Cambridge International AS & A Level

CANDIDATE NAME			
CENTRE NUMBER		CANDIDATE NUMBER	

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CHEMISTRY **9701/42**

Paper 4 A Level Structured Questions **February/March 2023**

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

1 **(a)** The most common zinc mineral contains zinc(II) sulfide, ZnS.

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

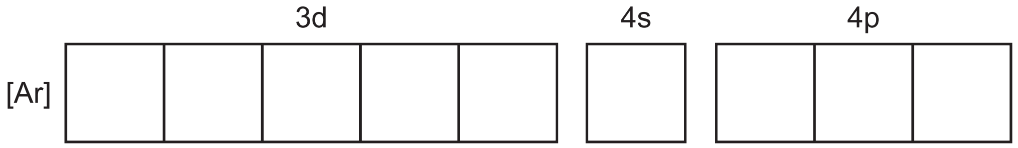


Fig. 1.1

[1]

(ii) Complete Fig. 1.2 to show the Born–Haber diagram for the ionic solid ZnS.

Include state symbols of relevant species.

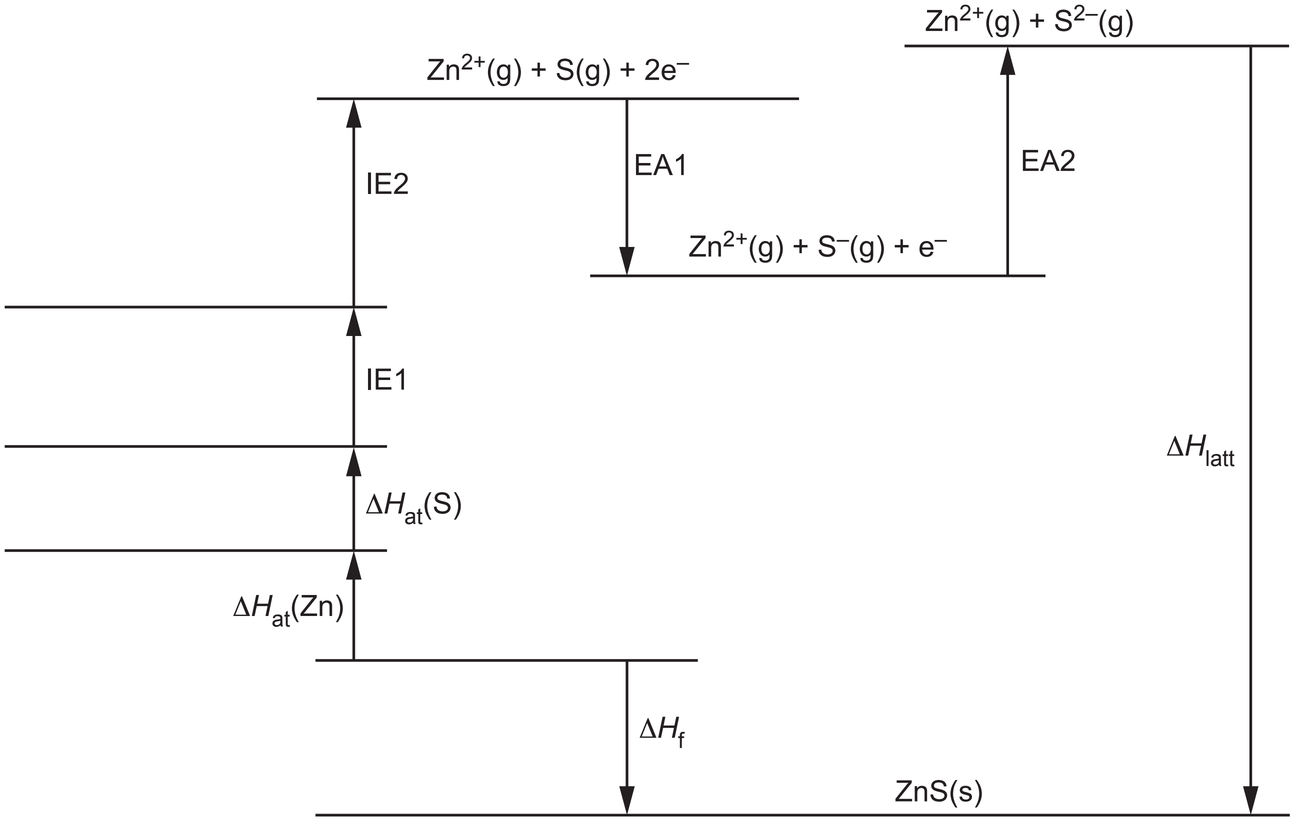


Fig. 1.2

[3]

(iii) Describe the trend in the first electron affinity of the Group 16 elements S to Te.

