ag_2SO_3 .

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

[1]

(ii) Calculate the equilibrium concentration of Ag^+ in a saturated solution of Ag_2SO_3 at 298 K.

[K_{sp} : Ag_2SO_3 , $1.50 \times 10^{-14} \text{ mol}^3 \text{ dm}^{-9}$ at 298 K]

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

(f) The standard enthalpy change of solution, $\Delta H_{\text{sol}}^\ominus$, of $\text{AgNO}_3(\text{s})$ in water is $+22.6 \text{ kJ mol}^{-1}$.

Suggest how the feasibility of dissolving $\text{AgNO}_3(\text{s})$ in water changes with temperature.

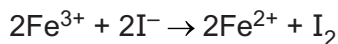
Explain your answer.

.....

 [2]

[Total: 12]

- 4 (a) In aqueous solution, iron(III) ions react with iodide ions, as shown.



A series of experiments is carried out using different concentrations of Fe^{3+} and I^{-} , as shown in Table 4.1.

Table 4.1

experiment	$[\text{Fe}^{3+}]/\text{mol dm}^{-3}$	$[\text{I}^{-}]/\text{mol dm}^{-3}$	initial rate/ $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.0400	0.0200	2.64×10^{-4}
2	0.1200	0.0200	7.92×10^{-4}
3	0.0800	0.0400	2.11×10^{-3}

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

.....

 [1]

- (ii) Use the data in Table 4.1 to deduce the order of reaction with respect to Fe^{3+} and with respect to I^{-} .

Explain your reasoning.

.....

 [2]

- (iii) Use your answer to (a)(ii) to construct the rate equation for this reaction.

rate = ... [1]

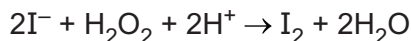
- (iv) Use your answer to (a)(iii) and the data from experiment 1 to calculate the rate constant, k , for this reaction. Include the units of k .

k = ... units [2]

- (v) Describe qualitatively the effect of an increase in temperature on the rate constant and on the rate of this reaction.

.....
 [1]

- (b) In aqueous solution, iodide ions react with acidified hydrogen peroxide, as shown.



The initial rate of reaction is found to be first order with respect to I^- , first order with respect to H_2O_2 and zero order with respect to H^+ .

Fig. 4.1 shows a possible four-step mechanism for this reaction.

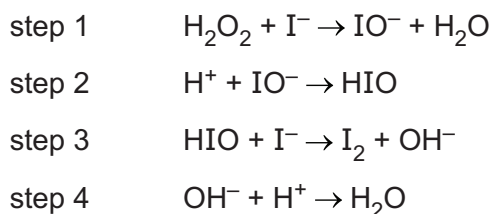


Fig. 4.1

- (i) Suggest which of the steps, 1, 2, 3 or 4, in this mechanism is the rate-determining step.

Explain your answer.

.....

 [1]

- (ii) Identify a step in Fig. 4.1 that involves a redox reaction.

Explain your answer in terms of oxidation numbers.

.....

 [1]

- (iii) Suggest the role of HIO in this mechanism.

Explain your reasoning.

.....

 [1]

[Total: 10]

5 (a) Methylbenzene can undergo different reactions, as shown in Fig. 5.1.

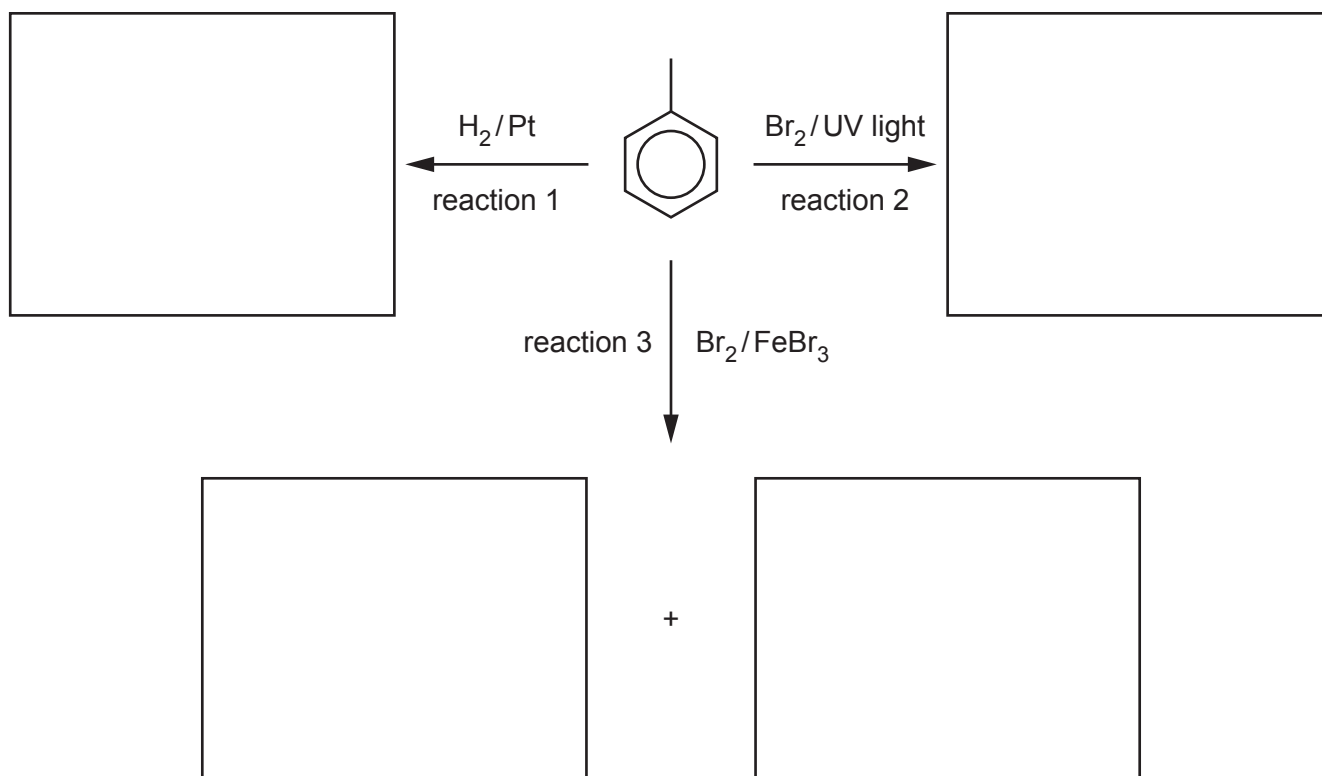


Fig. 5.1

(i) Draw structures in Fig. 5.1 for the possible organic products of the three reactions shown. [3]

(ii) Complete Table 5.1.

Table 5.1

	type of reaction	mechanism
reaction 1		
reaction 2		

[2]

(b) When methylbenzene reacts with an electrophile, a substitution reaction occurs. No addition reaction takes place under these conditions.

Explain why no addition reaction takes place.

.....
 [1]

- (c) The reaction of methylbenzene with thionyl bromide, SOBr_2 , in the presence of an iron(III) bromide catalyst, FeBr_3 , is shown in Fig. 5.2.

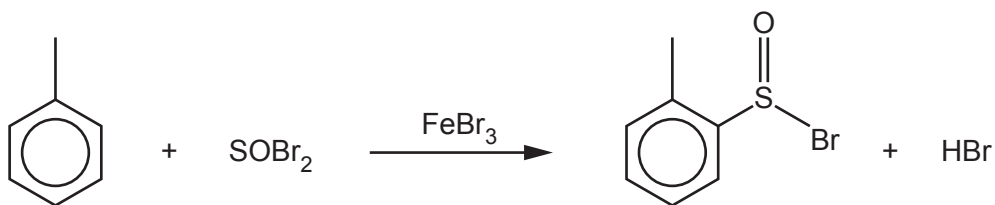
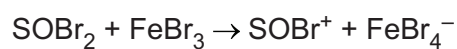


Fig. 5.2

The mechanism of this reaction is similar to that of the bromination of benzene.

The first step of the mechanism generates the SOBr^+ electrophile, as shown.



- (i) The reaction of methylbenzene with SOBr^+ ions is shown in Fig. 5.3. Complete the mechanism in Fig. 5.3.

Include all relevant curly arrows and charges.

Draw the structure of the organic intermediate.

