CAMBRIDGE
International Education

Cambridge International AS & A Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

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.

DC (WW/TC) 357405/6

[Turn over

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 $[Cr(H_2O)_6]^{3+}$ complex ion.

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

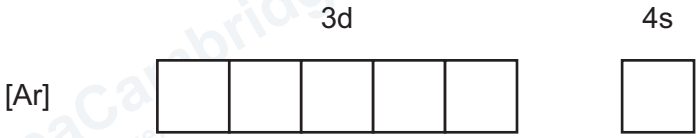


Figure 1.1

[1]

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

..... [1]

(c) Explain why transition elements form complex ions.

.....

.....

..... [1]

(d) $[Cr(H_2O)_6]^{3+}$ can be converted into the $[Cr(H_2O)_3(OH)_3]$ complex.

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

reagent .....

type of reaction .....

[1]

(ii) $[Cr(H_2O)_3(OH)_3]$ reacts with an excess of $NH_3(aq)$ to form $[Cr(NH_3)_6]^{3+}$.

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

$[Cr(H_2O)_3(OH)_3]$ + ...

type of reaction .....

[2]

(e) $[Cr(H_2O)_3(OH)_3]$ shows stereoisomerism.

Draw three-dimensional diagrams in Figure 1.2 to suggest the **two** stereoisomers of $[Cr(H_2O)_3(OH)_3]$.

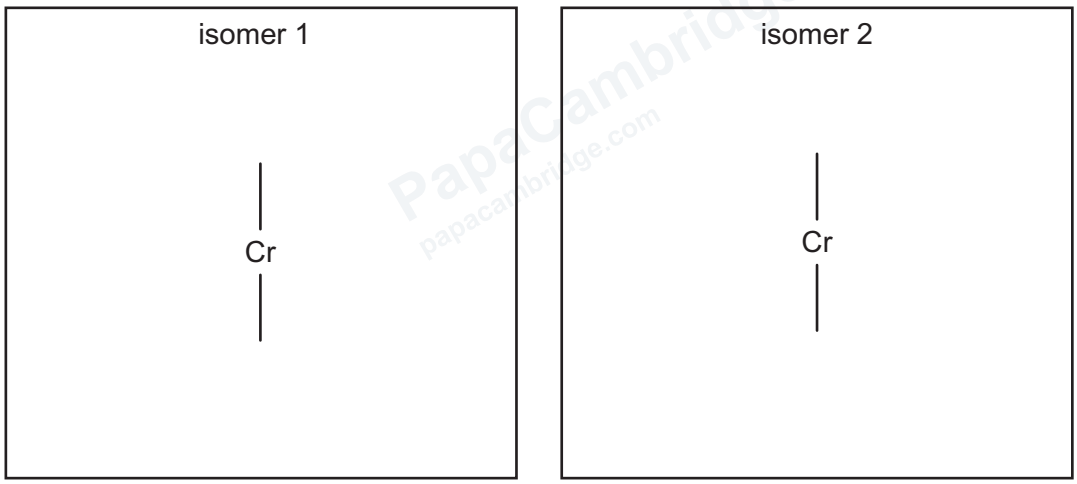


Figure 1.2

[2]

(f) **(i)** An aqueous solution of iron(III) ions, Fe^{3+}, contains the $[Fe(H_2O)_6]^{3+}$ 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 $[Fe(H_2O)_6]^{2+}$ complex ion. This solution is also acidic.

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

.....

.....

..... [1]

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

.....

.....

.....

..... [2]

(h) A mixture contains sodium ethanedioate, $Na_2C_2O_4$, ethanedioic acid dihydrate, $H_2C_2O_4 \cdot 2H_2O$, 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 mol dm^{-3} $MnO_4^-(aq)$ to reach the end-point.

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

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.

$$H_2C_2O_4 + 2OH^- \rightarrow C_2O_4^{2-} + 2H_2O$$

Calculate the percentage by mass of $Na_2C_2O_4$ in the mixture.