Explain your answer.

....

....

....

.... [2]

(iv) Explain why the lattice energy, ΔH_{latt}, of ZnO is more exothermic than that of ZnS.

....

....

....

.... [2]

(b) Zinc metal can be obtained in a two-step process as shown.

step 1 $2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$

step 2 $ZnO(s) + C(s) \rightarrow Zn(l) + CO(g)$

The reactions are carried out at 800 °C.

(i) Predict the sign of the entropy change, $\Delta S^{\ominus}$, of the reaction in **step 1**.

Explain your answer.

....

.... [1]

(ii) Use the data in Table 1.1 to calculate $\Delta S^{\ominus}$ of the reaction shown in **step 2**.

Table 1.1

chemical	ZnO(s)	C(s)	Zn(l)	CO(g)
$S^{\ominus}$ / J K^{-1} mol^{-1}	43.7	5.7	50.8	197.7

$\Delta S^{\ominus}$ = ... J K^{-1} mol^{-1} [1]

(iii) An equation for the direct reduction of ZnS by carbon is shown.

$$2ZnS(s) + C(s) \longrightarrow 2Zn(l) + CS_2(g) \qquad \Delta H^{\ominus} = +733\,kJ\,mol^{-1}$$
$$\Delta S^{\ominus} = +218\,J\,K^{-1}\,mol^{-1}$$

This reaction is **not** feasible at 800 °C.

Calculate $\Delta G^{\ominus}$ for this reaction at 800 °C.

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

(c) $Zn(NO_3)_2$ undergoes thermal decomposition when heated. The reaction is similar to the thermal decomposition of Group 2 nitrates.

(i) Construct an equation for the thermal decomposition of $Zn(NO_3)_2$.

.... [1]

(ii) The radii of some Group 2 cations and Zn^{2+} are shown in Table 1.2.

Table 1.2

cation	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Zn^{2+}
radius / pm	65	99	113	135	74

State and explain the trend in thermal stability of the Group 2 nitrates down the group.

....

....

.... [2]

(iii) Use Table 1.2 to suggest which Group 2 nitrates are **less** thermally stable than zinc nitrate.

.... [1]

[Total: 16]

2 Hypophosphorous acid is an inorganic acid.

The conjugate base of hypophosphorous acid is $H_2PO_2^-$.

(a) Give the formula of hypophosphorous acid.

.... [1]

(b) $H_2PO_2^-$ is a strong reducing agent. It can be used to reduce metal cations without the need for electrolysis.

equation 1 $\quad HPO_3^{2-} + 2H_2O + 2e^- \rightleftharpoons H_2PO_2^- + 3OH^- \quad E^{\ominus} = -1.57\,V$

(i) In an experiment, an alkaline $HPO_3^{2-}/H_2PO_2^-$ half-cell is constructed with $[H_2PO_2^-] = 0.050\,mol\,dm^{-3}$.

All other ions are at their standard concentration.

Predict how the value of *E* of this half-cell differs from its $E^{\ominus}$ value.

Explain your answer.

....

....

....

.... [2]

(ii) The Cr^{3+}/Cr half-cell has a standard electrode potential of –0.74 V.

An electrochemical cell consists of an alkaline $HPO_3^{2-}/H_2PO_2^-$ half-cell and a Cr^{3+}/Cr half-cell.

Calculate the standard cell potential, $E^{\ominus}_{cell}$.

$E^{\ominus}_{cell}$ = ... V [1]

(iii) Complete the diagram in Fig. 2.1 to show how the standard electrode potential of the Cr^{3+}/Cr half-cell can be measured relative to that of the standard hydrogen electrode.

Identify the chemicals, conditions and relevant pieces of apparatus.