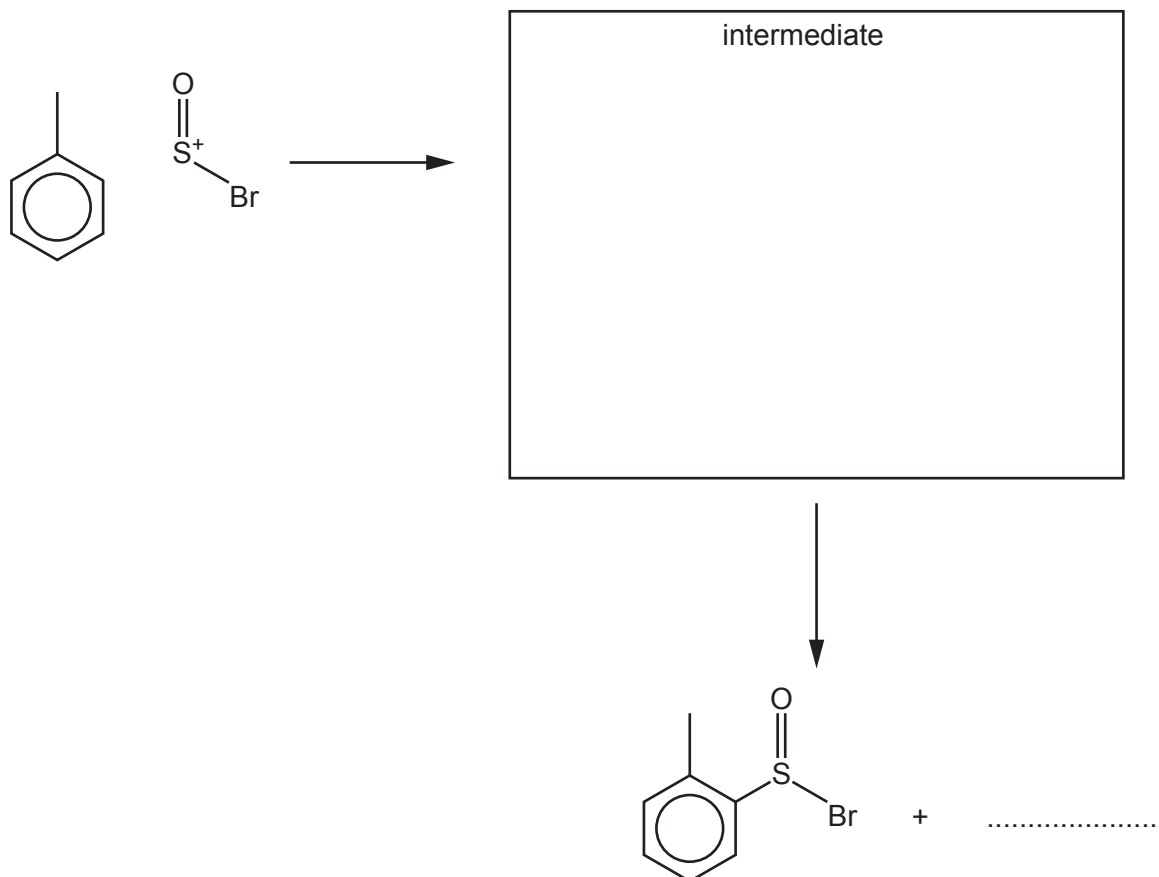


Fig. 5.3

[3]

- (ii) The reaction shown in Fig. 5.2 produces a small amount of a by-product, **P**, with the molecular formula $C_{14}H_{14}OS$.

Suggest a structure for by-product **P**.

[1]

- (d) Acyl bromides, $RCOBr$, can be synthesised by the reaction of a carboxylic acid and $SOBr_2$.

This is a similar reaction to the synthesis of acyl chlorides using $SOCl_2$.

- (i) Give an equation for the reaction between ethanoic acid and $SOBr_2$.

..... [1]

- (ii) Suggest the relative ease of hydrolysis of acyl bromides, $RCOBr$, acyl chlorides, $RCOCl$, and alkyl chlorides, RCI .

Explain your answer.

..... > >
 easiest to hydrolyse hardest to hydrolyse

.....

[3]

[Total: 14]

- 6 (a) Perindopril is a drug used to treat heart disease.

perindopril

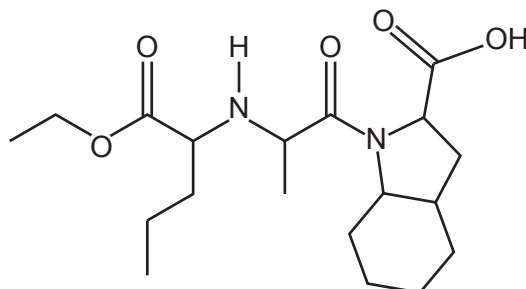


Fig. 6.1

- (i) State the number of chiral carbon atoms present in one molecule of perindopril.

..... [1]

- (ii) Suggest **one** benefit and **one** disadvantage of producing a drug such as perindopril as a single pure optical isomer.

benefit

.....

disadvantage

.....

[2]

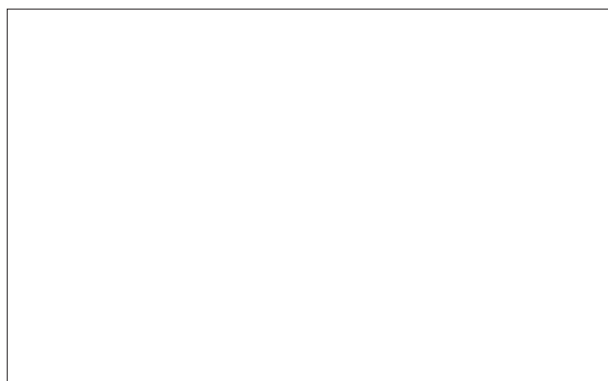
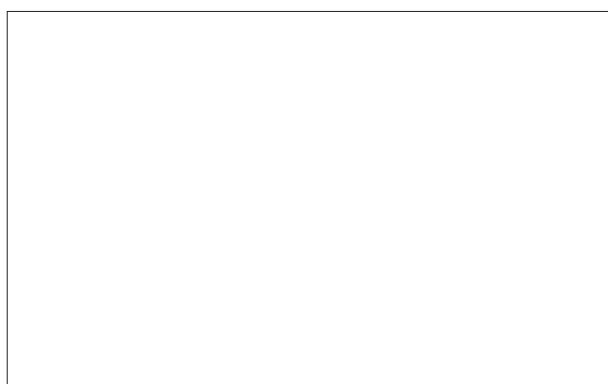
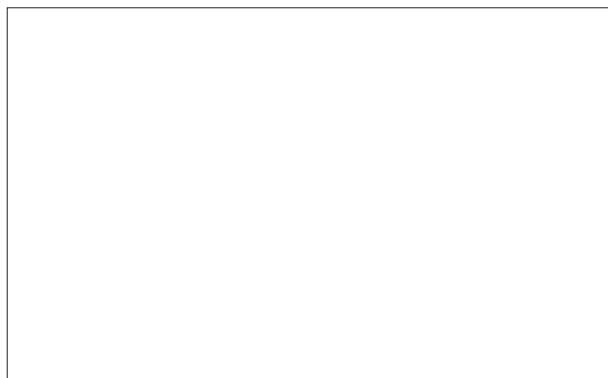
- (b) (i) Name all the functional groups in perindopril.

.....

..... [2]

- (ii) A sample of perindopril is hydrolysed with hot aqueous acid.

Draw the structures of the **three** organic products of the **complete** acid hydrolysis of perindopril.



[3]

[Total: 8]

- 7 (a) Explain why phenol is brominated much more easily than benzene is brominated.

.....

 [3]

- (b) Iodine monobromide, I–Br, reacts with benzene in the presence of an $AlBr_3$ catalyst.

Predict whether the organic product will be bromobenzene or iodobenzene.
 Explain your answer.

.....

 [1]

- (c) Fig. 7.1 shows some reactions of phenol.

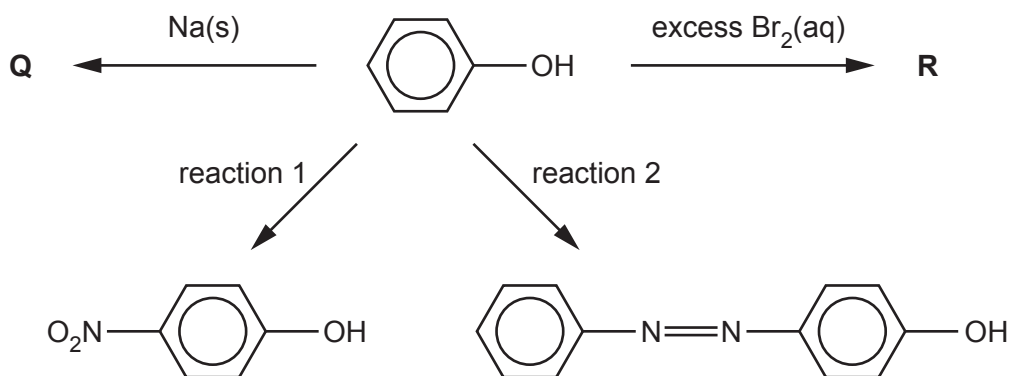


Fig. 7.1

- (i) Give an equation for the reaction of phenol with Na(s).

..... [1]

- (ii) Draw the structure of the organic product, **R**, formed when phenol reacts with an excess of $\text{Br}_2(\text{aq})$.