[M_r: $Na_2C_2O_4$, 134.0]

percentage by mass of $Na_2C_2O_4$ = ...% [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.

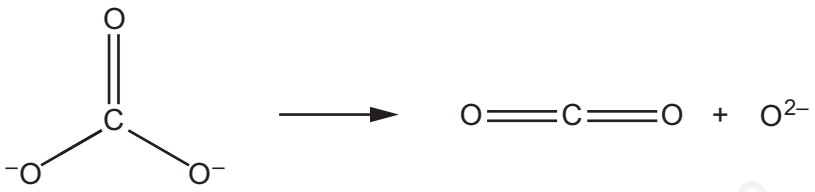


Figure 2.1

[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, $Mg(OH)_2$, is sparingly soluble in water at 298 K.

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

K_{sp} =

units .....
[2]

(ii) A saturated solution of $Mg(OH)_2$ 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 $Mg(OH)_2$.

K_{sp} for $Mg(OH)_2$ = ... [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.

reaction 1 $$CH_3CHO + 2CH_3OH \xrightarrow{H^+} \mathbf{B} \quad CH_3CH(OCH_3)_2 + H_2O$$

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	$[CH_3CHO]$ / mol dm^{-3}	$[CH_3OH]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	initial rate / mol dm^{-3} 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	$[CH_3CHO]$ / mol dm^{-3}	$[CH_3OH]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}
5	0.250	0.250	0.250

Calculate the initial rate of experiment 5.

initial rate = ... mol dm^{-3} 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.

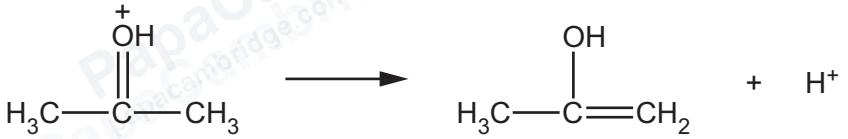
reaction 2 $\quad CH_3COCH_3 + Br_2 \xrightarrow{H^+} CH_3COCH_2Br + HBr$

The rate of reaction is first order with respect to $[CH_3COCH_3]$ and first order with respect to $[H^+]$ 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)	
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.

$$H_2C_2O_4 + 2NaOH \rightarrow Na_2C_2O_4 + 2H_2O$$

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

K_{pc} = ... [3]

(c) The formula of ethanedioic acid is HOOCCOOH.

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	$E^{\ominus}$/V
1	$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
2	$NO_3^- + 10H^+ + 8e^- \rightleftharpoons NH_4^+ + 3H_2O$	+0.87
3	$Zn^{2+} + 2e^- \rightleftharpoons Zn$	–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.

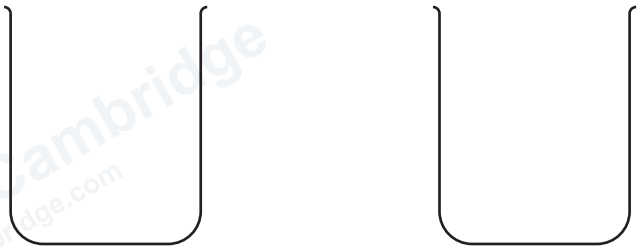


Figure 5.1

[3]

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

$$Cr + 3Mn^{3+} \rightarrow 3Mn^{2+} + Cr^{3+} \qquad \Delta G^{\ominus} = -645.6\,kJ\,mol^{-1}$$

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

$E^{\ominus}_{cell}$ = ... V [2]

[Total: 11]

6 **(a)** Phenol reacts with $Br_2(aq)$.

(i) State **all** the expected observations when $Br_2(aq)$ 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 $Br_2(aq)$.

[1]

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

.....

.....

.....

..... [2]

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

C

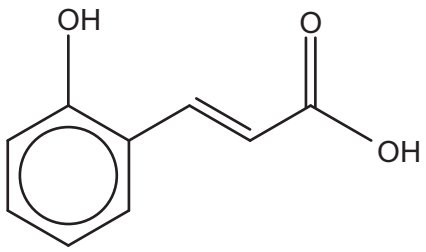


Figure 6.1

(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 $H_2(g)$ with a nickel catalyst.