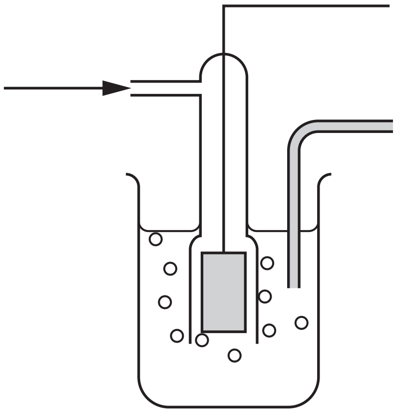


Fig. 2.1

[3]

(iv) Label Fig. 2.1 to show:

- which is the positive electrode
- the direction of electron flow in the external circuit.

[1]

(v) $H_2PO_2^-$ reduces Ni^{2+} to Ni in alkaline conditions.

Use equation 1 to construct the ionic equation for this reaction.

equation 1 $HPO_3^{2-} + 2H_2O + 2e^- \rightleftharpoons H_2PO_2^- + 3OH^-$

.... [1]

(c) $H_2PO_2^-(aq)$ reacts with $OH^-(aq)$.

$$H_2PO_2^-(aq) + OH^-(aq) \longrightarrow HPO_3^{2-}(g) + H_2(g)$$

Table 2.1 shows the results of a series of experiments used to investigate the rate of this reaction.

Table 2.1

experiment	$[H_2PO_2^-(aq)]$ / $mol\,dm^{-3}$	$[OH^-(aq)]$ / $mol\,dm^{-3}$	volume of H_2 produced in 60 s / cm^3
1	0.40	2.00	6.4
2	0.80	2.00	12.8
3	1.20	1.00	4.8

(i) The volume of H_2 was measured under room conditions.

Use the molar volume of gas, V_m, and the data from experiment 1 to calculate the rate of reaction in $mol\,dm^{-3}\,s^{-1}$.

rate of reaction = ... $mol\,dm^{-3}\,s^{-1}$ [1]

(ii) The rate equation was found to be:

$$\text{rate} = k\,[H_2PO_2^-(aq)]\,[OH^-(aq)]^2$$

Show that the data in Table 2.1 is consistent with the rate equation.

....

....

....

....

.... [2]

(iii) State the units of the rate constant, *k*, for the reaction.

.... [1]

(iv) The experiment is repeated using a large excess of $OH^-(aq)$.

Under these conditions, the rate equation is:

$$\text{rate} = k_1\,[H_2PO_2^-(aq)]$$

$k_1 = 8.25 \times 10^{-5}\,s^{-1}$

Calculate the value of the half-life, $t_{\frac{1}{2}}$, of the reaction.

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

(v) Describe how an increase in temperature affects the value of the rate constant, k_1.

....

.... [1]

(d) A student suggests that the reaction between $H_2PO_2^-(aq)$ and $OH^-(aq)$ might happen more quickly in the presence of a heterogeneous catalyst.

Describe the mode of action of a heterogeneous catalyst.

....

....

....

.... [2]

[Total: 17]

3 Vanadium is a transition element in Period 4 of the Periodic Table.

(a) Define transition element.

....

.... [1]

(b) Vanadium shows typical chemical properties of transition elements, including variable oxidation states.

(i) State **two** other typical chemical properties of transition elements.

1 ....

2 ....
[1]

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

....

.... [1]

(c) VO_2^+ can be reduced to V^{2+} by $C_2O_4^{2-}$ in acidic conditions.

equation 2 $\qquad 2VO_2^+ + 3C_2O_4^{2-} + 8H^+ \rightarrow 2V^{2+} + 6CO_2 + 4H_2O$

(i) In a titration, 25.00 cm^3 of 0.0300 mol dm^{-3} VO_2^+(aq) is added to 10 cm^3 of dilute sulfuric acid.

A solution of 0.0400 mol dm^{-3} $C_2O_4^{2-}$(aq) is then added from a burette until the end-point is reached.

The titration is repeated and concordant results obtained, as shown in Table 3.1.

Table 3.1

	1	2
volume of $C_2O_4^{2-}$(aq) added / cm^3	28.15	28.10

Show that these results are consistent with the stoichiometry of equation 2.

[2]

(ii) An excess of $C_2O_4^{2-}$ reacts with VO_2^+ to form a mixture of two octahedral complex ions. The complex ions are stereoisomers of each other.

Each complex ion contains a V^{2+} cation and three $C_2O_4^{2-}$ ions.