[1]

- (iii) State the reagents and conditions for reaction 1 and reaction 2 in Fig. 7.1.

reaction 1

reaction 2

[2]

[Total: 8]

- 8 (a) Describe the difference in reactivity between chloroethane and chlorobenzene with $\text{OH}^-(\text{aq})$.
Explain your answer.

.....

 [2]

- (b) Compound **T**, $\text{C}_5\text{H}_9\text{O}_2\text{Cl}$, is a useful synthetic intermediate.

Fig. 8.1 shows some reactions of **T**.

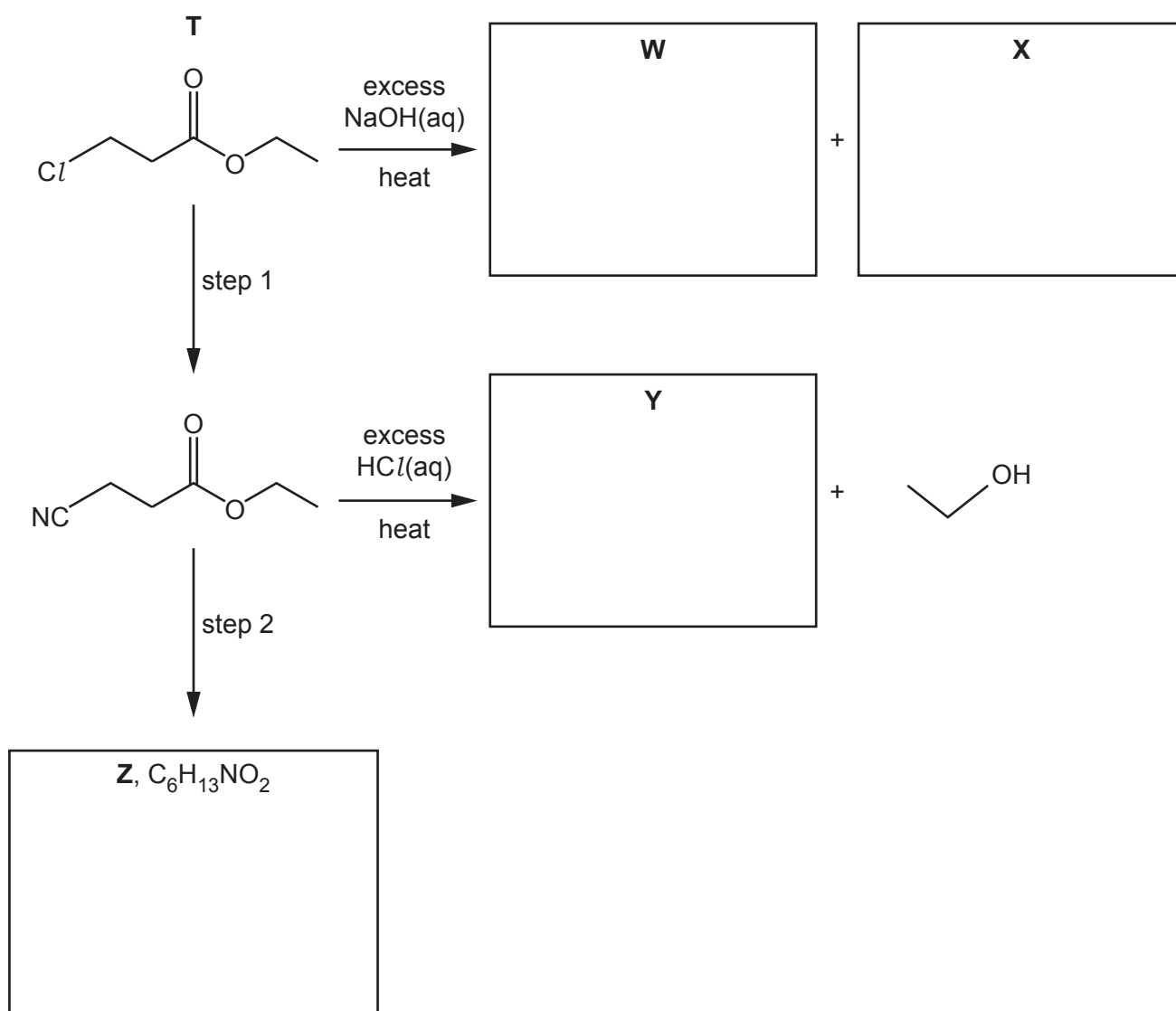


Fig. 8.1

(i) Give the systematic name for **T**.

..... [1]

(ii) Draw the structures of **W**, **X**, **Y** and **Z** in Fig. 8.1. [4]

(iii) State the reagents and conditions for steps 1 and 2 in Fig. 8.1.

step 1

step 2

[2]

(c) The proton (^1H) NMR spectrum of compound **T**, $\text{C}_5\text{H}_9\text{O}_2\text{Cl}$, in CDCl_3 is shown in Fig. 8.2.

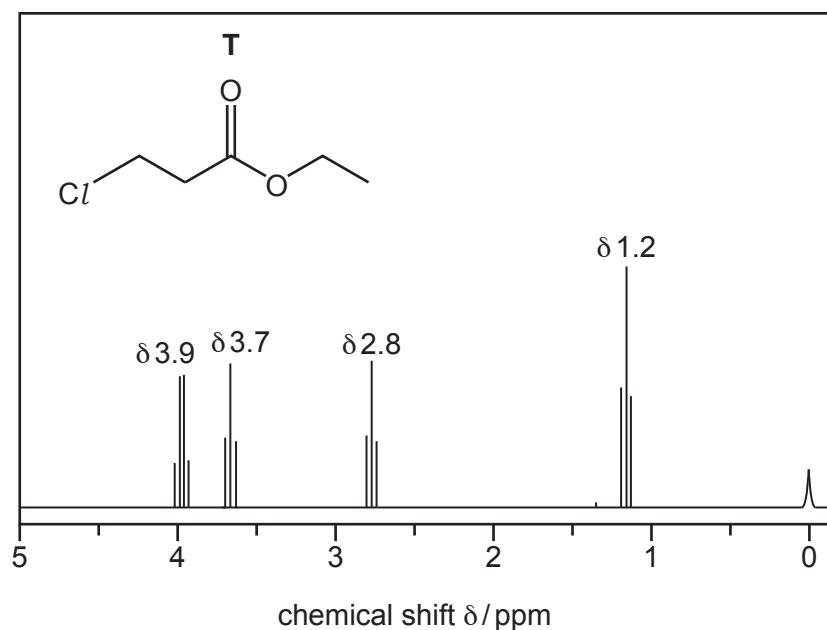


Fig. 8.2

Table 8.1

environment of proton	example	chemical shift range δ /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	CH_3-Ar , $-\text{CH}_2-\text{Ar}$, $>\text{CH}-\text{Ar}$	2.3–3.0
alkyl next to electronegative atom	CH_3-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	HCOR	9.3–10.5
alcohol	ROH	0.5–6.0
phenol	$\text{Ar}-\text{OH}$	4.5–7.0
carboxylic acid	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	RCONHR	5.0–12.0

- (i) Suggest why CDCl_3 is used as a solvent instead of CHCl_3 for the proton (^1H) NMR spectrum.

.....
 [1]

- (ii) Complete Table 8.2 for the proton (^1H) NMR spectrum of **T**.

Table 8.2

chemical shift δ/ppm	environment of proton	splitting pattern	number of ^1H atoms responsible for the peak
1.2			
2.8			
3.7			
3.9			

[4]

- (iii) Explain the splitting pattern of the peak at δ 3.9 ppm.

.....
 [1]

[Total: 15]

- 9 (a) Define standard cell potential, $E_{\text{cell}}^{\ominus}$.

.....
 [1]

- (b) An electrochemical cell is set up to measure $E_{\text{cell}}^{\ominus}$ of a cell consisting of an $\text{Fe}^{3+}/\text{Fe}^{2+}$ half-cell and a Cl_2/Cl^- half-cell.

Draw a labelled diagram of this electrochemical cell.

Include all necessary substances. It is **not** necessary to state conditions used.

[3]

- (c) The cell reaction for the electrochemical cell in (b) is shown.



Calculate $\Delta G^{\ominus}$, in kJ mol^{-1} , for this cell reaction.

$\Delta G^{\ominus} = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

(d) Another experiment is set up using the same electrochemical cell.

In this experiment the Fe^{2+} concentration is 0.15 mol dm^{-3} . All other concentrations remain at their standard values.

The Nernst equation is shown.

$$E = E^\ominus + (0.059/z) \log \frac{[\text{oxidised species}]}{[\text{reduced species}]}$$

(i) Use the Nernst equation to calculate the electrode potential, E , for the $\text{Fe}^{3+}/\text{Fe}^{2+}$ half-cell in this experiment.

$$[E^\ominus: \text{Fe}^{3+}/\text{Fe}^{2+} = +0.77 \text{ V}]$$

$$E = \dots\dots\dots \text{ V [1]}$$

(ii) Use your answer to (d)(i) to calculate E_{cell} for this electrochemical cell.