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

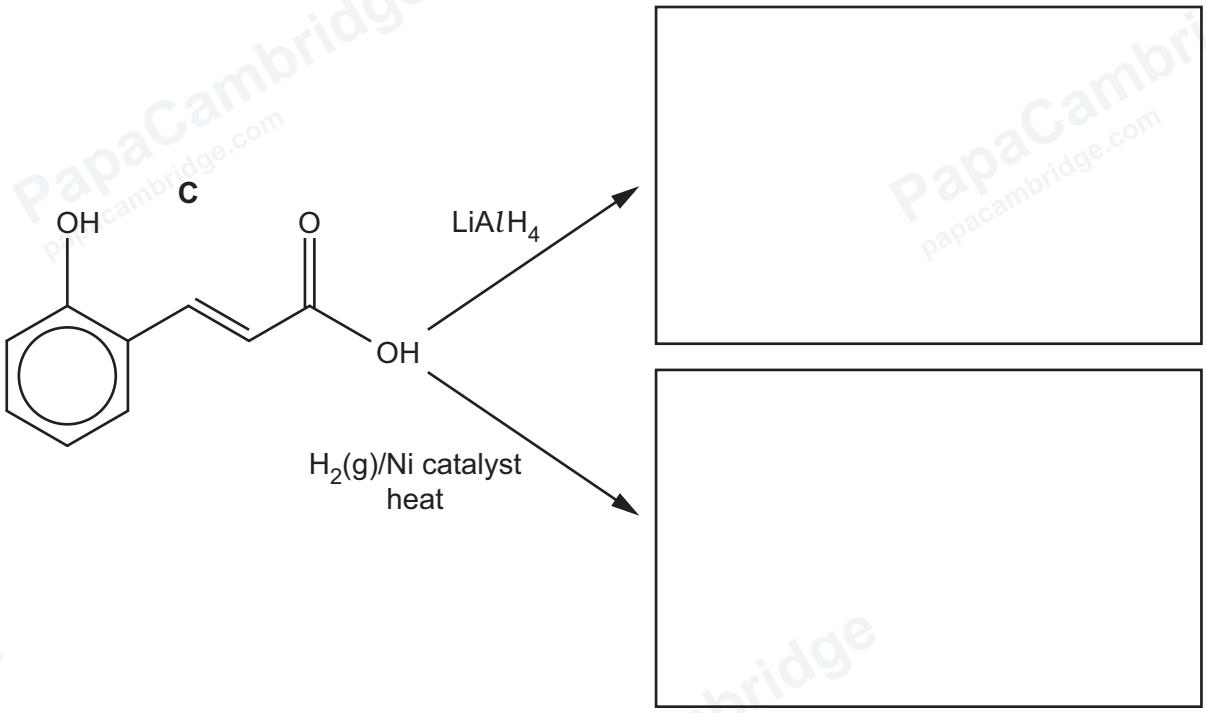


Figure 6.2

[2]

