



Cambridge International AS & A Level

CANDIDATE
NAMECENTRE
NUMBER

--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--

CHEMISTRY**9701/41**

Paper 4 A Level Structured Questions

October/November 2025**2 hours**

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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

INFORMATION

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

This document has **28** pages. Any blank pages are indicated.



- 1 (a) Solutions of Group 2 hydrogencarbonates, $M(\text{HCO}_3)_2$, decompose on heating to give the corresponding metal carbonate, carbon dioxide and water.

(i) Write an equation for the decomposition of strontium hydrogencarbonate, $\text{Sr}(\text{HCO}_3)_2$.

..... [1]

(ii) The thermal stability of Group 2 carbonates increases down the group.

Explain this trend.

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

(b) The hydroxides and fluorides of Group 2 elements show similar trends in solubility.

Describe the trend in the solubility of the fluorides of calcium, strontium and barium.

Explain your answer.

.....
least soluble most soluble

explanation
.....
.....
.....
.....
.....
..... [4]



(c) (i) Define enthalpy change of hydration, ΔH_{hyd} .

.....

.....

..... [1]

(ii) State the main factors that affect the magnitude of enthalpy change of hydration.

Explain your answer.

.....

.....

.....

..... [2]

(d) Table 1.1 shows various energy changes.

Table 1.1

energy change	value / kJ mol^{-1}
lattice energy of MgF_2	–2957
enthalpy change of hydration, ΔH_{hyd} , of Mg^{2+}	–1926
enthalpy change of hydration, ΔH_{hyd} , of F^-	–505

Use data from Table 1.1 to calculate the enthalpy change of solution, ΔH_{sol} , for $\text{MgF}_2(\text{s})$.

It may be helpful to draw a labelled energy cycle. Show your working.

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



(e) Mercury(I) fluoride, Hg_2F_2 , is sparingly soluble in water.

The cation in Hg_2F_2 exists as the diatomic ion Hg_2^{2+} with a covalent Hg–Hg bond.

(i) Write the expression for the solubility product, K_{sp} , of Hg_2F_2 . Include the units.

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

units [2]

(ii) The solubility of Hg_2F_2 is $9.20 \times 10^{-3} \text{ mol dm}^{-3}$ at 298 K.

Calculate the value of K_{sp} of Hg_2F_2 at 298 K.

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

[Total: 15]



- 2 (a) Iron can form stable ions in the +2 and +3 oxidation states.

Explain why transition elements have variable oxidation states.

.....
 [1]

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

Define complex ion.

.....
 [1]

- (c) $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ can be converted into $[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$.

- (i) Suggest a suitable reagent for this conversion. State the type of reaction.

reagent
 type of reaction [1]

- (ii) $[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$ is a green precipitate that turns brown on standing in air.

Table 2.1 shows electrode potentials for some electrode reactions.

Table 2.1

electrode reaction	$E^\ominus / \text{V}$
$\text{Fe}(\text{H}_2\text{O})_3(\text{OH})_3 + \text{H}_2\text{O} + \text{e}^- \rightleftharpoons \text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2 + \text{OH}^-$	-0.56
$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightleftharpoons 4\text{OH}^-$	+0.40

Use the information in Table 2.1 to explain why $[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$ turns brown on standing in air.

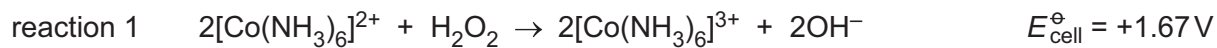
Include an equation for this reaction.

.....

 [3]



(d) The complex $[\text{Co}(\text{NH}_3)_6]^{2+}$ reacts with hydrogen peroxide as shown.



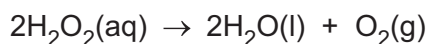
Calculate $\Delta G^\ominus$, in kJ mol^{-1} , for reaction 1.

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

[Total: 8]



- 3 (a) Solid manganese(IV) oxide, MnO_2 , catalyses the decomposition of hydrogen peroxide.



State the type of catalysis for this reaction. Explain your answer.

.....
 [1]

- (b) Hydrogen peroxide reacts with iodide ions in acidic conditions as shown.



The initial rate of this reaction is investigated with different concentrations of H_2O_2 , I^- and H^+ . The results obtained are shown in Table 3.1.

Table 3.1

experiment	$[\text{H}_2\text{O}_2]/\text{mol dm}^{-3}$	$[\text{I}^-]/\text{mol dm}^{-3}$	$[\text{H}^+]/\text{mol dm}^{-3}$	initial rate/ $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.0450	0.0300	0.0125	2.42×10^{-3}
2	0.0225	0.0600	0.0125	2.42×10^{-3}
3	0.0225	0.120	0.0125	4.84×10^{-3}
4	0.0450	0.120	0.0500	9.68×10^{-3}

- (i) Use the information in Table 3.1 to deduce the rate equation for this reaction.

Explain your reasoning.

.....

 [4]

- (ii) Use your rate equation from (b)(i) and the data from Experiment 1 to calculate the rate constant, k , for this reaction. Include the units of k .

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



(c) The rate of the thermal decomposition of azomethane, $\text{CH}_3\text{N}=\text{NCH}_3$, is investigated.

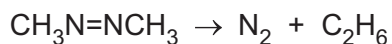


Fig. 3.1 shows the results obtained. The reaction is first order with respect to $\text{CH}_3\text{N}=\text{NCH}_3$.

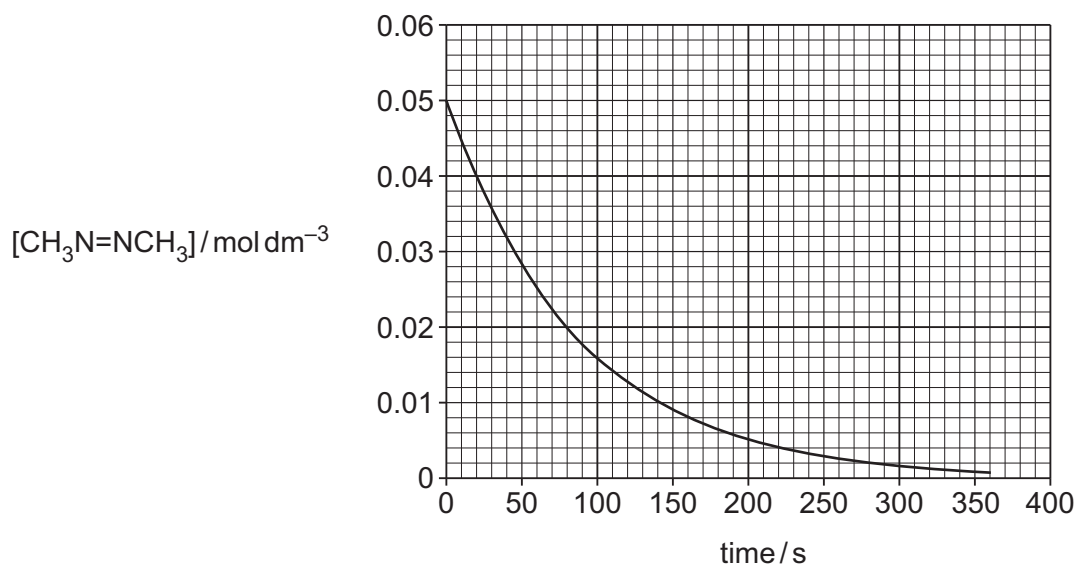


Fig. 3.1

(i) Use Fig. 3.1 to calculate **two** half-lives, $t_{1/2}$, to show that the reaction is first order.

.....

 [2]

(ii) Use your answer to (c)(i) to calculate the rate constant, k , for the decomposition of azomethane.

$k = \dots\dots\dots \text{s}^{-1}$ [1]

(d) Describe the effect of increasing temperature on the rate constant and on the rate of a reaction.

.....

 [1]

[Total: 11]



- 4 (a) Define standard cell potential, $E_{\text{cell}}^{\ominus}$. Include a description of standard conditions.

.....

 [2]

- (b) The Daniell cell is an electrochemical cell consisting of a $\text{Cu}^{2+}(\text{aq})/\text{Cu}(\text{s})$ electrode and a $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ electrode.

- (i) Draw a labelled diagram of this electrochemical cell.

Include all necessary substances and relevant pieces of apparatus needed to measure the $E_{\text{cell}}^{\ominus}$.

It is **not** necessary to state the conditions used.

[3]

- (ii) State the charge carriers that transfer current through the solutions and through the wire.

the solutions the wire [1]

- (iii) The standard electrode potential, $E^{\ominus}$, for the $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ electrode is -0.76 V .

Water is added to a standard $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ electrode.

The new concentration of $\text{Zn}^{2+}(\text{aq})$ is 0.25 mol dm^{-3} .

Use the Nernst equation to calculate the electrode potential, E , for this new $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ electrode.

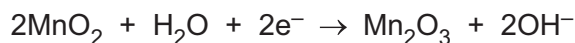
$E (\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})) = \dots\dots\dots \text{ V}$ [2]



- (c) An electrochemical cell consists of a ZnO/Zn electrode and a MnO₂/Mn₂O₃ electrode in an alkaline electrolyte.

The standard cell potential, $E^\ominus_{\text{cell}}$, for this cell is +1.47 V.

The half-equation at each electrode when this cell is discharging is shown.



- (i) Use this information to determine the change in oxidation state of manganese when this cell is discharging.

from to [1]

- (ii) Write the equation for the overall reaction that occurs when this cell is discharging.

..... [1]

- (iii) The $E^\ominus$ for the ZnO/Zn electrode is -1.28 V.

Calculate the standard electrode potential, $E^\ominus$, for the MnO₂/Mn₂O₃ electrode.

$E^\ominus (\text{MnO}_2/\text{Mn}_2\text{O}_3) = \dots\dots\dots \text{V}$ [1]

[Total: 11]



- 5 (a) Copper shows typical properties of transition elements, including its behaviour as a catalyst.

Complete Table 5.1 to show the total number of **unpaired** electrons in the 3d and 4s orbitals of an isolated gaseous Cu atom and a Cu^{2+} ion.

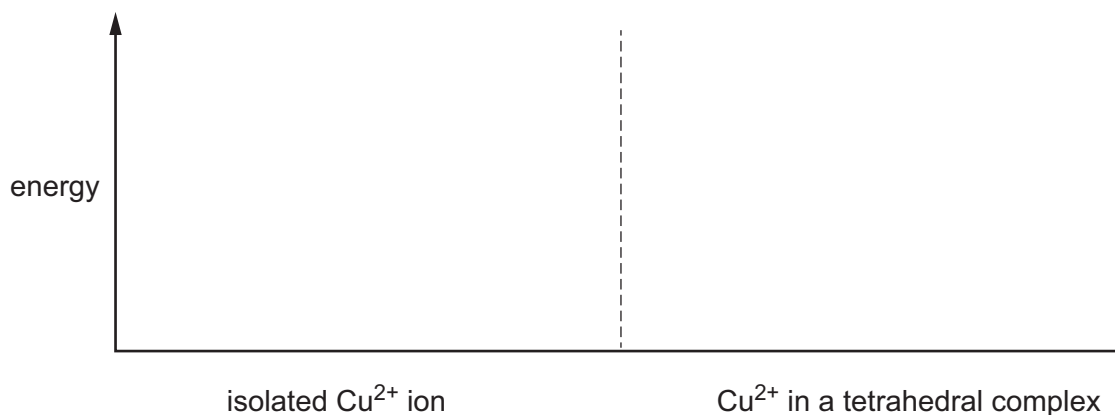
Table 5.1

species	number of unpaired electrons	
	3d	4s
Cu		
Cu^{2+}		

[1]

- (b) The 3d orbitals in an isolated Cu^{2+} ion are degenerate.

Complete the diagram to show the relative energies of the 3d orbitals in an isolated Cu^{2+} ion and in Cu^{2+} in a tetrahedral complex.



[2]

- (c) Explain why transition elements behave as catalysts.

.....

 [2]



(d) CN^- is a monodentate ligand.

Table 5.2 shows information about two complex ions that contain only CN^- ions as ligands.

Complete Table 5.2.

Table 5.2

metal ion	coordination number	formula of complex ion	charge of complex ion
Ag^+	2		
Fe^{2+}			4–

[2]

(e) The complex ion $[\text{Au}(\text{CN})_2\text{Br}_2]^-$ displays geometrical (cis/trans) isomerism.

Draw the structure of *trans*- $[\text{Au}(\text{CN})_2\text{Br}_2]^-$. State its shape and the Br-Au-Br bond angle.

shape

Br-Au-Br bond angle = ...

[2]





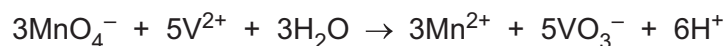
- (f) An impure sample of a vanadium(V) compound of mass 0.250 g is dissolved in aqueous acid. This solution contains VO_3^- ions.

An excess of zinc is added to this solution. All the VO_3^- ions are reduced to V^{2+} ions and Zn atoms are oxidised to Zn^{2+} ions.

The unreacted zinc is removed and the resulting solution is titrated with acidified MnO_4^- .

The end-point is reached when 22.5 cm^3 of $0.0750 \text{ mol dm}^{-3} \text{ MnO}_4^-$ is added.

A redox reaction takes place and all the V^{2+} reacts forming VO_3^- .



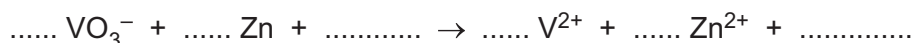
- (i) Calculate the percentage by mass of vanadium in the 0.250 g of impure sample.

Assume the impurities do not contain any vanadium ions.

Show your working.

percentage of vanadium = ... [3]

- (ii) Complete the equation for the reaction between acidified VO_3^- ions and Zn metal.



[2]

[Total: 14]





- 6 (a) Thin-layer and gas/liquid chromatography can be used to separate mixtures into their individual components.

- (i) Define the following terms used in chromatography.

R_f value

.....

retention time

.....

[2]

- (ii) Each type of chromatography makes use of a stationary phase and a mobile phase.

Complete Table 6.1 with a description of each of these.

Table 6.1

	stationary phase	mobile phase
thin-layer chromatography	X	
gas/liquid chromatography		X

[1]

- (b) A mixture of two substances **A** and **B** is analysed by thin-layer chromatography.

The R_f value of substance **A** is larger than that of substance **B**.

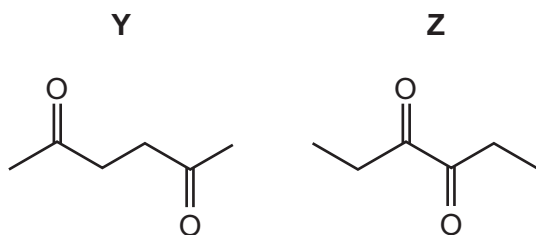
Suggest why substance **A** has a larger R_f value.

.....

..... [1]



(c) The two isomeric compounds **Y** and **Z** are analysed by proton (^1H) NMR spectroscopy.



- (i) Complete Table 6.2 to predict the number of peaks observed in the proton (^1H) NMR spectra for **Y** and **Z**.

Table 6.2

compound	number of peaks observed
Y	
Z	

[1]

- (ii) Name **all** the different splitting patterns observed in the proton (^1H) NMR spectra for **Y** and **Z**.

Y

Z

[2]

[Total: 7]



- 7 (a) State the relative acidities of bromoethanoic acid, BrCH_2COOH , chloroethanoic acid, ClCH_2COOH , ethanoic acid, CH_3COOH and ethanol, $\text{CH}_3\text{CH}_2\text{OH}$.

Explain your answer.

.....

most acidic least acidic

.....

.....

.....

.....

.....

.....

[4]

- (b) Fig. 7.1 shows the reaction of methylbenzene and ethanedioic acid with KMnO_4 .

Predict the major carbon-containing product for each of these reactions.

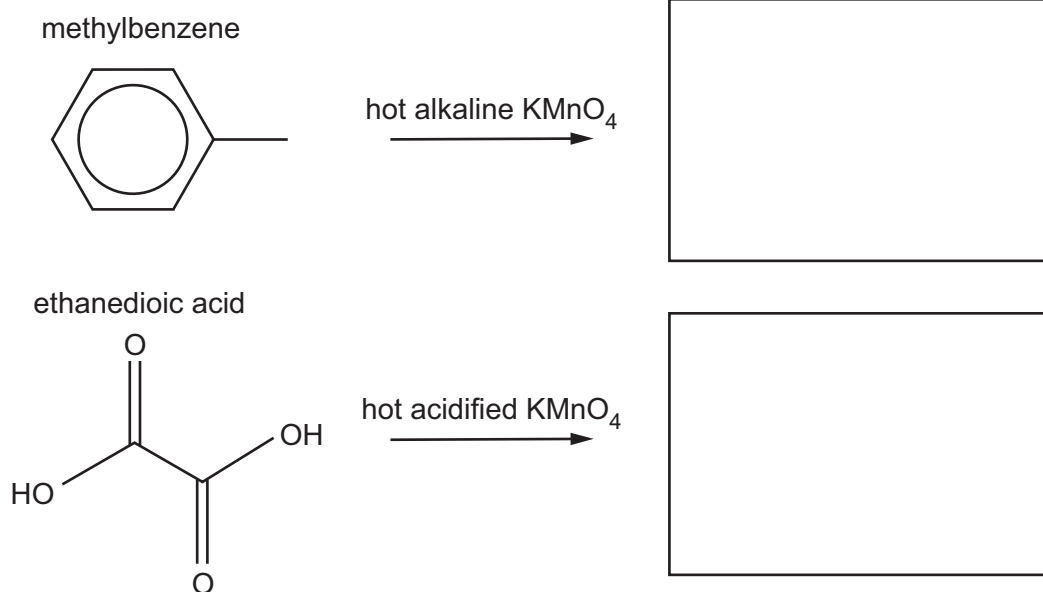


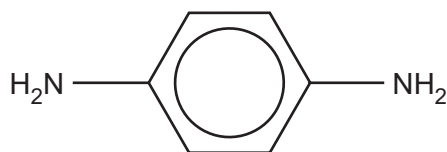
Fig. 7.1

[2]



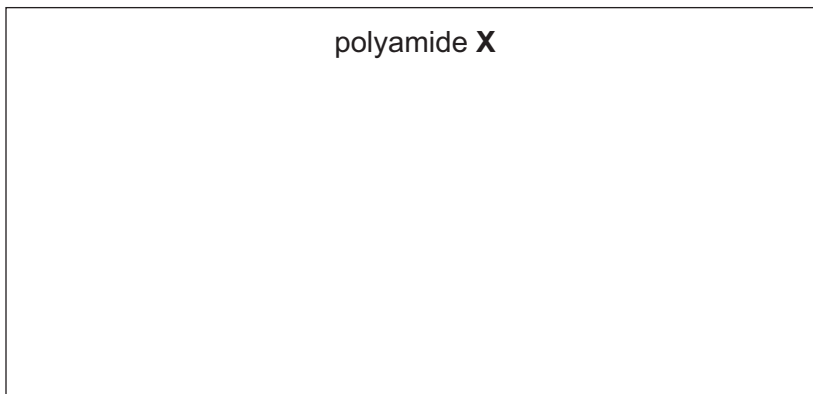
(c) Polyamide **X** can be synthesised from ethanedioic acid and benzene-1,4-diamine.

benzene-1,4-diamine



(i) Draw the repeat unit of polyamide **X** in the box.