Complete the diagram to show the three-dimensional structure of **one** of the complex ions.

Include the charge of the complex ion.

Use  to represent a $C_2O_4^{2-}$ ion.

[2]

(d) $V^{2+}(aq)$ can be oxidised by $H_2O_2(aq)$.

Table 3.2 gives some relevant data.

Table 3.2

	half-equation	$E^\ominus$ /V
1	$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
2	$VO_2^+(aq) + 2H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + H_2O(l)$	+1.00
3	$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l)$	+0.34
4	$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	–0.26

(i) Identify the vanadium species that forms when an excess of $H_2O_2(aq)$ reacts with $V^{2+}(aq)$ under standard conditions.

Explain your answer with reference to the data in Table 3.2.

....

....

.... [1]

(ii) Concentrated acidified H_2O_2 can react with V^{2+} to form red VO_2^{3+} ions.

VO_2^{3+} contains vanadium combined with the peroxide anion, O_2^{2-}.

Deduce the oxidation state of vanadium in VO_2^{3+}.

.... [1]

[Total: 9]

4 Ethylamine and phenylamine are primary amines.

ethylamine

$CH_3CH_2NH_2$

phenylamine

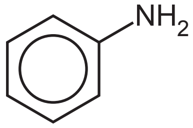


Fig. 4.1

These two compounds are synthesised by different methods.

(a) Several methods can be used to form ethylamine.

(i) Ethylamine forms when ethanamide, CH_3CONH_2, is reduced by $LiA\mathit{l}H_4$.

Write an equation for this reaction. Use [H] to represent one atom of hydrogen from the reducing agent.

.... [1]

(ii) Ethylamine is a product of the reaction of bromoethane with ammonia.

Name the mechanism of this reaction and state the conditions used.

mechanism ....

conditions ....
[2]

(iii) The reaction in **(a)(ii)** also forms secondary and tertiary amines.

Suggest the identity of a secondary or tertiary amine formed by the reaction in **(a)(ii)**.

.... [1]

(b) Ethylamine is a weak base.

State the relative basicities of ammonia, ethylamine and phenylamine.

Explain your answer.

.... < .... < ....
least basic most basic

....

....

....

....

....

....

.... [4]

(c) Pure phenylamine, $C_6H_5NH_2$, can be prepared from benzene in two steps.

Draw the structure of the intermediate compound.

Suggest reagents and conditions for each step.

....

....

....

....

.... [3]

(d) Fig. 4.2 shows some reactions of phenylamine.

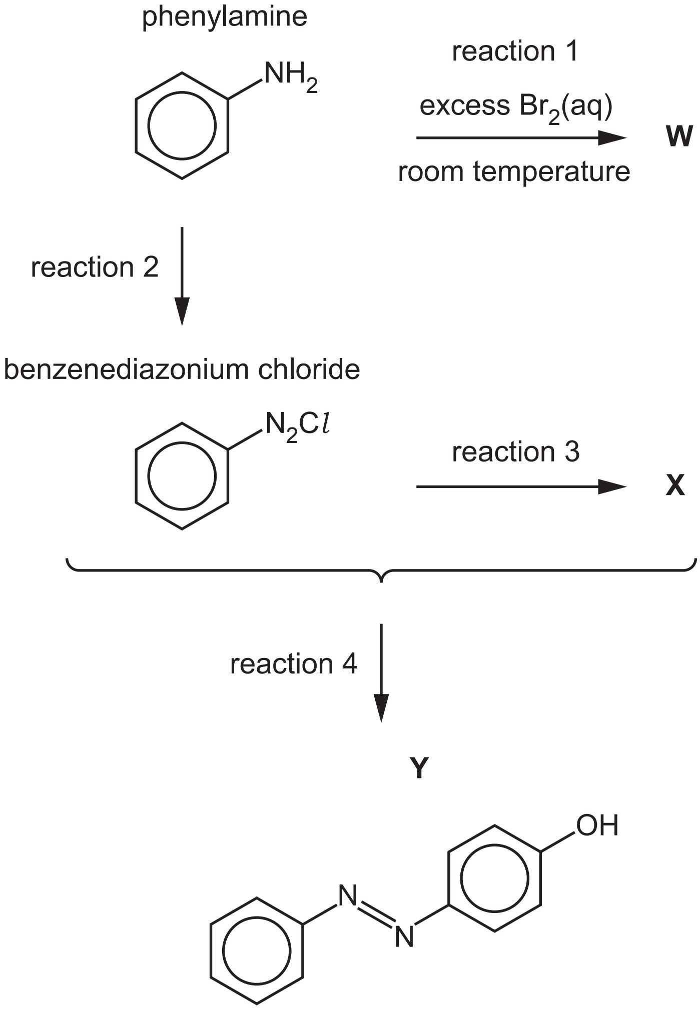


Fig. 4.2

(i) Draw the structure of **W**, the organic product of reaction 1.