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

[Total: 8]

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	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
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) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ 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																																								
1 H hydrogen 1.0 Key atomic number atomic symbol name relative atomic mass 2 He helium 4.0 3 Li lithium 6.9 4 Be beryllium 9.0 5 B boron 10.8 6 C carbon 12.0 7 N nitrogen 14.0 8 O oxygen 16.0 9 F fluorine 19.0 10 Ne neon 20.2 11 Na sodium 23.0 12 Mg magnesium 24.3 13 Al aluminium 27.0 14 Si silicon 28.1 15 P phosphorus 31.0 16 S sulfur 32.1 17 Cl chlorine 35.5 18 Ar argon 39.9 19 K potassium 39.1 20 Ca calcium 40.1 21 Sc scandium 45.0 22 Ti titanium 47.9 23 V vanadium 50.9 24 Cr chromium 52.0 25 Mn manganese 54.9 26 Fe iron 55.8 27 Co cobalt 58.9 28 Ni nickel 58.7 29 Cu copper 63.5 30 Zn zinc 65.4 31 Ga gallium 69.7 32 Ge germanium 72.6 33 As arsenic 74.9 34 Se selenium 79.0 35 Br bromine 79.9 36 Kr krypton 83.8 37 Rb rubidium 85.5 38 Sr strontium 87.6 39 Y yttrium 88.9 40 Zr zirconium 91.2 41 Nb niobium 92.9 42 Mo molybdenum 95.9 43 Tc technetium — 44 Ru ruthenium 101.1 45 Rh rhodium 102.9 46 Pd palladium 106.4 47 Ag silver 107.9 48 Cd cadmium 112.4 49 In indium 114.8 50 Sn tin 118.7 51 Sb antimony 121.8 52 Te tellurium 127.6 53 I iodine 126.9 54 Xe xenon 131.3 55 Cs caesium 132.9 56 Ba barium 137.3 57–71 lanthanoids — 72 Hf hafnium 178.5 73 Ta tantalum 180.9 74 W tungsten 183.8 75 Re rhenium 186.2 76 Os osmium 190.2 77 Ir iridium 192.2 78 Pt platinum 195.1 79 Au gold 197.0 80 Hg mercury 200.6 81 Tl thallium 204.4 82 Pb lead 207.2 83 Bi bismuth 209.0 84 Po polonium — 85 At astatine — 86 Rn radon — 87 Fr francium — 88 Ra radium — 89–103 actinoids — 104 Rf rutherfordium — 105 Db dubnium — 106 Sg seaborgium — 107 Bh bohrium — 108 Hs hassium — 109 Mt meitnerium — 110 Ds darmstadtium — 111 Rg roentgenium — 112 Cn coppernium — 113 Nh nihonium — 114 Fl flerovium — 115 Mc moscovium — 116 Lv livermorium — 117 Ts tennessine — 118 Og oganeson —																																																											
lanthanoids																																																											
57	La	lanthanum	138.9	58	Ce	cerium	140.1	59	Pr	praseodymium	140.9	60	Nd	neodymium	144.4	61	Pm	promethium	—	62	Sm	samarium	150.4	63	Eu	euporium	152.0	64	Gd	gadolinium	157.3	65	Tb	terbium	158.9	66	Dy	dysprosium	162.5	67	Ho	holmium	164.9	68	Er	erbium	167.3	69	Tm	thulium	168.9	70	Yb	yterbium	173.1	71	Lu	lutetium	175.0
actinoids																																																											
89	Ac	actinium	—	90	Th	thorium	232.0	91	Pa	protactinium	231.0	92	U	uranium	238.0	93	Np	neptunium	—	94	Pu	plutonium	—	95	Am	americium	—	96	Cm	curium	—	97	Bk	berkelium	—	98	Cf	californium	—	99	Es	einsteinium	—	100	Fm	fermium	—	101	Md	mendelevium	—	102	No	nobelium	—	103	Lr	lawrencium	—

lanthanoids

actinoids



CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/43

May/June 2023

2 hours

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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 **28** pages. Any blank pages are indicated.

- 1 (a) Group 2 nitrates decompose when heated.

Describe how the thermal stability of Group 2 nitrates changes with increasing proton number.
Explain your answer.

.....

 [3]

- (b) Copper(II) nitrate decomposes in a similar manner to Group 2 nitrates.

Write an equation for the decomposition of $\text{Cu}(\text{NO}_3)_2$.

..... [1]

- (c) $\text{Cu}(\text{NO}_3)_2$ is added to water to form solution A.

Fig. 1.1 shows some reactions of solution A.

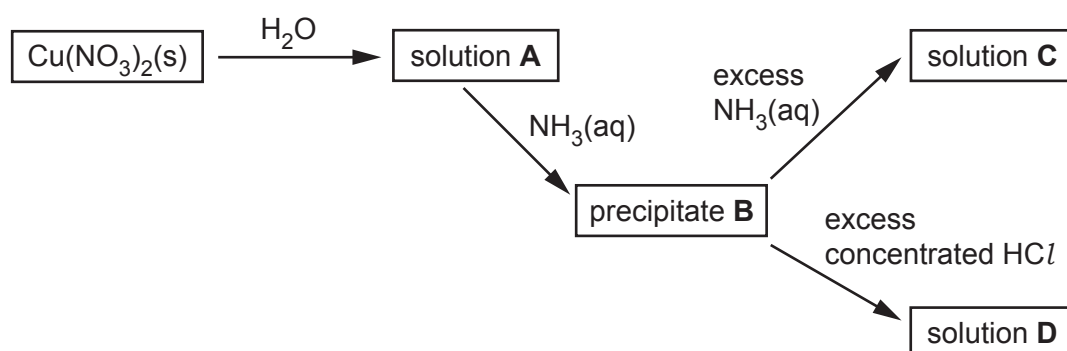


Fig. 1.1

Complete Table 1.1 to show the formula and colour of each of the copper-containing species present in A, B, C and D.

Table 1.1

	formula of copper-containing species formed	colour of copper-containing species formed
A		
B		
C		
D		

[4]

(d) EDTA^{4-} is a polydentate ligand.

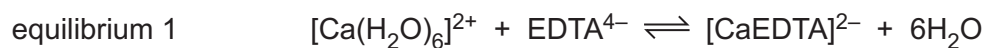
(i) Explain what is meant by a polydentate ligand.

.....

 [2]

(ii) Group 2 metal ions can form complexes similar to those of transition elements.

A solution of EDTA^{4-} is added to water containing $[\text{Ca}(\text{H}_2\text{O})_6]^{2+}$ to form a new complex, $[\text{CaEDTA}]^{2-}$, as shown.



Circle on the structure of EDTA^{4-} in Fig. 1.2 the **six** atoms that form bonds with the metal ion.

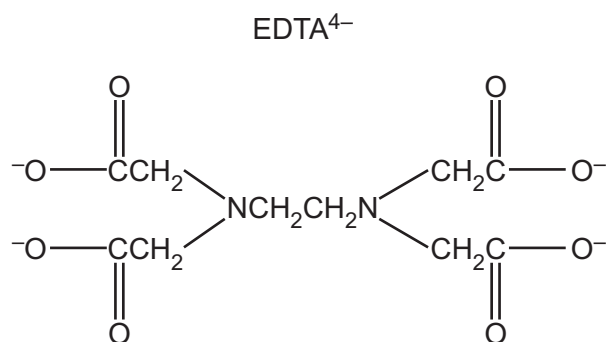


Fig. 1.2

[1]

(iii) The calcium ions in $[\text{Ca}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{CaEDTA}]^{2-}$ have a coordination number of 6.

Explain what is meant by coordination number.

.....
 [1]

- (iv) The complex $[\text{CaEDTA}]^{2-}$ can be used to remove toxic metals from the body.

Table 1.2 shows the numerical values for the stability constants, K_{stab} , for some metal ions with EDTA^{4-} .

Table 1.2

complex	K_{stab}
$[\text{CaEDTA}]^{2-}$	5.0×10^{10}
$[\text{CrEDTA}]^{-}$	2.5×10^{23}
$[\text{FeEDTA}]^{-}$	1.3×10^{25}
$[\text{PbEDTA}]^{2-}$	1.1×10^{18}

An aqueous solution containing $[\text{CaEDTA}]^{2-}$ is added to a solution containing equal concentrations of $\text{Cr}^{3+}(\text{aq})$, $\text{Fe}^{3+}(\text{aq})$ and $\text{Pb}^{2+}(\text{aq})$. The resulting mixture is left to reach a state of equilibrium.