The new functional group formed should be shown displayed.

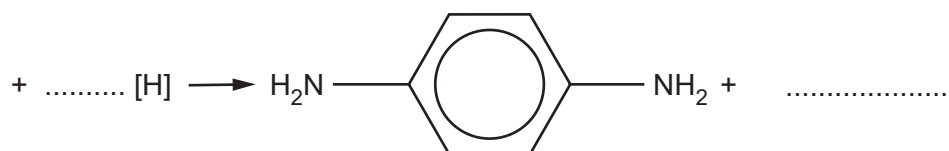
polyamide **X**

[2]

(ii) Benzene-1,4-diamine can be formed by reduction of 1,4-dinitrobenzene.

Complete the equation for this reduction.

[H] represents one atom of hydrogen from a reducing agent.



[1]



(d) Fig. 7.2 shows the two-step synthesis of the azo compound **W**.

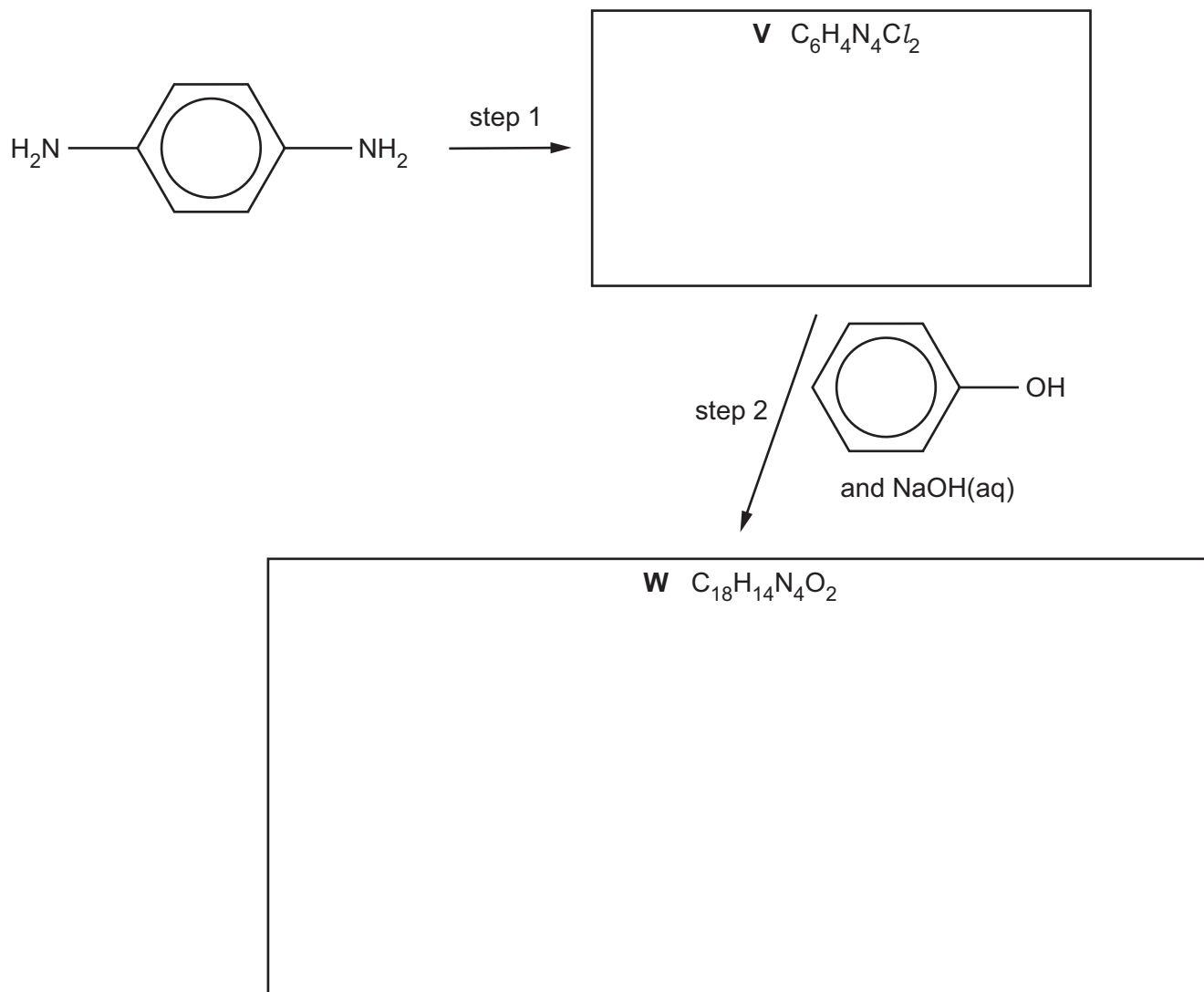


Fig. 7.2

- (i) Suggest structures for compounds **V** and **W** and draw them in the boxes in Fig. 7.2. [2]
- (ii) Give the reagents and conditions for step 1.

..... [1]

[Total: 12]





- 8 (a) In the electrophilic substitution of arenes, different substituents can direct to different ring positions.

(i) Describe the directing effect of the $-\text{NO}_2$ group. Explain your answer.

.....
 [1]

(ii) The nitration of arenes uses a mixture of concentrated HNO_3 and concentrated H_2SO_4 to generate the NO_2^+ electrophile.

Write an equation for the formation of the NO_2^+ electrophile.

..... [1]

(b) Carbon-carbon bond formation is an important reaction in organic synthesis.

Fig. 8.1 shows the synthesis of compound **Q** from benzene in two reaction steps.

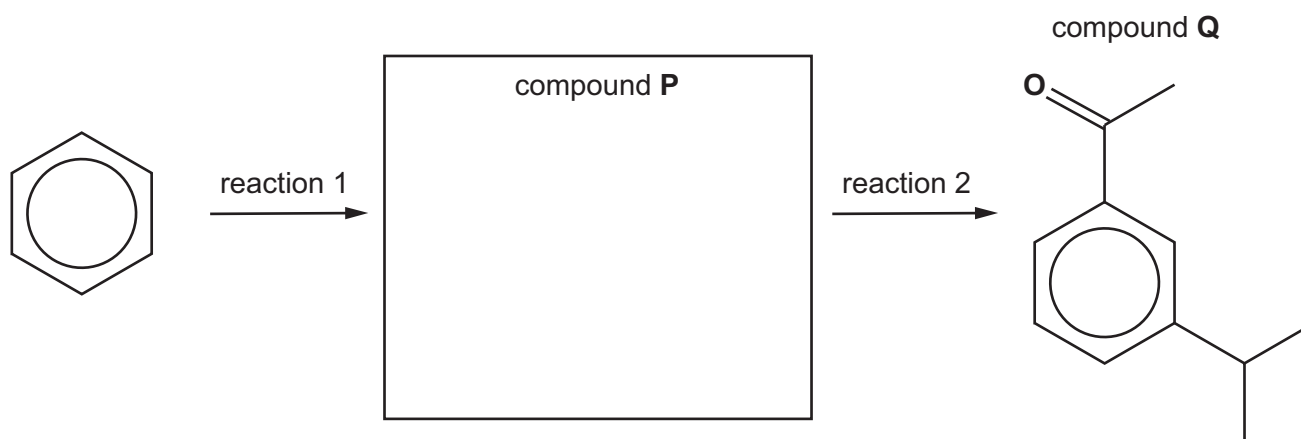


Fig. 8.1

(i) Draw the structure of compound **P** in the box in Fig. 8.1. [1]

(ii) Suggest reagents and conditions for reactions 1 and 2 in Fig. 8.1.

reaction 1

reaction 2 [2]



(c) Separate samples of $\text{C}_6\text{H}_5\text{Br}$ and $\text{C}_6\text{H}_5\text{CH}_2\text{Br}$ are added to warm $\text{AgNO}_3(\text{aq})$.

State the expected observations, if any. Explain your answer.

$\text{C}_6\text{H}_5\text{Br}$ with $\text{AgNO}_3(\text{aq})$

$\text{C}_6\text{H}_5\text{CH}_2\text{Br}$ with $\text{AgNO}_3(\text{aq})$

explanation

.....

.....

.....

[3]

(d) Acyl bromides, RCOBr , react readily with H_2O .

The mechanism of this reaction is similar to that of the reaction of H_2O with acyl chlorides, RCOCl .

(i) Name the mechanism of this reaction.

..... [1]

(ii) Complete the mechanism in Fig. 8.2 for the reaction of RCOBr with H_2O .

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

Draw the structure of the intermediate.

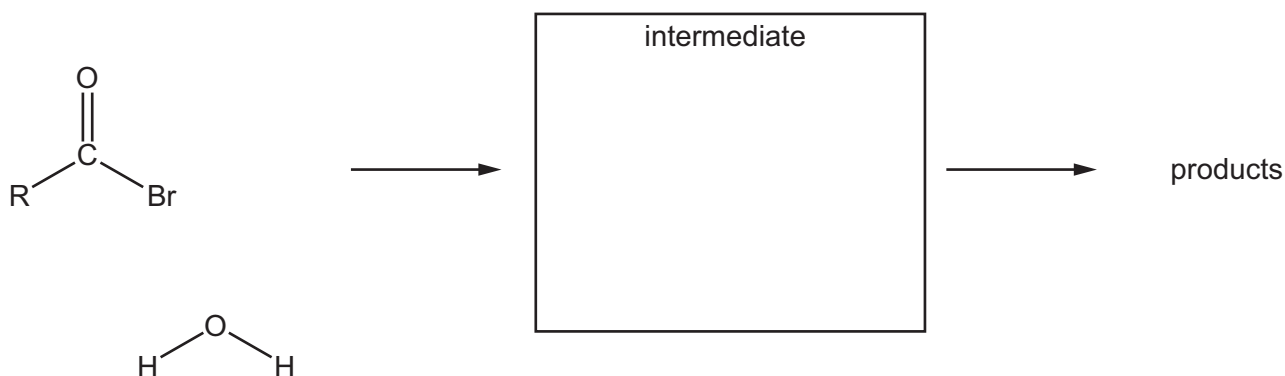


Fig. 8.2

[4]

[Total: 13]



- 9 (a) Explain why amides are much weaker bases than amines.

.....

.....

.....

..... [2]

- (b) Fig. 9.1 shows the preparation of 2-phenylethylamine, $\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NH}_2$, by three different routes.

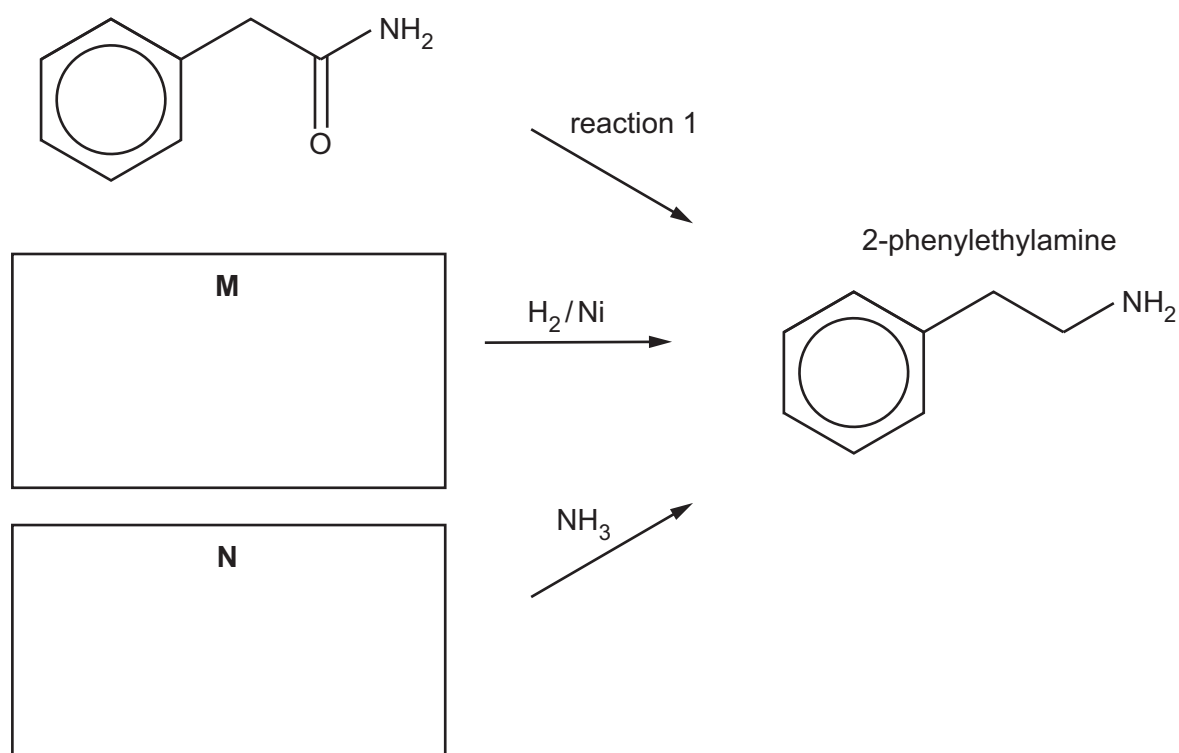


Fig. 9.1

- (i) Suggest structures for compounds **M** and **N** and draw them in the boxes in Fig. 9.1. [2]
- (ii) Give the reagents and conditions for reaction 1.

..... [1]



(c) Fig. 9.2 shows compound **H** which is a useful starting material in organic synthesis.

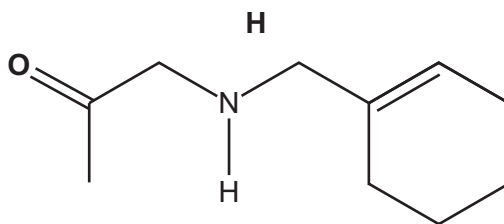


Fig. 9.2

H contains an alkene and an amine functional group.

Name the **other** functional group and give the classification of the amine group in **H**.

other functional group in **H**

classification of amine

[1]

(d) Ozonolysis involves the oxidative cleavage of a C=C bond in alkenes using ozone, O_3 , as shown in Fig. 9.3.

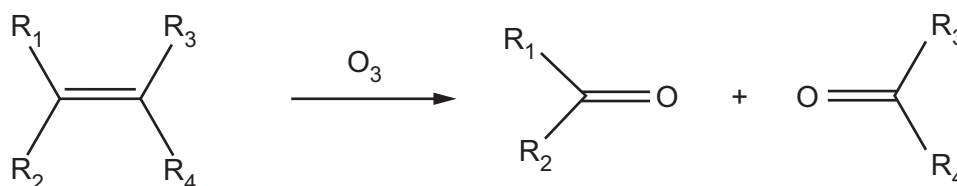


Fig. 9.3

Fig. 9.4 shows the first step in this reaction which involves the formation of an ozonide intermediate.

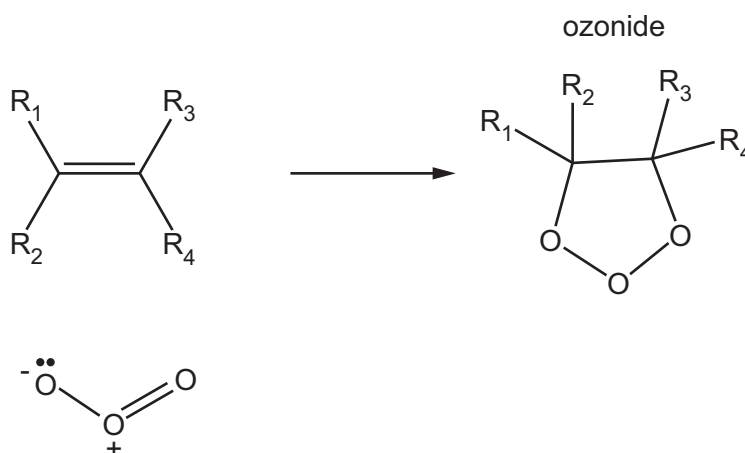


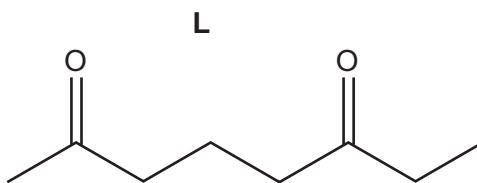
Fig. 9.4

(i) On Fig. 9.4, draw **three** curly arrows to complete the mechanism of this step.