[1]

(ii) State the reagents used in reaction 2.

.... [1]

Benzenediazonium chloride, $C_6H_5N_2Cl$, and **X** react together in reaction 4 to form **Y**, an azo compound.

(iii) Name **X**, the organic product of reaction 3.

.... [1]

(iv) State the necessary conditions for reaction 4 to occur.

.... [1]

(v) Suggest a use for **Y**.

.... [1]

(e) Methylamine, CH_3NH_2, is another primary amine. CH_3NH_2 can act as a monodentate ligand.

(i) Define monodentate ligand.

....

....

.... [2]

(ii) $Cu^{2+}(aq)$ reacts with CH_3NH_2 to form $[Cu(CH_3NH_2)_2(H_2O)_4]^{2+}$.

Draw three-dimensional diagrams to show the two geometrical isomers of $[Cu(CH_3NH_2)_2(H_2O)_4]^{2+}$.

[2]

(iii) State the coordination number of copper in $[Cu(CH_3NH_2)_2(H_2O)_4]^{2+}$.

.... [1]

(f) $Cd^{2+}(aq)$ ions form tetrahedral complexes with CH_3NH_2, OH^- and Cl^- ions, as shown in equilibria 1, 2 and 3.

equilibrium 1 $Cd^{2+}(aq) + 4CH_3NH_2(aq) \rightleftharpoons [Cd(CH_3NH_2)_4]^{2+}(aq)$ $K_{stab} = 3.3 \times 10^6$

equilibrium 2 $Cd^{2+}(aq) + 4OH^-(aq) \rightleftharpoons Cd(OH)_4{}^{2-}(aq)$ $K_{stab} = 5.0 \times 10^8$

equilibrium 3 $Cd^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons CdCl_4{}^{2-}(aq)$ $K_{stab} = 6.3 \times 10^2$

(i) Give the units of K_{stab} for equilibrium 1.

.... [1]

(ii) Write an expression for K_{stab} for equilibrium 3.

K_{stab} =

[1]

(iii) A solution of $Cl^-(aq)$ is added to $Cd^{2+}(aq)$ and allowed to reach equilibrium. The equilibrium concentrations are given.

$$[Cd^{2+}(aq)] = 0.043\,mol\,dm^{-3}$$
$$[Cl^-(aq)] = 0.072\,mol\,dm^{-3}$$

Use your expression in **(f)(ii)** to calculate the concentration of $CdCl_4^{2-}(aq)$ in the equilibrium mixture.

$[CdCl_4^{2-}(aq)]$ = ... mol dm^{-3} [1]

(iv) When $CH_3NH_2(aq)$ is added to $Cd^{2+}(aq)$, a mixture of $[Cd(CH_3NH_2)_4]^{2+}(aq)$ and $[Cd(OH)_4]^{2-}(aq)$ forms.

Suggest how the $[Cd(OH)_4]^{2-}(aq)$ is formed.

....

.... [1]

(v) $Cd^{2+}(aq)$ exists as a complex ion, $[Cd(H_2O)_6]^{2+}(aq)$.

Identify the most stable and the least stable of the complexes in Table 4.1 by placing **one** tick (✓) in each column.

Explain your answer.

Table 4.1

complex	most stable	least stable
$[Cd(H_2O)_6]^{2+}(aq)$		
$[Cd(OH)_4]^{2-}(aq)$		
$[Cd(CH_3NH_2)_4]^{2+}(aq)$		
$[CdCl_4]^{2-}(aq)$		

explanation ....

....