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

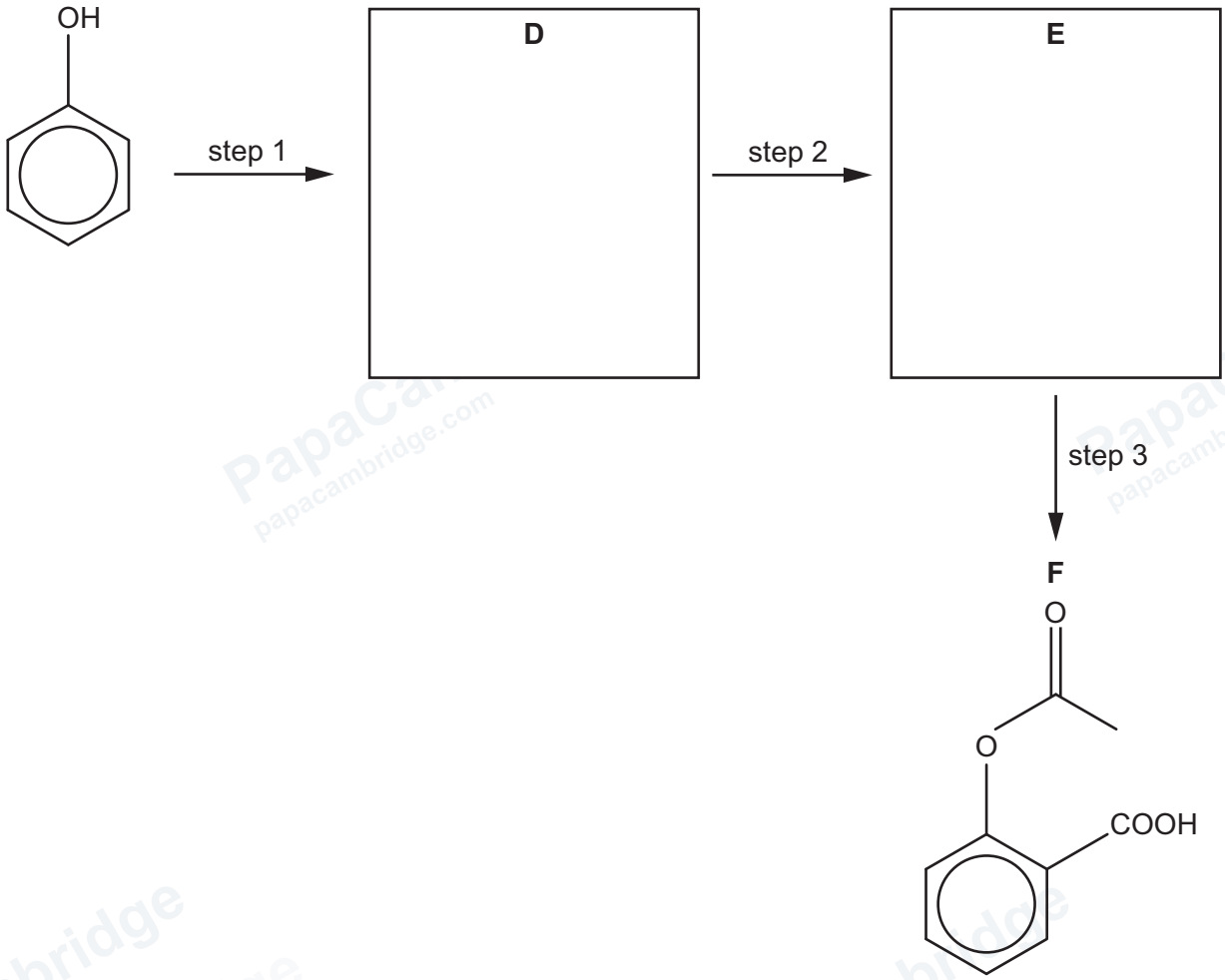


Figure 6.3

(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, $CH_3CH(NH_2)COOH$, 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.