State the type of reaction when $[\text{CaEDTA}]^{2-}$ reacts with $\text{Cr}^{3+}(\text{aq})$, $\text{Fe}^{3+}(\text{aq})$ and $\text{Pb}^{2+}(\text{aq})$.

..... [1]

- (v) Deduce the relative concentrations of $[\text{CrEDTA}]^{-}$, $[\text{FeEDTA}]^{-}$ and $[\text{PbEDTA}]^{2-}$ present in the resulting mixture.

Explain your answer.

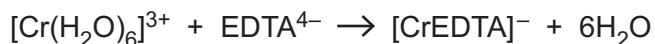
..... > >
highest concentration lowest concentration

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

(e) The number of moles of water of crystallisation in a hydrated ionic salt can be determined by titration using aqueous EDTA^{4-} ions with a suitable indicator.

- 0.255 g of hydrated chromium(III) sulfate, $\text{Cr}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$, is dissolved in water and made up to 100 cm^3 in a volumetric flask.
- 25.0 cm^3 of this solution requires 26.2 cm^3 of $0.00800\text{ mol dm}^{-3}$ aqueous EDTA^{4-} ions to reach the end-point.

The reaction occurs as shown.



Use the data to calculate the value of n in the formula of $\text{Cr}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$.

Show your working.

$n = \dots\dots\dots$ [3]

(f) A solution of $\text{Cr}^{3+}(\text{aq})$ and a solution of $\text{Fe}^{3+}(\text{aq})$ have different colours.

Explain why the two complexes have different colours.

.....

 [2]

[Total: 19]

BLANK PAGE

- 2 (a) Some transition element complexes can show stereoisomerism.

State **two** types of stereoisomerism shown by transition element complexes.

1

2

[1]

- (b) The complexes $[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$ and $[\text{Pt}(\text{en})_2]^{2+}$ have the same geometry (shape) around the metal ion.

$[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$ exists as two stereoisomers whereas $[\text{Pt}(\text{en})_2]^{2+}$ only has one possible structure.

State the geometry around the metal ion.

..... [1]

- (c) The complex $[\text{Cr}(\text{en})_3]^{2+}$ exists as two stereoisomers whereas the complex $[\text{Cr}(\text{OCH}_2\text{CH}_2\text{NH}_2)_3]^-$ exists as four stereoisomers.

Complete the three-dimensional diagrams in Fig. 2.1 to show the four stereoisomers of $[\text{Cr}(\text{OCH}_2\text{CH}_2\text{NH}_2)_3]^-$.

Represent the ligand $^-\text{OCH}_2\text{CH}_2\text{NH}_2$ by using .

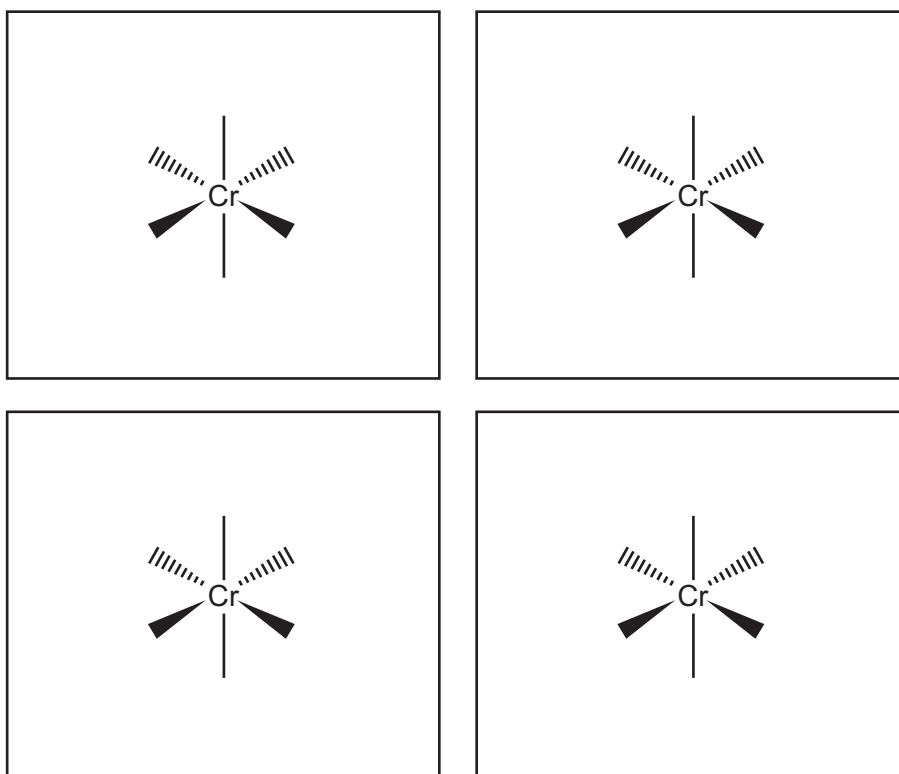


Fig. 2.1

- (d) The complex $[\text{Cr}(\text{OCH}_2\text{CH}_2\text{NH}_2)_3]^-$ is formed by reacting $\text{Cr}^{2+}(\text{aq})$ with the conjugate base of 2-aminoethanol.

A synthesis of 2-aminoethanol is shown in Fig. 2.2.

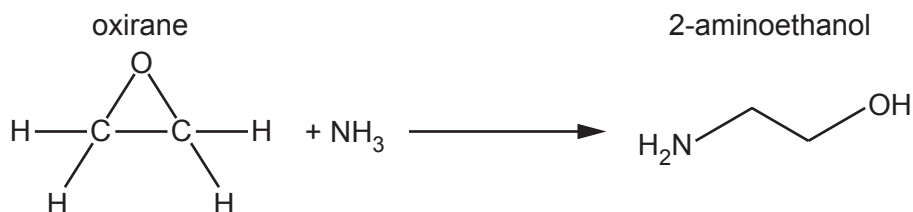


Fig. 2.2

- (i) Suggest the mechanism for step 1 of the reaction of oxirane with ammonia in Fig. 2.3.

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

Draw the structure of the organic intermediate.

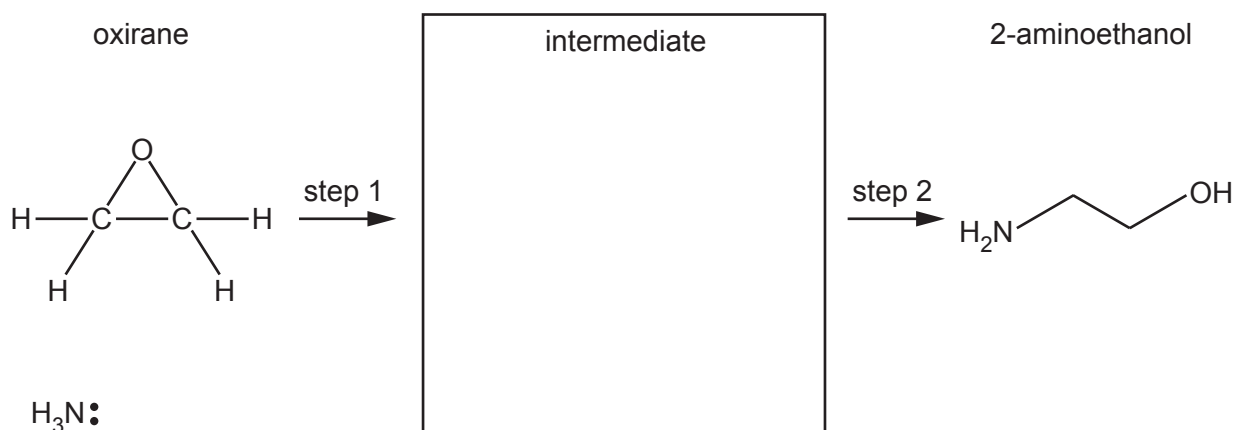


Fig. 2.3

[3]

- (ii) A small amount of by-product **E**, shown in Fig. 2.4, is produced during the reaction shown in Fig. 2.2.

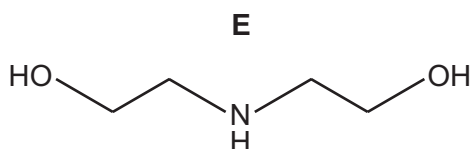


Fig. 2.4

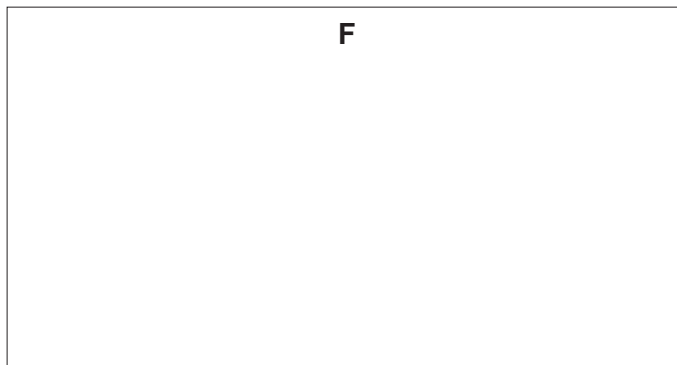
Suggest how the formation of by-product **E** can be minimised.