.... [2]

[Total: 27]

5 Tulobuterol is used in some medicines.

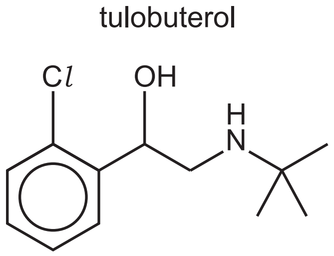


Fig. 5.1

(a) Tulobuterol contains a benzene ring in its structure.

Describe and explain the shape of benzene.

In your answer, include:

- the bond angle between carbon atoms
- the hybridisation of the carbon atoms
- how orbital overlap forms σ and π bonds between the carbon atoms.

....

....

....

.... [3]

(b) In a synthesis of tulobuterol, the first step involves the formation of chlorobenzene. Benzene reacts with Cl_2 in the presence of an $AlCl_3$ catalyst.

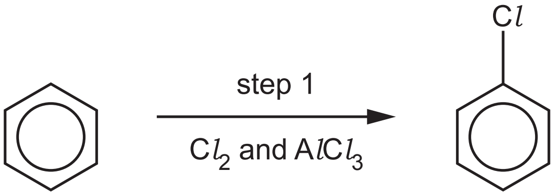


Fig. 5.2

(i) Write an equation to show how Cl_2 reacts with $AlCl_3$ to generate an electrophile.

.... [1]

(ii) Complete the mechanism in Fig. 5.3 for the reaction of benzene with the electrophile generated in **(b)(i)**.

Include all relevant curly arrows and charges.

Draw the structure of the intermediate.

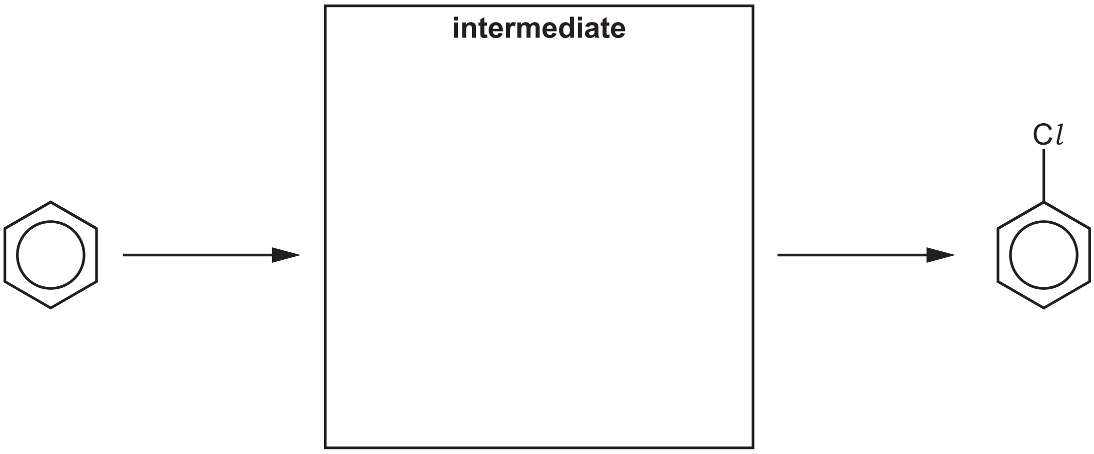


Fig. 5.3

[3]

(c) The second step of the synthesis involves the reaction of chlorobenzene with $ClCOCH_2Cl$, also in the presence of an $AlCl_3$ catalyst, forming compound **Q**.

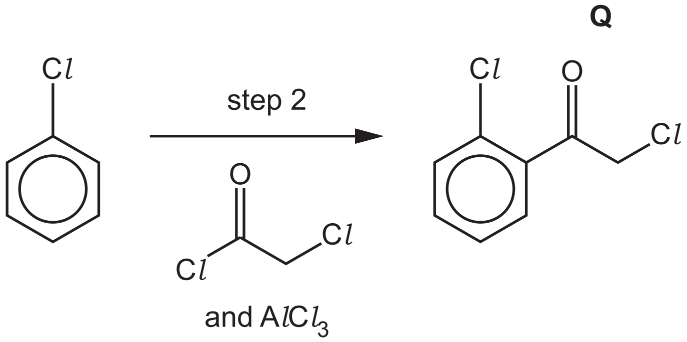


Fig. 5.4

(i) Name the mechanism of the reaction in step 2.

.... [1]

(ii) Draw the structure of an isomer of **Q** that forms as an organic by-product of the reaction in step 2.