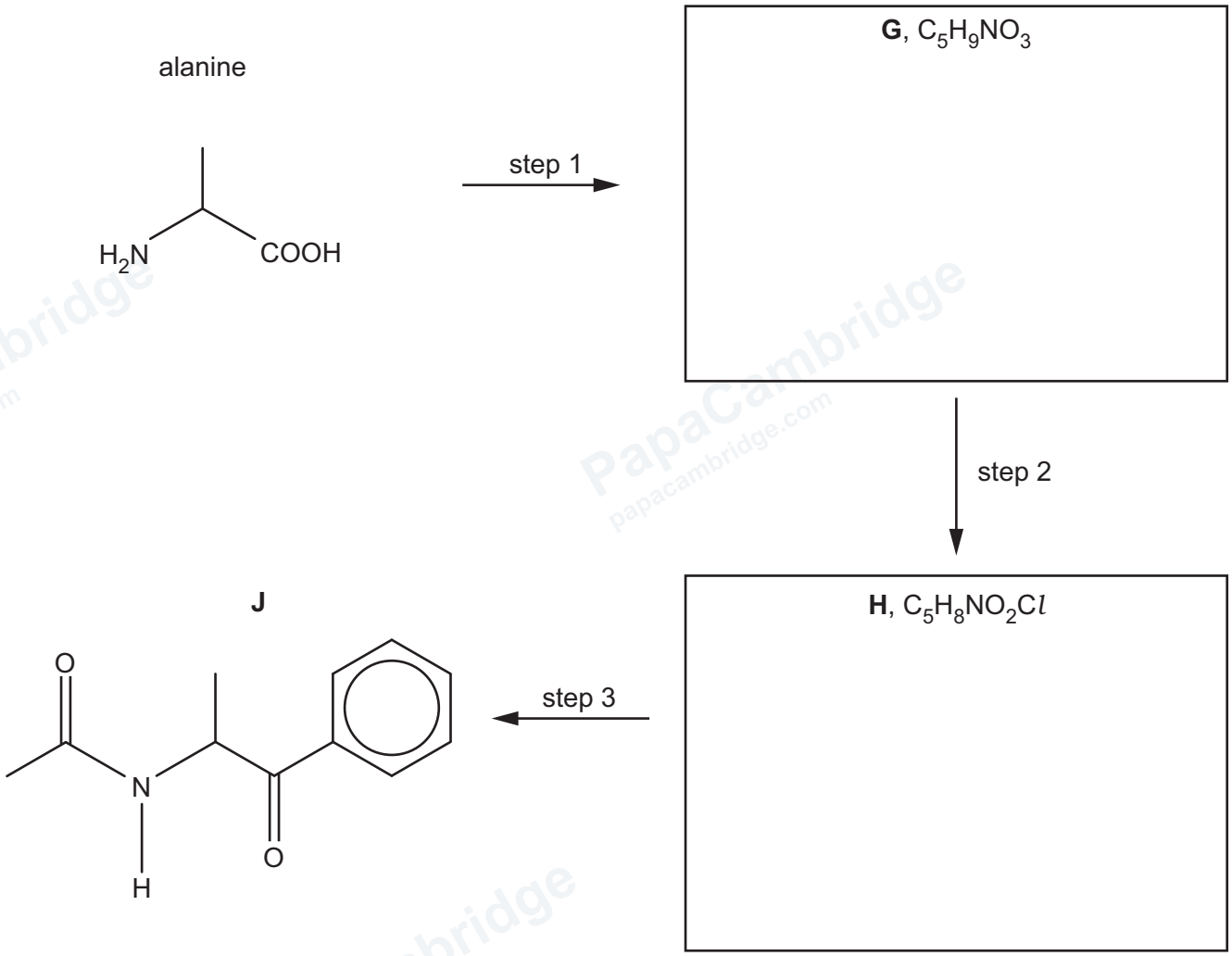


Figure 7.1

(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 (^{1}H) NMR spectroscopy in D_2O.

K

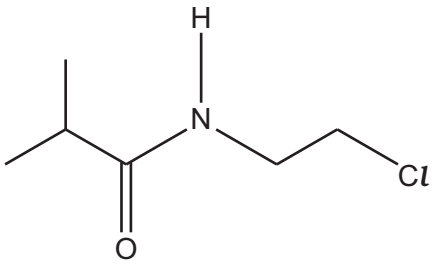


Figure 8.1

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

..... [1]

(ii) The proton (^{1}H) 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.