.....
 [1]

- (iii) Compound **F**, $\text{C}_4\text{H}_9\text{NO}$, can be formed from the reaction of by-product **E**, $\text{C}_4\text{H}_{11}\text{NO}_2$, with concentrated H_2SO_4 .

Compound **F** is a **saturated** and basic organic compound.

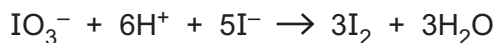
Suggest a structure for compound **F**. State the type of reaction undergone by **E** to form **F**.



type of reaction [2]

[Total: 11]

- 3 (a) Aqueous acidified iodate(V) ions, IO_3^- , react with iodide ions, as shown.



The initial rate of this reaction is investigated. Table 3.1 shows the results obtained.

Table 3.1

experiment	$[\text{IO}_3^-]/\text{mol dm}^{-3}$	$[\text{H}^+]/\text{mol dm}^{-3}$	$[\text{I}^-]/\text{mol dm}^{-3}$	initial rate/ $\text{mol dm}^{-3}\text{min}^{-1}$
1	0.0400	0.0150	0.0250	4.20×10^{-2}
2	0.120	to be calculated	0.0125	7.09×10^{-2}

The rate equation for this reaction is $\text{rate} = k[\text{IO}_3^-][\text{H}^+]^2[\text{I}^-]^2$.

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

.....

 [1]

- (ii) Complete Table 3.2.

Table 3.2

the order of reaction with respect to $[\text{IO}_3^-]$	
the order of reaction with respect to $[\text{H}^+]$	
the order of reaction with respect to $[\text{I}^-]$	
the overall order of reaction	

[1]

- (iii) Use your answer to (a)(ii) to sketch lines in Fig. 3.1 to show the relationship between the initial rates and the concentrations of $[\text{IO}_3^-]$ and $[\text{I}^-]$.

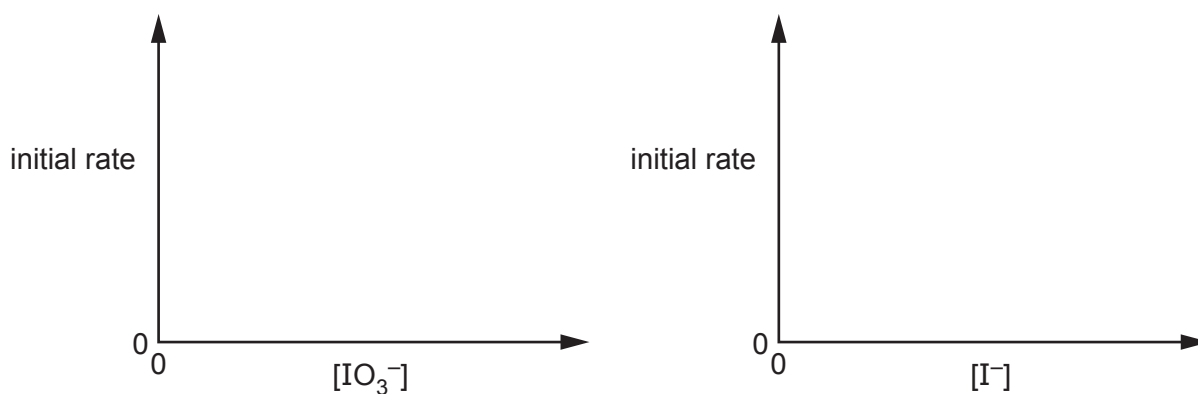


Fig. 3.1

[1]

- (iv) Use data from Table 3.1 to calculate the rate constant, k , for this reaction.

Include the units of k .

$k = \dots\dots\dots$ units $\dots\dots\dots$ [2]

- (v) Use data from Table 3.1 to calculate the concentration of hydrogen ions, $[H^+]$, in experiment 2.

$[H^+] = \dots\dots\dots$ mol dm⁻³ [1]

- (vi) This reaction is repeated in two separate experiments.

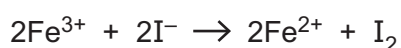
The experiments are carried out at the same temperature and with the same concentrations of I^- and IO_3^- .

One experiment takes place at pH 1.0 and the other experiment takes place at pH 2.0.

Calculate the value of $\frac{\text{rate at pH 1.0}}{\text{rate at pH 2.0}}$.

value of $\frac{\text{rate at pH 1.0}}{\text{rate at pH 2.0}} = \dots\dots\dots$ [1]

- (b) In aqueous solution, iron(III) ions react with iodide ions, as shown.



The initial rate of reaction is first order with respect to Fe^{3+} and second order with respect to I^- .

The mechanism for this reaction has three steps.

Each step involves only **two** ions reacting together.

Suggest equations for the **three** steps of this mechanism. Identify the rate-determining step.

step 1 $\dots\dots\dots$

step 2 $\dots\dots\dots$

step 3 $\dots\dots\dots$

rate-determining step = $\dots\dots\dots$

[3]

[Total: 10]

[Turn over]

- 4 (a) State the hybridisation of the carbon atoms and the C–C–H bond angle in benzene, C_6H_6 . Explain how orbital overlap leads to the formation of σ and π bonds in benzene.

.....

.....

.....

.....

..... [3]

- (b) Compound **Z** can be synthesised from benzene in three steps by the route shown in Fig. 4.1.

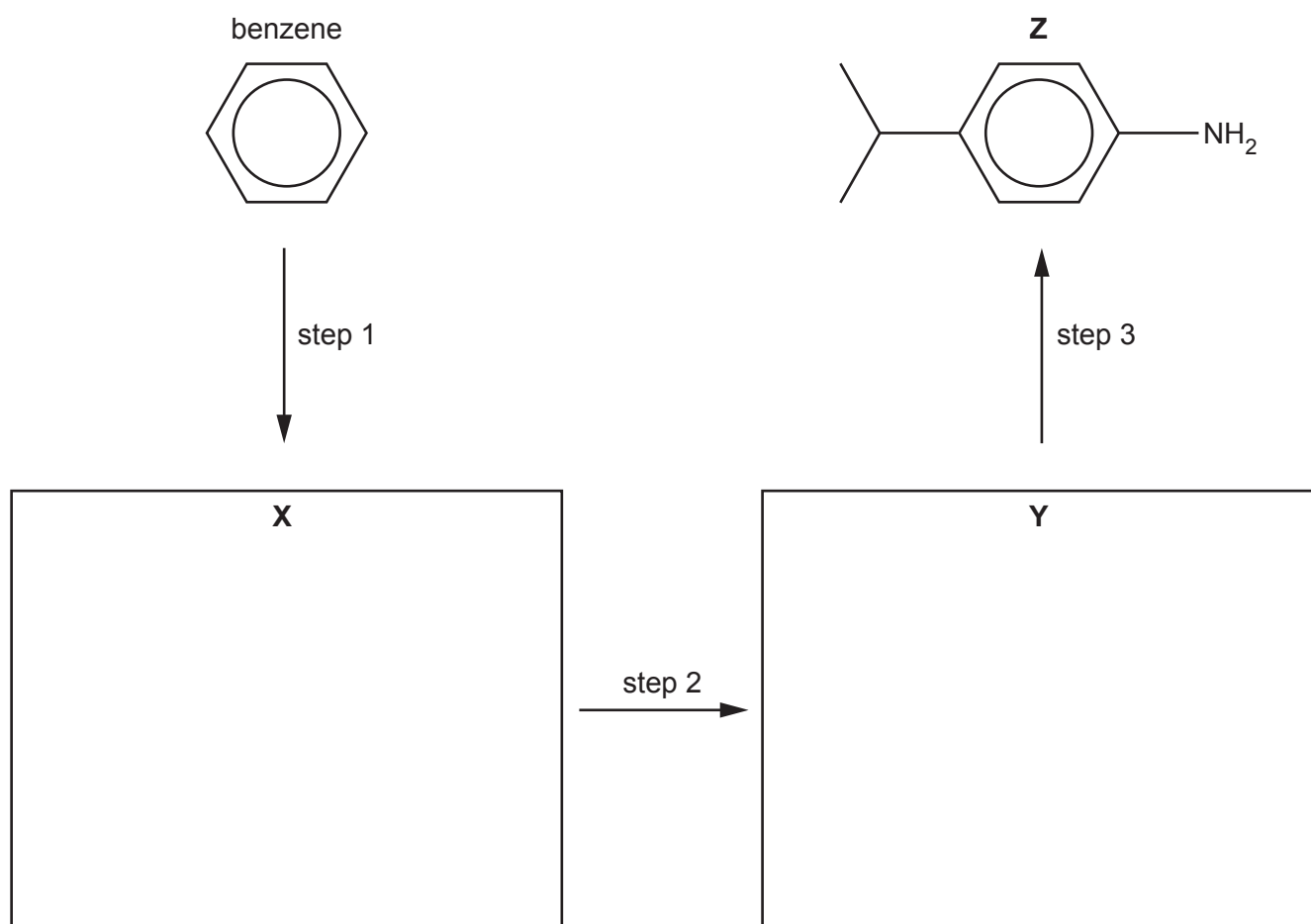


Fig. 4.1

- (i) Draw structures for **X** and **Y** in Fig. 4.1. [2]
- (ii) Give the reagents and conditions for steps 1, 2 and 3.

step 1

step 2

step 3

[3]

- (c) Compound **W** is an isomer of **Z**.

