Cambridge Assessment
International Education

Cambridge International AS & A Level

CANDIDATE NAME	

CENTRE NUMBER						CANDIDATE NUMBER					

CHEMISTRY **9701/42**

Paper 4 A Level Structured Questions **May/June 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 **(a)** **(i)** Calcium nitrate, $Ca(NO_3)_2$, decomposes on heating.

Write an equation for the decomposition of calcium nitrate.

.... [1]

(ii) Describe the trend in the decomposition temperature of the Group 2 nitrates.

Explain your answer.

....

....

....

....

.... [3]

(b) A sample of 0.333 g of strontium oxide, SrO, is completely dissolved in distilled water to form a solution of strontium hydroxide, $Sr(OH)_2$.

The resulting solution is added to a volumetric flask and made up to 250.0 cm^3 with distilled water.

Calculate the pH of this solution at 298 K. Give your answer to **two** decimal places.

pH = ... [4]

[Total: 8]

2 **(a)** When cobalt(II) sulfate, $CoSO_4$, is dissolved in distilled water, solution **A** is formed.

The reaction scheme in Fig. 2.1 shows some reactions of solution **A**.

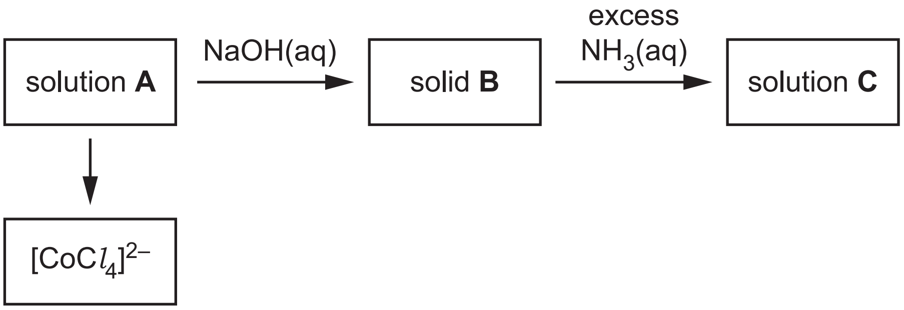


Fig. 2.1

(i) Complete Table 2.1 to show the formula and colour of each of the cobalt-containing species present in **A**, **B** and **C**. Identify the type of reaction **forming** each of **B** and **C**.

Table 2.1

	formula of cobalt-containing species	colour of cobalt-containing species	type of reaction
A			☒
B			
C			

[4]

(ii) Suggest a suitable reagent for the formation of $[CoCl_4]^{2-}$ from solution **A**.

.... [1]

(b) The complex ion $[CoCl_4]^{2-}$ has tetrahedral geometry.

The 3d orbitals in an isolated Co^{2+} ion are degenerate.

(i) Complete Fig. 2.2 to show the relative energies of the 3d orbitals in an isolated Co^{2+} ion and in Co^{2+} in a tetrahedral complex.

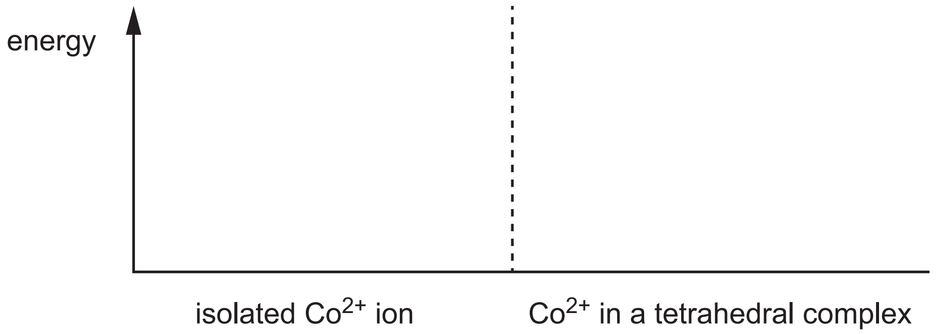


Fig. 2.2

[2]

(ii) Draw a three-dimensional diagram to show the structure of the complex ion $[CoCl_4]^{2-}$.

[1]

(c) H_2O_2 can act as an oxidising agent or a reducing agent when reacting with species that contain manganese.

Table 2.2 shows electrode potentials, $E^\ominus$, for some electrode reactions.