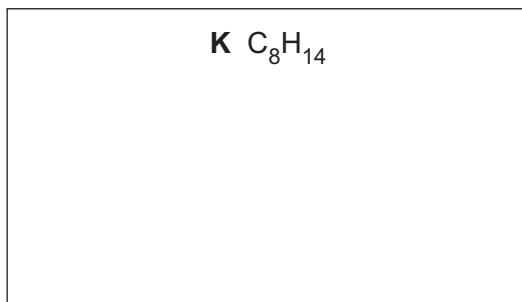
[2]



(ii) **L** is formed from alkene **K**, C_8H_{14} , by a similar reaction to that shown in Fig. 9.3.



Suggest the structure of **K**.



[1]

[Total: 9]



Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ 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	1														13	14	15	16	17	18																																
		1 H hydrogen 1.0																																																			
		2 He helium 4.0																																																			
3	Li lithium 6.9	4	Be beryllium 9.0	Key atomic number atomic symbol name relative atomic mass														5	6	7	8	9	10	11	12	13	14	15	16	17	18																						
11	Na sodium 23.0	12	Mg magnesium 24.3	3	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr																	
19	K potassium 39.1	20	Ca calcium 40.1	41	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe																	
37	Rb rubidium 85.5	38	Sr strontium 87.6	57–71	lanthanoids	72	Hf	73	Ta	74	W	75	Re	76	Os	77	Ir	78	Pt	79	Au	80	Hg	81	Tl	82	Pb	83	Bi	84	Po	85	At	86	Rn																		
55	Cs caesium 132.9	56	Ba barium 137.3															87	Fr francium	88	Ra radium	89–103	actinoids	104	Rf	105	Db	106	Sg	107	Bh	108	Hs	109	Mt	110	Ds	111	Rg	112	Cn	113	Nh	114	Fl	115	Mc	116	Lv	117	Ts	118	Og
87	Fr francium	88	Ra radium															104	Rf	105	Db	106	Sg	107	Bh	108	Hs	109	Mt	110	Ds	111	Rg	112	Cn	113	Nh	114	Fl	115	Mc	116	Lv	117	Ts	118	Og						



Cambridge International AS & A Level

CANDIDATE
NAME

--

CENTRE
NUMBER

--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--

CHEMISTRY

9701/42

Paper 4 A Level Structured Questions

October/November 2025

2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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

INFORMATION

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

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



- 1 Magnesium nitrate, $\text{Mg}(\text{NO}_3)_2$, and strontium nitrate, $\text{Sr}(\text{NO}_3)_2$, both decompose when heated to form the metal oxide and a mixture of gases.

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

..... [1]

(b) State which of $\text{Mg}(\text{NO}_3)_2$ or $\text{Sr}(\text{NO}_3)_2$ decomposes at a lower temperature.

Explain your answer.

compound that decomposes at a lower temperature

explanation

.....

.....

.....

.....

[2]

(c) Magnesium oxide, MgO , and strontium oxide, SrO , both react with dilute sulfuric acid.

MgO forms a soluble salt, **A**.

SrO forms an insoluble salt, **B**.

(i) Identify the products formed when MgO reacts with dilute sulfuric acid.

..... [1]

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

.....

.....

.....

.....

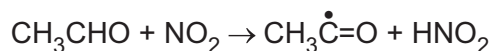
.....

..... [3]

[Total: 7]



- 2 Ethanal, CH_3CHO , reacts with nitrogen dioxide, NO_2 . The products of the first step of this reaction are a $\text{CH}_3\dot{\text{C}}=\text{O}$ radical and a molecule of nitrous acid, HNO_2 .



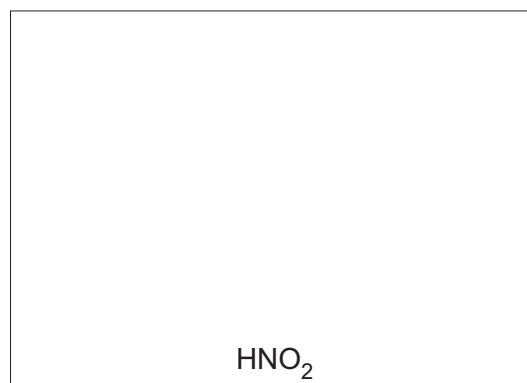
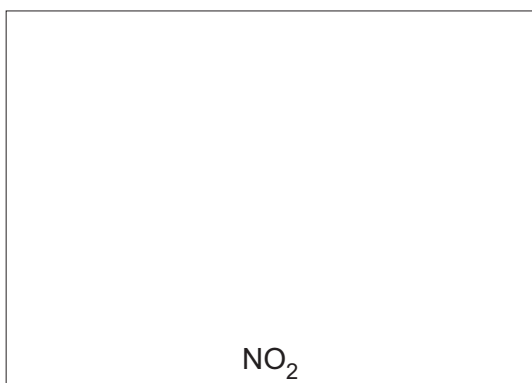
- (a) (i) Use **two** words to complete the sentence.

This reaction involves of the single covalent bond between a hydrogen atom and a carbon atom in CH_3CHO .

[1]

- (ii) The hydrogen atom mentioned in (a)(i) forms a covalent bond with one of the oxygen atoms of an NO_2 molecule. An NO_2 molecule has a single, unpaired electron on the nitrogen atom. All electrons are paired in an HNO_2 molecule.

Draw dot-and-cross diagrams of NO_2 and HNO_2 in the boxes. Show outer shell electrons only.



[1]

- (iii) Use VSEPR theory to predict the bond angle at the nitrogen atom in an HNO_2 molecule.

bond angle = ... [1]

- (b) The rate equation for the reaction between CH_3CHO and NO_2 is shown.

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

Under certain conditions, when the concentrations of both CH_3CHO and NO_2 are $0.200 \text{ mol dm}^{-3}$, the rate of the reaction is $1.53 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$.

Calculate the value of the rate constant, k , under these conditions. Give the units of k .

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



- (c) The reaction mixture described in (b) is monitored over a period of time.

Predict whether the graph of $[\text{NO}_2]$ against time shows a constant half-life.

Explain your answer.

prediction

explanation

[1]

- (d) NO_2 also reacts with ozone, O_3 .

The rate equation is shown.

$$\text{rate} = k_1[\text{NO}_2]$$

Under certain conditions, the value of k_1 is 0.0848s^{-1} .

The reaction has a constant half-life under these conditions.

Calculate the half-life in seconds.

half-life = ...s [1]

- (e) NO_2 is present in the exhaust gases of cars. It can react with carbon monoxide, CO , on the surface of a heterogeneous catalyst in the car's catalytic converter.

Describe the mode of action of this heterogeneous catalyst.

.....

.....

.....

.....

.....

.....

.....

..... [2]

[Total: 9]



- 3 (a) (i) Define conjugate acid–base pair.

.....
 [1]

- (ii) Give the formulas of the conjugate acid and the conjugate base of the hydrogen phosphate ion, HPO_4^{2-} .

conjugate acid of HPO_4^{2-}

conjugate base of HPO_4^{2-} [1]

- (b) The K_a of propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, is $1.35 \times 10^{-5} \text{ mol dm}^{-3}$ at 298 K.

Solution C is a solution of $\text{CH}_3\text{CH}_2\text{COOH}$ with a pH of 3.60 at 298 K.

- (i) Calculate the concentration of $\text{CH}_3\text{CH}_2\text{COOH}$ in solution C.

$[\text{CH}_3\text{CH}_2\text{COOH}] = \dots\dots\dots \text{mol dm}^{-3}$ [2]

- (ii) Calculate the concentration of hydroxide ions in solution C.

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

- (iii) Calculate the concentration of a solution of hydrochloric acid with the same pH as solution C.

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



(iv) Table 3.1 shows three possible values of the K_a of dimethylpropanoic acid, $(\text{CH}_3)_3\text{CCOOH}$.

Place a tick in Table 3.1 to show the correct value. Explain your answer.

Table 3.1

value of K_a / mol dm^{-3}	place one tick (✓) in this column
9.33×10^{-6}	
1.35×10^{-5}	
3.35×10^{-5}	

explanation

.....

.....

.....

..... [3]

(c) Solution **D** is made by mixing 100 cm^3 of 0.100 mol dm^{-3} $\text{CH}_3\text{CH}_2\text{COOH}$ and 100 cm^3 of 0.100 mol dm^{-3} NaCl .

The pH of solution **D** is measured as small amounts of $\text{H}_2\text{SO}_4(\text{aq})$ are added to it, and when small amounts of $\text{NaOH}(\text{aq})$ are added to it.

Solution **D** only acts as a buffer solution when **one** of these solutions is added to it.

(i) Complete the sentence and write an equation for the reaction that occurs.

Solution **D** acts as a buffer when is added to it.

equation [1]

(ii) Complete the sentence and explain why solution **D** does **not** act as a buffer when the other solution is added.

Solution **D** does **not** act as a buffer when is added to it.

explanation

..... [1]



(d) Manganese(II) hydroxide, $\text{Mn}(\text{OH})_2$, is only slightly soluble in water.

The solubility of $\text{Mn}(\text{OH})_2$ in water is $3.28 \times 10^{-3} \text{ g dm}^{-3}$ at 298 K.

(i) Calculate the concentration of a saturated solution of $\text{Mn}(\text{OH})_2$ at 298 K.

$$[\text{Mn}(\text{OH})_2] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

(ii) Write an expression for the K_{sp} of $\text{Mn}(\text{OH})_2$. Give the units of K_{sp} .

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

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

(iii) Use your answers to (d)(i) and (d)(ii) to calculate the value of K_{sp} of $\text{Mn}(\text{OH})_2$ at 298 K.

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

[Total: 15]



- 4 (a) Define enthalpy change of atomisation, ΔH_{at} .

.....
 [1]

- (b) Define first electron affinity, EA.

.....
 [1]

- (c) Explain why the first electron affinity of chlorine is more exothermic than the first electron affinity of iodine.

.....

 [2]

- (d) The enthalpy change for the reaction $\text{Cl}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{Cl}^-(\text{g})$ is -486 kJ mol^{-1} .

The first electron affinity of chlorine is -364 kJ mol^{-1} .

Calculate the enthalpy change of atomisation of chlorine.

ΔH_{at} of chlorine = ... kJ mol^{-1} [2]

[Total: 6]



- 5 Cobalt is a transition element which forms compounds containing Co^{2+} and Co^{3+} ions. Cobalt(II) sulfate dissolves in water to form a solution containing the $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ complex ion.

(a) (i) Complete the electronic configurations of a Co^{2+} ion and a Co^{3+} ion.

$\text{Co}^{2+} = [\text{Ar}] \dots\dots\dots$

$\text{Co}^{3+} = [\text{Ar}] \dots\dots\dots$

[1]

(ii) Explain why transition elements can form complex ions.

.....

..... [1]

(iii) An excess of concentrated HCl is added to a solution containing $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.

Describe the colour change observed and the state of the cobalt-containing product.

The colour changes from to

The state of the cobalt-containing product is

[2]

(iv) Write an equation for the reaction occurring in (a)(iii).

..... [1]

(v) Name the type of reaction occurring in (a)(iii).

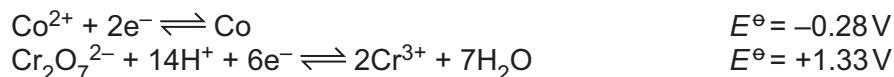
..... [1]

(vi) Write an equation for the reaction that occurs when an excess of $\text{NaOH}(\text{aq})$ is added to a solution containing $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.

..... [1]



- (b) Cobalt metal can be oxidised by acidified $\text{K}_2\text{Cr}_2\text{O}_7$. The relevant half-equations, and their $E^\ominus$ values, are shown.



- (i) A Co^{2+}/Co electrode is constructed in which $[\text{Co}^{2+}]$ is $0.020 \text{ mol dm}^{-3}$ at 298 K .

Use the Nernst equation to show that the E value for this Co^{2+}/Co electrode is -0.33 V .

[2]

- (ii) An electrochemical cell is constructed using the Co^{2+}/Co electrode described in (b)(i) and a $\text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+}$ electrode in which all conditions are standard.

Calculate the value of E_{cell} .

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

- (iii) A current is drawn from the electrochemical cell described in (b)(ii).

Write an equation for the reaction taking place in the cell.

..... [1]

- (iv) Complete the sentences to identify the negative electrode and the direction of electron flow when a current is drawn from the cell described in (b)(ii).

The electrode is the negative electrode.

Electrons flow from the electrode to the electrode. [1]

- (c) A molten Co^{2+} salt is electrolysed using a current of 0.500 A .

0.547 g of cobalt metal forms at the cathode. Under the conditions used no other reduction reaction occurs at the cathode.

Calculate the time in minutes for which the current flows to produce this mass of cobalt.

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

time = ... min [3]

[Total: 15]

[Turn over]



6 (a) Nickel forms complexes.

- (i) Give the formula and charge of the tetrahedral complex formed by Ni atoms with carbon monoxide molecules. Carbon monoxide is a monodentate ligand. This is complex **E**.

E = ... [1]

- (ii) Give the formula and charge of the octahedral complex formed by Ni^{2+} ions with ethanedioate ions. This is complex **F**.

F = ... [2]

- (iii) Identify which complex, **E** or **F**, exists as a mixture of two stereoisomers and the type of stereoisomerism involved.

The complex which exists as a mixture of two stereoisomers is

The type of stereoisomerism involved is

[1]

- (b) Cadmium forms complexes with methylamine, CH_3NH_2 , and 1,2-diaminoethane, *en*. The values of the stability constants, K_{stab} , of these complex ions are given in Table 6.1.

Table 6.1

complex	K_{stab}
$[\text{Cd}(\text{CH}_3\text{NH}_2)_4]^{2+}$	3.5×10^6
$[\text{Cd}(\text{en})_2]^{2+}$	4.0×10^{10}

- (i) Explain, by reference to its structure, why CH_3NH_2 acts as a monodentate ligand.

..... [1]

- (ii) Some $\text{Cd}^{2+}(\text{aq})$ is added to a solution containing equal concentrations of CH_3NH_2 and *en*.

Predict which of the two complexes in Table 6.1 forms at the higher concentration.

Explain your answer.

complex that forms at the higher concentration

explanation

.....

[1]

- (iii) Complete the expression for the K_{stab} of $[\text{Cd}(\text{CH}_3\text{NH}_2)_4]^{2+}$.

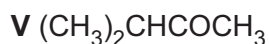
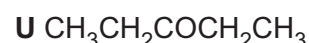
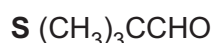
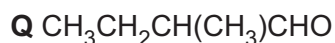
$K_{\text{stab}} =$

[1]

[Total: 7]

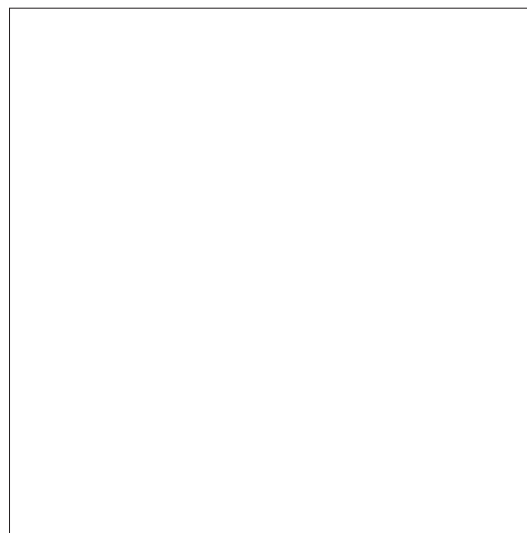
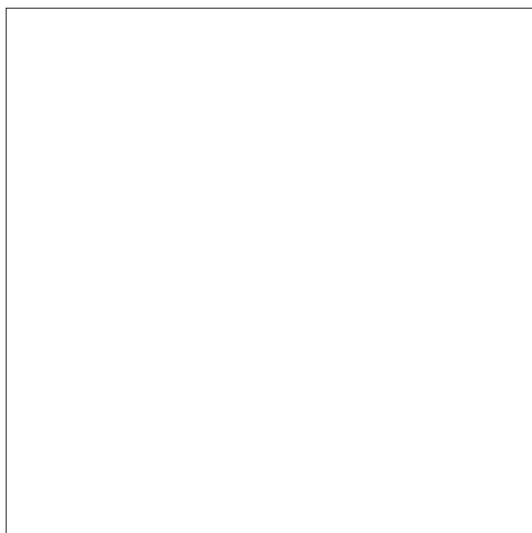


- 7 **P, Q, R, S, T, U, and V** are the seven structural isomers with molecular formula $C_5H_{10}O$ that have a carbonyl group.



- (a) Only one of these seven compounds has stereoisomers.

Draw three-dimensional diagrams of the **two** stereoisomers of this compound.



[2]

- (b) **P, Q, R, S, T, U, and V** are treated separately with alkaline $I_2(aq)$ and the product mixture is acidified.

- (i) Identify the **two** compounds that give a positive result with alkaline $I_2(aq)$.

..... and [1]

- (ii) Describe the observations when **one** of the compounds you have identified in (b)(i) is treated with alkaline $I_2(aq)$ and give the structural formulae of the **two** carbon-containing products of this reaction.

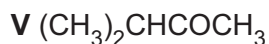
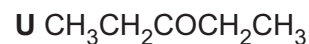
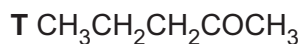
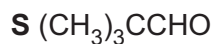
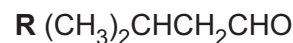
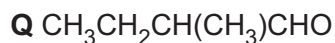
observations

two carbon-containing products

and

[2]





(c) The proton (^1H) NMR spectra of **P**, **Q**, **R**, **S**, **T**, **U**, and **V** are compared.