[1]

(iii) The reactants used in step 2 contain acyl chloride, alkyl chloride and aryl chloride functional groups.

State and explain the relative ease of hydrolysis of acyl chlorides, alkyl chlorides and aryl chlorides.

.... , ... , ...

easiest to hydrolyse — hardest to hydrolyse

....

....

....

....

.... [3]

(d) Tulobuterol is produced from **Q** as shown in Fig. 5.5.

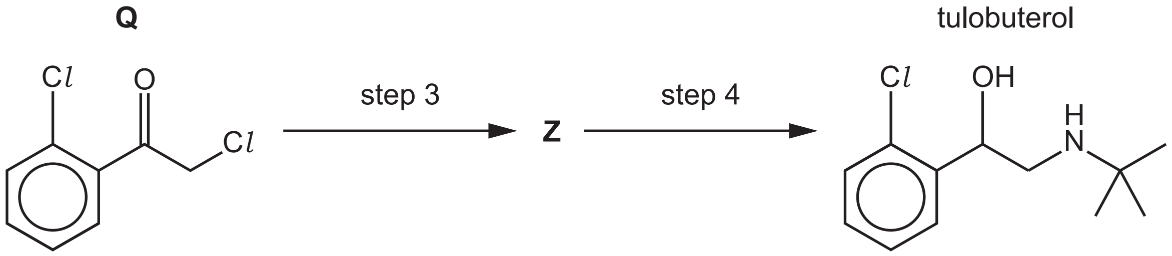


Fig. 5.5

Suggest reagents and conditions for steps 3 and 4.

Draw the structure of **Z** in the box.

step 3 ....

step 4 ....

Z

[3]

(e) The synthesis produces two enantiomers of tulobuterol.

(i) Define enantiomers.

....

....

.... [1]

(ii) Suggest **one** disadvantage of producing two enantiomers in this synthesis.

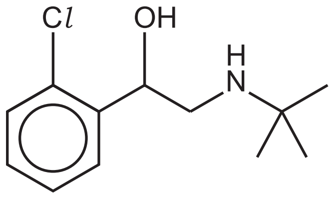
....

.... [1]

(iii) Suggest a method of adapting the synthesis to produce a single enantiomer.

.... [1]

tulobuterol



(f) **(i)** Predict the number of peaks that would be seen in the carbon-13 NMR spectrum of tulobuterol.

.... [1]

(ii) The proton (^1H) NMR spectrum of tulobuterol dissolved in D_2O shows peaks in four different types of proton environment.

The peak for the —CH_2N— environment is a doublet in the chemical shift range $\delta = 2.0–3.0$ ppm.

Give details for each of the other **three** peaks in the proton NMR spectrum of tulobuterol, to include:

- chemical shift
- environment of the proton
- splitting pattern
- number of ^1H atoms responsible.

Table 5.1 gives information about typical chemical shift values.

....

....

....

....

....

....

.... [3]

Table 5.1

environment of proton	example	chemical shift range δ / ppm
alkane	$–C\mathbf{H}_3$, $–C\mathbf{H}_2–$, $>C\mathbf{H}–$	0.9–1.7
alkyl next to C=O	$C\mathbf{H}_3–C=O$, $–C\mathbf{H}_2–C=O$, $>C\mathbf{H}–C=O$	2.2–3.0
alkyl next to aromatic ring	$C\mathbf{H}_3–Ar$, $–C\mathbf{H}_2–Ar$, $>C\mathbf{H}–Ar$	2.3–3.0
alkyl next to electronegative atom	$C\mathbf{H}_3–O$, $–C\mathbf{H}_2–O$, $–C\mathbf{H}_2–Cl$	3.2–4.0
attached to alkene	$=C\mathbf{H}R$	4.5–6.0
attached to aromatic ring	$\mathbf{H}–Ar$	6.0–9.0
aldehyde	$\mathbf{H}COR$	9.3–10.5
alcohol	$RO\mathbf{H}$	0.5–6.0
phenol	$Ar–O\mathbf{H}$	4.5–7.0
carboxylic acid	$RCOO\mathbf{H}$	9.0–13.0
alkyl amine	$R–N\mathbf{H}–$	1.0–5.0
aryl amine	$Ar–N\mathbf{H}_2$	3.0–6.0
amide	$RCON\mathbf{H}R$	5.0–12.0

[Total: 22]

6 A student uses thin-layer chromatography (TLC) to analyse a mixture containing different metal cations. The student repeats the experiment using different solvents.