Table 2.2

electrode reaction	$E^\ominus$/V
$MnO_2 + 2H_2O + 2e^- \rightleftharpoons Mn(OH)_2 + 2OH^-$	–0.04
$MnO_2 + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$	+1.22
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.78
$H_2O_2 + OH^- + 2e^- \rightleftharpoons 3OH^-$	+0.88
$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	+0.68

Use **only** the species listed in Table 2.2 to suggest:

- one reaction in which H_2O_2 acts as an oxidising agent and
- one reaction in which H_2O_2 acts as a reducing agent.

Include the value of the standard cell potential, $E^\ominus_{cell}$, and an overall equation for each reaction.

H_2O_2 acting as an oxidising agent ....

....

....

....

H_2O_2 acting as a reducing agent ....

....

....

....

[4]

(d) Acidified manganate(VII) ions, MnO_4^-, can be used to analyse the content of iron tablets by titration.

Two identical iron tablets are crushed and dissolved in distilled water.

The resulting solution is made up to $150.0\,cm^3$ with distilled water.

$25.0\,cm^3$ of this solution requires $18.60\,cm^3$ of $0.0500\,mol\,dm^{-3}$ acidified MnO_4^- to reach the end-point. All the Fe^{2+} ions are oxidised.

The relevant half-equations are shown.

$$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$$

$$Fe^{2+} \rightleftharpoons Fe^{3+} + e^-$$

(i) Describe the colour change observed at the end-point of this titration.

from .... to .... [1]

(ii) Calculate the mass, in mg, of iron in **one** tablet.

Assume that all the iron in the tablets is Fe^{2+}.

Show your working.

mass of iron in one tablet = ... mg [4]

[Total: 17]

3 **(a)** Define entropy.

....

.... [1]

(b) Fig. 3.1 shows how the entropy, S, of a pure substance changes with temperature, T.

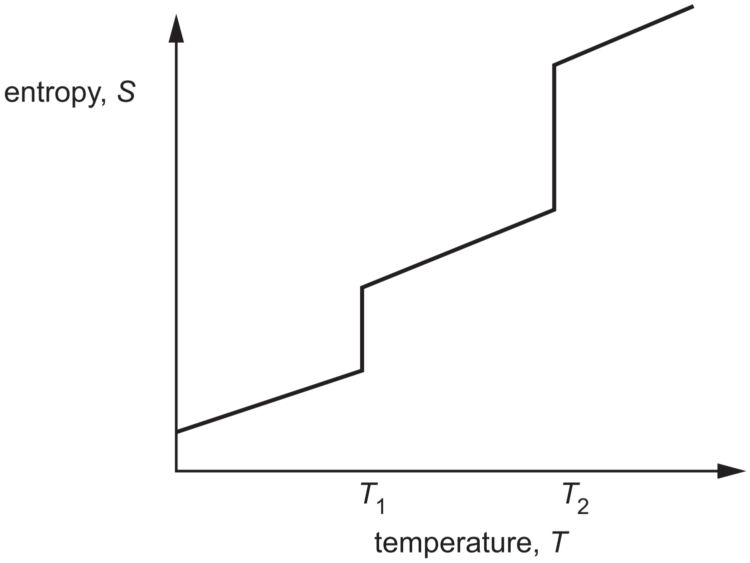


Fig. 3.1

(i) Identify the process occurring at each of the temperatures T_1 and T_2.

T_1 .... T_2 .... [1]

(ii) Explain why the entropy change, ΔS, at T_2 is bigger than the entropy change at T_1.

....

....

.... [1]

(c) The equation for the reduction of iron(III) oxide by carbon monoxide at 450 °C is shown.

$$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g) \qquad \Delta G^{\ominus} = -36.2\,kJ\,mol^{-1}$$

Table 3.1 shows the enthalpy of formation, $\Delta H_f^{\ominus}$, and the entropy, $S^{\ominus}$, for some substances.

Table 3.1

	$Fe_2O_3(s)$	CO(g)	Fe(s)	$CO_2(g)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	–824.2	–110.5	0.0	–393.5
$S^{\ominus}$ / J K^{-1} mol^{-1}	87.4	to be calculated	27.3	213.8

Use the data in Table 3.1 to calculate the entropy, $S^{\ominus}$, of carbon monoxide at 450 °C.

Show your working.