(i) Identify the only compound that gives a spectrum with two singlets and no other peaks.

..... [1]

Fig. 7.1 shows the spectrum obtained from one of the compounds.

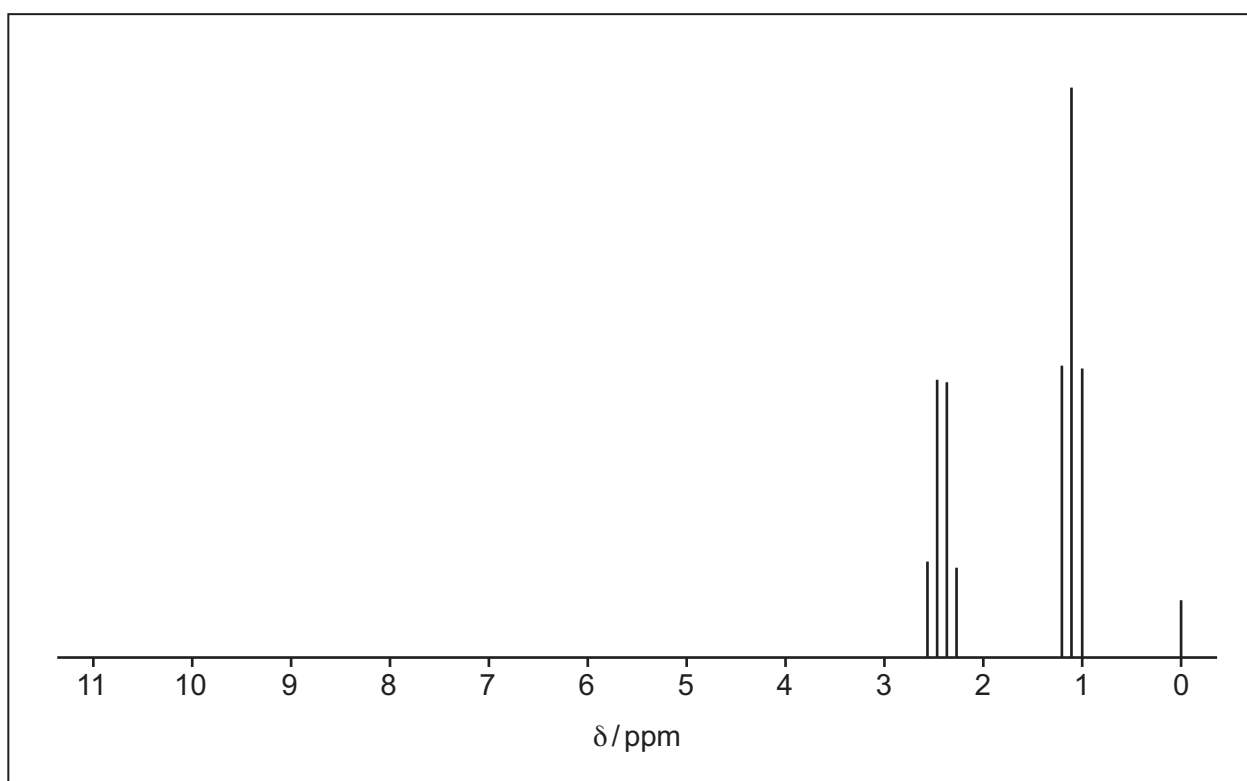


Fig. 7.1

(ii) Identify the compound that gives this spectrum.

..... [1]

(iii) Name the splitting pattern of the peak at $\delta = 1.1$ in Fig. 7.1.

Give the reason for this splitting.

name

reason [1]

(iv) Identify the substance that gives the small peak at $\delta = 0$ in Fig. 7.1.

..... [1]



(d) The carbon-13 NMR spectra of **R**, **S**, **T** and **U** are compared.

Complete Table 7.1 to state the number of peaks in the spectrum of each compound.

Table 7.1

compound	number of peaks
R $(\text{CH}_3)_2\text{CHCH}_2\text{CHO}$	
S $(\text{CH}_3)_3\text{CCHO}$	
T $\text{CH}_3\text{CH}_2\text{CH}_2\text{COCH}_3$	
U $\text{CH}_3\text{CH}_2\text{COCH}_2\text{CH}_3$	

[2]

[Total: 11]



- 8 Asparagine and aspartic acid are two naturally occurring amino acids. Their structures and isoelectric points are shown in Table 8.1.

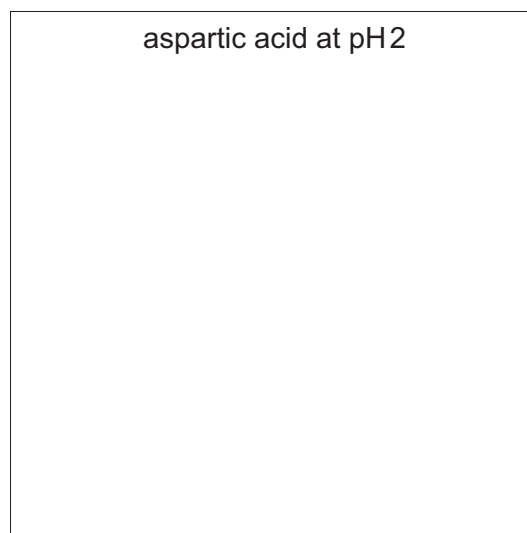
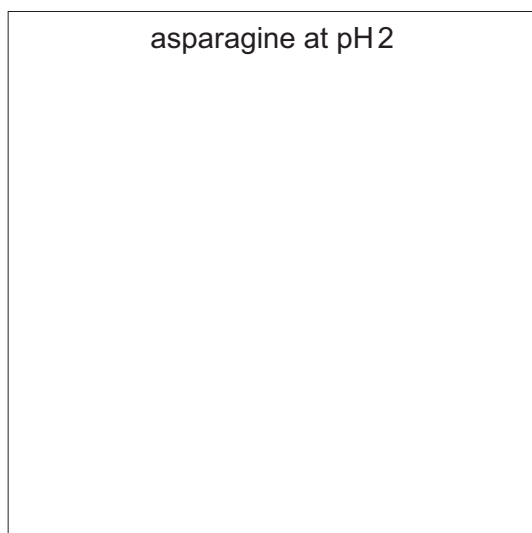
Table 8.1

amino acid	structure	isoelectric point
asparagine	$\text{HOOCCH}(\text{NH}_2)\text{CH}_2\text{CONH}_2$	5.41
aspartic acid	$\text{HOOCCH}(\text{NH}_2)\text{CH}_2\text{COOH}$	2.77

- (a) Define isoelectric point.

.....
 [1]

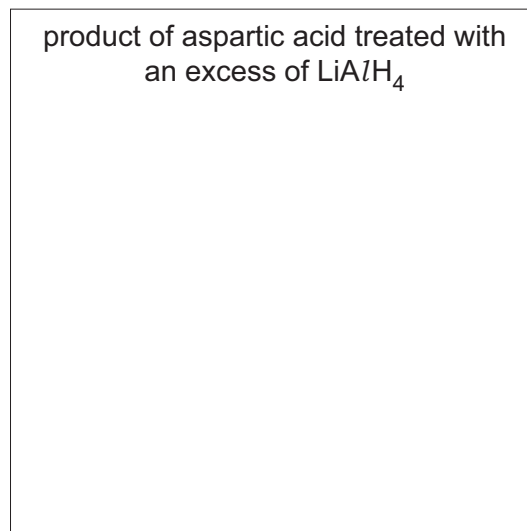
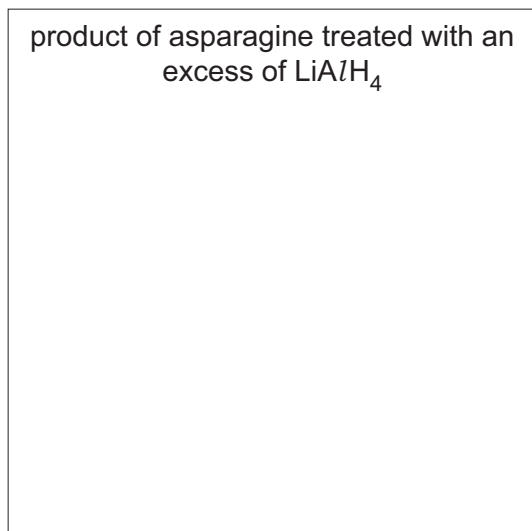
- (b) Draw the structures of asparagine and aspartic acid at pH2.



[2]

- (c) Asparagine and aspartic acid are treated separately with an excess of LiAlH_4 .

Draw the structures of the organic products of these reactions.



[2]



- (d) Propanedioic acid, $\text{HOOCCH}_2\text{COOH}$, is treated with an excess of thionyl chloride, SOCl_2 . Propanedioyl chloride, $\text{ClOCCH}_2\text{COCl}$, is formed.

(i) Write an equation for this reaction.

..... [1]

- (ii) Propanedioyl chloride reacts with an excess of asparagine to form compound **G** with molecular formula $\text{C}_{11}\text{H}_{16}\text{N}_4\text{O}_8$.

Each molecule of compound **G** has four amide groups.

Draw the structure of compound **G**.

Compound **G**, $\text{C}_{11}\text{H}_{16}\text{N}_4\text{O}_8$

[2]

- (e) Asparagine is hydrolysed with an excess of hot NaOH(aq) .

Draw the structure of the organic product of this reaction.

[2]

- (f) A polymer can form from asparagine, $\text{HOOCCH}(\text{NH}_2)\text{CH}_2\text{CONH}_2$, as the only monomer.

Draw a length of the polymer chain containing **three** monomer residues.

Clearly label the repeat unit of the polymer on your diagram.

[3]



(g) Aspartic acid exists in two optically active forms.

- (i) Plane polarised light is passed through pure samples of these two optically active forms in solutions of the same concentration.

Describe **two** similarities and **one** difference in their effect on the plane polarised light.

similarities

.....

difference

.....

[2]

- (ii) Give the term used to describe a mixture of equal amounts of the two optically active forms.

..... [1]

[Total: 16]





Question 9 starts on page 20.



9 Compound **X** is made from benzene by the route shown in Fig. 9.1.

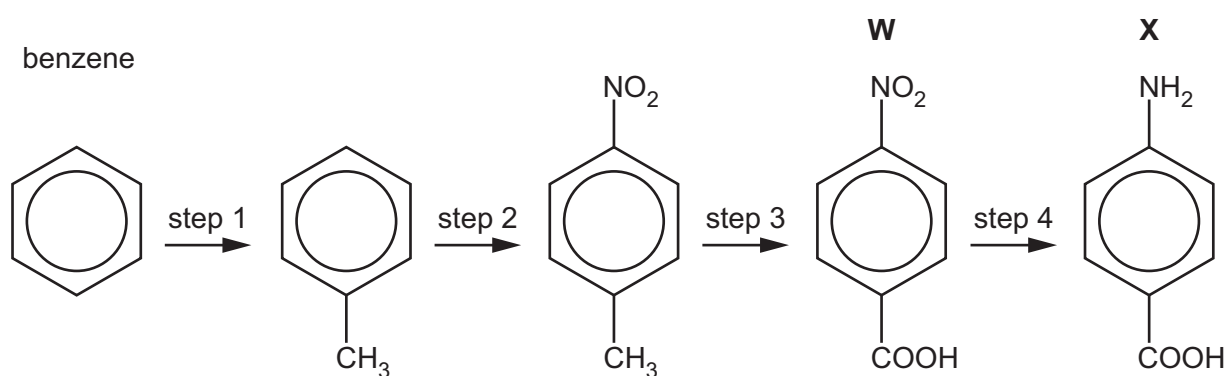


Fig. 9.1

(a) Describe the bonding in benzene, C_6H_6 .

Your answer should include:

- the hybridisation of the six carbon atoms
- the types of bond between the carbon atoms
- the orbitals that overlap to produce the bonds between the carbon atoms
- the type of bond between the carbon atoms and the hydrogen atoms
- the orbitals that overlap to produce the bonds between the carbon atoms and the hydrogen atoms.

.....

.....

.....

.....

.....

.....

.....

..... [3]

(b) Describe the reagents and conditions required for step 1 in Fig. 9.1.

.....

..... [1]



(c) In step 1 of Fig. 9.1 benzene reacts with $^+\text{CH}_3$.

Complete Fig. 9.2 to show the mechanism for this reaction, including:

- the movement of electron pairs using curly arrows
- the structure of the intermediate involved.

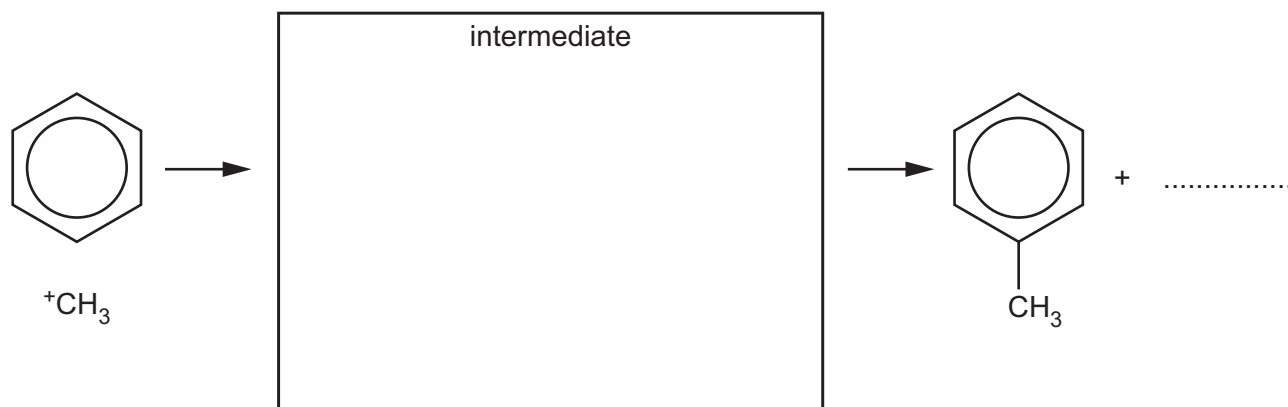


Fig. 9.2

[3]

(d) Describe the reagents and conditions required for step 2 of Fig. 9.1.

.....
 [2]

(e) Identify the reagents required for step 3 of Fig. 9.1. Compound **W** is the product of this step.

..... [1]

(f) Name compound **W**.

..... [1]

(g) The reagents commonly used for step 4 will **not** reduce the $-\text{COOH}$ group.

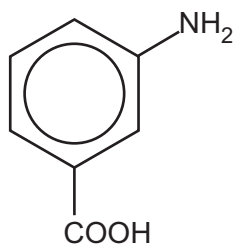
Identify the reagents and conditions required for step 4 of Fig. 9.1.

..... [1]



(h) Benzene can also be used as a starting material to make compound **Y**.

compound **Y**



Describe how the route described in Fig. 9.1 (repeated below) can be changed to give compound **Y** instead of compound **X**.

Explain your answer.

.....

.....

.....

..... [2]

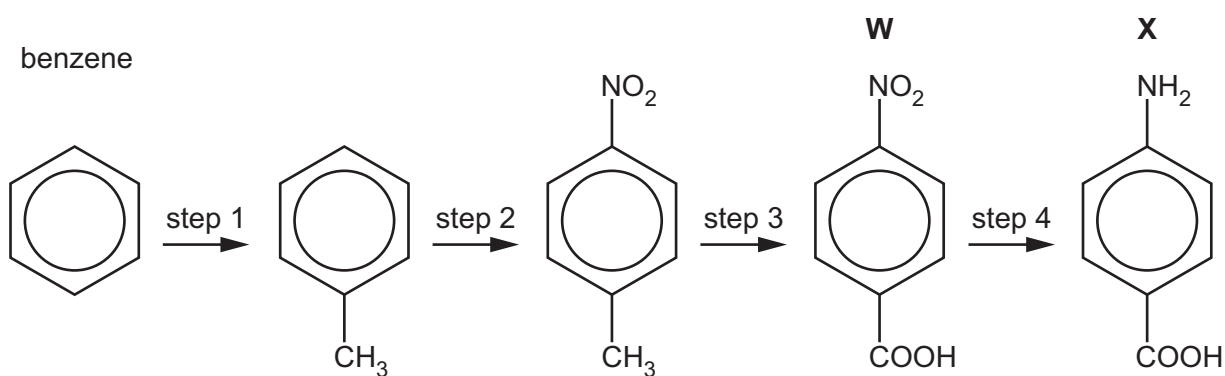


Fig. 9.1

[Total: 14]



Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ 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	Key										13	14	15	16	17	18			
		atomic number atomic symbol name relative atomic mass										1 H hydrogen 1.0							2 He helium 4.0	
3	4											5	6	7	8	9				
Li lithium 6.9	Be beryllium 9.0											B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0	Ne neon 20.2			
11	12											13	14	15	16	17	18			
Na sodium 23.0	Mg magnesium 24.3											Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5	Ar argon 39.9			
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36			
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8			
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54			
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3			
55	56	57–71 lanthanoids	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86			
Cs caesium 132.9	Ba barium 137.3											Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —			
87	88	89–103 actinoids	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118			
Fr francium —	Ra radium —											Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganesson —			

lanthanoids

actinoids

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





Cambridge International AS & A Level

CANDIDATE
NAMECENTRE
NUMBER

--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--

CHEMISTRY**9701/43**

Paper 4 A Level Structured Questions

October/November 2025**2 hours**

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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

INFORMATION

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

This document has **28** pages. Any blank pages are indicated.



- 1 (a) Solutions of Group 2 hydrogencarbonates, $M(\text{HCO}_3)_2$, decompose on heating to give the corresponding metal carbonate, carbon dioxide and water.