Fig. 6.1 shows the chromatogram obtained by the student using water as a solvent.

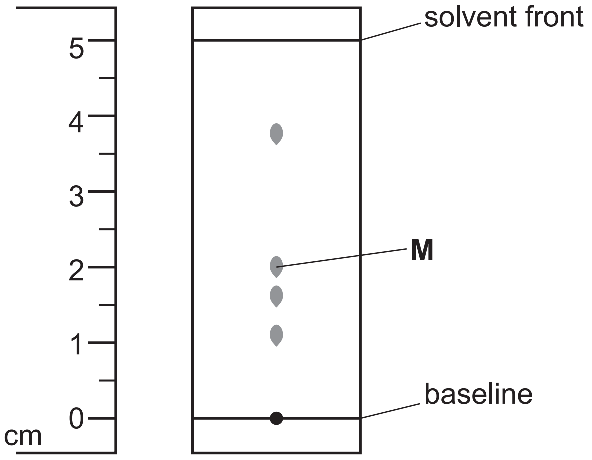


Fig. 6.1

(a) (i) Suggest a compound that could be used as the stationary phase in this experiment.

.... [1]

(ii) Table 6.1 shows the R_f values for different metal cations when separated by TLC using water as a solvent.

Table 6.1

cation	R_f value (water)
$Cd^{2+}(aq)$	0.40
$Co^{2+}(aq)$	0.77
$Cu^{2+}(aq)$	0.32
$Fe^{3+}(aq)$	0.12
$Hg^{2+}(aq)$	0.23
$Ni^{2+}(aq)$	0.75

Suggest the identity of the cation that causes the spot at **M** in Fig. 6.1.

Explain your answer.

....

.... [1]

(b) The student repeats the experiment using butan-1-ol as a solvent.

The metal cations do **not** travel as far up the TLC plate in this experiment.

Suggest why the metal cations do not move as far up the TLC plate with butan-1-ol as a solvent.

....

.... [1]

(c) The student sprays the TLC plate in Fig. 6.1 with KSCN(aq).

The colour of some of the spots changes, as some of the metal cations undergo a ligand exchange reaction.

Identify the ligands involved in the ligand exchange reaction.

.... exchanges with ....
[1]

(d) In a third experiment, the pH of the mixture of metal ions is kept constant using a buffer solution.

The student prepares the buffer solution by mixing 20.0 cm^3 of 0.150 mol dm^{-3} KOH(aq) and 50.0 cm^3 of 0.100 mol dm^{-3} $C_8H_5O_4K$(aq).

$C_8H_5O_4K$ is a weak carboxylic acid that has $pK_a = 5.40$.

$C_8H_5O_4K$

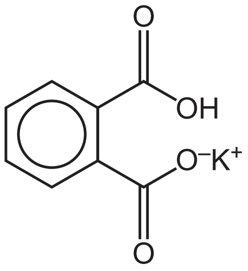


Fig. 6.2

(i) Complete the equation for the reaction of $C_8H_5O_4K$(aq) with KOH(aq).

$C_8H_5O_4K$ + ... [1]

(ii) Calculate the pH of the buffer solution. Show all your working.

pH = ... [4]

[Total: 9]

Important values, constants and standards

molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
Faraday constant	$F = 9.65 \times 10^{4}\,\mathrm{C\,mol^{-1}}$
Avogadro constant	$L = 6.022 \times 10^{23}\,\mathrm{mol^{-1}}$
electronic charge	$e = -1.60 \times 10^{-19}\,\mathrm{C}$
molar volume of gas	$V_m = 22.4\,\mathrm{dm^3\,mol^{-1}}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,\mathrm{dm^3\,mol^{-1}}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,\mathrm{mol^2\,dm^{-6}}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,\mathrm{kJ\,kg^{-1}\,K^{-1}}$ ($4.18\,\mathrm{J\,g^{-1}\,K^{-1}}$)

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
3 Li lithium 6.9	4 Be beryllium 9.0			atomic number atomic symbol name relative atomic mass								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	3	4	5	6	7	8	9	10	11	12	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 –