



Cambridge International AS & A Level

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CHEMISTRY

9701/42

Paper 4 A Level Structured Questions

May/June 2026
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. Do **not** use correction fluid or tape.
- 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.

- 1 (a) (i) Transition elements have variable oxidation states and form complex ions.

State **two** other typical chemical properties of a transition element.

- 1
- 2 [1]

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

.....

.....

..... [1]

- (b) An aqueous solution of chromium(III) ions, Cr^{3+} , contains the $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ complex ion.

- (i) Complete Figure 1.1 to show the electronic configuration for Cr^{3+} .

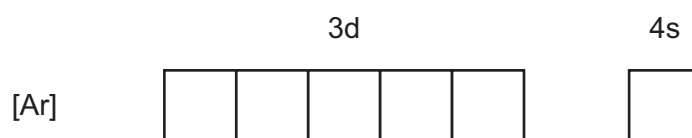


Figure 1.1

[1]

- (ii) State the type of bonding that exists between H_2O and Cr^{3+} in $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$.

..... [1]

- (c) Explain why transition elements form complex ions.

.....

.....

..... [1]

- (d) $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ can be converted into the $[\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3]$ complex.

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

reagent

type of reaction [1]



- (ii) $[\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3]$ reacts with an excess of $\text{NH}_3(\text{aq})$ to form $[\text{Cr}(\text{NH}_3)_6]^{3+}$.

Complete the equation for this reaction. State the type of reaction.



type of reaction $\dots\dots\dots$

[2]

- (e) $[\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3]$ shows stereoisomerism.

Draw three-dimensional diagrams in Figure 1.2 to suggest the **two** stereoisomers of $[\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3]$.

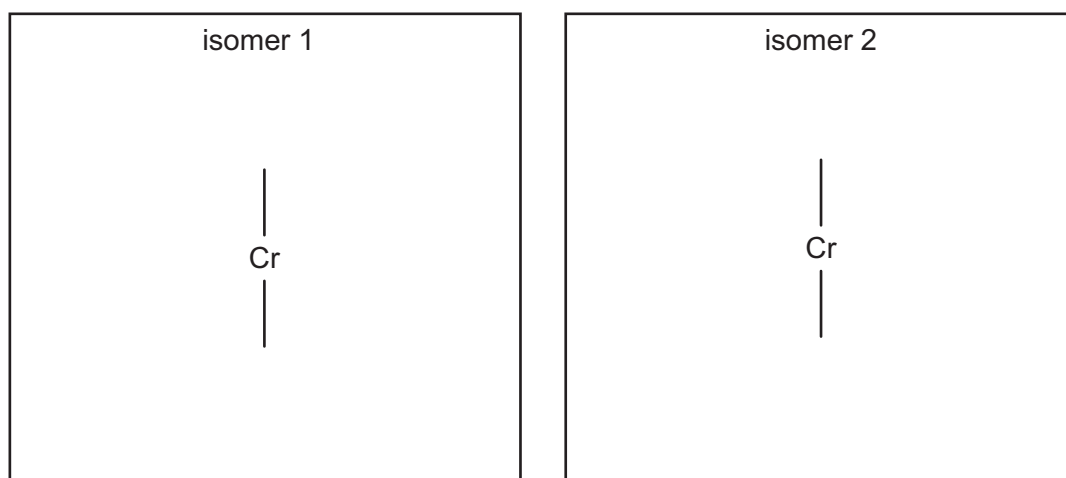


Figure 1.2

[2]

- (f) (i) An aqueous solution of iron(III) ions, Fe^{3+} , contains the $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ complex ion. This solution is acidic in a similar way to an aqueous solution of Al^{3+} .

Suggest why a solution of Fe^{3+} is acidic. Include an equation in your answer.

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

- (ii) An aqueous solution of iron(II) ions, Fe^{2+} , contains the $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ complex ion. This solution is also acidic.

Predict how the pH of $1.00 \text{ mol dm}^{-3} \text{ Fe}^{2+}(\text{aq})$ differs from the pH of $1.00 \text{ mol dm}^{-3} \text{ Fe}^{3+}(\text{aq})$. Explain your answer.

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

- (g) Suggest why solutions of silver(I) salts are colourless.

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

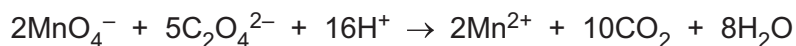


- (h) A mixture contains sodium ethanedioate, $\text{Na}_2\text{C}_2\text{O}_4$, ethanedioic acid dihydrate, $\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$, and an unreactive solid.

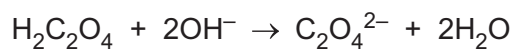
5.00 g of this mixture is dissolved in distilled water and made up to 500 cm^3 in a volumetric flask to form solution **A**.

Two different titration experiments are carried out using **A**.

In the first experiment, 25.0 cm^3 of **A** requires 21.80 cm^3 of acidified $0.0250\text{ mol dm}^{-3}$ MnO_4^- (aq) to reach the end-point.



In the second experiment, 25.0 cm^3 of **A** requires 13.60 cm^3 of 0.150 mol dm^{-3} OH^- (aq) to reach the end-point.



Calculate the percentage by mass of $\text{Na}_2\text{C}_2\text{O}_4$ in the mixture.

$[M_r: \text{Na}_2\text{C}_2\text{O}_4, 134.0]$

percentage by mass of $\text{Na}_2\text{C}_2\text{O}_4 = \dots\dots\dots\%$ [5]

[Total: 20]

- 2 Group 2 carbonates decompose on heating to form the corresponding metal oxide and carbon dioxide.

- (a) The mechanism for this decomposition involves the carbonate ion breaking down to form carbon dioxide and oxide ions.

Add **two** curly arrows to the carbonate ion in Figure 2.1 to suggest a mechanism for this decomposition.

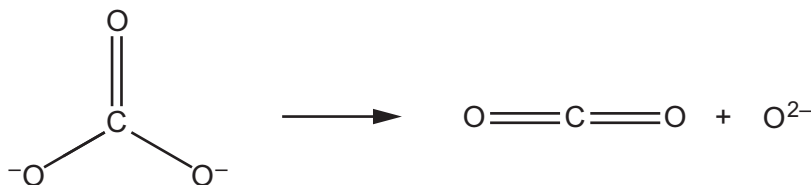


Figure 2.1

[1]

- (b) The radii of some cations are shown in Table 2.1.

Table 2.1

cation	Ca ²⁺	Cu ²⁺	Pb ²⁺
radius/nm	0.099	0.073	0.120

Use the data in Table 2.1 to predict the trend in thermal stability of the metal carbonates containing these cations.

Explain your answer.

..... > >
 most stable least stable

explanation

.....

.....

.....

.....

[2]



(c) Suggest why the solubility of the Group 2 sulfates decreases down the group.

.....

.....

.....

.....

.....

..... [3]

(d) Magnesium hydroxide, $\text{Mg}(\text{OH})_2$, is sparingly soluble in water at 298 K.

(i) Write the expression for the solubility product, K_{sp} , of $\text{Mg}(\text{OH})_2$. State the units for K_{sp} .

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

units [2]

(ii) A saturated solution of $\text{Mg}(\text{OH})_2$ has a pH of 10.35 at 298 K.

Calculate the concentration of hydroxide ions, OH^- , in mol dm^{-3} , in this solution.

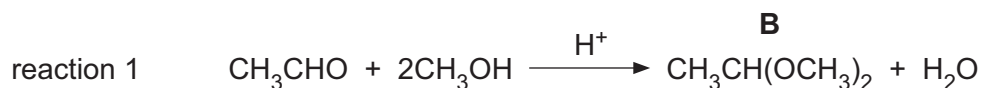
concentration of OH^- = mol dm^{-3} [1]

(iii) Use your answers to **2(d)(i)** and **2(d)(ii)** to calculate the value of K_{sp} for $\text{Mg}(\text{OH})_2$.

K_{sp} for $\text{Mg}(\text{OH})_2$ = [1]

[Total: 10]

- 3 (a) Ethanal, CH_3CHO , reacts with methanol, CH_3OH , under acidic conditions to form compound **B**, as shown in reaction 1.



The initial rate of reaction is investigated using different starting concentrations of CH_3CHO , CH_3OH and H^+ . The results obtained are shown in Table 3.1.

Table 3.1

experiment	$[\text{CH}_3\text{CHO}]$ $/\text{mol dm}^{-3}$	$[\text{CH}_3\text{OH}]$ $/\text{mol dm}^{-3}$	$[\text{H}^+]$ $/\text{mol dm}^{-3}$	initial rate $/\text{mol dm}^{-3} \text{s}^{-1}$
1	0.500	0.040	0.100	2.500×10^{-3}
2	0.500	0.060	0.100	3.750×10^{-3}
3	0.250	0.120	0.300	1.125×10^{-2}
4	0.250	0.120	0.400	1.500×10^{-2}

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

Explain your reasoning. State clearly which experiments you use in your explanation.

.....

.....

.....

.....

.....

.....

.....

.....

rate =

[4]

- (ii) State the units of the rate constant, k , for this reaction.

..... [1]



(iii) Another experiment to investigate reaction 1 is carried out as shown in Table 3.2.

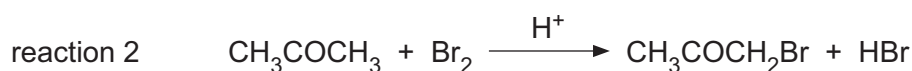
Table 3.2

experiment	$[\text{CH}_3\text{CHO}]/\text{mol dm}^{-3}$	$[\text{CH}_3\text{OH}]/\text{mol dm}^{-3}$	$[\text{H}^+]/\text{mol dm}^{-3}$
5	0.250	0.250	0.250

Calculate the initial rate of experiment 5.

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

- (b) The reaction of propanone, CH_3COCH_3 , with bromine, Br_2 , in the presence of an acid catalyst is shown in reaction 2.



The rate of reaction is first order with respect to $[\text{CH}_3\text{COCH}_3]$ and first order with respect to $[\text{H}^+]$ under certain conditions.

A three-step mechanism for reaction 2 is suggested.

Complete Table 3.3 to suggest steps 1 and 3 of the mechanism.

Table 3.3

step 1 (fast)	
step 2 (slow)	$\begin{array}{c} \text{OH}^+ \\ \\ \text{H}_3\text{C}-\text{C}-\text{CH}_3 \end{array} \longrightarrow \begin{array}{c} \text{OH} \\ \\ \text{H}_3\text{C}-\text{C}=\text{CH}_2 \end{array} + \text{H}^+$
step 3 (fast)	

[2]



(c) Catalysts can be described as homogeneous or heterogeneous.

Describe the mode of action of a heterogeneous catalyst.

.....

.....

.....

..... [2]

[Total: 10]



- 4 (a) State what is meant by partition coefficient, K_{pc} .

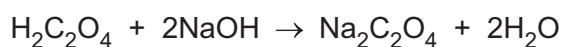
.....

 [1]

- (b) Ethanedioic acid, $H_2C_2O_4$, is more soluble in water than in the organic solvent ethoxyethane.

2.70 g of ethanedioic acid is shaken with a mixture of 50 cm^3 of ethoxyethane and 50 cm^3 of water at 298 K and left until there is no further change in concentrations.

The ethoxyethane layer requires 16.5 cm^3 of 0.200 mol dm^{-3} NaOH(aq) for complete neutralisation.



Calculate the partition coefficient, K_{pc} , for ethanedioic acid between ethoxyethane and water.

$$K_{pc} = \dots\dots\dots [3]$$

- (c) The formula of ethanedioic acid is $HOOC-COOH$.

The formula of butanedioic acid is $HOOCCH_2CH_2COOH$.

Both acids are soluble in ethoxyethane and in water.

Suggest how the value of K_{pc} of butanedioic acid between ethoxyethane and water compares to the value of K_{pc} for ethanedioic acid between ethoxyethane and water.

Explain your answer.

.....

 [2]

[Total: 6]



- 5 (a) Define standard electrode potential, $E^\ominus$, including a description of standard conditions.

.....

.....

..... [2]

- (b) Table 5.1 shows the standard electrode potentials for three redox systems.

Table 5.1

redox system	electrode reaction	$E^\ominus/\text{V}$
1	$\text{Fe}^{3+} + \text{e}^- \rightleftharpoons \text{Fe}^{2+}$	+0.77
2	$\text{NO}_3^- + 10\text{H}^+ + 8\text{e}^- \rightleftharpoons \text{NH}_4^+ + 3\text{H}_2\text{O}$	+0.87
3	$\text{Zn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Zn}$	-0.76

- (i) Use the information in Table 5.1 to write equations for **two** reactions that are feasible.

Explain why these reactions are feasible.

equation 1

equation 2

explanation

.....

..... [3]

- (ii) Suggest why the feasible reactions in 5(b)(i) may **not** take place under standard conditions.

.....

..... [1]



- (iii) An electrochemical cell is set up to measure $E^\ominus$ for redox system 2 in Table 5.1.

Complete Figure 5.1 to show a labelled diagram of this electrochemical cell.

Include all necessary substances and relevant pieces of apparatus needed to measure $E^\ominus$.

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

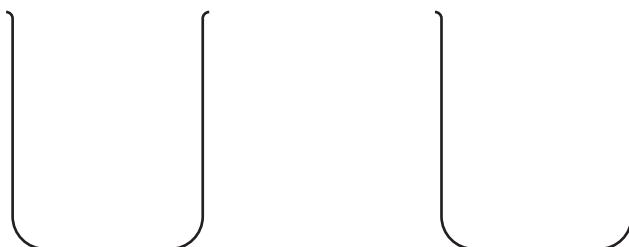
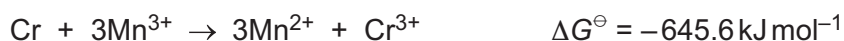


Figure 5.1

[3]

- (c) A different electrochemical cell is set up. The cell reaction for this electrochemical cell is shown.



Calculate the standard cell potential, $E_{\text{cell}}^\ominus$, for this cell reaction.

$$E_{\text{cell}}^\ominus = \dots\dots\dots \text{ V [2]}$$

[Total: 11]

6 (a) Phenol reacts with $\text{Br}_2(\text{aq})$.

- (i) State **all** the expected observations when $\text{Br}_2(\text{aq})$ is added dropwise to a solution of phenol.

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

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

[1]

- (b) Explain the relative acidities of phenol and water.

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



(c) Compound **C** can undergo both addition and condensation polymerisation.

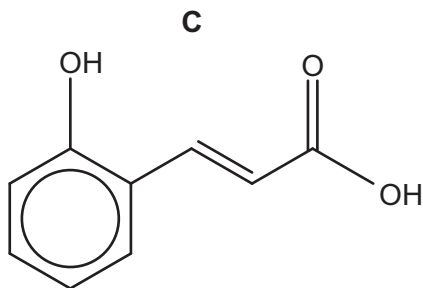


Figure 6.1

(i) Draw **one** repeat unit of the addition polymer formed from **C**.

[1]

(ii) Draw **two** repeat units of the condensation polymer formed from **C**.

The new functional group formed should be displayed.

[2]

(d) **C** can react with LiAlH_4 . **C** can also react with an excess of $\text{H}_2(\text{g})$ with a nickel catalyst.

Draw the structure of the organic product formed in each reaction in Figure 6.2.

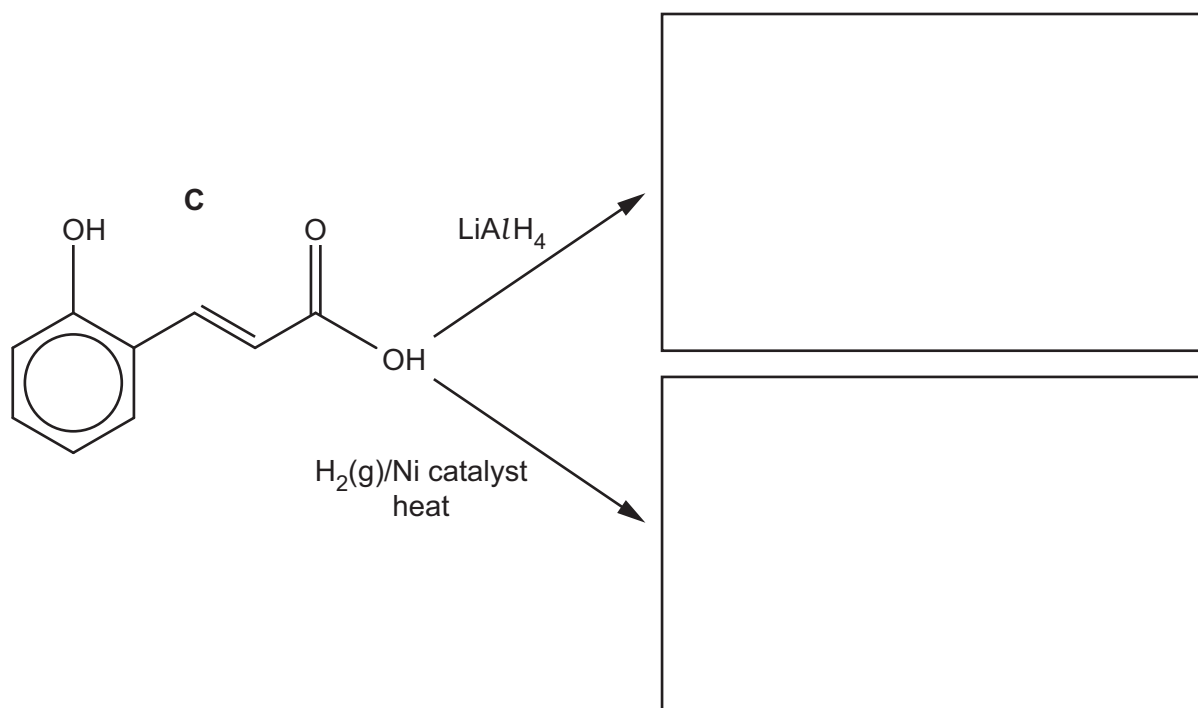


Figure 6.2

[2]



(e) Compound **F** can be synthesised from phenol in three steps, as shown in Figure 6.3.

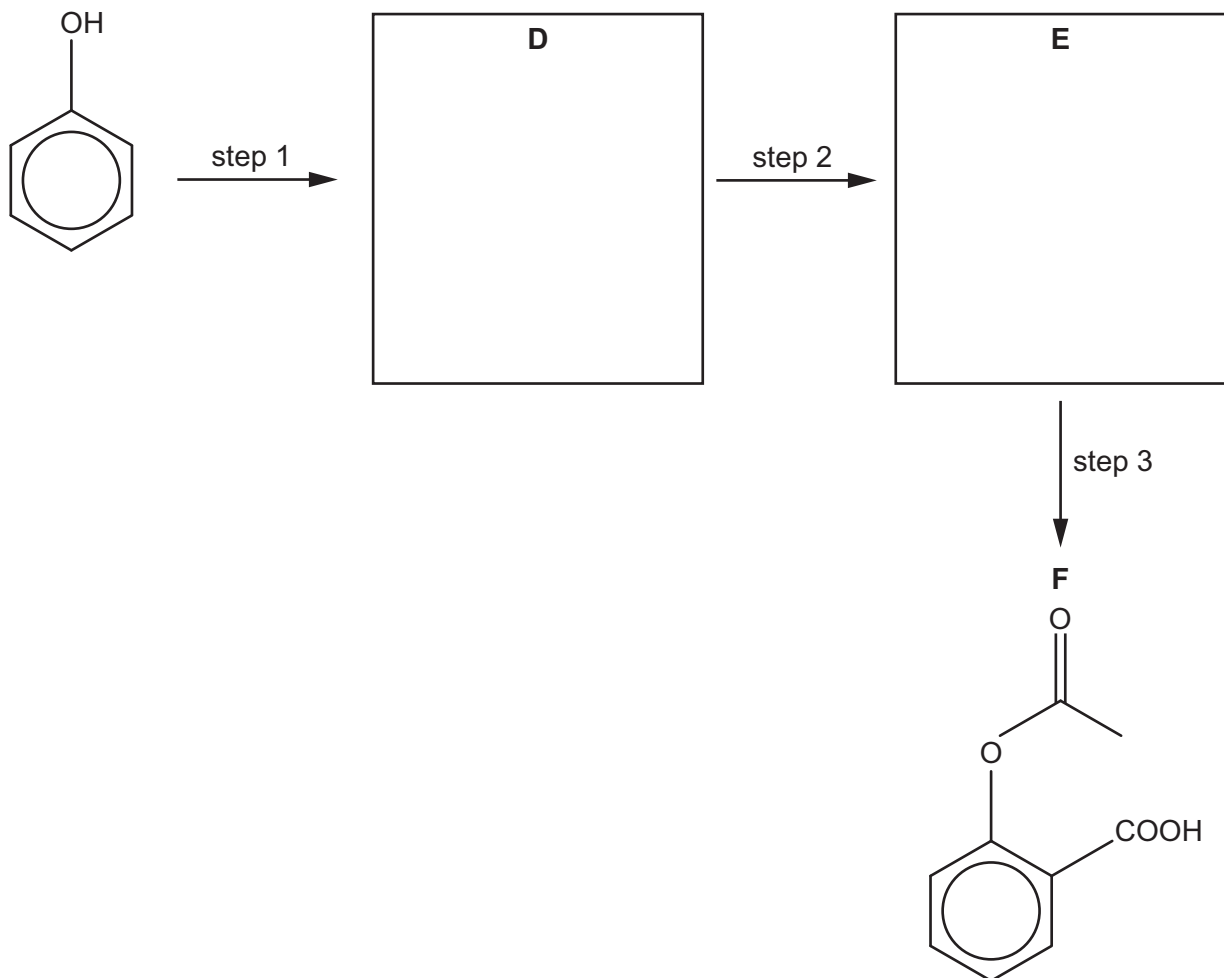


Figure 6.3

(i) Draw the structures of compounds **D** and **E** in the boxes in Figure 6.3. [2]

(ii) Suggest reagents and conditions for steps 1 to 3 in Figure 6.3.

step 1

step 2

step 3

[3]

[Total: 14]



- 7 (a) Alanine, $\text{CH}_3\text{CH}(\text{NH}_2)\text{COOH}$, is an amino acid that contains a chiral centre.

Different synthetic routes to produce alanine can lead to the formation of an optically active sample or a racemic mixture.

- (i) Describe what is meant by optically active.

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

- (ii) Describe what is meant by racemic mixture.

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

- (b) Alanine has an isoelectric point of 6.11.

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

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

- (ii) Draw the structure of alanine at pH 10.

[1]

- (c) Alanine molecules can react together to form the tripeptide Ala–Ala–Ala.

Draw the structure for this tripeptide. The functional groups formed should be displayed.

[2]



(d) Compound **J** can be synthesised from alanine in three steps, as shown in Figure 7.1.

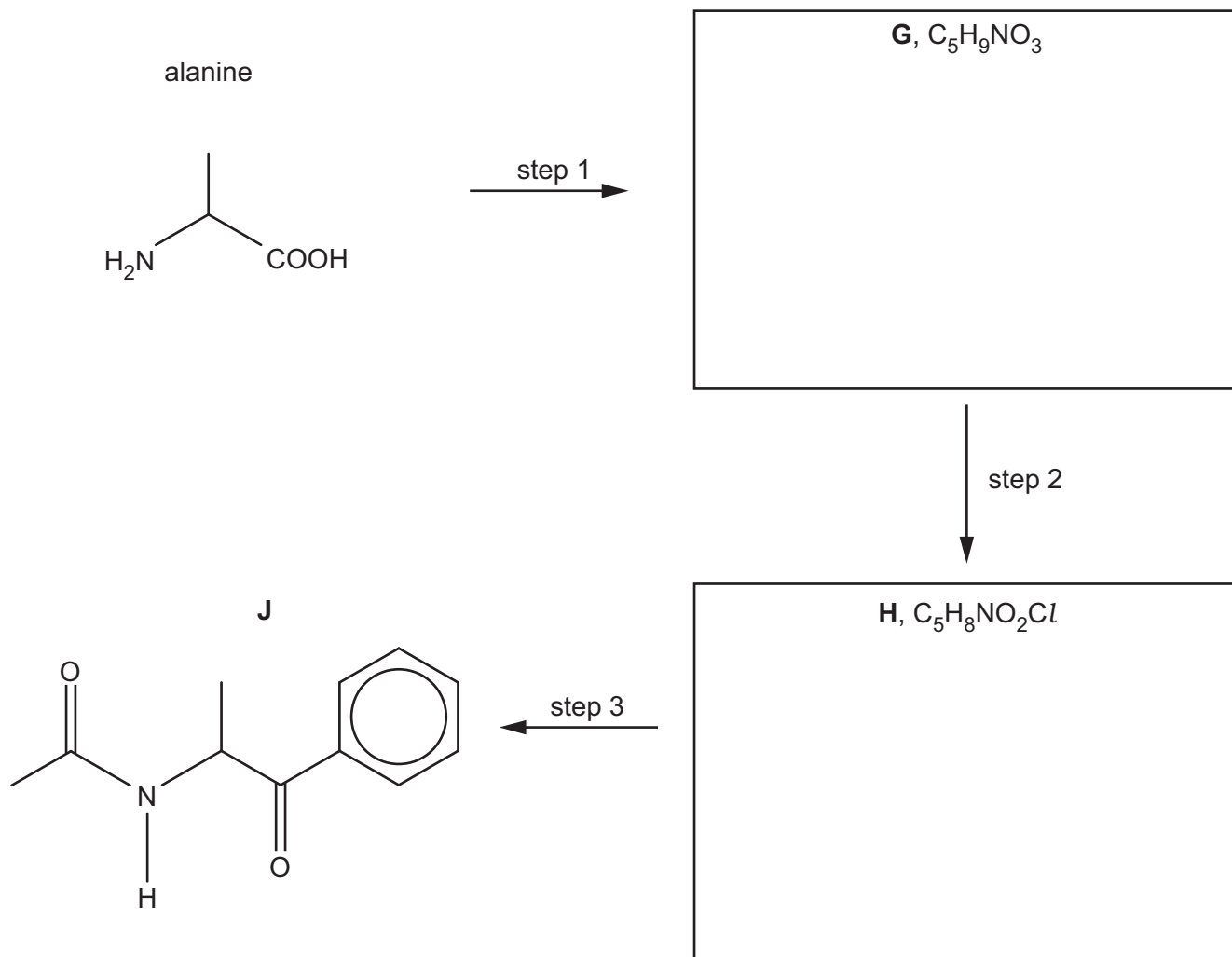


Figure 7.1

- (i) Draw the structures of compounds **G** and **H** in the boxes in Figure 7.1. [2]
- (ii) Suggest reagents and conditions for steps 1 to 3 in Figure 7.1.

step 1

step 2

step 3 [3]

[Total: 11]

- 8 (a) Give the full name of the substance used in NMR spectroscopy as the standard for chemical shift measurements.

..... [1]

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

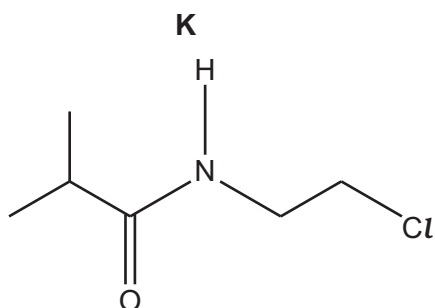


Figure 8.1

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

..... [1]

- (ii) The proton (^1H) NMR spectrum of **K** in D_2O shows four peaks, for the proton environments labelled **w**, **x**, **y** and **z** on the structure of **K** in Figure 8.2.

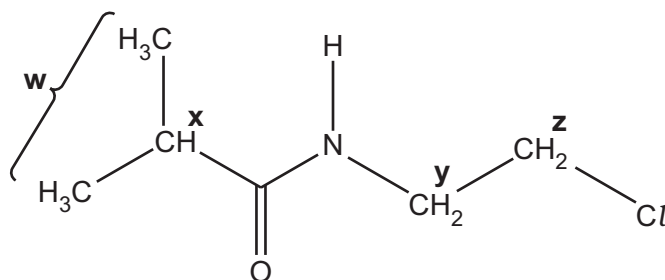


Figure 8.2

Complete Table 8.1 to identify the splitting patterns for proton environments **w**, **x**, **y** and **z**.

Table 8.1

proton environment	name of splitting pattern
w	
x	
y	
z	

[2]



- (iii) A separate sample of **K** is dissolved in CDCl_3 and analysed using proton (^1H) NMR spectroscopy.

The proton (^1H) NMR spectrum of **K** dissolved in CDCl_3 contains one more peak than the spectrum of **K** dissolved in D_2O .

Explain why there is one more peak, and suggest the chemical shift range in which it occurs.

.....

.....

.....

chemical shift range $\delta =$ ppm
[2]

Table 8.2

environment of proton	example	chemical shift range δ/ppm
alkane	$-\text{CH}_3$, $-\text{CH}_2-$, $>\text{CH}-$	0.9–1.7
alkyl next to $\text{C}=\text{O}$	$\text{CH}_3-\text{C}=\text{O}$, $-\text{CH}_2-\text{C}=\text{O}$, $>\text{CH}-\text{C}=\text{O}$	2.2–3.0
alkyl next to aromatic ring	CH_3-Ar , $-\text{CH}_2-\text{Ar}$, $>\text{CH}-\text{Ar}$	2.3–3.0
alkyl next to electronegative atom	CH_3-O , $-\text{CH}_2-\text{O}$, $-\text{CH}_2-\text{Cl}$	3.2–4.0
attached to alkene	$=\text{CHR}$	4.5–6.0
attached to aromatic ring	$\text{H}-\text{Ar}$	6.0–9.0
aldehyde	HCOR	9.3–10.5
alcohol	ROH	0.5–6.0
phenol	$\text{Ar}-\text{OH}$	4.5–7.0
carboxylic acid	RCOOH	9.0–13.0
alkyl amine	$\text{R}-\text{NH}-$	1.0–5.0
aryl amine	$\text{Ar}-\text{NH}_2$	3.0–6.0
amide	RCONHR	5.0–12.0

(c) Compound **K** reacts with an excess of hot NaOH(aq).

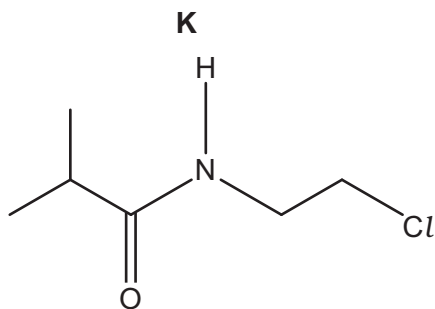
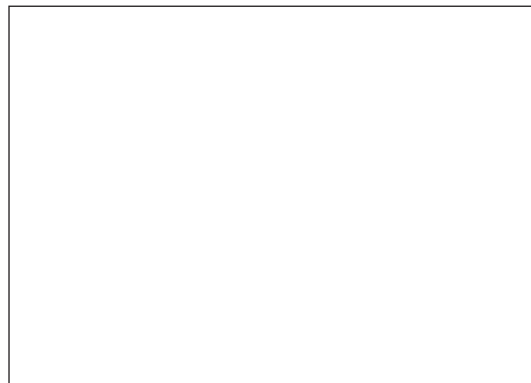
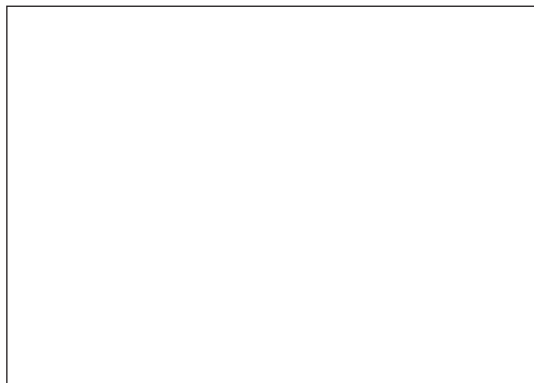


Figure 8.3

The products are isolated from the reaction mixture at pH 10.

Draw the structures of the **two** organic products of the complete alkaline hydrolysis of **K**.



[2]

[Total: 8]





Turn over





9 (a) Compound **P** and compound **Q** are isomers.

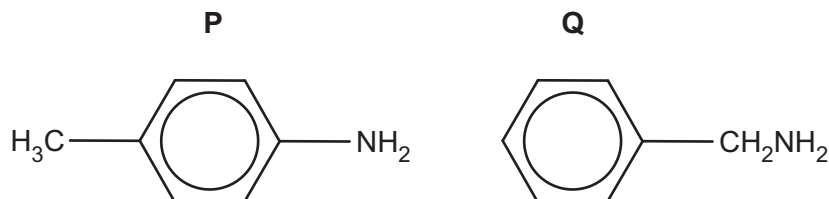


Figure 9.1

State the relative basicities of **P**, **Q** and ammonia.

Explain your answer.

..... > >
 most basic least basic

explanation

.....

.....

.....

.....

.....

.....

[4]



(b) **P** can be prepared from methylbenzene in two steps, as shown in Figure 9.2.

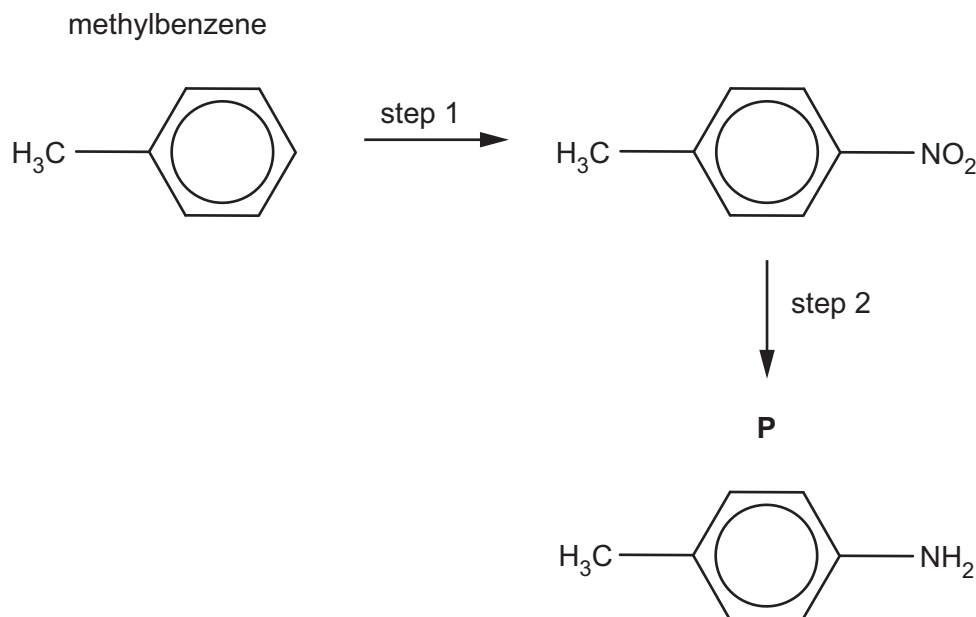


Figure 9.2

(i) Suggest reagents and conditions for steps 1 and 2 in Figure 9.2.

step 1

step 2 [2]

(ii) Complete the equation in Figure 9.3 for step 2.

Use [H] to represent an atom of hydrogen from the reducing agent.

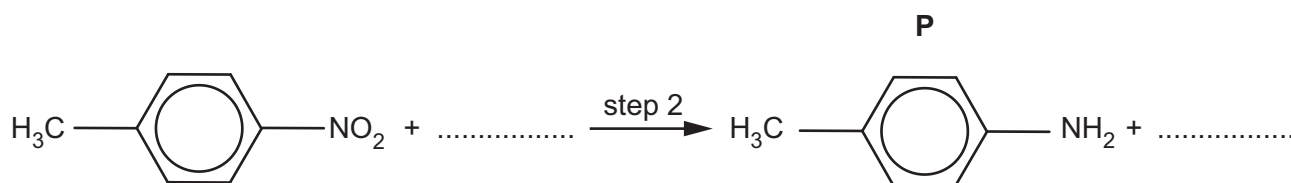


Figure 9.3

[1]

(c) Figure 9.4 shows a two-step synthesis of azo dye **N**.

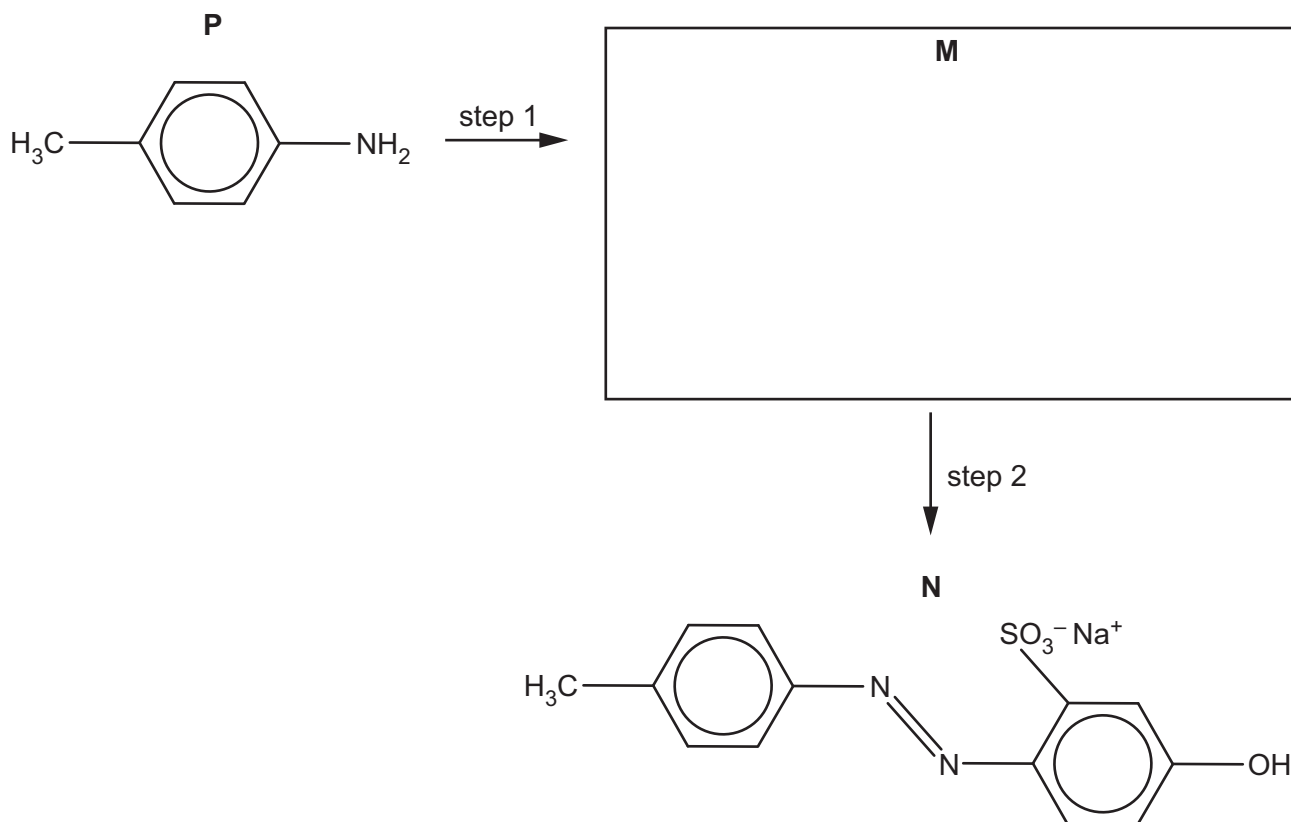


Figure 9.4

- (i) Draw the structure of compound **M** in the box in Figure 9.4. [1]
- (ii) Give the reagents and conditions for steps 1 and 2 in Figure 9.4.

step 1

step 2 [2]

[Total: 10]





Important values, constants and standards

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

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The Periodic Table of Elements

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

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	euporium	152.0	64	Gd	gadolinium	157.3	65	Tb	terbium	158.9	66	Dy	dyprosium	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	mendelevium	—	102	No	nobelium	—	103	Lr	lawrencium	—