(i) Write an equation for the decomposition of strontium hydrogencarbonate, $\text{Sr}(\text{HCO}_3)_2$.

..... [1]

(ii) The thermal stability of Group 2 carbonates increases down the group.

Explain this trend.

.....

 [2]

(b) The hydroxides and fluorides of Group 2 elements show similar trends in solubility.

Describe the trend in the solubility of the fluorides of calcium, strontium and barium.

Explain your answer.

..... least soluble most soluble

explanation

 [4]



(c) (i) Define enthalpy change of hydration, ΔH_{hyd} .

.....

.....

..... [1]

(ii) State the main factors that affect the magnitude of enthalpy change of hydration.

Explain your answer.

.....

.....

.....

..... [2]

(d) Table 1.1 shows various energy changes.

Table 1.1

energy change	value / kJ mol^{-1}
lattice energy of MgF_2	–2957
enthalpy change of hydration, ΔH_{hyd} , of Mg^{2+}	–1926
enthalpy change of hydration, ΔH_{hyd} , of F^-	–505

Use data from Table 1.1 to calculate the enthalpy change of solution, ΔH_{sol} , for $\text{MgF}_2(\text{s})$.

It may be helpful to draw a labelled energy cycle. Show your working.

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



(e) Mercury(I) fluoride, Hg_2F_2 , is sparingly soluble in water.

The cation in Hg_2F_2 exists as the diatomic ion Hg_2^{2+} with a covalent Hg–Hg bond.

(i) Write the expression for the solubility product, K_{sp} , of Hg_2F_2 . Include the units.

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

units
[2]

(ii) The solubility of Hg_2F_2 is $9.20 \times 10^{-3} \text{ mol dm}^{-3}$ at 298 K.

Calculate the value of K_{sp} of Hg_2F_2 at 298 K.

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

[Total: 15]



- 2 (a) Iron can form stable ions in the +2 and +3 oxidation states.

Explain why transition elements have variable oxidation states.

.....
 [1]

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

Define complex ion.

.....
 [1]

- (c) $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ can be converted into $[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$.

- (i) Suggest a suitable reagent for this conversion. State the type of reaction.

reagent
 type of reaction [1]

- (ii) $[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$ is a green precipitate that turns brown on standing in air.

Table 2.1 shows electrode potentials for some electrode reactions.

Table 2.1

electrode reaction	$E^\ominus / \text{V}$
$\text{Fe}(\text{H}_2\text{O})_3(\text{OH})_3 + \text{H}_2\text{O} + \text{e}^- \rightleftharpoons \text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2 + \text{OH}^-$	-0.56
$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightleftharpoons 4\text{OH}^-$	+0.40

Use the information in Table 2.1 to explain why $[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$ turns brown on standing in air.

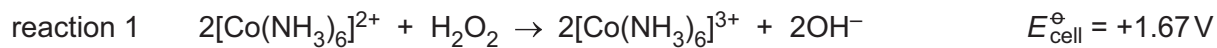
Include an equation for this reaction.

.....

 [3]



(d) The complex $[\text{Co}(\text{NH}_3)_6]^{2+}$ reacts with hydrogen peroxide as shown.



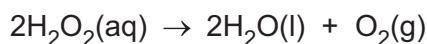
Calculate $\Delta G^\ominus$, in kJ mol^{-1} , for reaction 1.

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

[Total: 8]



- 3 (a) Solid manganese(IV) oxide, MnO_2 , catalyses the decomposition of hydrogen peroxide.



State the type of catalysis for this reaction. Explain your answer.

.....
 [1]

- (b) Hydrogen peroxide reacts with iodide ions in acidic conditions as shown.



The initial rate of this reaction is investigated with different concentrations of H_2O_2 , I^- and H^+ . The results obtained are shown in Table 3.1.

Table 3.1

experiment	$[\text{H}_2\text{O}_2]/\text{mol dm}^{-3}$	$[\text{I}^-]/\text{mol dm}^{-3}$	$[\text{H}^+]/\text{mol dm}^{-3}$	initial rate/ $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.0450	0.0300	0.0125	2.42×10^{-3}
2	0.0225	0.0600	0.0125	2.42×10^{-3}
3	0.0225	0.120	0.0125	4.84×10^{-3}
4	0.0450	0.120	0.0500	9.68×10^{-3}

- (i) Use the information in Table 3.1 to deduce the rate equation for this reaction.

Explain your reasoning.

.....

 [4]

- (ii) Use your rate equation from (b)(i) and the data from Experiment 1 to calculate the rate constant, k , for this reaction. Include the units of k .

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



(c) The rate of the thermal decomposition of azomethane, $\text{CH}_3\text{N}=\text{NCH}_3$, is investigated.

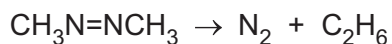


Fig. 3.1 shows the results obtained. The reaction is first order with respect to $\text{CH}_3\text{N}=\text{NCH}_3$.

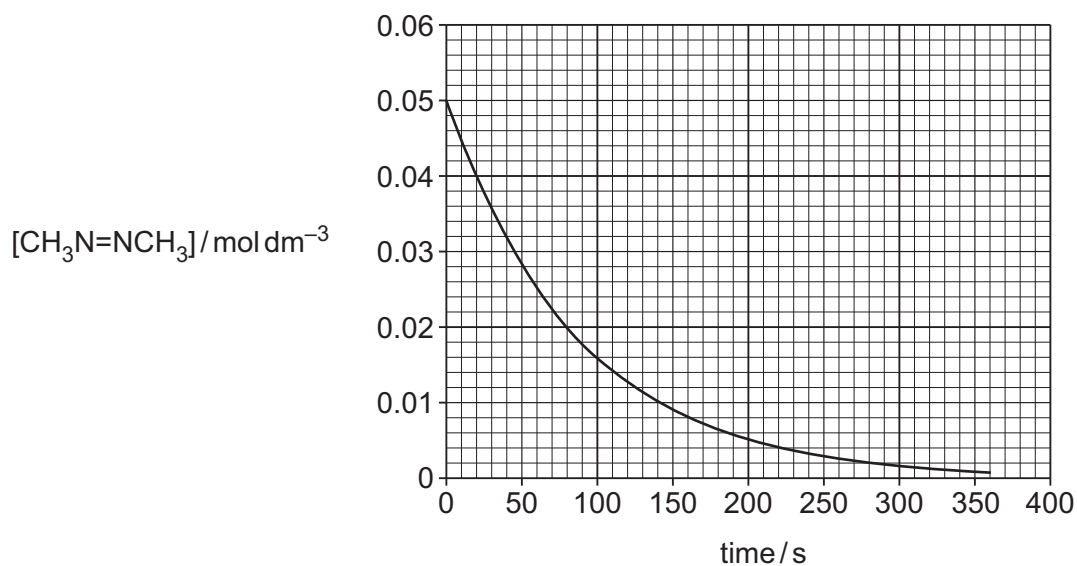


Fig. 3.1

(i) Use Fig. 3.1 to calculate **two** half-lives, $t_{1/2}$, to show that the reaction is first order.

.....

 [2]

(ii) Use your answer to (c)(i) to calculate the rate constant, k , for the decomposition of azomethane.

$k = \dots\dots\dots \text{s}^{-1}$ [1]

(d) Describe the effect of increasing temperature on the rate constant and on the rate of a reaction.

.....

 [1]

[Total: 11]



- 4 (a) Define standard cell potential, $E_{\text{cell}}^{\ominus}$. Include a description of standard conditions.

.....

 [2]

- (b) The Daniell cell is an electrochemical cell consisting of a $\text{Cu}^{2+}(\text{aq})/\text{Cu}(\text{s})$ electrode and a $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ electrode.

- (i) Draw a labelled diagram of this electrochemical cell.

Include all necessary substances and relevant pieces of apparatus needed to measure the $E_{\text{cell}}^{\ominus}$.

It is **not** necessary to state the conditions used.

[3]

- (ii) State the charge carriers that transfer current through the solutions and through the wire.

the solutions the wire [1]

- (iii) The standard electrode potential, $E^{\ominus}$, for the $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ electrode is -0.76 V .

Water is added to a standard $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ electrode.

The new concentration of $\text{Zn}^{2+}(\text{aq})$ is 0.25 mol dm^{-3} .

Use the Nernst equation to calculate the electrode potential, E , for this new $\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})$ electrode.

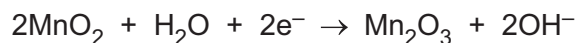
$E (\text{Zn}^{2+}(\text{aq})/\text{Zn}(\text{s})) = \dots\dots\dots \text{ V}$ [2]



- (c) An electrochemical cell consists of a ZnO/Zn electrode and a MnO₂/Mn₂O₃ electrode in an alkaline electrolyte.

The standard cell potential, $E^\ominus_{\text{cell}}$, for this cell is +1.47 V.

The half-equation at each electrode when this cell is discharging is shown.



- (i) Use this information to determine the change in oxidation state of manganese when this cell is discharging.

from to [1]

- (ii) Write the equation for the overall reaction that occurs when this cell is discharging.

..... [1]

- (iii) The $E^\ominus$ for the ZnO/Zn electrode is -1.28 V.

Calculate the standard electrode potential, $E^\ominus$, for the MnO₂/Mn₂O₃ electrode.

$E^\ominus (\text{MnO}_2/\text{Mn}_2\text{O}_3) = \dots\dots\dots \text{V}$ [1]

[Total: 11]



- 5 (a) Copper shows typical properties of transition elements, including its behaviour as a catalyst.

Complete Table 5.1 to show the total number of **unpaired** electrons in the 3d and 4s orbitals of an isolated gaseous Cu atom and a Cu^{2+} ion.

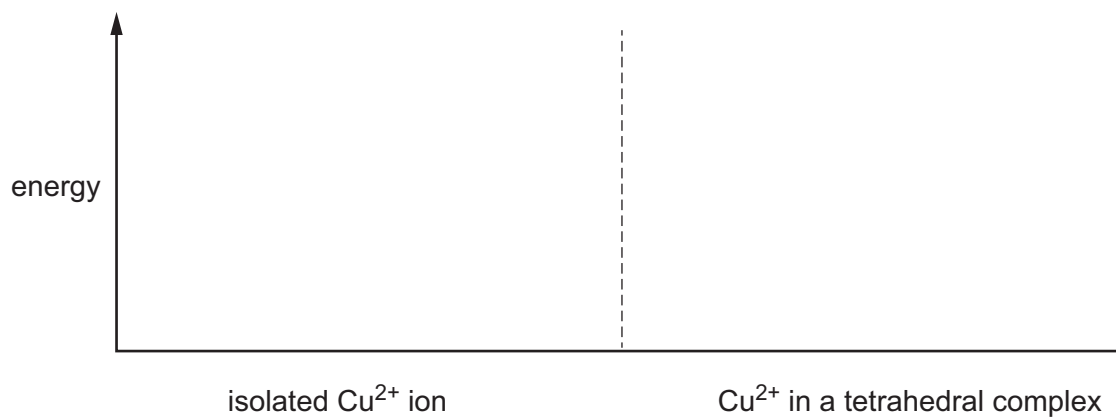
Table 5.1

species	number of unpaired electrons	
	3d	4s
Cu		
Cu^{2+}		

[1]

- (b) The 3d orbitals in an isolated Cu^{2+} ion are degenerate.

Complete the diagram to show the relative energies of the 3d orbitals in an isolated Cu^{2+} ion and in Cu^{2+} in a tetrahedral complex.



[2]

- (c) Explain why transition elements behave as catalysts.

.....

 [2]



(d) CN^- is a monodentate ligand.

Table 5.2 shows information about two complex ions that contain only CN^- ions as ligands.

Complete Table 5.2.

Table 5.2

metal ion	coordination number	formula of complex ion	charge of complex ion
Ag^+	2		
Fe^{2+}			4–

[2]

(e) The complex ion $[\text{Au}(\text{CN})_2\text{Br}_2]^-$ displays geometrical (cis/trans) isomerism.

Draw the structure of *trans*- $[\text{Au}(\text{CN})_2\text{Br}_2]^-$. State its shape and the Br-Au-Br bond angle.

shape

Br-Au-Br bond angle = ...

[2]





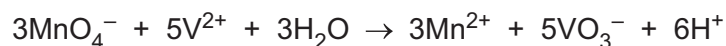
- (f) An impure sample of a vanadium(V) compound of mass 0.250 g is dissolved in aqueous acid. This solution contains VO_3^- ions.

An excess of zinc is added to this solution. All the VO_3^- ions are reduced to V^{2+} ions and Zn atoms are oxidised to Zn^{2+} ions.

The unreacted zinc is removed and the resulting solution is titrated with acidified MnO_4^- .

The end-point is reached when 22.5 cm^3 of $0.0750 \text{ mol dm}^{-3} \text{ MnO}_4^-$ is added.

A redox reaction takes place and all the V^{2+} reacts forming VO_3^- .



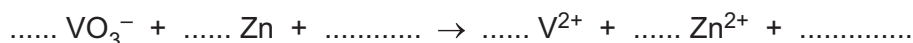
- (i) Calculate the percentage by mass of vanadium in the 0.250 g of impure sample.

Assume the impurities do not contain any vanadium ions.

Show your working.

percentage of vanadium = ... [3]

- (ii) Complete the equation for the reaction between acidified VO_3^- ions and Zn metal.



[2]

[Total: 14]





- 6 (a) Thin-layer and gas/liquid chromatography can be used to separate mixtures into their individual components.

- (i) Define the following terms used in chromatography.

R_f value

.....

retention time

.....

[2]

- (ii) Each type of chromatography makes use of a stationary phase and a mobile phase.

Complete Table 6.1 with a description of each of these.

Table 6.1

	stationary phase	mobile phase
thin-layer chromatography	X	
gas/liquid chromatography		X

[1]

- (b) A mixture of two substances **A** and **B** is analysed by thin-layer chromatography.

The R_f value of substance **A** is larger than that of substance **B**.

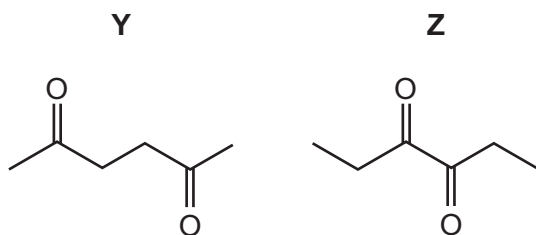
Suggest why substance **A** has a larger R_f value.

.....

..... [1]



(c) The two isomeric compounds **Y** and **Z** are analysed by proton (^1H) NMR spectroscopy.



- (i) Complete Table 6.2 to predict the number of peaks observed in the proton (^1H) NMR spectra for **Y** and **Z**.

Table 6.2

compound	number of peaks observed
Y	
Z	

[1]

- (ii) Name **all** the different splitting patterns observed in the proton (^1H) NMR spectra for **Y** and **Z**.

Y

Z

[2]

[Total: 7]



- 7 (a) State the relative acidities of bromoethanoic acid, BrCH_2COOH , chloroethanoic acid, ClCH_2COOH , ethanoic acid, CH_3COOH and ethanol, $\text{CH}_3\text{CH}_2\text{OH}$.

Explain your answer.

.....

most acidic least acidic

.....

.....

.....

.....

.....

.....

.....

[4]

- (b) Fig. 7.1 shows the reaction of methylbenzene and ethanedioic acid with KMnO_4 .

Predict the major carbon-containing product for each of these reactions.

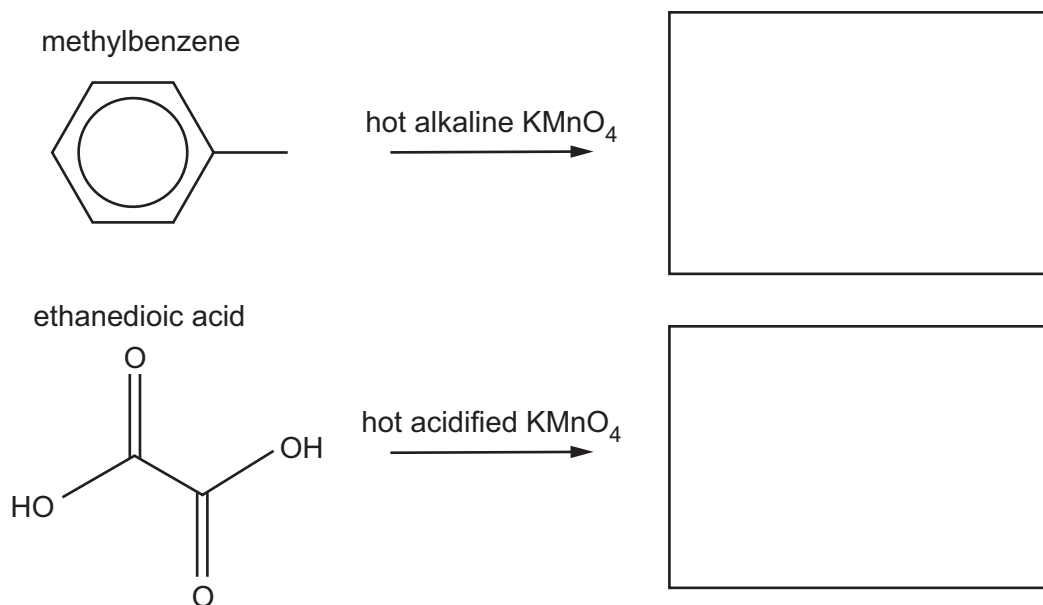


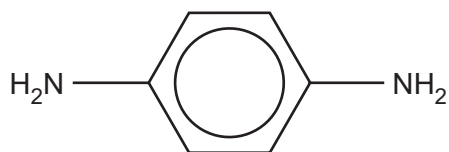
Fig. 7.1

[2]



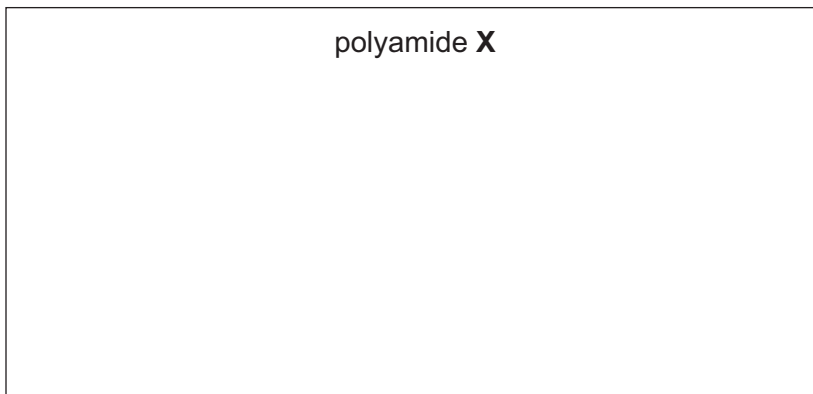
(c) Polyamide **X** can be synthesised from ethanedioic acid and benzene-1,4-diamine.

benzene-1,4-diamine



(i) Draw the repeat unit of polyamide **X** in the box.

