CAMBRIDGE
International Education

Cambridge International AS & A Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

CHEMISTRY **9701/42**

Paper 4 A Level Structured Questions **February/March 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. Any blank pages are indicated.

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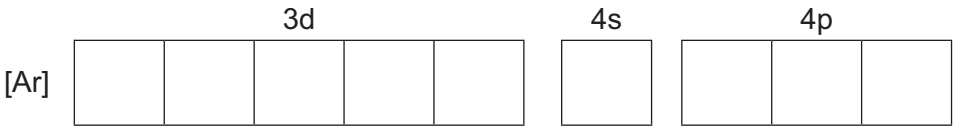
1 Chromium is a transition element that forms coloured compounds.

(a) (i) Define transition element.

.....

..... [1]

(ii) Complete the electrons-in-boxes diagram to show the electronic configuration of an isolated gaseous chromium atom.



[1]

(iii) Sketch the shape of a $3d_{z^2}$ orbital in Figure 1.1.

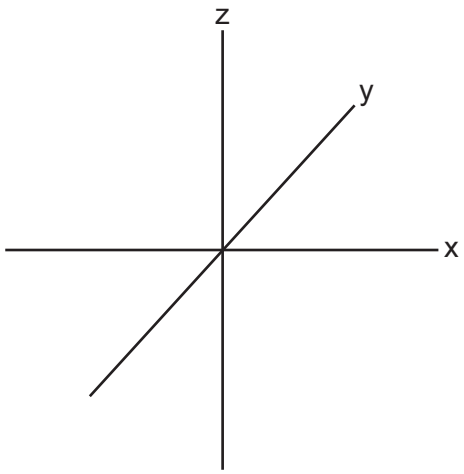


Figure 1.1

[1]

(iv) State **two** reasons that explain why chromium compounds can behave as catalysts.

1 .....

.....

2 .....

.....

[2]

(b) Table 1.1 lists standard electrode potentials, $E^{\ominus}$, for some electrode reactions of chromium and other species.

Table 1.1

electrode reaction	$E^{\ominus}$/V
$Cr^{2+}(aq) + 2e^- \rightleftharpoons Cr(s)$	–0.91
$Cr^{3+}(aq) + e^- \rightleftharpoons Cr^{2+}(aq)$	–0.41
$Cr(OH)_3(s) + e^- \rightleftharpoons Cr(OH)_2(s) + OH^-(aq)$	–1.26
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$CrO_4^{2-}(aq) + 4H_2O(l) + 3e^- \rightleftharpoons Cr(OH)_3(s) + 5OH^-(aq)$	–0.13
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40

(i) Define standard electrode potential, $E^{\ominus}$, including a description of standard conditions.

.....

.....

.....

..... [2]

(ii) Explain fully, with reference to relevant data in Table 1.1, why solutions of $Cr^{2+}(aq)$ need to be stored in an atmosphere of argon instead of in air.

.....

.....

..... [2]

(iii) A green precipitate of $Cr(OH)_3$ forms when aqueous NaOH is added to aqueous $CrCl_3$.

Construct an ionic equation for the formation of this green precipitate.

..... [1]

(iv) Green $Cr(OH)_3(s)$ dissolves in alkali to form a yellow solution containing $CrO_4^{2-}(aq)$ when it is left in air for several hours.

Use Table 1.1 to construct an ionic equation for this reaction.

..... [2]

(c) The equation for the decomposition of ammonium dichromate, $(NH_4)_2Cr_2O_7$, is shown.

reaction 1 $(NH_4)_2Cr_2O_7(s) \rightarrow Cr_2O_3(s) + N_2(g) + 4H_2O(g)$

$\Delta S^{\ominus} = +915\,J\,K^{-1}\,mol^{-1}$

(i) Explain why the standard entropy change, $\Delta S^{\ominus}$, is positive in reaction 1.

.....

..... [1]

(ii) Table 1.2 gives some standard entropy values relevant to reaction 1.

Table 1.2

substance	standard entropy, $S^{\ominus}$ / $J\,K^{-1}\,mol^{-1}$
$(NH_4)_2Cr_2O_7(s)$	114
$Cr_2O_3(s)$	81
$N_2(g)$	192

Use the information in this question to calculate the standard entropy, $S^{\ominus}$, in $J\,K^{-1}\,mol^{-1}$, of $H_2O(g)$.

$S^{\ominus}$ of $H_2O(g)$ = ... $J\,K^{-1}\,mol^{-1}$ [2]

(iii) Thermodynamic data for reaction 1 is shown.

reaction 1 $(NH_4)_2Cr_2O_7(s) \rightarrow Cr_2O_3(s) + N_2(g) + 4H_2O(g)$

$\Delta H^{\ominus} = -341\,kJ\,mol^{-1}$
$\Delta S^{\ominus} = +915\,J\,K^{-1}\,mol^{-1}$

statement 1 Reaction 1 is feasible at all temperatures.

statement 2 Reaction 1 will **not** occur unless $(NH_4)_2Cr_2O_7$ is heated strongly.