$S^{\ominus}$ of CO(g) = ... J K^{-1} mol^{-1} [3]

(d) Iron(II) oxide can also be reduced to iron by carbon monoxide, as shown.

$$FeO(s) + CO(g) \rightarrow Fe(s) + CO_2(g) \qquad \Delta H^{\ominus} = -11.1\,kJ\,mol^{-1}$$
$$\Delta S^{\ominus} = -15.2\,J\,K^{-1}\,mol^{-1}$$

State the effect of increasing temperature on the feasibility of this reaction.

Explain your answer.

....

....

....

.... [2]

[Total: 8]

4 **(a)** In aqueous solution, iodide ions react with acidified hydrogen peroxide, as shown in reaction 1.

reaction 1 $2I^- + H_2O_2 + 2H^+ \rightarrow I_2 + 2H_2O$

The rate equation for reaction 1 is shown.

$$\text{rate} = k\,[I^-][H_2O_2]$$

(i) Explain what is meant by order of reaction.

....

....

.... [1]

(ii) Complete Table 4.1.

Table 4.1

the order of reaction with respect to $[H^+]$	
the order of reaction with respect to $[I^-]$	
the order of reaction with respect to $[H_2O_2]$	
overall order of the reaction	

[2]

(iii) Sketch a line on Fig. 4.1 to show the relationship between $[I^-]$ and time.

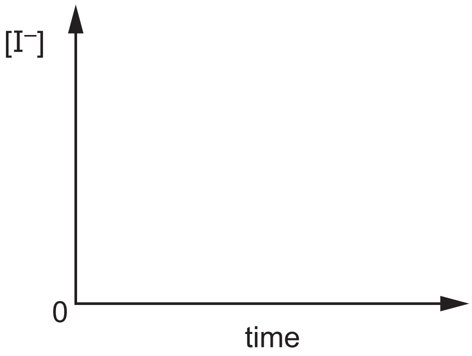


Fig. 4.1

[1]

(b) Nitrogen dioxide, NO_2, reacts with ozone, O_3, as shown in reaction 2.

reaction 2 $2NO_2 + O_3 \rightarrow O_2 + N_2O_5$

The rate equation for reaction 2 is shown.

$$\text{rate} = k\,[NO_2][O_3]$$

(i) Two experiments are carried out to measure the rate of reaction 2.

In the first experiment, the initial rate is measured starting with known concentrations of NO_2 and O_3. In the second experiment, the concentrations of NO_2 and O_3 are **both** increased by a factor of four.

Predict how the initial rate for reaction 2 would change.

.... [1]

(ii) The reaction mechanism for reaction 2 has two steps.

Define rate-determining step.

.... [1]

(iii) Suggest equations for the **two** steps of the reaction mechanism for reaction 2.

step 1 ....

step 2 ....

[2]

(c) Dinitrogen pentoxide, N_2O_5, can decompose to NO_2 and O_2.

The rate equation for this decomposition is shown.

$$\text{rate} = k\,[N_2O_5]$$

Fig. 4.2 shows the graph of rate against $[N_2O_5]$ for this decomposition.

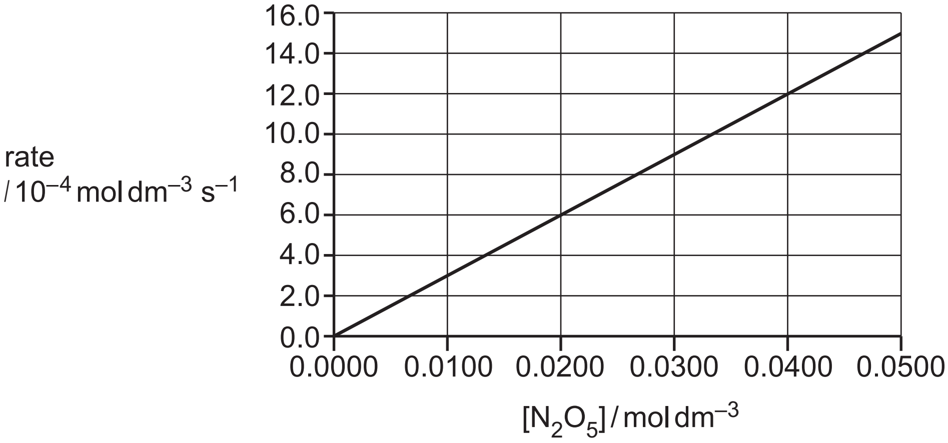


Fig. 4.2

(i) Use Fig. 4.2 to calculate a value for the rate constant, *k*, for this decomposition.

k = ... [1]

(ii) Use your answer to **(c)(i)** to calculate the half-life, $t_{\frac{1}{2}}$, in seconds, for this decomposition.

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

[Total: 10]

5 **(a)** Chloric(I) acid, $HClO$, is a weak Brønsted–Lowry acid.

When chloric(I) acid is added to aqueous sodium hydroxide, an acid–base reaction takes place, as shown.

$$HClO + NaOH \rightarrow NaClO + H_2O$$

(i) Identify the **two** conjugate acid–base pairs in this reaction.

acid I $HClO$ conjugate base of acid I ....

acid II .... conjugate base of acid II ....

[1]

(ii) The value for the acid dissociation constant, K_a, of $HClO(aq)$ is 3.70×10^{-8}.

Calculate the concentration, in $mol\,dm^{-3}$, of $HClO(aq)$ at a pH of 4.51.

concentration of $HClO$ = ... $mol\,dm^{-3}$ [2]

(iii) When a solution of $HClO(aq)$ is heated, chloric(V) acid and a strong acid **not** containing oxygen are formed as the only products.

Write an equation for this reaction.

.... [1]

(b) **(i)** Define a buffer solution.

....

.... [1]

(ii) Suggest a substance that could be added to aqueous ethanoic acid to form a buffer solution.

Explain your answer.

....

....

.... [1]

(c) Some fertilisers contain calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$.

An aqueous solution containing dihydrogenphosphate ions, $H_2PO_4^-$, can act as a buffer solution.

Write **two** equations to show how $H_2PO_4^-$ ions can act as a buffer.

equation 1 ....

equation 2 ....
[2]

(d) The solubility of calcium phosphate, $Ca_3(PO_4)_2$, is $1.14 \times 10^{-7}\,mol\,dm^{-3}$ at 25 °C.

(i) The expression for the solubility product, K_{sp}, of $Ca_3(PO_4)_2$ is shown.

$$K_{sp} = [Ca^{2+}]^3[PO_4^{3-}]^2$$

Calculate the value of K_{sp} for $Ca_3(PO_4)_2$. Include units.

K_{sp} = ... units ....
[3]

(ii) Some solid sodium phosphate is added to a saturated solution of $Ca_3(PO_4)_2$.

Predict the effect, if any, on the solubility of $Ca_3(PO_4)_2$.

Explain your answer.

....

....

.... [1]

[Total: 12]

6 **(a)** Methylbenzene reacts readily with nitronium ions, NO_2^+.

NO_2^+ ions are generated by the reaction between concentrated nitric acid and concentrated sulfuric acid.

(i) Write an equation for the formation of the NO_2^+ ion.

.... [1]

(ii) Complete the mechanism in Fig. 6.1 for the nitration of methylbenzene to form 1-methyl-2-nitrobenzene.

Include all relevant curly arrows and charges.

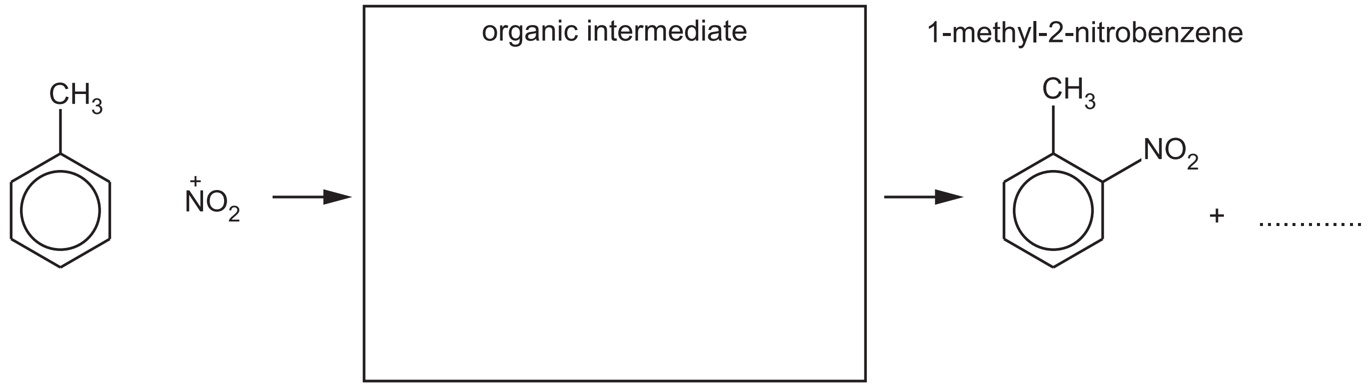


Fig. 6.1

[3]

(b) Phenol can be nitrated with dilute nitric acid.

Explain why the nitration of phenol occurs under **milder** conditions than the nitration of benzene.

....

....

....

....

.... [2]

(c) A sample of 2-nitrophenol is reacted with sodium.

Complete the equation in Fig. 6.2 for the reaction of 2-nitrophenol with sodium.

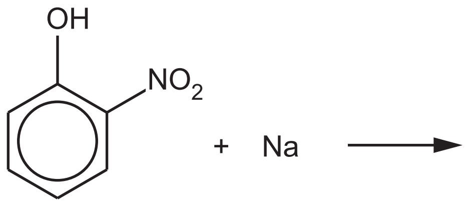


Fig. 6.2

[1]

(d) 2-nitrophenol can undergo different reactions as shown in Fig. 6.3.

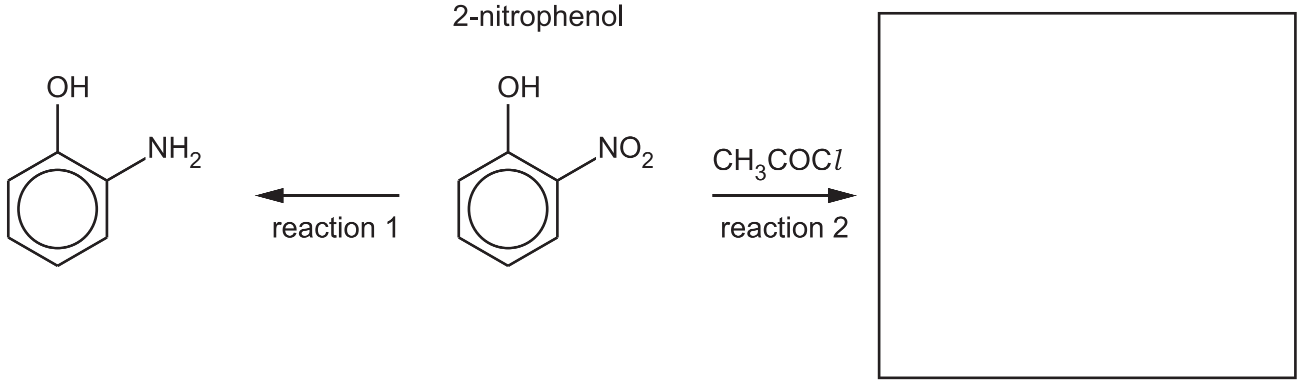


Fig. 6.3

(i) Suggest reagents and conditions for reaction 1.

.... [1]

(ii) Name the type of reaction for reaction 1.

.... [1]

(iii) Reaction 2 is carried out at room temperature.

Draw the structure of the organic product from reaction 2 in Fig. 6.3. [1]

(iv) Name the mechanism for reaction 2.

.... [1]

(e) The NO_2 group in 2-nitrophenol is electron withdrawing.

Suggest the relative acidities of ethanol, 2-nitrophenol, phenol and water.

Explain your answer.

....
most acidic least acidic

....

....

....

....

....

....
[4]

(f) Salbutamol is a pharmaceutical drug that contains a phenol functional group.

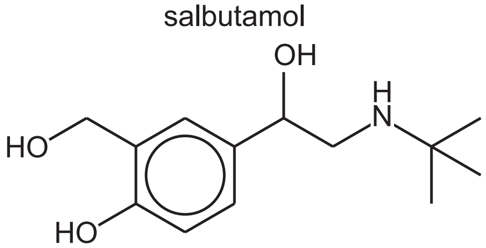


Fig. 6.4

(i) Name and classify the **three** other functional groups in salbutamol in Table 6.1.

Table 6.1

name of functional group	classification of functional group

[2]

(ii) Salbutamol reacts with $Br_2(aq)$ to form organic product **X**.

Draw the structure of **X**.

[1]

(iii) Salbutamol reacts with an excess of $SOCl_2$ to form organic product **Y**.

The molecular formula of **Y** is $C_{13}H_{19}Cl_2NO$.

Draw the structure of **Y**.

[1]

[Total: 19]

7 **(a)** 2-aminobutane, $CH_3CH(NH_2)CH_2CH_3$, exists as a mixture of two enantiomers.

Define enantiomers.

....

.... [1]

(b) **(i)** Explain why an aqueous solution of 2-aminobutane has a pH greater than 7.

Include an equation in your answer.

....

....

.... [2]

(ii) A $0.10\,mol\,dm^{-3}$ solution of diethylamine, $(CH_3CH_2)_2NH$, has a higher pH than a $0.10\,mol\,dm^{-3}$ solution of 2-aminobutane, $CH_3CH(NH_2)CH_2CH_3$.

Suggest why.

....

....

....

.... [2]

(iii) $(CH_3CH_2)_2NH$ reacts with ethanoic acid, CH_3COOH.

Complete the equation for this reaction.

$(CH_3CH_2)_2NH + CH_3COOH \rightarrow$ .... [1]

(iv) $(CH_3CH_2)_2NH$ reacts with ethanoyl chloride, CH_3COCl.

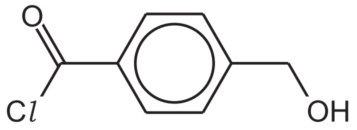
Complete the equation for this reaction.

$(CH_3CH_2)_2NH + CH_3COCl \rightarrow$ .... [1]

(c) Table 7.1 shows monomers that can undergo polymerisation.

(i) Complete Table 7.1.

Table 7.1

monomer	type of polymerisation
$CH_2C(CH_3)COOH$	
	
$CH_3CH(NH_2)COOH$	

[1]

(ii) Ethanedioic acid, HOOCCOOH, can react with propane-1,3-diamine, $H_2NCH_2CH_2CH_2NH_2$, to form polymer **W**.

Draw a section of polymer **W** showing only **one** repeat unit.

The new functional group formed should be displayed.

[2]

(iii) Poly(alkenes) biodegrade very slowly. Explain why.

....

.... [1]

[Total: 11]

8 **(a)** Compound **A** is analysed by carbon-13 NMR and proton (^1H) NMR spectroscopy.

A

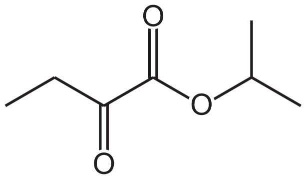


Fig. 8.1

State the reference substance and a solvent that can be used in NMR spectroscopy.

reference ....

solvent ....

[1]

(b) Predict the number of peaks in the carbon-13 NMR spectrum of **A**.

.... [1]

(c) The proton (^1H) NMR spectrum of **A** shows peaks in four different chemical environments.

Complete Table 8.1 for the proton (^1H) NMR spectrum of **A**.

Table 8.1

chemical shift δ / ppm	splitting pattern	number of protons on adjacent carbon atoms	number of ^1H atoms responsible for the peak
1.10			
1.50			6
2.85			
3.75			

[4]

[Total: 6]

Table 8.2

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

9 **(a)** The structures of the amino acids serine and lysine are shown in Fig. 9.1.

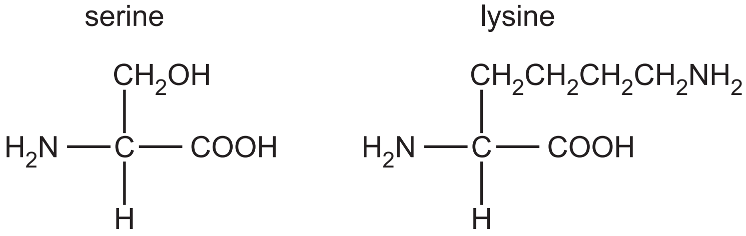


Fig. 9.1

Draw the structure for the dipeptide, ser–lys, with molecular formula $C_9H_{19}N_3O_4$.
The peptide functional group formed should be displayed.

[2]

(b) The isoelectric point of serine is 5.7 and of lysine is 9.7.

(i) State what is meant by isoelectric point.

....

.... [1]

(ii) A mixture of serine, lysine and ser–lys is analysed by electrophoresis using a buffer at pH 5.7.

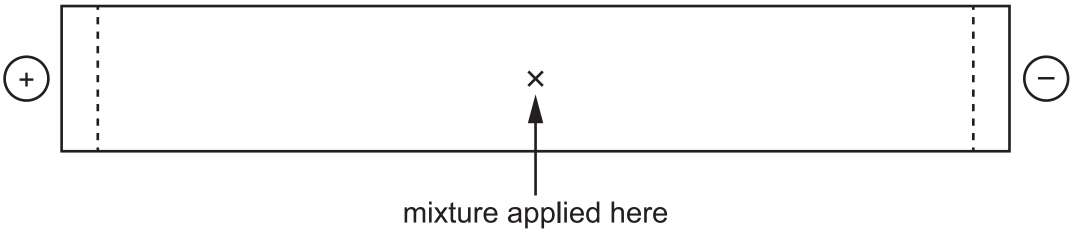


Fig. 9.2

Draw and label **three** spots on Fig. 9.2 to indicate the predicted position of each of these three species, serine, lysine and ser–lys, after electrophoresis.

Explain your answer.

....

....

....

.... [3]

(c) Fig. 9.3 shows the synthesis of compound **R** from compound **P**.

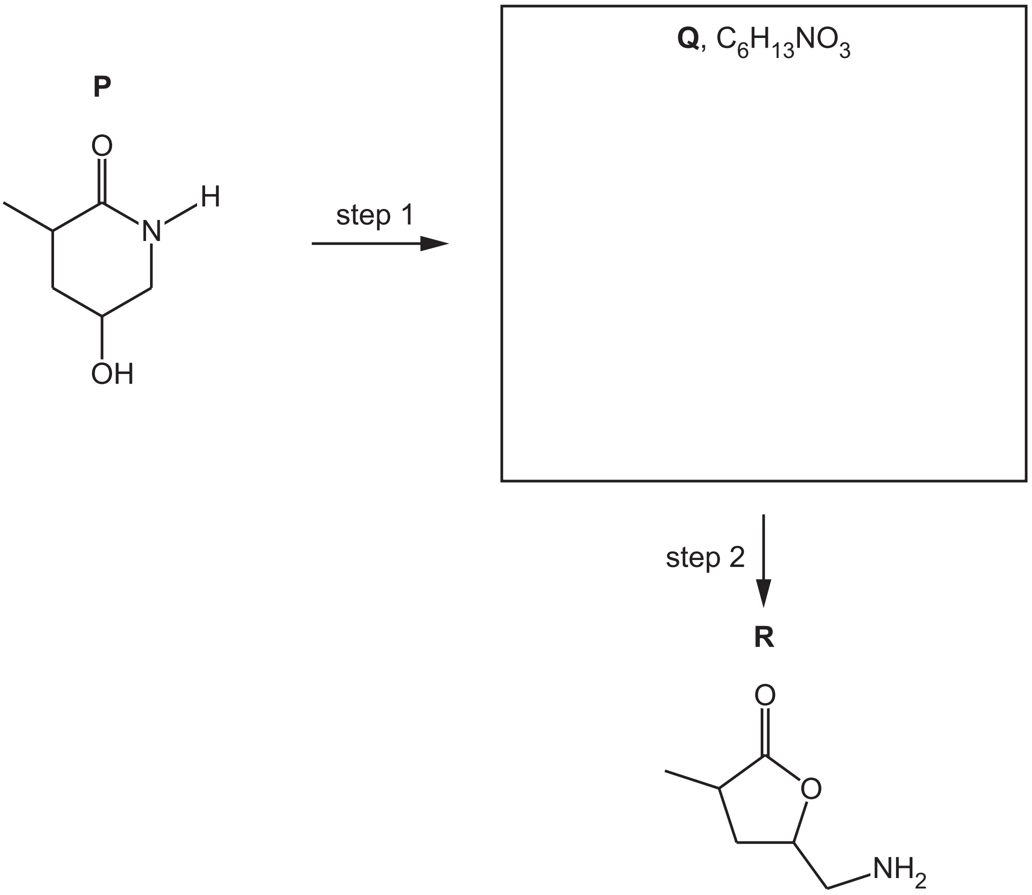


Fig. 9.3

(i) Draw the structure of **Q** in Fig. 9.3. [1]

(ii) State the reagents and conditions for steps 1 and 2 in Fig. 9.3.

step 1 ....

step 2 ....

[2]

[Total: 9]

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Important values, constants and standards

molar gas constant	$R = 8.31\,\text{J}\,\text{K}^{-1}\,\text{mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\,\text{C}\,\text{mol}^{-1}$
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	$c = 4.18\,\text{kJ}\,\text{kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J}\,\text{g}^{-1}\,\text{K}^{-1}$)

The Periodic Table of Elements

Group

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

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	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 –