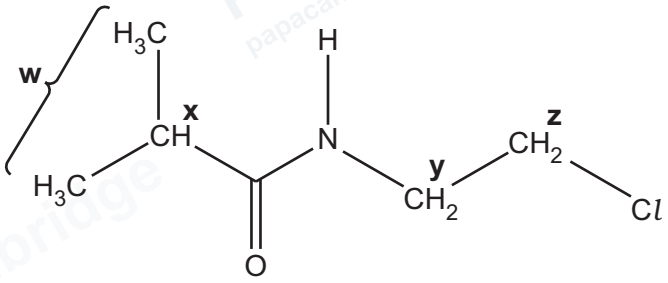


Figure 8.2

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 δ = ... ppm

[2]

Table 8.2

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

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

K

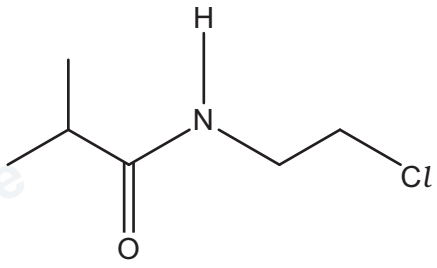


Figure 8.3

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.

P **Q**

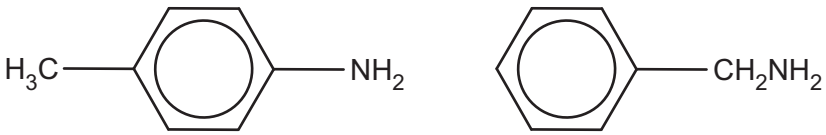


Figure 9.1

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.

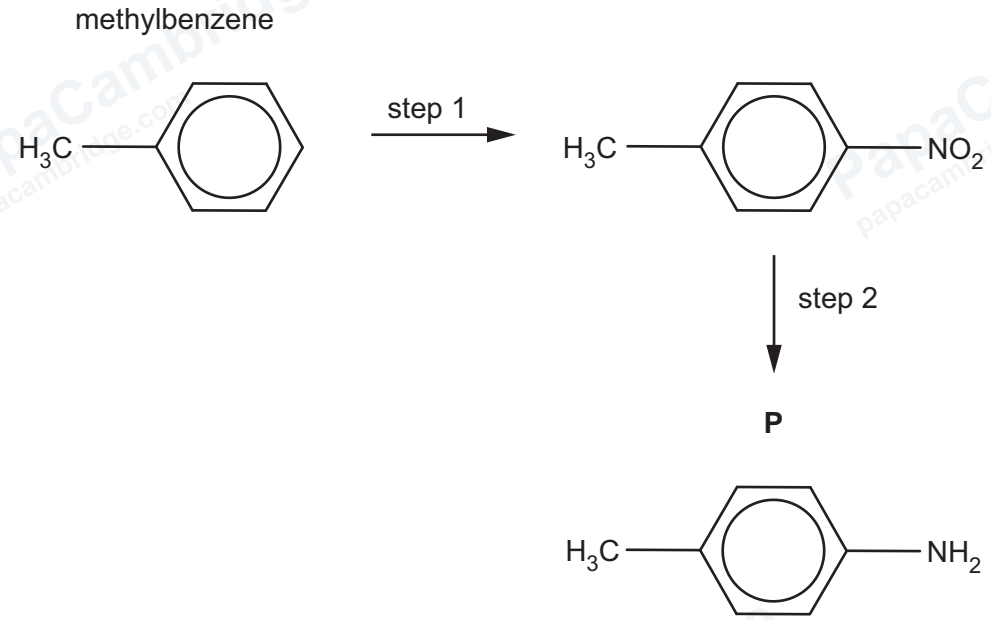


Figure 9.2

(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.

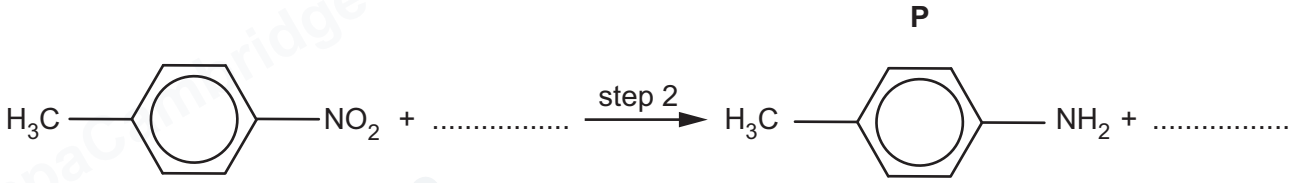


Figure 9.3

[1]