Explain statements 1 and 2. Refer to the Gibbs equation in your answer.

.....

.....

.....

..... [2]

(d) Figure 1.2 shows the Born–Haber diagram for the ionic solid Cr_2O_3. Relevant data is given in Table 1.3.

$\Delta H_{i1–3}$ represents the sum of the first, second and third ionisation energies of Cr.

$\Delta H_{EA1–2}$ represents the sum of the first and second electron affinities of O.

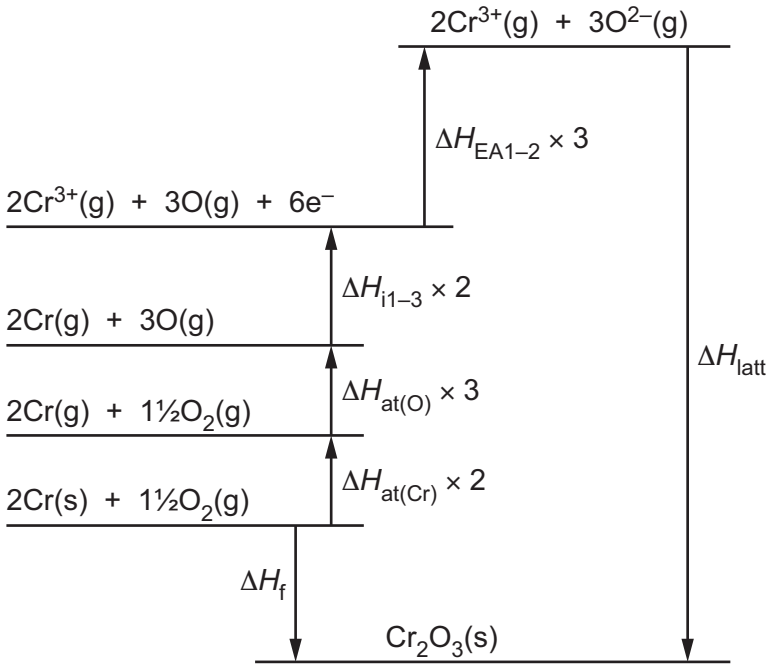


Figure 1.2

Table 1.3

enthalpy change	value / kJ mol^{-1}
$\Delta H_{at(Cr)}$	+398
$\Delta H_{at(O)}$	+248
ΔH_{i1-3}	+5233
ΔH_{EA1-2}	+702
ΔH_f	–1128

(i) Define first electron affinity.

.....

.....

..... [2]

(ii) Use Figure 1.2 and data in Table 1.3 to calculate the lattice energy, ΔH_{latt}, in kJ mol^{-1}, of Cr_2O_3.

ΔH_{latt} = ... kJ mol^{-1} [2]

(iii) The ionic radius of Cr^{3+} is 0.069 nm. The ionic radius of Al^{3+} is 0.050 nm.

Suggest how the lattice energies of Cr_2O_3 and Al_2O_3 differ.

Explain your answer.

.....

.....

..... [2]

[Total: 23]

2 The manganate(VII) ion, MnO_4^-, is used in chemistry as an oxidising agent.

Three reactions each involve MnO_4^- as a reagent.

reaction 2 $MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

reaction 3 $C_6H_5CH_3 + 3[O] \rightarrow C_7H_6O_2 + H_2O$

reaction 4 $MnO_4^- + 4Mn(OH)_2 + 16H^+ \rightarrow 5Mn^{3+} + 12H_2O$

(a) Oxygen slowly oxidises $Fe^{2+}(aq)$. Reaction 2 can be used to determine the percentage of $Fe^{2+}(aq)$ that is oxidised over a certain time.

A student prepares a 250 cm^3 solution using 17.70 g of $FeSO_4 \cdot 7H_2O$. After one week, the student titrates 25.0 cm^3 portions of this solution with acidified $KMnO_4(aq)$ of concentration 0.0500 mol dm^{-3}.

The average titre is 23.80 cm^3.

(i) Calculate the percentage of Fe^{2+} ions in the original sample that were oxidised during one week.

[M_r: $FeSO_4 \cdot 7H_2O$, 277.9]

percentage of Fe^{2+} ions oxidised = ... % [3]

(ii) Explain why an indicator is **not** needed in this titration.

.....

..... [1]

(b) Reaction 3 uses hot alkaline $KMnO_4$ as the reagent. The reaction mixture is then acidified.

Draw the structure of the organic product, $C_7H_6O_2$, of reaction 3.

[1]

(c) Reaction 4 is called a reverse disproportionation reaction.

Suggest the meaning of reverse disproportionation. Use oxidation numbers to explain your reasoning.

.....

.....

.....

..... [2]

(d) The solubility of $Mn(OH)_2$ in water is 3.20×10^{-3} g dm^{-3} at 298 K.

(i) Write an expression for the solubility product, K_{sp}, of $Mn(OH)_2$.

K_{sp} =

[1]

(ii) Calculate the value of K_{sp} of $Mn(OH)_2$ at 298 K. State its units.

value of K_{sp} = ...

units .....