The new functional group formed should be shown displayed.

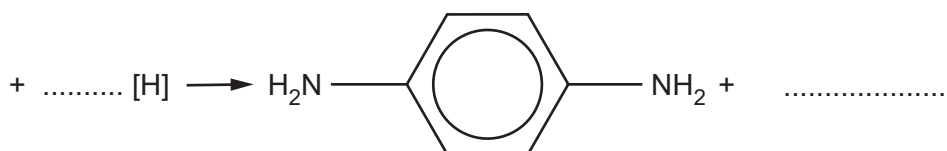
polyamide **X**

[2]

(ii) Benzene-1,4-diamine can be formed by reduction of 1,4-dinitrobenzene.

Complete the equation for this reduction.

[H] represents one atom of hydrogen from a reducing agent.



[1]



(d) Fig. 7.2 shows the two-step synthesis of the azo compound **W**.

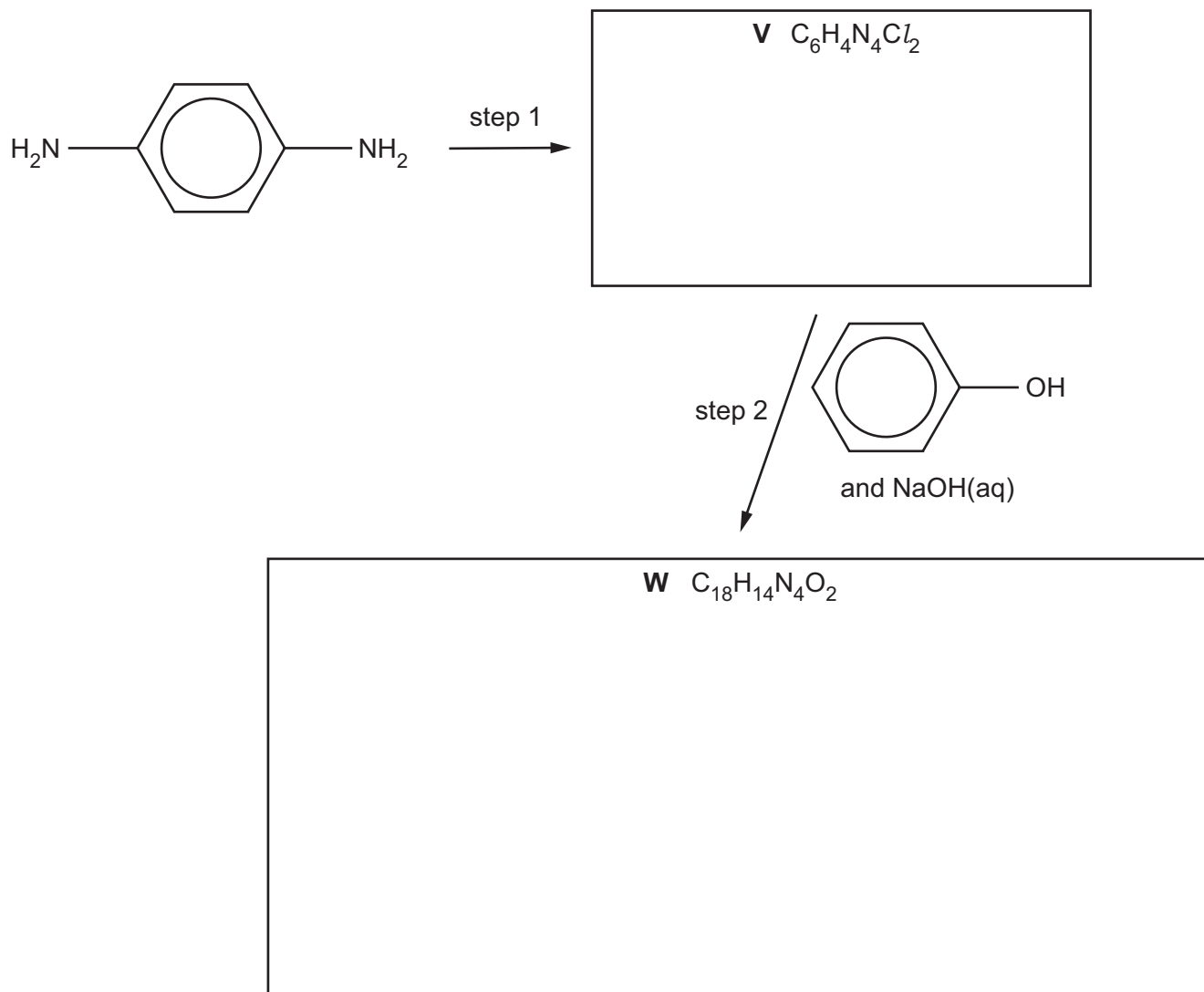


Fig. 7.2

- (i) Suggest structures for compounds **V** and **W** and draw them in the boxes in Fig. 7.2. [2]
- (ii) Give the reagents and conditions for step 1.

..... [1]

[Total: 12]





- 8 (a) In the electrophilic substitution of arenes, different substituents can direct to different ring positions.

(i) Describe the directing effect of the $-\text{NO}_2$ group. Explain your answer.

.....
 [1]

(ii) The nitration of arenes uses a mixture of concentrated HNO_3 and concentrated H_2SO_4 to generate the NO_2^+ electrophile.

Write an equation for the formation of the NO_2^+ electrophile.

..... [1]

(b) Carbon-carbon bond formation is an important reaction in organic synthesis.

Fig. 8.1 shows the synthesis of compound **Q** from benzene in two reaction steps.

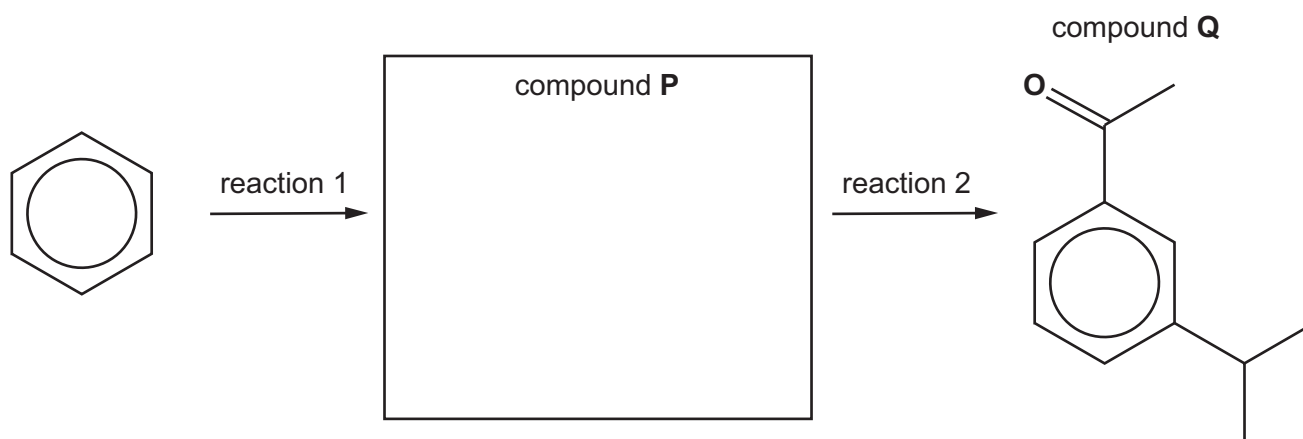


Fig. 8.1

(i) Draw the structure of compound **P** in the box in Fig. 8.1. [1]

(ii) Suggest reagents and conditions for reactions 1 and 2 in Fig. 8.1.

reaction 1

reaction 2 [2]



(c) Separate samples of $\text{C}_6\text{H}_5\text{Br}$ and $\text{C}_6\text{H}_5\text{CH}_2\text{Br}$ are added to warm $\text{AgNO}_3(\text{aq})$.

State the expected observations, if any. Explain your answer.

$\text{C}_6\text{H}_5\text{Br}$ with $\text{AgNO}_3(\text{aq})$

$\text{C}_6\text{H}_5\text{CH}_2\text{Br}$ with $\text{AgNO}_3(\text{aq})$

explanation

.....

.....

.....

[3]

(d) Acyl bromides, RCOBr , react readily with H_2O .

The mechanism of this reaction is similar to that of the reaction of H_2O with acyl chlorides, RCOCl .

(i) Name the mechanism of this reaction.

..... [1]

(ii) Complete the mechanism in Fig. 8.2 for the reaction of RCOBr with H_2O .

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

Draw the structure of the intermediate.

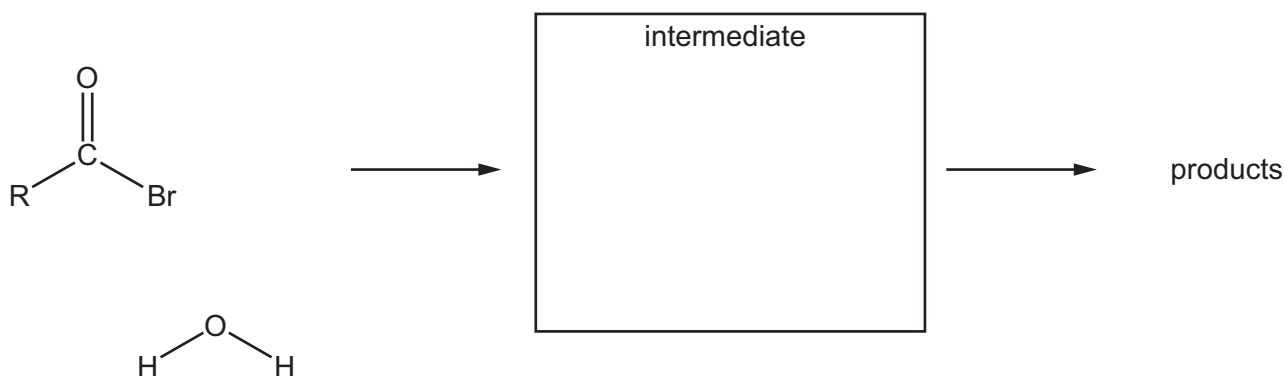


Fig. 8.2

[4]

[Total: 13]



- 9 (a) Explain why amides are much weaker bases than amines.

.....

.....

.....

..... [2]

- (b) Fig. 9.1 shows the preparation of 2-phenylethylamine, $\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NH}_2$, by three different routes.

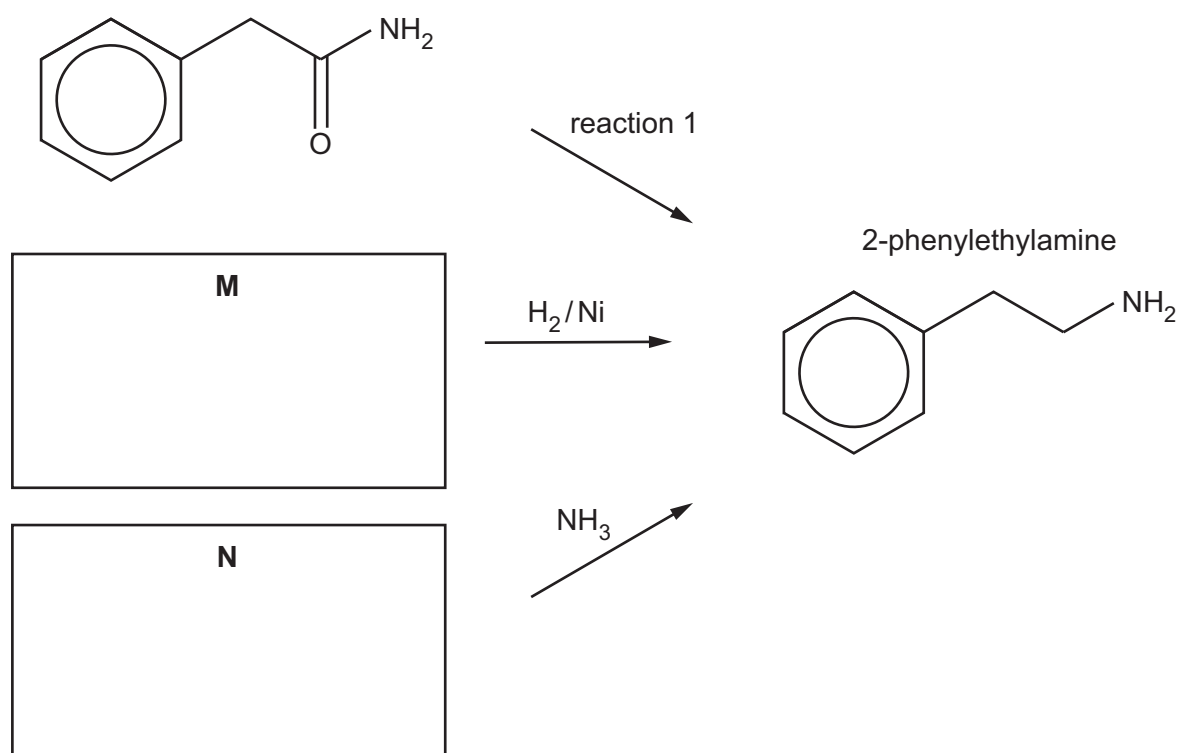


Fig. 9.1

- (i) Suggest structures for compounds **M** and **N** and draw them in the boxes in Fig. 9.1. [2]
- (ii) Give the reagents and conditions for reaction 1.

..... [1]



(c) Fig. 9.2 shows compound **H** which is a useful starting material in organic synthesis.

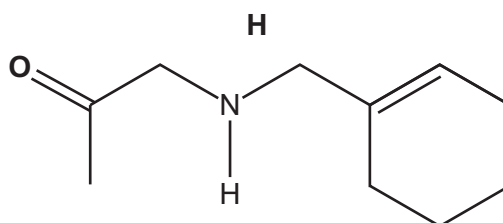


Fig. 9.2

H contains an alkene and an amine functional group.

Name the **other** functional group and give the classification of the amine group in **H**.

other functional group in **H**

classification of amine

[1]

(d) Ozonolysis involves the oxidative cleavage of a C=C bond in alkenes using ozone, O_3 , as shown in Fig. 9.3.

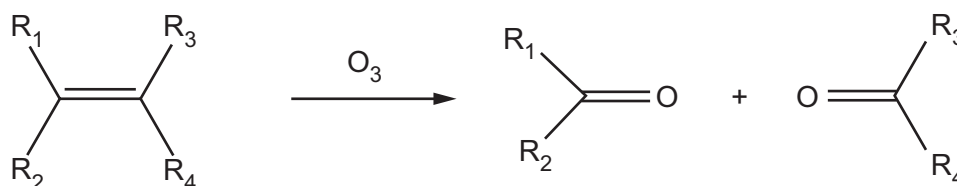


Fig. 9.3

Fig. 9.4 shows the first step in this reaction which involves the formation of an ozonide intermediate.

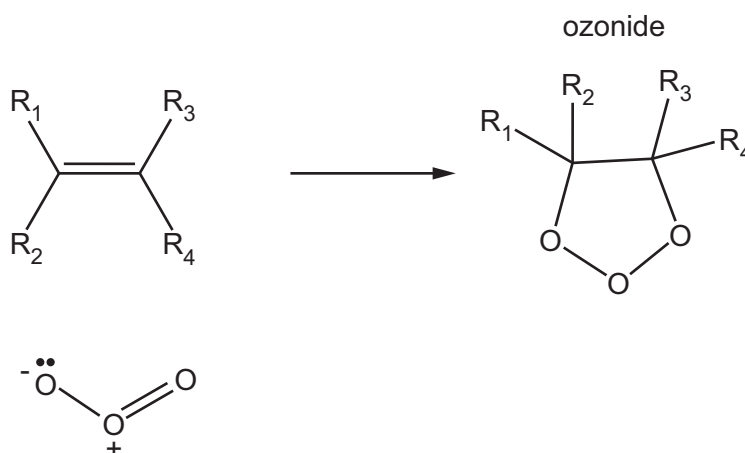


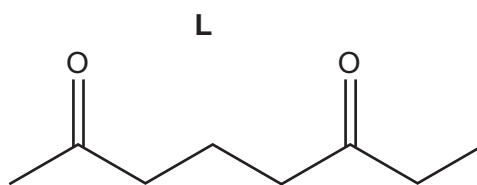
Fig. 9.4

(i) On Fig. 9.4, draw **three** curly arrows to complete the mechanism of this step.

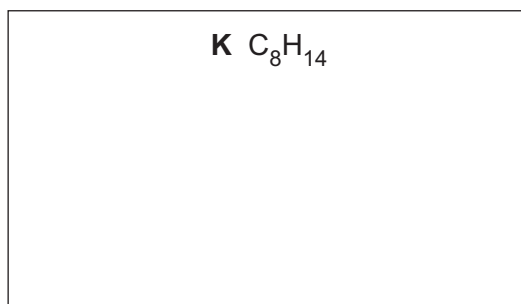
[2]



(ii) **L** is formed from alkene **K**, C_8H_{14} , by a similar reaction to that shown in Fig. 9.3.



Suggest the structure of **K**.



[1]

[Total: 9]



Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ 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	Key										13	14	15	16	17	18	
		atomic number atomic symbol name relative atomic mass										1 H hydrogen 1.0						
3 Li lithium 6.9	4 Be beryllium 9.0																	
11 Na sodium 23.0	12 Mg magnesium 24.3	3 Sc scandium 45.0	4 Ti titanium 47.9	5 V vanadium 50.9	6 Cr chromium 52.0	7 Mn manganese 54.9	8 Fe iron 55.8	9 Co cobalt 58.9	10 Ni nickel 58.7	11 Cu copper 63.5	12 Zn zinc 65.4	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	
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	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	
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 oganeson —	

lanthanoids

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.2
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	euroium	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
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	209.0
85	At	astatine	210.0
86	Rn	radon	222.0
87	Fr	francium	223.0
88	Ra	radium	226.0
89	Ac	actinium	227.0
90	Th	thorium	232.0
91	Pa	protactinium	231.0
92	U	uranium	238.0
93	Np	neptunium	237.0
94	Pu	plutonium	244.1
95	Am	americium	243.1
96	Cm	curium	247.1
97	Bk	berkelium	247.1
98	Cf	californium	251.1
99	Es	einsteinium	252.1
100	Fm	fermium	257.1
101	Md	mendelievium	258.1
102	No	nobelium	259.1
103	Lr	lawrencium	262.1

actinoids

To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced online in the Cambridge Assessment International Education Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download at www.cambridgeinternational.org after the live examination series.



Cambridge International AS & A Level

CANDIDATE
NAMECENTRE
NUMBER

--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--

CHEMISTRY**9701/44**

Paper 4 A Level Structured Questions

October/November 2025**2 hours**

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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

INFORMATION

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

This document has **24** pages.

1 (a) Define a transition element.

.....

 [1]

(b) The 3d orbitals in an isolated gaseous Cu^{2+} ion are degenerate.

(i) Define the term degenerate.

.....
 [1]

(ii) Complete the electronic configuration of Cu^{2+} .

$1s^2$ [1]

(c) (i) State the colours of the aqueous solutions for the **two** copper(II) complex ions shown.

- $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq})$
- $[\text{CuCl}_4]^{2-}(\text{aq})$ [1]

(ii) Explain why aqueous complex ions of transition elements are usually coloured.

.....

 [3]

(d) (i) When an excess of $\text{NH}_3(\text{aq})$ is added to a solution of $[\text{CuCl}_4]^{2-}(\text{aq})$, $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq})$ is formed.

State the type of reaction.

Complete the equation for this reaction. State symbols are **not** required.

type of reaction

equation

$[\text{CuCl}_4]^{2-} + \dots \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + \dots$ [2]



- (ii) The $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion shows stereoisomerism.

Complete the three-dimensional diagrams in Fig. 1.1 to show the **two** different stereoisomers of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$.

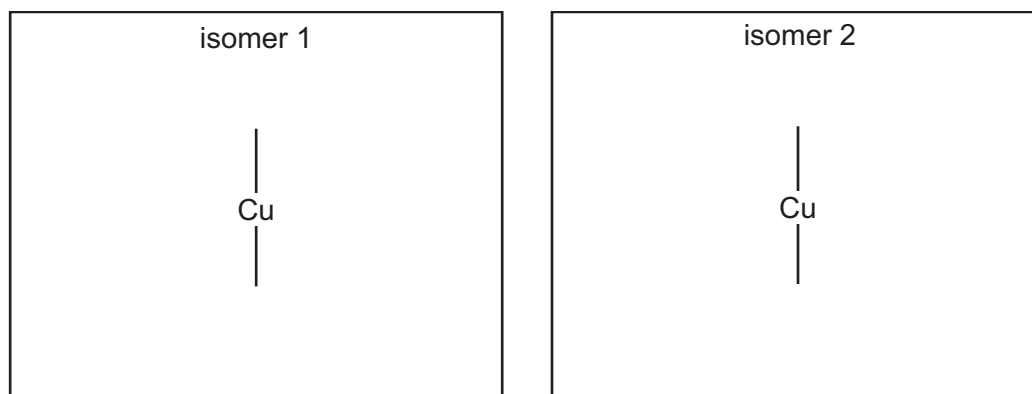


Fig. 1.1

[2]

- (iii) Deduce which stereoisomer in (d)(ii) is polar.

Explain your answer.

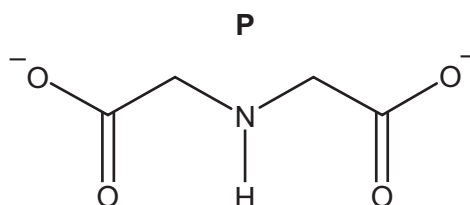
polar isomer

explanation

.....

[1]

- (e) The dianion **P** can act as a tridentate ligand.



- (i) Suggest how **P** can form **three** dative covalent bonds.

.....

.....

..... [1]

- (ii) 2 moles of dianion **P**, $\text{C}_4\text{H}_5\text{NO}_4^{2-}$, react with 1 mole of aqueous cobalt(III) ions, $[\text{Co}(\text{H}_2\text{O})_6]^{3+}$ to form 1 mole of complex ion **Q**.

Deduce the formula and charge of **Q**.

..... [1]



(f) Table 1.1 shows values for the stability constants, K_{stab} , of some silver(I) complexes.

Table 1.1

complex	value of K_{stab}
$[\text{Ag}(\text{CN})_2]^{-}(\text{aq})$	1.1×10^{18}
$[\text{Ag}(\text{NH}_3)_2]^{+}(\text{aq})$	1.2×10^7
$[\text{Ag}(\text{S}_2\text{O}_3)_2]^{3-}(\text{aq})$	2.9×10^{13}

(i) Define the stability constant of a complex.

.....

 [1]

(ii) Use the information in Table 1.1 to identify the most stable silver(I) complex.

Explain your answer.

most stable
 explanation
 [1]

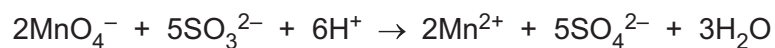


(g) Sodium sulfite, Na_2SO_3 , is used as a food preservative.

A 3.75 g sample of impure Na_2SO_3 is dissolved in distilled water and made up to 250 cm^3 in a volumetric flask.

10.0 cm^3 of this solution requires 18.70 cm^3 of acidified $0.0150\text{ mol dm}^{-3}$ MnO_4^- (aq) to reach the end-point.

The equation for the reaction is shown.



Calculate the percentage by mass of Na_2SO_3 in the sample.

percentage by mass of Na_2SO_3 = ... [3]

[Total: 19]



- 2 (a) The Group 2 sulfates and the Group 2 chromates show similar trends in solubility.

Suggest the trend in the solubility of the Group 2 chromates down the group.

Explain your answer.

.....

.....

.....

.....

.....

..... [4]

- (b) Silver(I) chromate, Ag_2CrO_4 , is sparingly soluble in water.

- (i) Write an ionic equation to show the equilibrium between solid Ag_2CrO_4 and its aqueous solution.

Include state symbols.

..... [1]

- (ii) The value of the solubility product, K_{sp} , of Ag_2CrO_4 is 1.12×10^{-12} at 298 K.

Calculate the equilibrium concentration of Ag^+ , in mol dm^{-3} , in a saturated solution of Ag_2CrO_4 at 298 K.

equilibrium concentration of Ag^+ = ... mol dm^{-3} [3]



(c) The hydrogenchromate ion, HCrO_4^- , is a weak acid. The $\text{p}K_{\text{a}}$ of HCrO_4^- is 6.49.

(i) Calculate the pH of a $0.0250 \text{ mol dm}^{-3}$ HCrO_4^- solution.

pH = ... [2]

(ii) HCrO_4^- can show amphoteric behaviour.

State the formula of:

- the conjugate acid of HCrO_4^-
- the conjugate base of HCrO_4^- [1]



(d) Table 2.1 shows some energy changes.

Table 2.1

energy change	value / kJ mol^{-1}
first ionisation energy of silver	+731
second ionisation energy of silver	+2074
first ionisation energy of sulfur	+1000
second ionisation energy of sulfur	+2251
first electron affinity of sulfur	-200
second electron affinity of sulfur	+532
enthalpy change of atomisation of sulfur	+279
enthalpy change of formation of silver(I) sulfide, $\text{Ag}_2\text{S}(\text{s})$	-33
lattice energy of silver(I) sulfide, $\text{Ag}_2\text{S}(\text{s})$	-2677

(i) Define the term first electron affinity.

.....

 [1]

(ii) Explain why the value for the second electron affinity of sulfur is positive.

.....

 [1]

(iii) Construct an equation for the lattice energy of Ag_2S .

Include state symbols.

..... [1]



- (iv) Calculate the enthalpy change of atomisation, ΔH_{at} , in kJ mol^{-1} , of silver using relevant data from Table 2.1.

It may be helpful to draw a labelled Born–Haber cycle.

Show your working.

ΔH_{at} of silver = ... kJ mol^{-1} [3]

- (e) Suggest how the magnitude for the lattice energy of $\text{Ag}_2\text{S(s)}$ differs from the lattice energy of $\text{Cu}_2\text{S(s)}$.

Explain your answer.

.....

 [1]

[Total: 18]



3 (a) Define the term entropy.

.....
 [1]

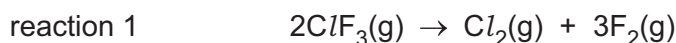
(b) (i) Place **one** tick (✓) in each row of Table 3.1 to show the sign of the entropy change, ΔS , for each process.

Table 3.1

process	ΔS is negative	ΔS is positive
steam condensing into water		
solid KCl dissolving in water		

[1]

(ii) Chlorine trifluoride, ClF_3 , decomposes on heating into its elements, as shown.



Standard entropies are shown in Table 3.2.

Table 3.2

substance	$\text{ClF}_3(\text{g})$	$\text{Cl}_2(\text{g})$	$\text{F}_2(\text{g})$
$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$	+281.6	+223.1	+203.0

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

$\Delta S^\ominus$ for reaction 1 = ... $\text{JK}^{-1} \text{mol}^{-1}$ [2]

(c) Group 2 carbonates decompose on heating. The decomposition for one of the Group 2 carbonates, MCO_3 , is shown in reaction 2.



(i) Predict the sign of the entropy change, ΔS , for reaction 2.

Explain your answer.

.....
 [1]



(ii) The Gibbs equation is shown.

$$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$$

Fig. 3.1 shows values of the Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1} , at different temperatures, T , in K, for reaction 2.

Assume $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$ values for this reaction remain constant over this temperature range.

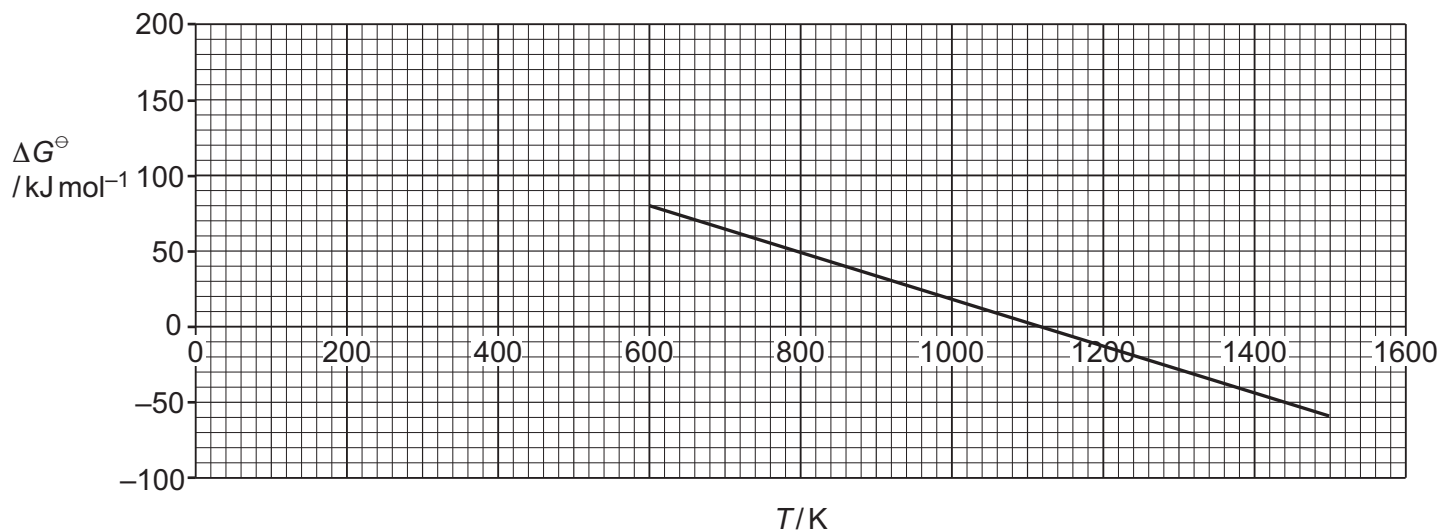


Fig. 3.1

Use the gradient and intercept on the y-axis in Fig. 3.1 and the Gibbs equation to determine:

- $\Delta S^{\ominus}$, in $\text{J K}^{-1} \text{mol}^{-1}$, for reaction 2
- the minimum temperature, T , in K, at which the reaction is feasible
- $\Delta H^{\ominus}$, in kJ mol^{-1} , for reaction 2.

$\Delta S^{\ominus}$ for reaction 2 = ... $\text{J K}^{-1} \text{mol}^{-1}$

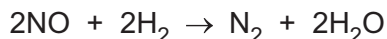
minimum temperature, T = ... K

$\Delta H^{\ominus}$ for reaction 2 = ... kJ mol^{-1}
[4]



- 4 (a) Nitrogen monoxide, NO, reacts with hydrogen, as shown in reaction 3.

reaction 3



- (i) The rate equation for reaction 3 is shown.

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

Complete Table 4.1.

Table 4.1

the order of reaction with respect to $[\text{H}_2]$	
the order of reaction with respect to $[\text{NO}]$	
the overall order of the reaction	

[1]

- (ii) Predict how the initial rate for reaction 3 changes when the concentration of NO is halved.

..... [1]

- (iii) Predict how the initial rate for reaction 3 changes when the concentrations of NO and H_2 are both increased **three** times.

..... [1]

- (iv) Suggest why reaction 3 is unlikely to proceed by a mechanism involving only a single step.

..... [1]

- (v) Suggest equations for the **three** steps of the reaction mechanism for reaction 3.

Each step involves a reaction between **two** molecules.

step 1 $\rightarrow$

step 2 + ... $\rightarrow \text{N}_2\text{O} +$

step 3 $\text{N}_2\text{O} +$ $\rightarrow$ + ...

[2]

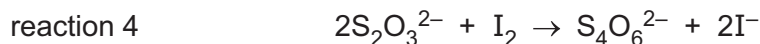
- (vi) Suggest the role of N_2O in this mechanism.

Explain your reasoning.

..... [1]



- (b) Iodine, I_2 , reacts with thiosulfate ions, $S_2O_3^{2-}$, as shown in reaction 4.



Reaction 4 is carried out in the presence of a large excess of I_2 . Under these conditions, the reaction is first order with respect to $[S_2O_3^{2-}]$ and zero order with respect to $[I_2]$.

The half-life, $t_{\frac{1}{2}}$, for reaction 4 is 720 s under certain conditions.

Calculate the value of the rate constant, k , for reaction 4. Include the units of k .

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

- (c) The reaction between iodide ions, $I^-(aq)$, and peroxydisulfate ions, $S_2O_8^{2-}(aq)$, is catalysed by $Co^{3+}(aq)$. The mechanism is similar to the mechanism of this reaction when $Fe^{3+}(aq)$ is used as the catalyst.

- (i) State the type of catalysis that occurs in this reaction.

Explain your reasoning.

$\dots\dots\dots$
 $\dots\dots\dots$ [1]

- (ii) Write **two** equations to show how $Co^{3+}(aq)$ catalyses this reaction.

equation 1 $\dots\dots\dots$
 equation 2 $\dots\dots\dots$ [2]

- (iii) Suggest why this reaction is slow in the absence of $Co^{3+}(aq)$.

$\dots\dots\dots$
 $\dots\dots\dots$ [1]

[Total: 12]



5 (a) Describe and explain the shape of benzene.

In your answer, include:

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

.....

.....

.....

.....

.....

.....

.....

.....

..... [4]

(b) Fig. 5.1 shows two reactions of benzoic acid.

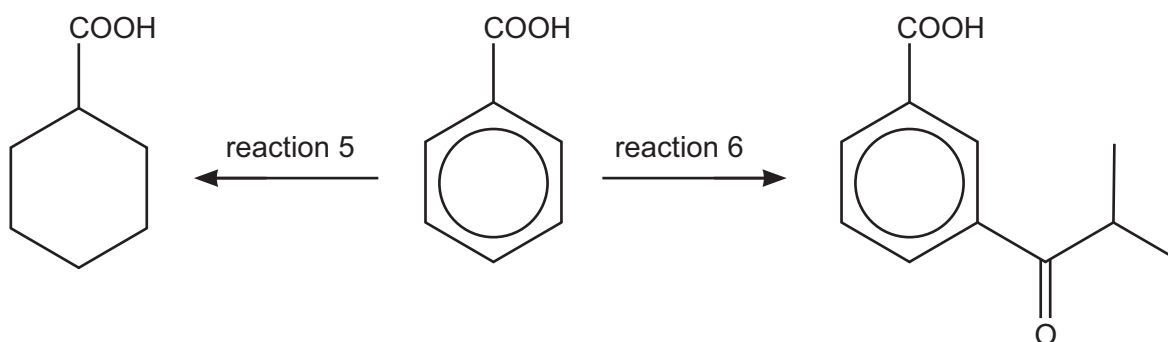


Fig. 5.1

(i) Suggest reagents and conditions for reaction 5 and for reaction 6 in Fig. 5.1.

reaction 5

reaction 6

[2]

(ii) State the type of reaction for reaction 5 in Fig. 5.1.

..... [1]



(c) In the electrophilic substitution of arenes, different substituents can direct to different ring positions.

(i) Describe the directing effect of the $-\text{CH}_2\text{CH}_3$ group.

Explain your answer.

.....
 [1]

(ii) The alkylation of arenes uses a mixture of $\text{CH}_3\text{CH}_2\text{Br}$ and FeBr_3 to generate the CH_3CH_2^+ electrophile.

Write an equation for the formation of the CH_3CH_2^+ electrophile.

..... [1]

(iii) Complete the mechanism in Fig. 5.2.

Include all relevant curly arrows and charges. Draw the structure of the organic intermediate.

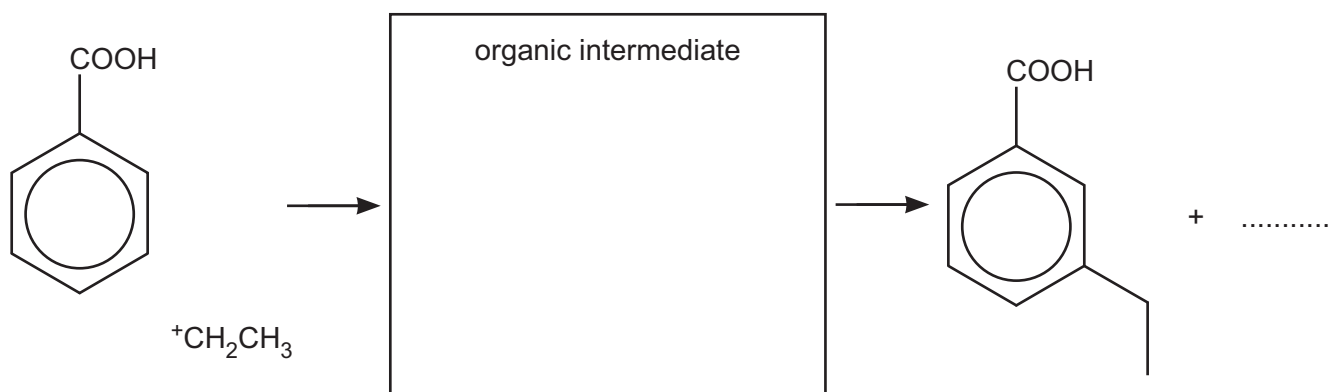


Fig. 5.2

[3]

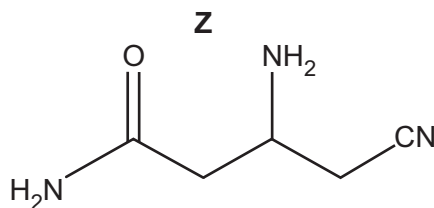
(iv) Write an equation to show how FeBr_3 is regenerated after the reaction in Fig. 5.2.

..... [1]

[Total: 13]



- 6 (a) Compound **Z** is used in organic synthesis.



Complete Table 6.1 to show the number of sp , sp^2 and sp^3 hybridised carbon atoms present in one molecule of **Z**.

Table 6.1

type of hybridisation	sp	sp^2	sp^3
number of carbon atoms			

[1]

- (b) **Z** can undergo different reactions, as shown in Fig. 6.1.

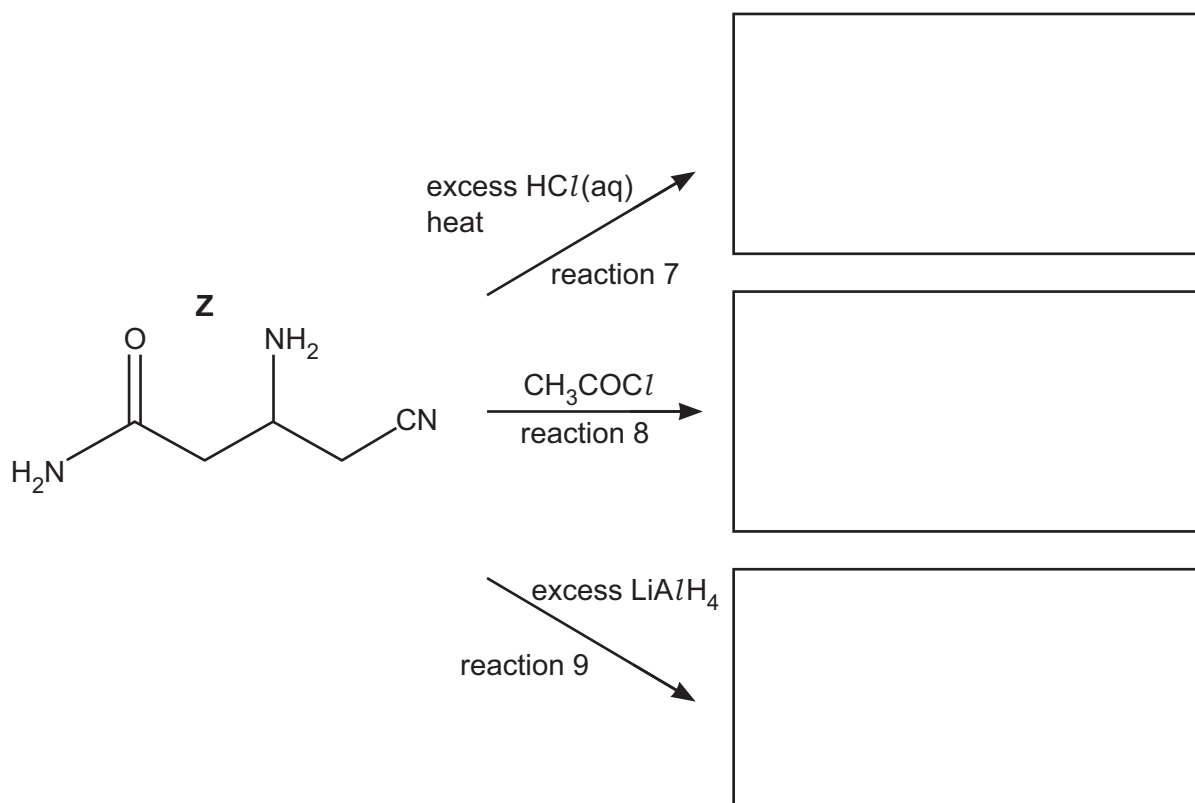


Fig. 6.1

- (i) Name the **two** types of reaction occurring in reaction 7 in Fig. 6.1.

..... and [1]

- (ii) Draw the structures of the organic products of reactions 7, 8 and 9 in Fig. 6.1.

[4]



(c) Compound **Z** is dissolved in D_2O and analysed by carbon-13 NMR and proton (^1H) NMR spectroscopy.

(i) Predict the number of peaks in the carbon-13 NMR spectrum of **Z**.

..... [1]

(ii) The proton (^1H) NMR spectrum of **Z** in D_2O gives three peaks for the proton environments, labelled **a**, **b** and **c**, as shown on Fig. 6.2.

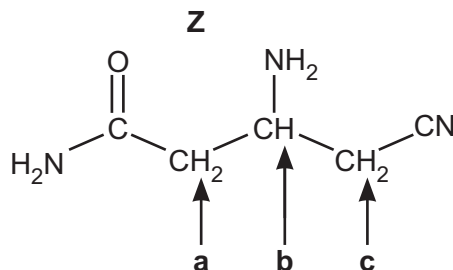


Fig. 6.2

Complete Table 6.2 for the proton (^1H) NMR spectrum of **Z** in D_2O .

Table 6.2

proton environment	a	b	c
name of splitting pattern			
chemical shift range, δ /ppm			

[2]

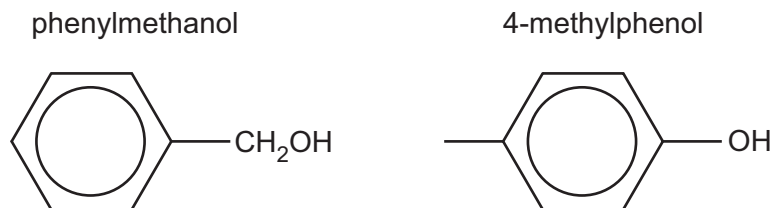
Table 6.3

environment of proton	example	chemical shift range, δ /ppm
alkane	$-CH_3$, $-CH_2-$, $>CH-$	0.9–1.7
alkyl next to $C=O$	$CH_3-C=O$, $-CH_2-C=O$, $>CH-C=O$	2.2–3.0
alkyl next to nitrile	$-CH_2-CN$	2.0–3.0
alkyl next to electronegative atom	CH_3-O , $-CH_2-O$, $-CH_2-N$	3.2–4.0
attached to alkene	$=CHR$	4.5–6.0
alkyl amine	$R-NH-$	1.0–5.0
amide	$RCONHR$	5.0–12.0

[Total: 9]



7 Phenylmethanol and 4-methylphenol are isomers.



(a) Complete Table 7.1 to show the relative acidities of benzoic acid ($\text{C}_6\text{H}_5\text{COOH}$), phenylmethanol, 4-methylphenol and water.

Explain your answer.

Table 7.1

	name of compound
most acidic	
least acidic	

explanation

.....

.....

.....

.....

.....

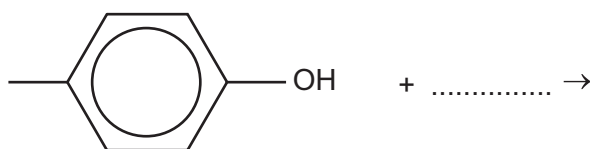
.....

.....

[4]

(b) 4-methylphenol reacts readily with sodium.

Complete the equation for this reaction.



[1]



- (c) Under certain conditions, ethane-1,2-diol, $\text{HOCH}_2\text{CH}_2\text{OH}$, reacts with propane-1,3-dioic acid, $\text{HOOCCH}_2\text{COOH}$, to form different organic products, as shown in Fig. 7.1.

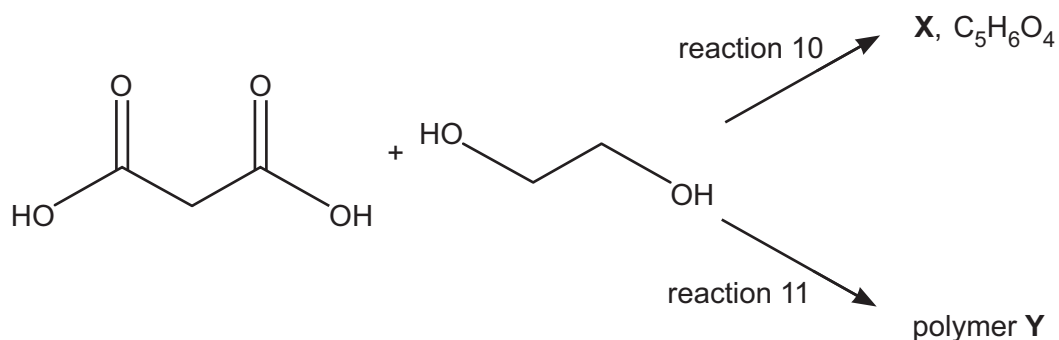


Fig. 7.1

- (i) **X** does **not** react with Na metal.

Draw the structure of the organic product **X**, $\text{C}_5\text{H}_6\text{O}_4$, shown in Fig. 7.1.

[1]

- (ii) Reactions 10 and 11 in Fig. 7.1 are different types of reaction.

Name the type of reaction for reaction 10 and for reaction 11.

reaction 10

reaction 11

[1]

- (iii) Draw a section of polymer **Y** showing only **one** repeat unit.

The new functional group formed should be displayed.

[2]



- 8 (a) Describe the difference in reactivity between ethanoyl chloride and chlorobenzene with water.

Explain your answer.

.....

.....

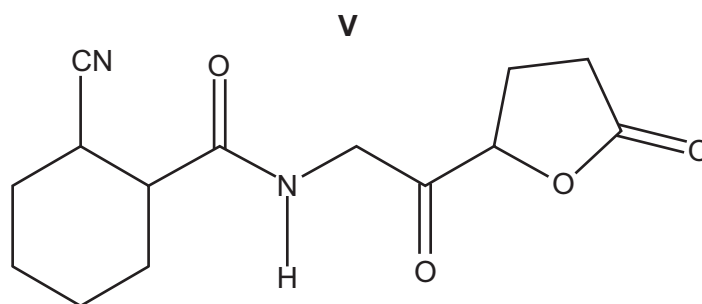
.....

.....

.....

..... [2]

- (b) The structure of compound **V** is shown.



- (i) Name all the functional groups in **V**.

.....

.....

..... [2]

- (ii) Deduce the number of possible optical isomers for **V**.

..... [1]

- (iii) Suggest **one** reason, other than better biological activity and lower dosage required, why it is beneficial to synthesise a single optical isomer of **V** for use as a drug.

.....

.....

..... [1]



(c) A sample of **V** is hydrolysed with an excess of hot aqueous alkali.

The products are isolated from the reaction mixture at pH 12.

Draw the structures of the **two** organic products of the **complete** alkaline hydrolysis of **V** in Fig. 8.1.

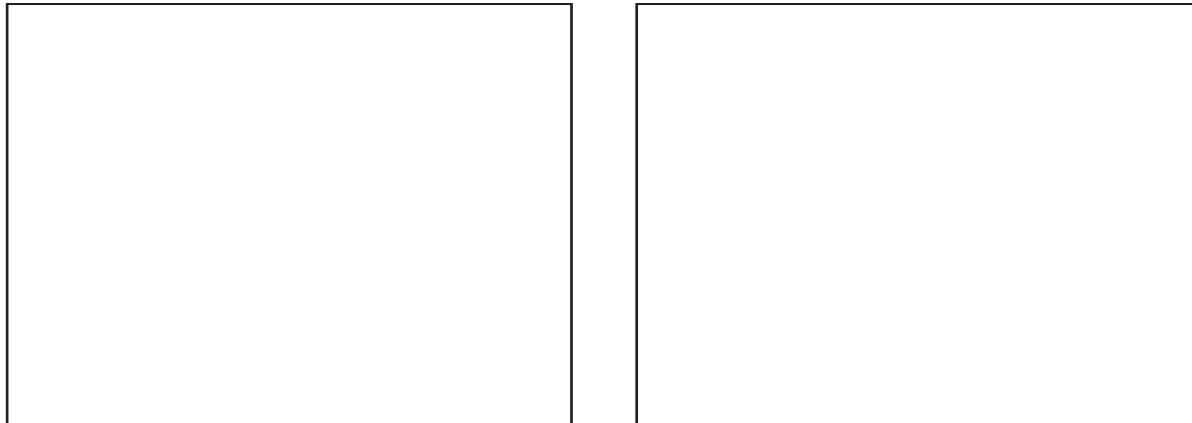


Fig. 8.1

[3]



- (d) A polypeptide formed from four amino acids, **A**, **B**, **C** and **D**, is completely hydrolysed and then analysed by gas–liquid chromatography.

The chromatogram produced is shown in Fig. 8.2.

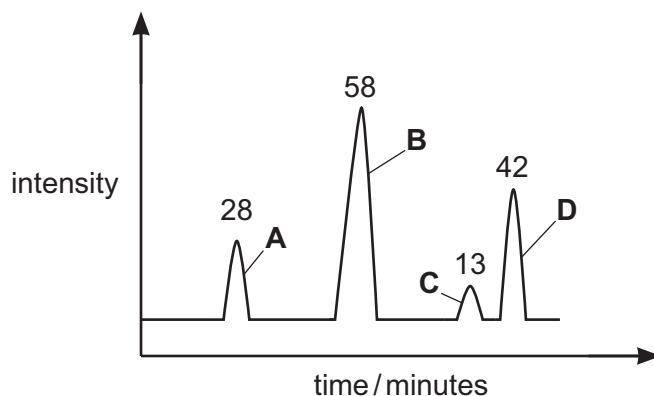


Fig. 8.2

The number above each peak represents the area under the peak.

The area under each peak is proportional to the mass of the respective amino acid in the mixture.

- (i) Calculate the percentage by mass of amino acid **A** in the original mixture.

percentage by mass of amino acid **A** = ... [1]

- (ii) The retention time for amino acid **D** is the longest.

Explain why **D** has a longer retention time than the **other** amino acids **A**, **B** and **C**.

.....

 [1]

[Total: 11]



Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ 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	Key												13	14	15	16	17	18								
		atomic number atomic symbol name relative atomic mass												1 H hydrogen 1.0							2 He helium 4.0						
3 Li lithium 6.9	4 Be beryllium 9.0																										
11 Na sodium 23.0	12 Mg magnesium 24.3																										
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 oganeson —									

Key

atomic number

atomic symbol

name

relative atomic mass

lanthanoids

actinoids

57	La	lanthanum	138.9	58	Ce	cerium	140.1	59	Pr	praseodymium	140.9	60	Nd	neodymium	144.2	61	Pm	promethium	—	62	Sm	samarium	150.4	63	Eu	europlum	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
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	merendelevium	—	102	No	nobelium	—	103	Lr	lawrencium	—

To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced online in the Cambridge Assessment International Education Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download at www.cambridgeinternational.org after the live examination series.