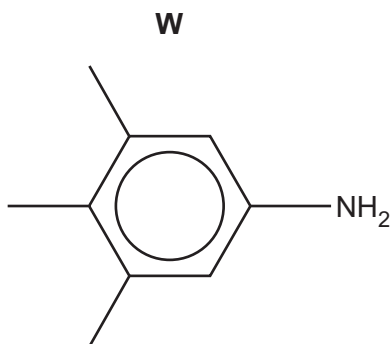


Fig. 4.2

Give the systematic name of **W**.

..... [1]

- (d) Complete Table 4.1 to show the number of peaks observed in the carbon-13 NMR spectrum for **W** and **Z**.

Table 4.1

compound	number of peaks observed
W	
Z	

[1]

[Total: 10]

- 5 (a) The exhaust systems of most modern gasoline-fuelled cars contain a catalytic converter with three metal catalysts.

These metals act as heterogeneous catalysts.

- (i) Name **three** metal catalysts used in catalytic converters.

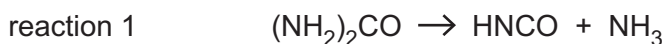
1 2 3 [1]

- (ii) Explain what is meant by a heterogeneous catalyst.

.....
 [1]

- (b) The exhaust systems of many diesel-fuelled cars contain an additional system to reduce vehicle emissions. This uses a liquid that is added to the exhaust system.

This liquid contains urea, $(\text{NH}_2)_2\text{CO}$, which decomposes on heating to isocyanic acid, HNCO , and ammonia.



Isocyanic acid reacts with water vapour to form ammonia and carbon dioxide.



Some values for standard enthalpy changes of formation, $\Delta H_f^\ominus$, and standard entropies, $S^\ominus$, are given in Table 5.1.

Table 5.1

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
HNCO(g)	−101.7	+238.2
$\text{H}_2\text{O(g)}$	−241.8	+188.8
$\text{NH}_3\text{(g)}$	−45.9	+192.8
$\text{CO}_2\text{(g)}$	−393.5	+213.8

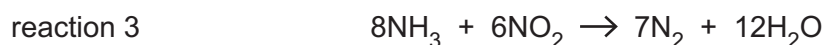
- (i) Explain what is meant by the term entropy of a system.

.....
 [1]

- (ii) Use the data in Table 5.1 to calculate $\Delta G^\ominus$ for **reaction 2** at 25 °C.
Show your working.

$$\Delta G^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [4]$$

- (c) The ammonia formed in reactions 1 and 2 can be used to remove nitrogen dioxide from exhaust emissions, as shown.



Use the equations for reactions 1, 2 and 3 to construct an overall equation for the reduction of NO_2 by $(\text{NH}_2)_2\text{CO}$.

..... [1]

- (d) Isocyanic acid, HNCO , can form cyanuric acid, $\text{C}_3\text{H}_3\text{N}_3\text{O}_3$, under certain conditions.

$\text{C}_3\text{H}_3\text{N}_3\text{O}_3$ has a cyclic structure containing alternating carbon and nitrogen atoms in the ring system.

Suggest a structure for cyanuric acid.

[1]

(e) Isocyanic acid, HNCO, is a weak acid.



(i) Write the mathematical expressions for $\text{p}K_{\text{a}}$ and pH.

$\text{p}K_{\text{a}} = \dots\dots\dots$

$\text{pH} = \dots\dots\dots$ [1]

(ii) Calculate the pH of $0.120 \text{ mol dm}^{-3}$ HNCO(aq).
Give your answer to **three** significant figures.

$\text{pH} = \dots\dots\dots$ [2]

(iii) Calculate the percentage of HNCO molecules that are ionised in $0.120 \text{ mol dm}^{-3}$ HNCO.

percentage ionisation of HNCO = $\dots\dots\dots$ [1]

[Total: 13]

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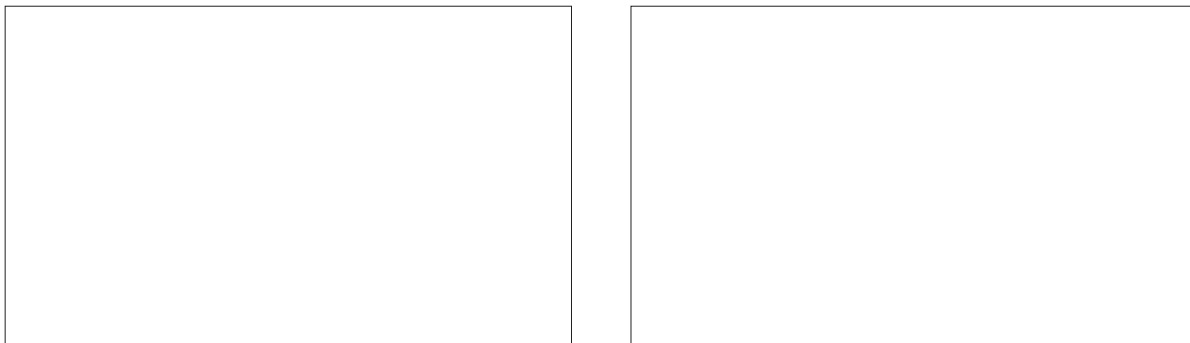
6 (a) Compound **H** has the structural formula $\text{CH}_2=\text{CHCH}(\text{NH}_2)\text{COOH}$.

(i) Name all the functional groups in **H**.

.....
 [2]

(ii) Compound **H** exhibits stereoisomerism.

Draw three-dimensional structures for the two stereoisomers of **H**.
 Name this type of stereoisomerism.



type of stereoisomerism [2]

(b) Compound **H** can be prepared from the reaction of **J** with an excess of hot aqueous acid.

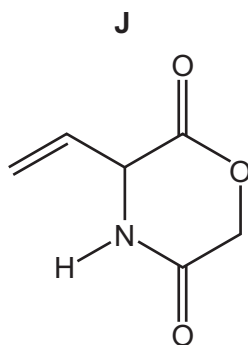


Fig. 6.1

(i) Complete Fig. 6.2 to show the equation for this reaction.

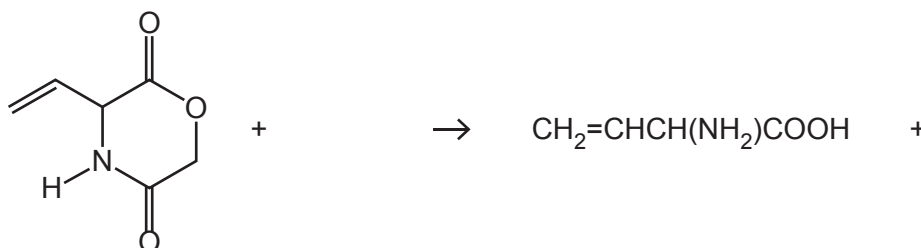


Fig. 6.2

[1]

(ii) Name the type of reaction in (b)(i).

..... [1]

(c) Polymers consist of monomers joined together by undergoing either addition or condensation polymerisation.

Compound **H** can react to form an addition polymer, **K**, or a condensation polymer, **L**, depending on the conditions.

(i) Draw **one** repeat unit of addition polymer **K**.

[1]

(ii) Draw **two** repeat units of condensation polymer **L**.

The new functional group formed should be displayed.

[2]

(iii) Explain why condensation polymers can normally biodegrade more readily than addition polymers.

.....

..... [1]

[Total: 10]

- 7 (a) State the relative basicities of ethanamide, diethylamine and ethylamine in aqueous solution. Explain your answer.

..... > >
 most basic least basic

.....

.....

.....

.....

.....

[4]

- (b) The amino acid alanine, $\text{H}_2\text{NCH}(\text{CH}_3)\text{COOH}$, can act as a buffer.

- (i) Define a buffer solution.

.....

.....

..... [2]

- (ii) Write **two** equations to show how an aqueous solution of alanine can act as a buffer solution.

.....

..... [2]

- (c) Glutamic acid is another amino acid that acts as a buffer.

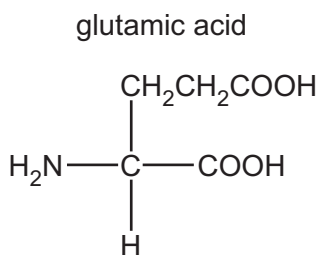


Fig. 7.1

- (i) Draw the **skeletal** formula for glutamic acid.

- (ii) Draw the structure for the dipeptide, ala-glu, formed from one molecule of alanine and one molecule of glutamic acid.

The peptide bond formed should be displayed.

[2]

- (d) The isoelectric point of alanine is 6.0 and of glutamic acid is 3.2.

A mixture of the dipeptide, ala-glu, and its two constituent amino acids, alanine and glutamic acid, is analysed by electrophoresis using a buffer at pH 6.0.

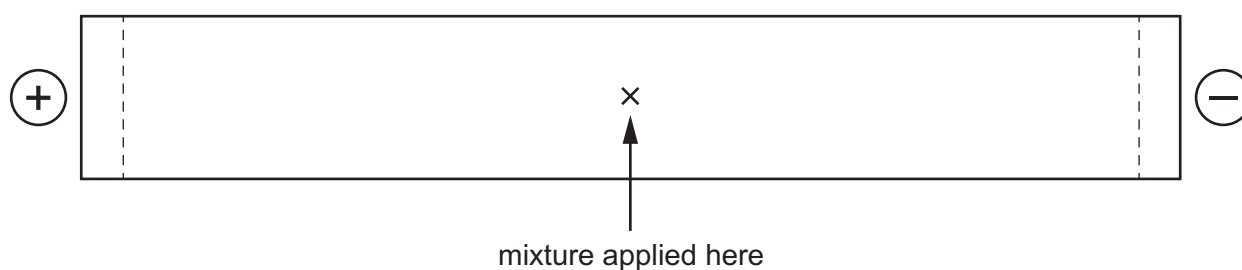


Fig. 7.2

Draw and label **three** spots on Fig. 7.2 to indicate the predicted position of each of these three species after electrophoresis.

Explain your answer.

.....

.....

.....

.....

..... [3]

- (e) Alanine, $\text{H}_2\text{NCH}(\text{CH}_3)\text{COOH}$, reacts with methanol to form the ester **G** under certain conditions.

The proton (^1H) NMR spectrum of **G** dissolved in D_2O is shown in Fig. 7.3.

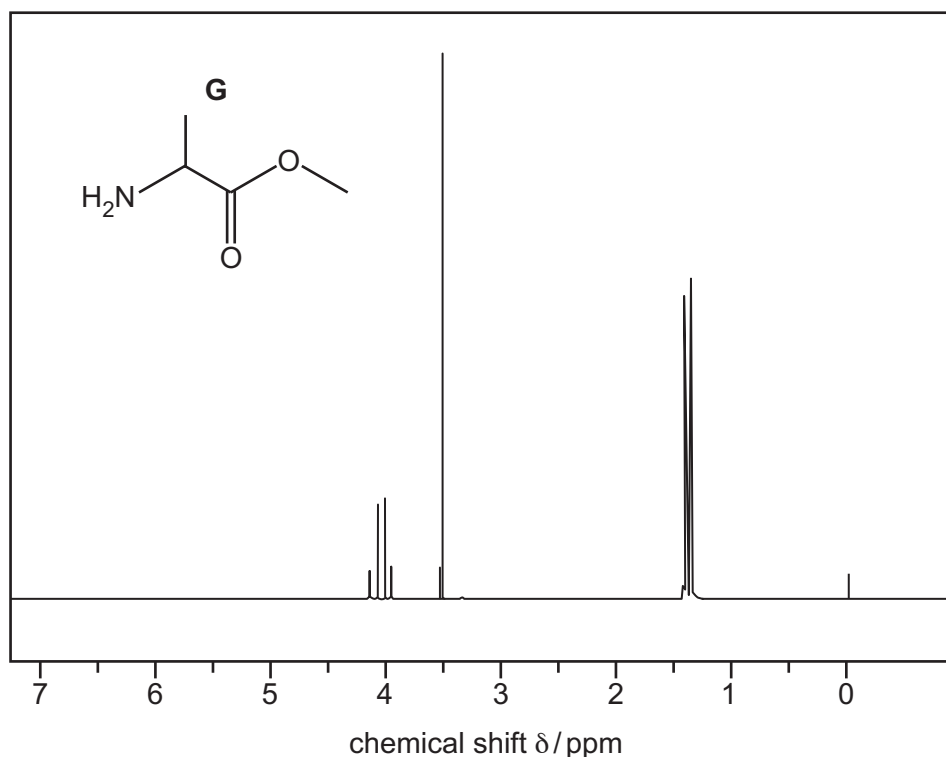


Fig. 7.3

Table 7.1

environment of proton	example	chemical shift range, δ/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	CH_3-Ar , $-\text{CH}_2-\text{Ar}$, $>\text{CH}-\text{Ar}$	2.3–3.0
alkyl next to electronegative atom	CH_3-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	HCOR	9.3–10.5
alcohol	ROH	0.5–6.0
phenol	$\text{Ar}-\text{OH}$	4.5–7.0
carboxylic acid	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	RCONHR	5.0–12.0

- (i) Complete Table 7.2 for the proton (^1H) NMR spectrum of **G**.

Table 7.2

chemical shift (δ)	splitting pattern	number of ^1H atoms responsible for the peak	number of protons on adjacent carbon atoms
1.4			
3.5			
4.0			

[3]

- (ii) The proton (^1H) NMR spectrum of **G** dissolved in CDCl_3 is obtained.

Describe the difference observed between this spectrum and the proton NMR spectrum in D_2O shown in Fig 7.3.

Explain your answer.

.....

 [1]

[Total: 18]

- 8 (a) Complete Table 8.1 by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

Table 8.1

energy change	always positive	always negative	can be either negative or positive
lattice energy			
enthalpy change of hydration			
enthalpy change of solution			

[1]

- (b) Define enthalpy change of hydration.

.....

.....

..... [1]

- (c) Table 8.2 shows various energy changes which can be used in the following questions.

Table 8.2

energy change	value / kJ mol ⁻¹
standard enthalpy change of atomisation of calcium	+178.2
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1145
standard enthalpy change of atomisation of bromine	+111.9
Br–Br bond energy	+192.9
standard enthalpy change of solution of calcium bromide, CaBr ₂ (s)	–103.1
standard enthalpy change of formation of calcium bromide, CaBr ₂ (s)	–682.8
standard enthalpy change of hydration of Ca ²⁺	–1579
first electron affinity of bromine	–324.6
first ionisation energy of bromine	+1140

- (i) Select and use relevant data from Table 8.2 to calculate the lattice energy, $\Delta H_{\text{latt}}^{\ominus}$, of $\text{CaBr}_2(\text{s})$.

It may be helpful to draw a labelled energy cycle.

Show your working.

$\Delta H_{\text{latt}}^{\ominus}$ of $\text{CaBr}_2(\text{s}) = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

- (ii) Select and use relevant data from Table 8.2 and your answer to (c)(i) to calculate the standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$, of Br^- .

It may be helpful to draw a labelled energy cycle.

If you were not able to answer (c)(i), use $-2500 \text{ kJ mol}^{-1}$ as your value for $\Delta H_{\text{latt}}^{\ominus}$ of $\text{CaBr}_2(\text{s})$. This is **not** the correct value.

Show your working.

$\Delta H_{\text{hyd}}^{\ominus}$ of $\text{Br}^- = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

- (iii) The enthalpy change of hydration of the Br^- ion is more negative than the enthalpy change of hydration of the I^- ion. Explain why.

.....

 [2]

[Total: 9]

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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	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
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) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ 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 ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group																							
1	2													13	14	15	16	17	18				
		Key												1 H hydrogen 1.0								2 He helium 4.0	
		atomic number atomic symbol name relative atomic mass																					
3 Li lithium 6.9	4 Be beryllium 9.0													5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2				
11 Na sodium 23.0	12 Mg magnesium 24.3													13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9				
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8						
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3						
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids		72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —	86 Rn radon —					
87 Fr francium —	88 Ra radium —	89–103 actinoids		104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganesson —					
lanthanoids		57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	61 Pm promethium —	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0							
actinoids		89 Ac actinium —	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —							

lanthanoids

actinoids

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La lanthanum 138.9	Ce cerium 140.1	Pr praseodymium 140.9	Nd neodymium 144.4	Pm promethium —	Sm samarium 150.4	Eu europium 152.0	Gd gadolinium 157.3	Tb terbium 158.9	Dy dysprosium 162.5	Ho holmium 164.9	Er erbium 167.3	Tm thulium 168.9	Yb ytterbium 173.1	Lu lutetium 175.0
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac actinium —	Th thorium 232.0	Pa protactinium 231.0	U uranium 238.0	Np neptunium —	Pu plutonium —	Am americium —	Cm curium —	Bk berkelium —	Cf californium —	Es einsteinium —	Fm fermium —	Md mendelevium —	No nobelium —	Lr lawrencium —