[3]

(e) (i) $Mn^{3+}(aq)$ ions are coloured. Explain why.

.....

.....

.....

.....

.....

..... [3]

(ii) Mn^{3+} ions form the complex ion $[Mn(C_2O_4)_3]^{3-}$, which shows stereoisomerism.

Complete Table 2.1 to give details of this complex. Use O O to represent the ligands in the three-dimensional structures of the stereoisomers of $[Mn(C_2O_4)_3]^{3-}$.

Table 2.1

formula of complex	$[Mn(C_2O_4)_3]^{3-}$	
formula of ligand		
shape of complex		
coordination number of Mn in complex		
type of stereoisomerism shown by complex	optical	
structures of stereoisomers	Mn	Mn

[4]

[Total: 18]

3 Figure 3.1 shows a reaction scheme starting from 4-hydroxybutanoic acid.

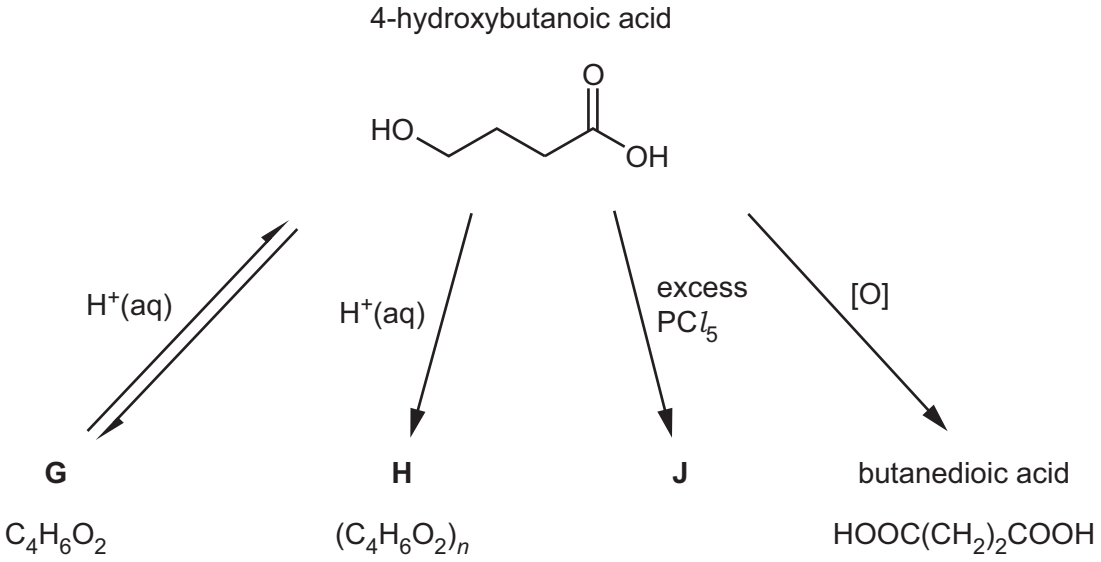


Figure 3.1

(a) Under acidic conditions, 4-hydroxybutanoic acid exists in equilibrium with compound **G**, $C_4H_6O_2$, and water. **G** does **not** react with Na.

4-hydroxybutanoic acid can also react to form condensation polymer **H**, which has formula $(C_4H_6O_2)_n$.

Draw the structures of **G** and **H**. Show only **one** repeat unit of **H**.

G, $C_4H_6O_2$	**H**, $(C_4H_6O_2)_n$

[2]

(b) Construct an equation for the reaction of 4-hydroxybutanoic acid with an excess of PCl_5, forming **J**.

..... [2]

(c) 4-hydroxybutanoic acid, $HO(CH_2)_3COOH$, is a weak acid with $K_a = 1.91 \times 10^{-5}\,mol\,dm^{-3}$ at 25 °C.

(i) Calculate the pH of a $0.150\,mol\,dm^{-3}$ solution of $HO(CH_2)_3COOH$ at 25 °C.

pH = ... [2]

(ii) When $HO(CH_2)_3COOH(aq)$ is mixed with its conjugate base, a buffer solution can form.

Define buffer solution.

.....

.....

..... [2]

(iii) State the structural formula of the conjugate base of $HO(CH_2)_3COOH$.

..... [1]

(iv) A student makes a buffer solution by reacting $25.0\,cm^3$ of $0.150\,mol\,dm^{-3}$ $HO(CH_2)_3COOH$ with $10.0\,cm^3$ of $0.200\,mol\,dm^{-3}$ NaOH(aq).

Calculate the pH of this buffer solution.

K_a of $HO(CH_2)_3COOH = 1.91 \times 10^{-5}\,mol\,dm^{-3}$ at 25 °C.

pH of buffer solution = ... [3]

(d) 4-hydroxybutanoic acid, $HO(CH_2)_3COOH$, can be used to produce butanedioic acid, $HOOC(CH_2)_2COOH$.

Suggest a suitable reagent and conditions for this reaction.

..... [1]

(e) A student does an experiment to determine the partition coefficient, K_{pc}, of butanedioic acid between the immiscible solvents ethoxyethane and water.

(i) State what is meant by partition coefficient.

.....

..... [1]

(ii) The student adds butanedioic acid to a flask containing 25.0 cm^3 of ethoxyethane and 25.0 cm^3 of water. The mixture is shaken and left to separate into two layers.

- 10.00 cm^3 of the ethoxyethane layer requires 7.50 cm^3 of 0.100 mol dm^{-3} NaOH(aq) for complete reaction.
- 10.00 cm^3 of the aqueous layer requires 11.10 cm^3 of 0.500 mol dm^{-3} NaOH(aq) for complete reaction.

$$HOOC(CH_2)_2COOH + 2NaOH \rightarrow NaOOC(CH_2)_2COONa + 2H_2O$$

Calculate the concentration of butanedioic acid in each solvent.

Hence, determine the value of the partition coefficient, K_{pc}, of butanedioic acid between ethoxyethane and water.

concentration of butanedioic acid in ethoxyethane = ... mol dm^{-3}

concentration of butanedioic acid in water = ... mol dm^{-3}

K_{pc} = ...

[2]

[Total: 16]

4 A student performs a series of experiments to investigate the chemistry of the ester methyl ethanoate, CH_3COOCH_3.

(a) CH_3COOCH_3 is hydrolysed under acidic conditions.

reaction 5 $CH_3COOCH_3(aq) + H_2O(l) \xrightarrow{H^+(aq)} CH_3COOH(aq) + CH_3OH(aq)$

The rate of reaction 5 is investigated.

A small amount of $H^+(aq)$ is added to a dilute solution of $CH_3COOCH_3(aq)$. The graph in Figure 4.1 shows how $[CH_3COOCH_3]$ changes with time.

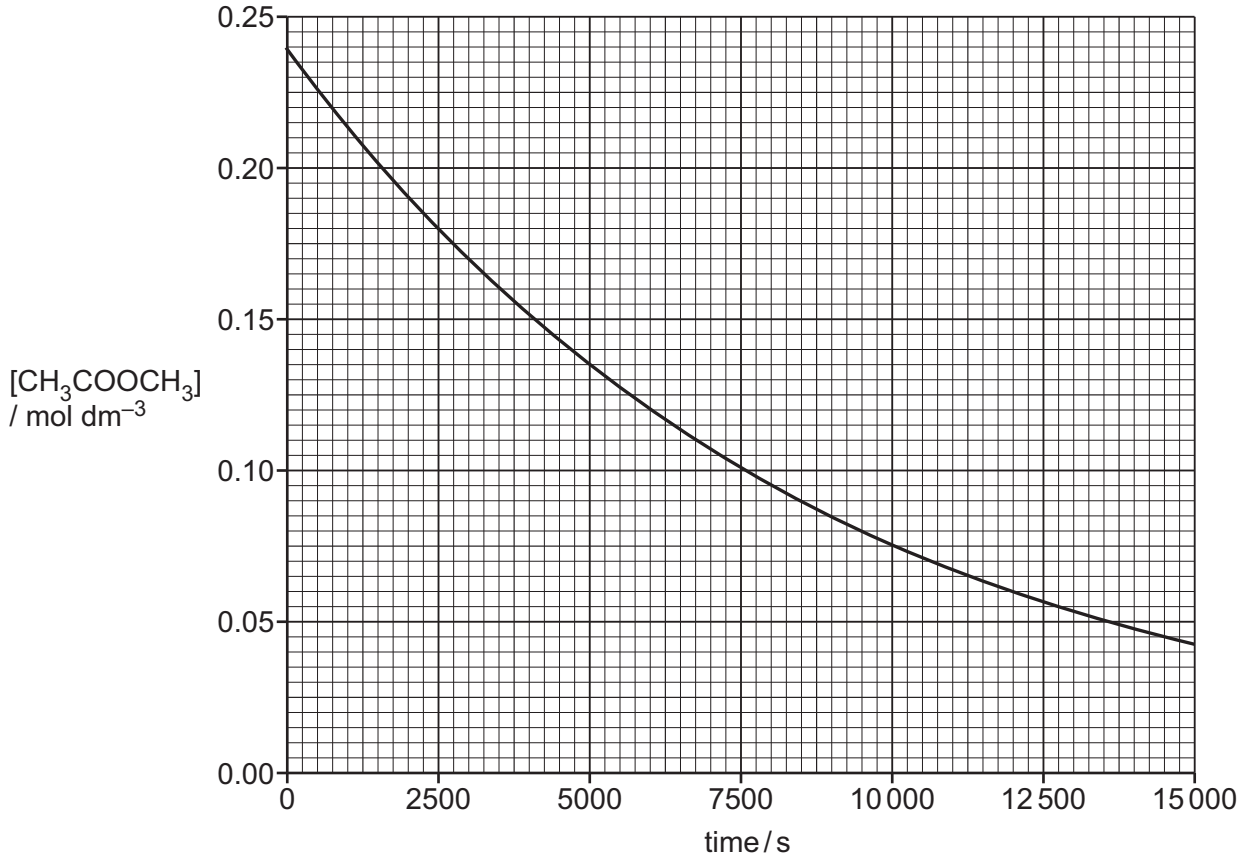


Figure 4.1

(i) Use Figure 4.1 to show that reaction 5 is first order with respect to $[CH_3COOCH_3]$.

Show any working fully and explain your reasoning.

.....

.....

.....

..... [2]

(ii) Use Figure 4.1 to calculate the initial rate of reaction in $mol\,dm^{-3}\,s^{-1}$.

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

(iii) Reaction 5 is first order with respect to $[H^+(aq)]$.

Use this statement and information from **4(a)(i)** to construct the overall rate equation for the hydrolysis reaction.

State the units of the rate constant, *k*, of this reaction.

rate = ...

units of *k* = ...
[2]

(b) Methyl ethanoate, CH_3COOCH_3, forms when CH_3OH reacts with either CH_3COCl or CH_3COOH.

Table 4.1

reaction	reactants	products
6	CH_3COCl(l) and CH_3OH(l)	CH_3COOCH_3(l) and HCl(g)
7	CH_3COOH(l) and CH_3OH(l)	CH_3COOCH_3(l) and H_2O(l)

(i) Suggest why reaction 6 gives a higher yield of CH_3COOCH_3 than reaction 7.

.....

.....

.....

..... [2]

(ii) Complete Figure 4.2 to describe the addition–elimination mechanism of reaction 6.

reaction 6 $CH_3COCl(l) + CH_3OH(l) \rightarrow CH_3COOCH_3(l) + HCl(g)$

Include all relevant curly arrows, charges and dipoles.

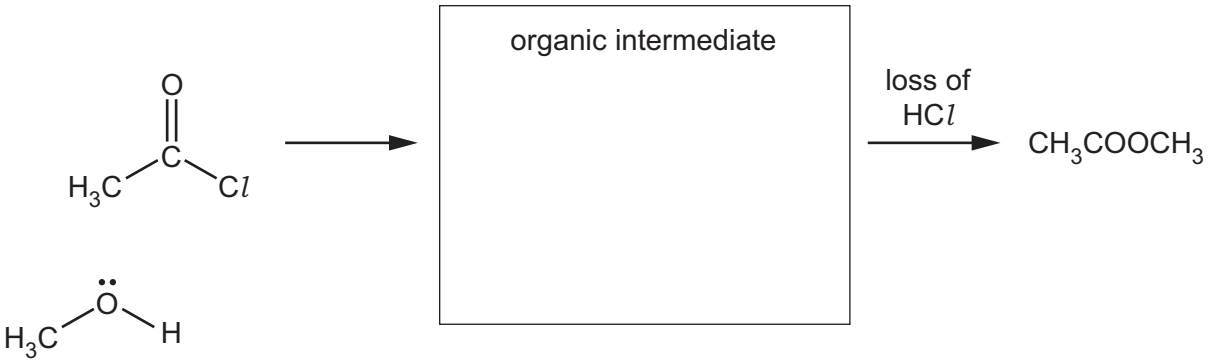


Figure 4.2

[4]

(c) The relative rate of hydrolysis of chloroethane, ethanoyl chloride and chlorobenzene is investigated.

chloroethane ethanoyl chloride chlorobenzene

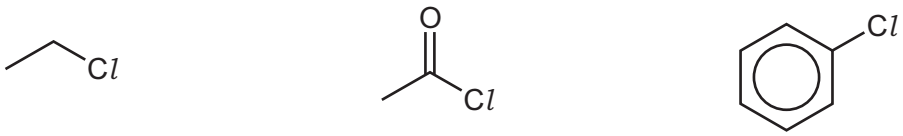


Figure 4.3

State the relative rate of hydrolysis of these three compounds. Explain your answer.

..... < ..... < .....
slowest fastest

.....

.....

.....

.....

.....

.....

[3]

[Total: 14]

Turn over

5 **(a)** 4-methylphenol can be synthesised from methylbenzene in three steps, as shown in Figure 5.1.

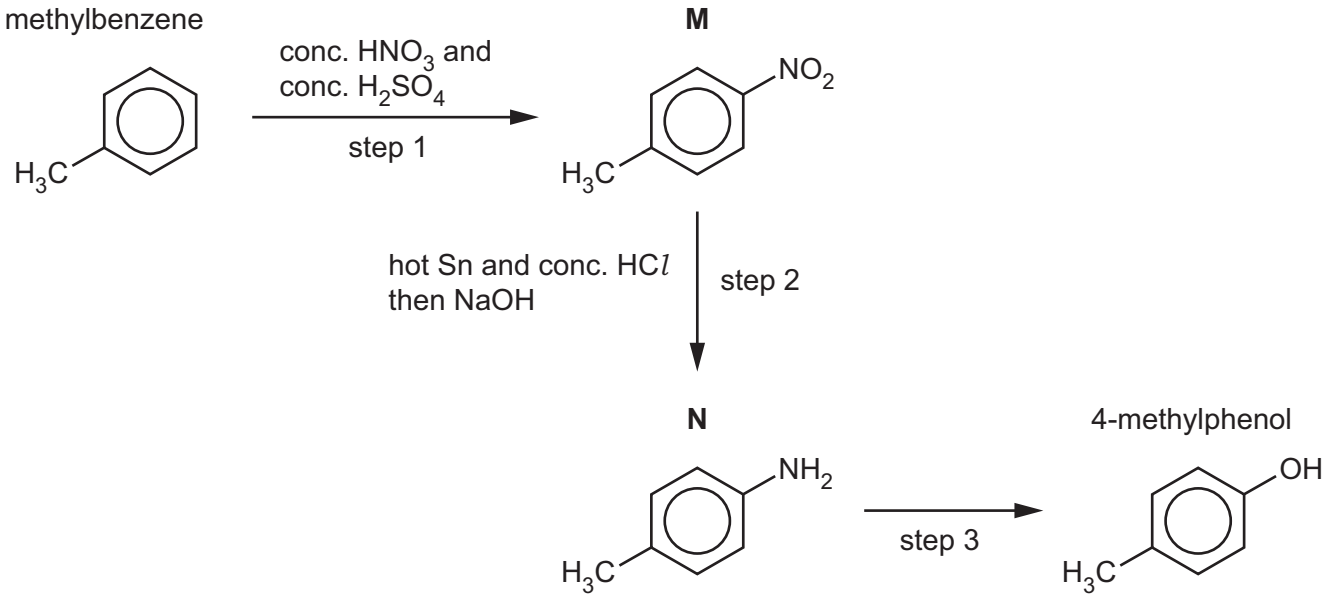


Figure 5.1

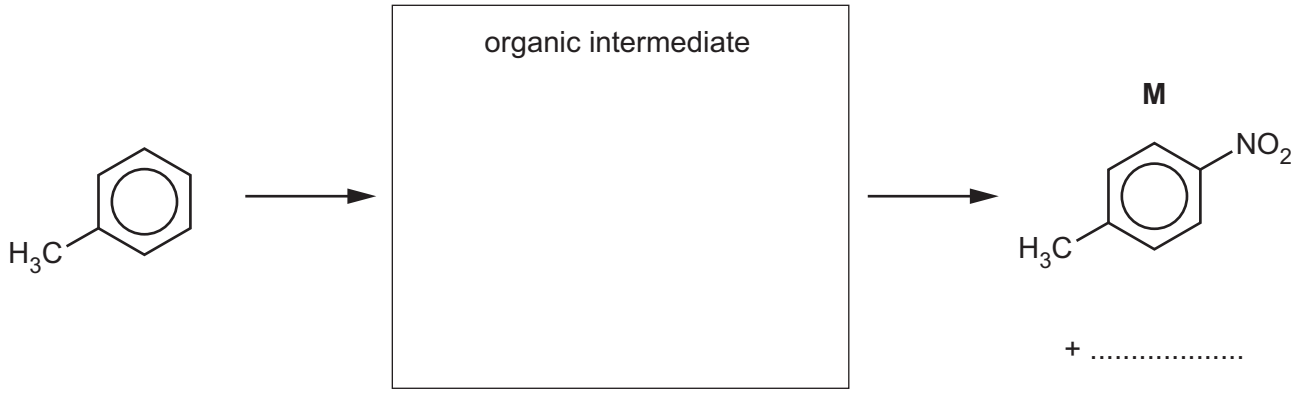
(i) In step 1, methylbenzene reacts with the NO_2^+ electrophile.

Write an equation for the formation of NO_2^+.

..... [1]

(ii) Draw the mechanism for the reaction, in step 1, of NO_2^+ with methylbenzene.

Include all relevant curly arrows and charges. Draw the organic intermediate. Include the by-product of the reaction on the dotted line.



[3]

(iii) 1-methyl-4-nitrobenzene, $CH_3C_6H_4NO_2$, is reduced in step 2.

Write an equation for step 2.

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

..... [1]

(iv) Step 3 is a two-stage process. Identify the reagents and conditions necessary for the two stages.

1 .....

2 .....

[2]

(v) A student suggests an alternative synthesis of 4-methylphenol from nitrobenzene. The student decides to use a Friedel–Crafts alkylation reaction as the first step, as shown in Figure 5.2.

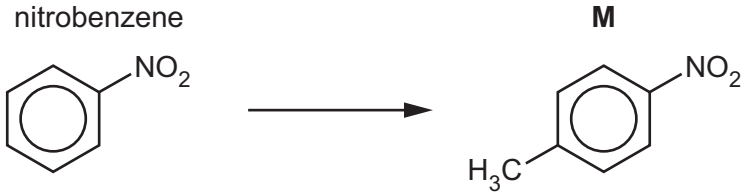


Figure 5.2

Suggest the reagents for this Friedel–Crafts alkylation reaction.

Explain why this reaction will produce a low yield of 1-methyl-4-nitrobenzene.

reagents .....

explanation .....

.....

.....

[2]

(b) The structures of three different phenols are shown in Figure 5.3.

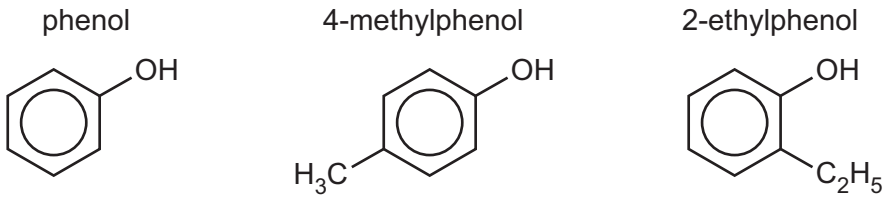


Figure 5.3

A mixture of these three phenols is analysed by gas/liquid chromatography.

The mobile phase is helium gas.

Figure 5.4 shows the gas/liquid chromatogram that is produced.

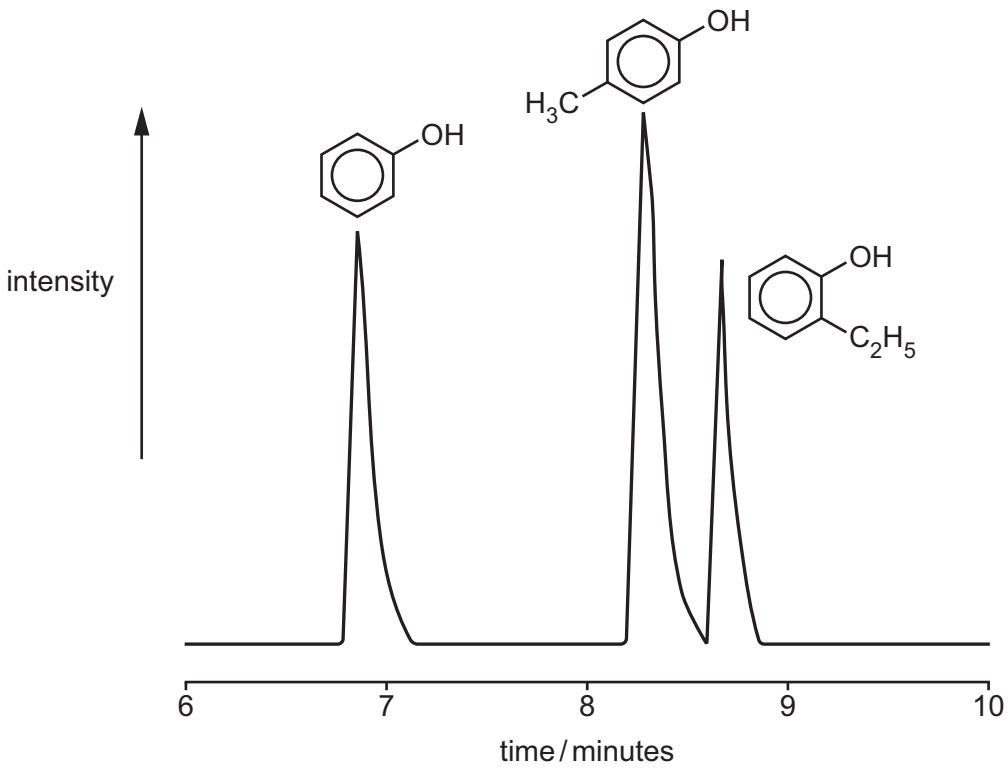


Figure 5.4

(i) Explain why helium gas is used as the mobile phase.

..... [1]

(ii) Suggest a stationary phase for use in gas/liquid chromatography.

..... [1]

(iii) Suggest why 2-ethylphenol has the longest retention time.

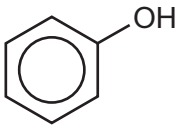
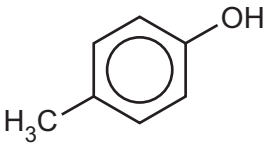
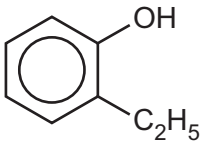
.....

.....

..... [1]

(iv) Table 5.1 shows the area underneath each peak in the chromatogram in Figure 5.4.

Table 5.1

compound	phenol 	4-methylphenol 	2-ethylphenol 
area underneath each peak	29	34	22

The area underneath each peak is proportional to the mass of the respective compound in the mixture.

Calculate the percentage by mass of 2-ethylphenol in the mixture.

percentage by mass of 2-ethylphenol = ... % [1]

(c) Describe the relative acidities of phenol, water and ethanol, C_2H_5OH. Explain your answer.

..... , ... , ...
weakest acid strongest acid

.....

.....

.....

.....

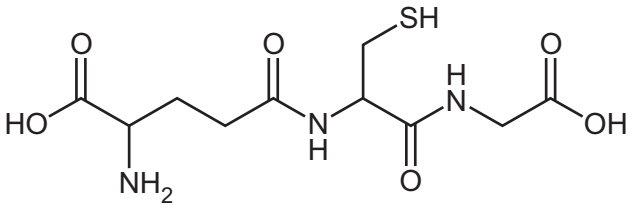
.....

.....
[4]

[Total: 17]

6 **(a)** Glutathione is a naturally occurring compound.

glutathione



Glutathione is hydrolysed to form three amino acids.

One of the amino acids is cysteine, $H_2NCH(CH_2SH)COOH$.

(i) Draw the structures of the two other amino acids that are formed by this hydrolysis.

[2]

(ii) Cysteine has an isoelectric point of 5.0.

Explain what is meant by isoelectric point.

.....

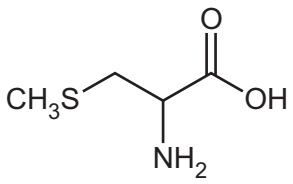
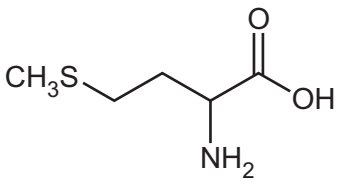
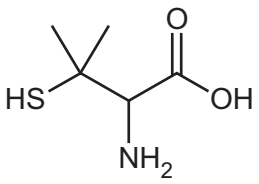
..... [1]

(iii) Draw the structure of cysteine at its isoelectric point.

[1]

(b) **X**, **Y** and **Z** are other amino acids that contain sulfur. Table 6.1 gives some details of these three compounds.

Table 6.1

amino acid	**X** 	**Y** 	**Z** 
M_r	135.1	149.1	149.1
isoelectric point	6.0	5.7	4.9

A mixture of these three amino acids, **X**, **Y** and **Z**, is analysed by electrophoresis, using a buffer solution at pH 5.5.

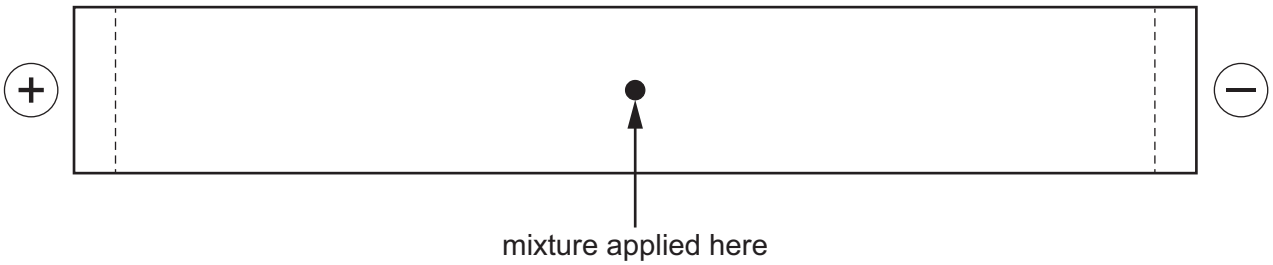


Figure 6.1

Draw and label **three** spots on Figure 6.1 to indicate the predicted position of each of these three amino acids, **X**, **Y** and **Z**, after electrophoresis at pH 5.5.

Explain your answer.

.....

.....

.....

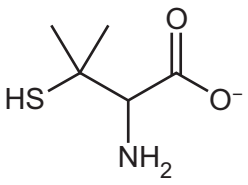
.....

.....

[3]

(c) Anion $\mathbf{Z}^-$ is a bidentate ligand.

$\mathbf{Z}^-$



(i) Define bidentate ligand.

.....

.....

..... [2]

(ii) Draw three-dimensional diagrams to show the two enantiomers of $\mathbf{Z}^-$.

[1]

(iii) Suggest **one** reason why it is desirable to use a single enantiomer of $\mathbf{Z}^-$ as a drug.

.....

..... [1]

Octahedral complex **C** forms when two moles of $\mathbf{Z}^-$ react with one mole of $Cu^{2+}(aq)$, as shown in Figure 6.2.

$\mathbf{Z}^-$

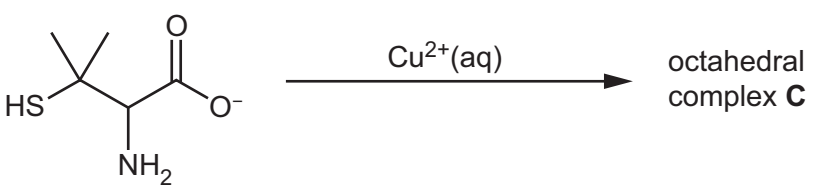


Figure 6.2

(iv) Complete the equation to describe the formation of octahedral complex **C** in Figure 6.2.

$[Cu(H_2O)_6]^{2+} + 2\mathbf{Z}^- \rightarrow$ ..... [1]

[Total: 12]

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Important values, constants and standards

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

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 –