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

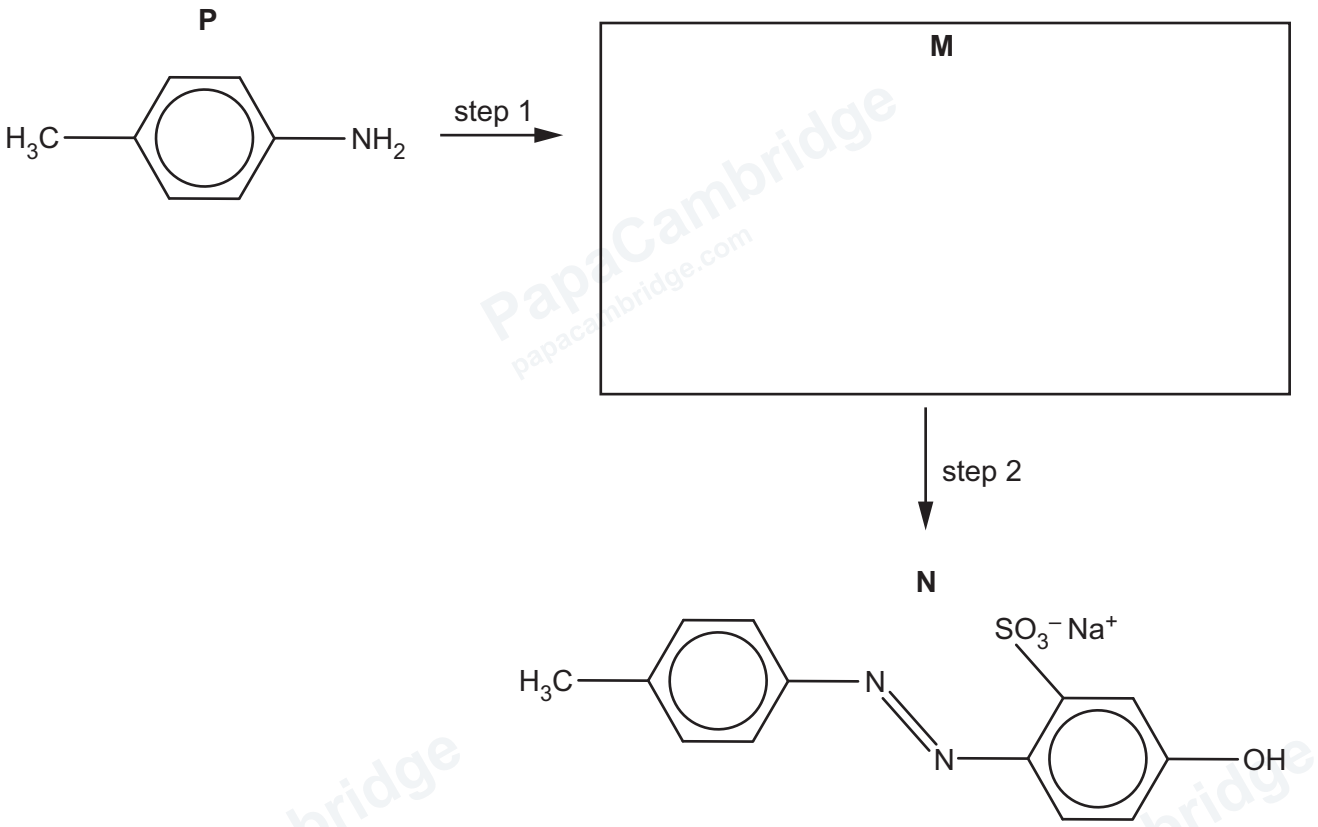


Figure 9.4

(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	$c = 4.18\,\text{kJ kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J g}^{-1}\,\text{K}^{-1}$)

The Periodic Table of Elements

Group 1	2											13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3	3	4	5	6	7	8	9	10	11	12	13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

Key

atomic number
atomic symbol
name
relative atomic mass

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 europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –