



Cambridge International AS & A Level

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CHEMISTRY

9701/43

Paper 4 A Level Structured Questions

May/June 2022

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.



Answer **all** the questions in the spaces provided.

- 1 (a) The solubility of the Group 2 sulfates decreases down the group.

Explain this trend.

.....
.....
.....
.....
..... [3]

- (b) Describe what is observed when magnesium and barium are reacted separately with an excess of dilute sulfuric acid.

magnesium

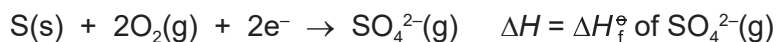
barium [1]

- (c) The solubility product, K_{sp} , of BaSO_4 is $1.08 \times 10^{-10} \text{ mol}^2 \text{ dm}^{-6}$ at 298 K.

Calculate the solubility of BaSO_4 in g per 100 cm^3 of solution.

solubility of BaSO_4 = g per 100 cm^3 of solution [2]

(d) (i) The equation for the formation of a gaseous sulfate ion is shown.



Calculate the standard enthalpy change of formation, ΔH_f^\ominus , of $\text{SO}_4^{2-}(\text{g})$. It may be helpful to draw a labelled energy cycle. Use relevant data from Table 1.1 in your calculations.

Table 1.1

| energy change | value / kJ mol^{-1} |
|---|------------------------------|
| lattice energy of barium sulfate, $\text{BaSO}_4(\text{s})$ | -2469 |
| standard enthalpy change of formation of barium sulfate | -1473 |
| standard enthalpy change of atomisation of barium | +180 |
| first ionisation energy of barium | +503 |
| second ionisation energy of barium | +965 |
| standard enthalpy change of atomisation of sulfur | +279 |
| standard enthalpy change for $\text{S}(\text{g}) \rightarrow \text{S}^{2-}(\text{g})$ | +440 |
| standard enthalpy change for $\text{O}(\text{g}) \rightarrow \text{O}^{2-}(\text{g})$ | +657 |
| O=O bond energy | +496 |

$$\Delta H_f^\ominus \text{ of SO}_4^{2-}(\text{g}) = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

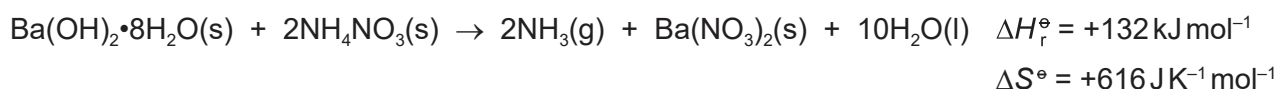
- (ii) Suggest how the lattice energy of $\text{BaSO}_4(\text{s})$ differs from the lattice energy of $\text{Cs}_2\text{SO}_4(\text{s})$. Explain your answer.

.....

 [2]

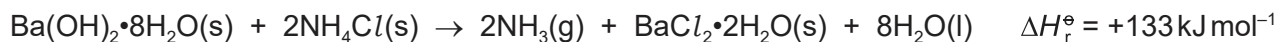
- (e) The reaction of solid hydrated barium hydroxide, $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$, with ammonium salts is endothermic.

- (i) Calculate the **minimum** temperature at which the reaction of $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ with NH_4NO_3 becomes feasible. Show all your working.



temperature = °C [2]

- (ii) Barium hydroxide reacts readily with ammonium chloride on mixing at room temperature.



Some relevant standard entropies are given in Table 1.2.

Table 1.2

| substance | $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$ | $\text{NH}_4\text{Cl}(\text{s})$ | $\text{NH}_3(\text{g})$ | $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}(\text{s})$ | $\text{H}_2\text{O}(\text{l})$ |
|---|--|----------------------------------|-------------------------|---|--------------------------------|
| $S^\ominus / \text{JK}^{-1} \text{ mol}^{-1}$ | 427 | 95 | 192 | 203 | 70 |

Calculate the standard Gibbs free energy change, ΔG^\ominus , for this reaction at 25 °C.

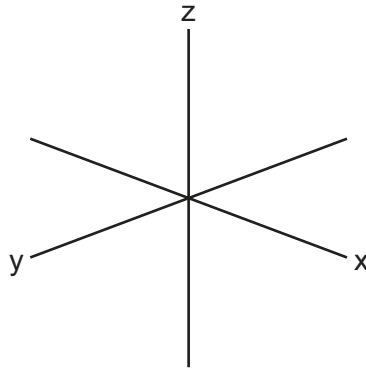
$\Delta G^\ominus = \dots\dots\dots \text{ kJ mol}^{-1}$ [3]

[Total: 16]

2 (a) Define transition element.

.....
 [1]

(b) Sketch the shape of a $3d_{z^2}$ orbital.



[1]

(c) Manganese(IV) oxide, MnO_2 , acts as a heterogeneous catalyst in the decomposition of hydrogen peroxide, H_2O_2 .

(i) Explain what is meant by a heterogeneous catalyst.

.....
 [1]

(ii) Describe the mode of action of a heterogeneous catalyst in a reaction.

.....

 [3]

(d) Manganese(VII) oxide, Mn_2O_7 , can be made by treatment of $KMnO_4$ with concentrated sulfuric acid (reaction 1).

Mn_2O_7 readily decomposes at room temperature to form manganese(IV) oxide and a colourless diatomic gas (reaction 2).

Construct equations for **both** the reactions described.

reaction 1

reaction 2

[2]

(e) Aqueous manganese(II) ions show similar chemical properties to aqueous copper(II) ions when reacted separately with NaOH(aq) and with concentrated HCl.

(i) Write the ionic equation, and state the type of reaction, for the reaction of $[\text{Mn}(\text{H}_2\text{O})_6]^{2+}$ with NaOH(aq).

ionic equation

type of reaction

[2]

(ii) Write the ionic equation, and state the type of reaction, for the reaction of $[\text{Mn}(\text{H}_2\text{O})_6]^{2+}$ with concentrated HCl.

ionic equation

type of reaction

[2]

(iii) Table 2.1 lists relevant electrode potentials for some electrode reactions.

Table 2.1

| electrode reaction | E°/V |
|--|--------------------|
| $\text{Mn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mn}$ | -1.18 |
| $\text{Cl}_2 + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$ | +1.36 |
| $2\text{HOCl} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Cl}_2 + 2\text{H}_2\text{O}$ | +1.64 |
| $\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O}$ | +1.23 |
| $\text{MnO}_4^- + 4\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{MnO}_2 + 2\text{H}_2\text{O}$ | +1.67 |

Suggest the formula of the manganese species formed when $\text{Mn}^{2+}(\text{aq})$ reacts with Cl_2 .

State the type of reaction.

formula of manganese species formed

type of reaction

[1]

[Total: 13]

- 3 (a) The rate of reaction between 2-chloro-2-methylpropane, $(\text{CH}_3)_3\text{CCl}$, and methanol is investigated. When a large excess of methanol is used, the overall reaction is first order.

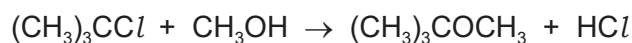


Fig. 3.1 shows the results obtained.

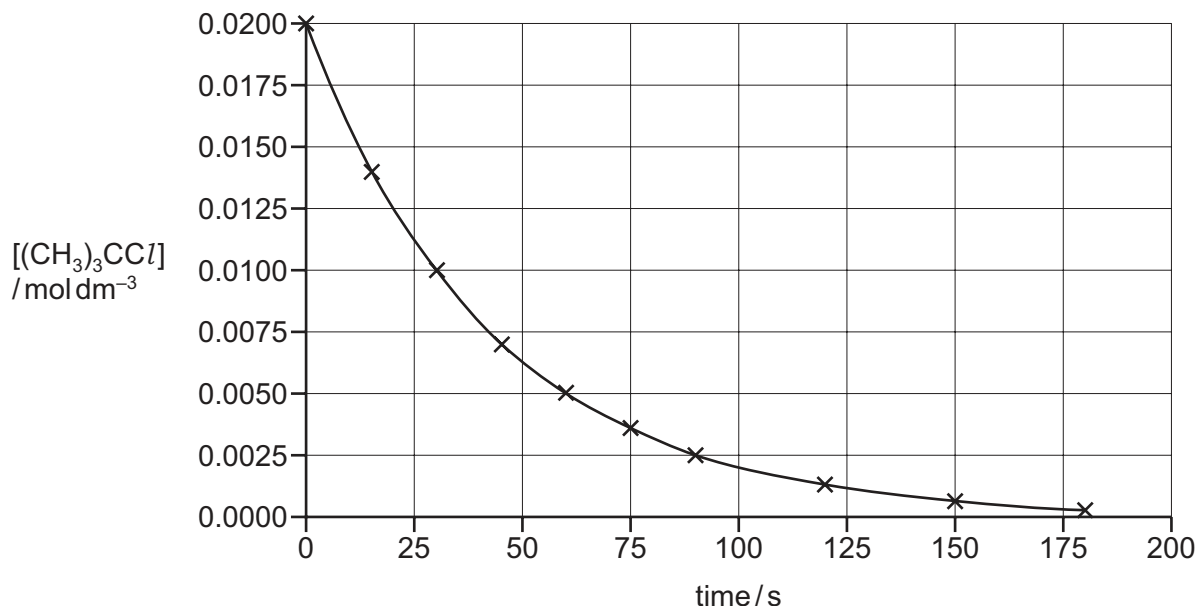


Fig. 3.1

- (i) Use the graph to determine the rate of reaction at 40 s. Show all your working.

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

- (ii) Use the graph to show that the overall reaction is first order. Explain your answer.

.....

 [2]

- (b) In a different reaction, which is also a first order reaction, 75% of the reactant is consumed in 320 s.

Calculate the rate constant, k , for this reaction. State the units for k .

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

(c) (i) Define standard electrode potential, E^\ominus .

.....

 [1]

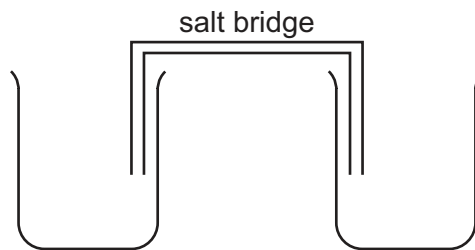
(ii) A salt bridge is used in an electrochemical cell.

State the function of the salt bridge. Explain your answer.

.....
 [1]

(iii) Complete the diagram of the apparatus that can be used to measure the E^\ominus of the $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$, $\text{H}^+(\text{aq})/\text{Cr}^{3+}(\text{aq})$ electrode against the standard hydrogen electrode.

Your diagram should be fully labelled to identify all apparatus, substances and conditions.



[3]

(iv) The E^\ominus of the $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$, $\text{H}^+(\text{aq})/\text{Cr}^{3+}(\text{aq})$ electrode is +1.33V.

Label the negative electrode and the direction of electron flow in the external circuit when the current flows in your diagram in (c)(iii). [1]

- (d) Table 3.1 lists relevant electrode potentials for some electrode reactions for use in (d)(i) and (d)(ii).

Table 3.1

| electrode reaction | E°/V |
|--|-------------|
| $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$ | +1.33 |
| $\text{CH}_3\text{CHO} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{CH}_3\text{CH}_2\text{OH}$ | -0.61 |
| $\text{CH}_3\text{COOH} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{CH}_3\text{CHO} + \text{H}_2\text{O}$ | -0.94 |
| $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$ | +1.23 |

- (i) Ethanal is oxidised to ethanoic acid in the presence of $\text{Cr}_2\text{O}_7^{2-}$ ions.

Construct the ionic equation for the oxidation of ethanal to ethanoic acid using dichromate(VI) in acid conditions. Calculate the E°_{cell} for this reaction.

ionic equation

$$E^\circ_{\text{cell}} = \dots\dots\dots \text{V}$$

[2]

- (ii) In an ethanol-oxygen fuel cell, $\text{CH}_3\text{CH}_2\text{OH}(\text{l})$ and $\text{O}_2(\text{g})$ are in contact with two inert electrodes immersed in an acidic solution.

The cell reaction for the oxidation of ethanol by oxygen is shown.



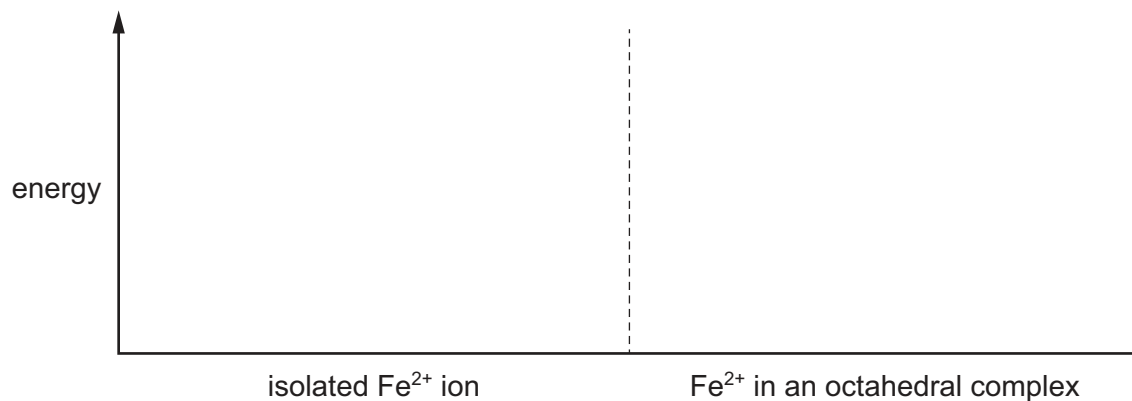
Calculate ΔG° , in kJ mol^{-1} , for the oxidation of ethanol by oxygen.

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

[Total: 15]

- 4 (a) The 3d orbitals in an isolated Fe^{2+} ion are degenerate.

Complete the diagram to show the splitting of the 3d orbital energy levels in an isolated Fe^{2+} ion and when Fe^{2+} forms an octahedral complex.



[2]

- (b) (i) Bipyridine, bipy, is a bidentate ligand.

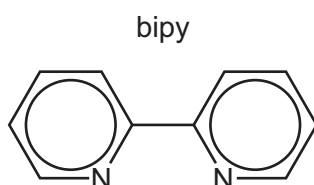


Fig. 4.1

Explain what is meant by bidentate ligand.

.....

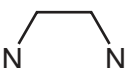
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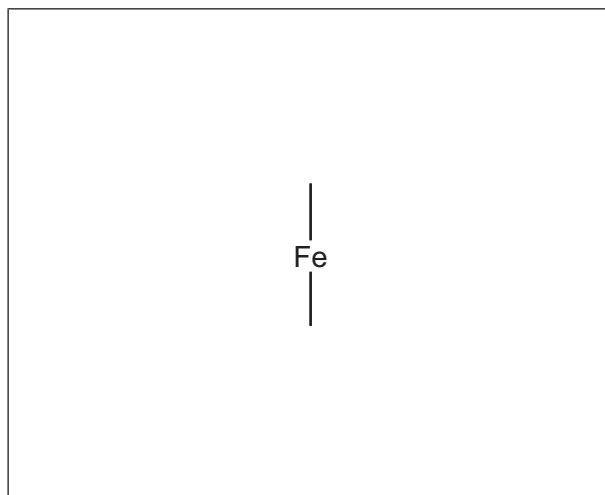
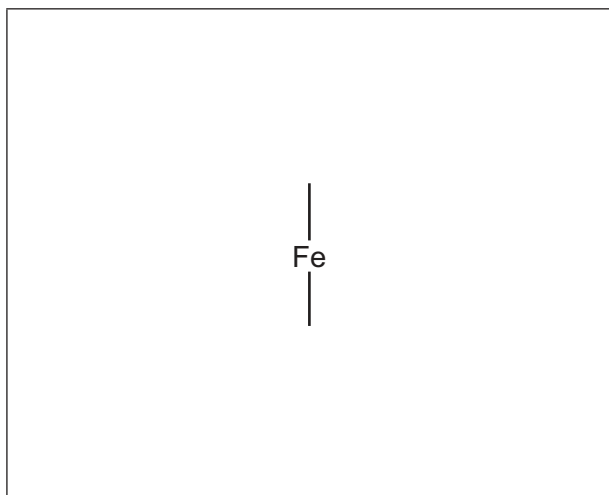
..... [2]

- (ii) The complex $[\text{Fe}(\text{bipy})_3]^{2+}$ exists as two stereoisomers.

Complete the three-dimensional diagrams to show the two stereoisomers of $[\text{Fe}(\text{bipy})_3]^{2+}$.

State the type of stereoisomerism shown.

Use  to represent bipy in your diagrams.



type of stereoisomerism [3]

- (c) Standard electrode potentials can be used to compare the stability of different complex ions for a given transition element.

Table 4.1 lists electrode potentials for some electrode reactions for $\text{Fe}^{3+}/\text{Fe}^{2+}$ systems.

Table 4.1

| electrode reaction | E^\ominus/V |
|---|----------------------|
| $[\text{Fe}(\text{H}_2\text{O})_6]^{3+} + \text{e}^- \rightleftharpoons [\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ | +0.77 |
| $[\text{Fe}(\text{CN})_6]^{3-} + \text{e}^- \rightleftharpoons [\text{Fe}(\text{CN})_6]^{4-}$ | +0.36 |
| $[\text{Fe}(\text{bipy})_3]^{3+} + \text{e}^- \rightleftharpoons [\text{Fe}(\text{bipy})_3]^{2+}$ | +0.96 |

Use relevant data from Table 4.1 to state which iron(III) complex is hardest to reduce. Explain your choice.

iron(III) complex

explanation

[1]

(d) Benzoyl chloride is hydrolysed by water at room temperature to form benzoic acid.

- (i) Complete the diagram to show the mechanism for the reaction between C_6H_5COCl and H_2O .

Include charges, dipoles, lone pairs of electrons and curly arrows as appropriate.



[4]

- (ii) Name the type of mechanism you showed in (d)(i).

..... [1]

(e) Acyl chlorides react with sodium carboxylates to form acid anhydrides as shown in Fig. 5.1.

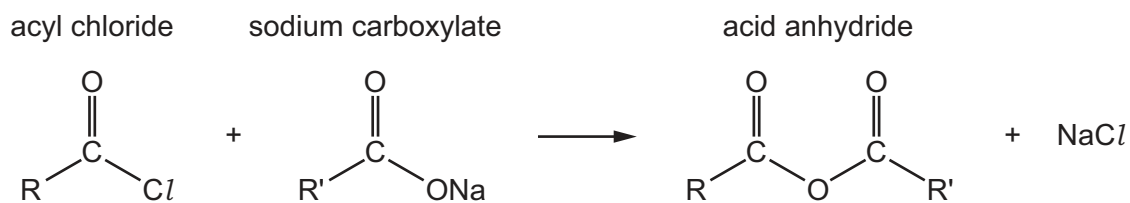


Fig. 5.1

The condensation polymers, polyanhydride and polyester, are formed by similar methods.

The repeat unit for a polyanhydride is shown in Fig. 5.2.

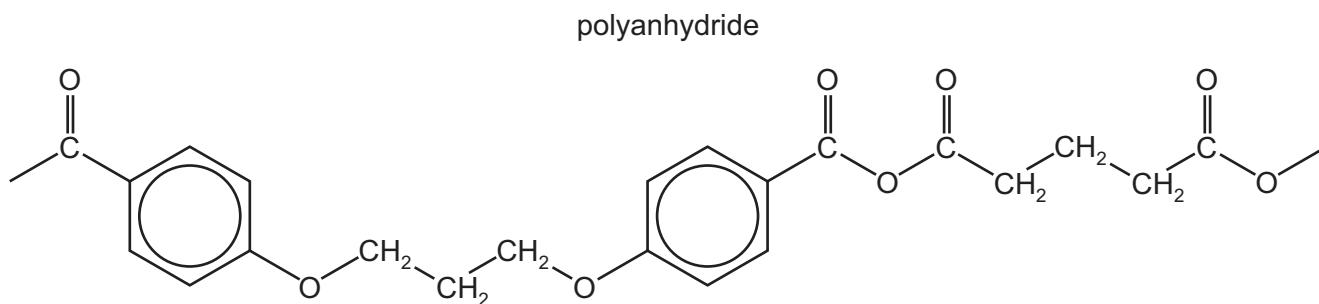


Fig. 5.2

(i) Use Fig. 5.1 and Fig. 5.2 to suggest the structures of the two monomers used to make this polyanhydride.



[2]

(ii) Polyanhydrides are biodegradable polymers.

Suggest how this polyanhydride can be degraded.

.....
 [1]

[Total: 16]

- 6 (a) Describe what is meant by a racemic mixture.

.....
 [1]

- (b) Asparagine is an amino acid that contains a chiral carbon atom and displays stereoisomerism.

Separate samples of asparagine are dissolved in CDCl_3 and analysed using carbon-13 and proton (^1H) NMR spectroscopy.

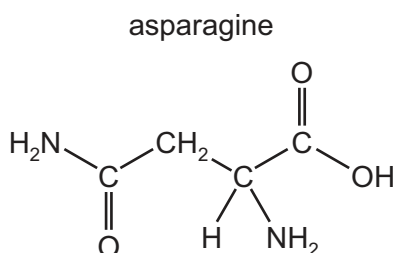


Fig. 6.1

Predict the number of peaks seen in the carbon-13 and proton (^1H) NMR spectra of asparagine.

| | carbon-13 NMR | proton (^1H) NMR |
|-----------------|---------------|-----------------------------|
| number of peaks | | |

[1]

- (c) The isoelectric point of asparagine, asn, is at pH 5.4.

- (i) Describe the meaning of the term isoelectric point.

.....
 [1]

- (ii) Draw the structure of asparagine at pH 1.0.

[1]

(d) Asparagine can polymerise to form poly(asparagine).

Draw the structure of poly(asparagine), showing **two** repeat units. The peptide linkage should be shown displayed.

[2]

(e) The isoelectric point of lysine, lys, is at pH 9.8.

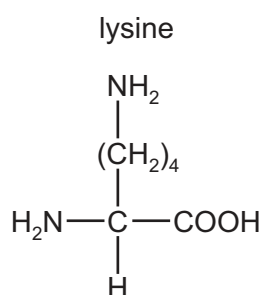


Fig. 6.2

A mixture of the dipeptide lys-asn and its two constituent amino acids, asparagine and lysine, is analysed by electrophoresis using a buffer at pH 5.0. The results obtained are shown in Fig. 6.3.

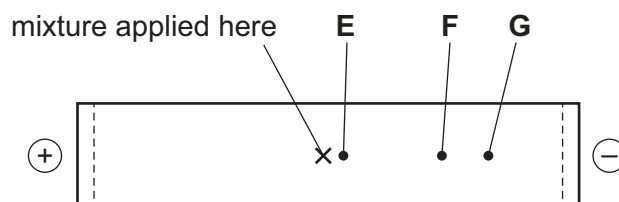


Fig. 6.3

Suggest identities for the species responsible for spots **E**, **F** and **G**. Explain your answers.

| spot | identity |
|----------|----------|
| E | |
| F | |
| G | |

.....

.....

.....

[3]

(f) Thin-layer and gas-liquid chromatography can be used to analyse mixtures of substances.

Each type of chromatography makes use of a stationary phase and a mobile phase.

(i) Complete Table 6.1 with an example of each of these.

Table 6.1

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

[1]

(ii) An unknown amino acid is analysed using thin-layer chromatography. Two chromatographs of the unknown amino acid and four reference amino acids, **P**, **Q**, **R** and **S**, are obtained using two different solvents.

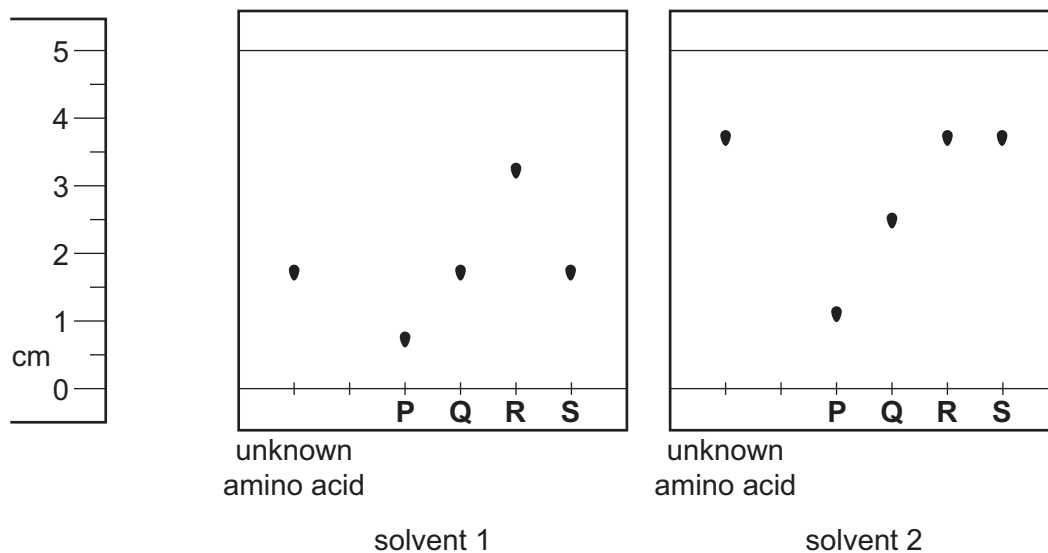


Fig. 6.4

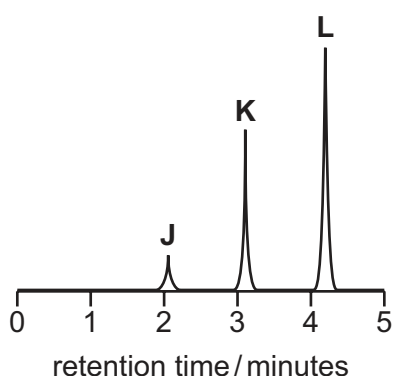
Identify the unknown amino acid. Justify your answer.

.....

.....

..... [1]

- (g) A mixture containing three organic compounds is analysed by gas chromatography and mass spectrometry. The gas chromatogram is shown.



| | | | |
|------------------------|----------|----------|----------|
| peak | J | K | L |
| area / mm ² | 8 | 44 | 58 |

Fig. 6.5

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

The concentration of **K** in the mixture is $5.52 \times 10^{-2} \text{ g dm}^{-3}$.

Calculate the concentration, in mol dm^{-3} , of compound **L** in the mixture.
 [M_r : **L**, 116]

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

[Total: 12]

- 7 Procaine is used as an anaesthetic in medicine. It can be synthesised from methylbenzene in five steps as shown in Fig. 7.1.

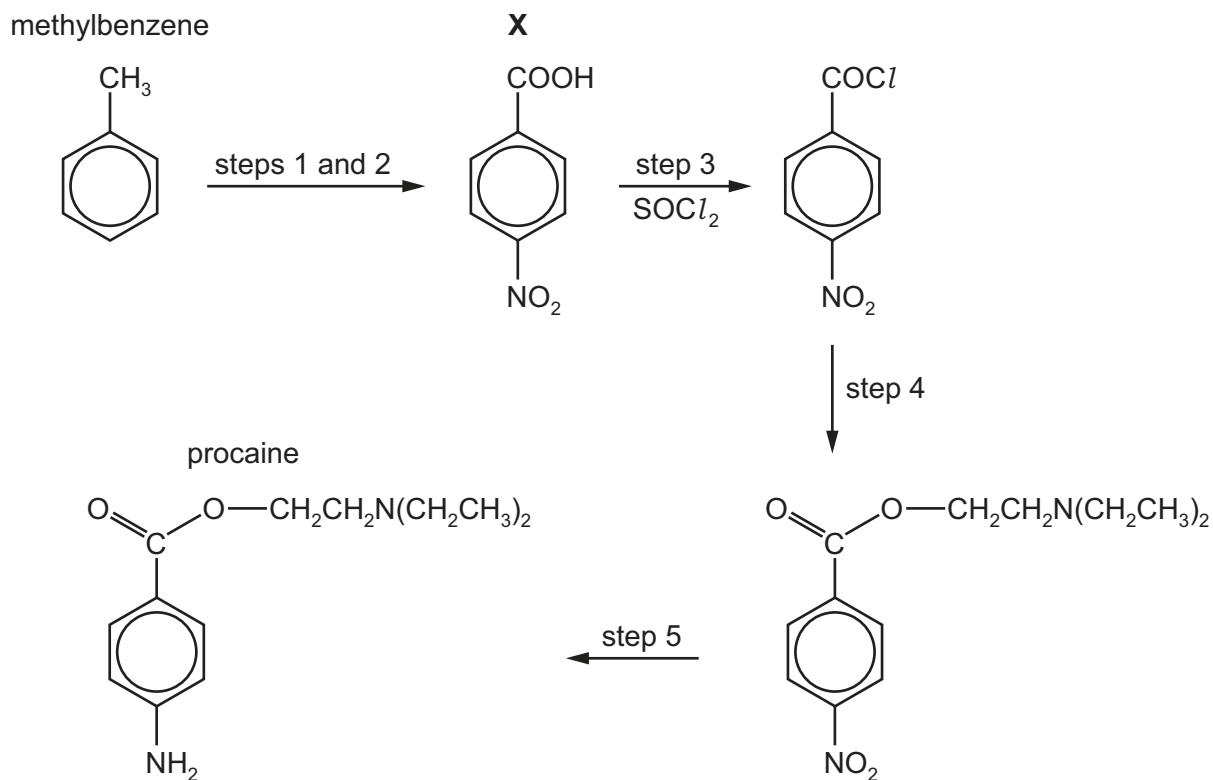


Fig. 7.1

- (a) (i) Name all the functional groups present in procaine.

..... [1]

- (ii) A molecule of procaine has 13 carbon atoms.

State the number of carbon atoms that are sp , sp^2 and sp^3 hybridised in procaine.

sp carbons = sp^2 carbons = sp^3 carbons = [1]

- (b) The proton (^1H) NMR spectrum of procaine dissolved in D_2O is recorded.

Predict the number of peaks observed.

..... [1]

- (c) State why procaine can act as a base.

.....
 [1]

(d) Compound **X** can be synthesised in two steps from methylbenzene.

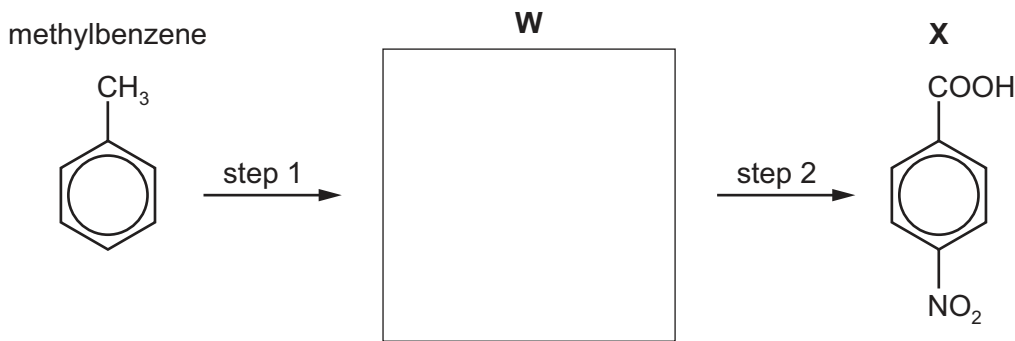


Fig. 7.2

(i) Draw the structure of compound **W** in the box provided. [1]

(ii) State the reagents and conditions for step 1 and step 2.

step 1

step 2

[2]

(e) Procaine is synthesised in three steps from **X**.

Suggest the reagents and conditions for step 4 and for step 5 in Fig. 7.1.

step 4

step 5

[3]

(f) (i) Explain what is meant by partition coefficient, K_{pc} .

.....

..... [2]

(ii) The partition coefficient of procaine between octan-1-ol and water is 1.77.

Octan-1-ol and water are immiscible. A solution containing 0.500 g of procaine in 75.0 cm³ of water is shaken with 50.0 cm³ of octan-1-ol.

Calculate the mass of procaine that is extracted into the octan-1-ol.

mass of procaine extracted = g [2]

[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 | $L = 6.022 \times 10^{23} \text{ mol}^{-1}$ |
| 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 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">1 H hydrogen 1.0</div> <div style="border: 1px solid black; padding: 2px;">2 He helium 4.0</div> </div> | | | | | | | | | | | | | | | |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">3 Li lithium 6.9</div> <div style="border: 1px solid black; padding: 2px;">4 Be beryllium 9.0</div> </div> | | | | | | | | | | | | | | | |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">5 B boron 10.8</div> <div style="border: 1px solid black; padding: 2px;">6 C carbon 12.0</div> <div style="border: 1px solid black; padding: 2px;">7 N nitrogen 14.0</div> <div style="border: 1px solid black; padding: 2px;">8 O oxygen 16.0</div> <div style="border: 1px solid black; padding: 2px;">9 F fluorine 19.0</div> <div style="border: 1px solid black; padding: 2px;">10 Ne neon 20.2</div> </div> | | | | | | | | | | | | | | | |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">11 Na sodium 23.0</div> <div style="border: 1px solid black; padding: 2px;">12 Mg magnesium 24.3</div> </div> | | | | | | | | | | | | | | | |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">13 Al aluminium 27.0</div> <div style="border: 1px solid black; padding: 2px;">14 Si silicon 28.1</div> <div style="border: 1px solid black; padding: 2px;">15 P phosphorus 31.0</div> <div style="border: 1px solid black; padding: 2px;">16 S sulfur 32.1</div> <div style="border: 1px solid black; padding: 2px;">17 Cl chlorine 35.5</div> <div style="border: 1px solid black; padding: 2px;">18 Ar argon 39.9</div> </div> | | | | | | | | | | | | | | | |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">19 K potassium 39.1</div> <div style="border: 1px solid black; padding: 2px;">20 Ca calcium 40.1</div> <div style="border: 1px solid black; padding: 2px;">21 Sc scandium 45.0</div> <div style="border: 1px solid black; padding: 2px;">22 Ti titanium 47.9</div> <div style="border: 1px solid black; padding: 2px;">23 V vanadium 50.9</div> <div style="border: 1px solid black; padding: 2px;">24 Cr chromium 52.0</div> <div style="border: 1px solid black; padding: 2px;">25 Mn manganese 54.9</div> <div style="border: 1px solid black; padding: 2px;">26 Fe iron 55.8</div> <div style="border: 1px solid black; padding: 2px;">27 Co cobalt 58.9</div> <div style="border: 1px solid black; padding: 2px;">28 Ni nickel 58.7</div> <div style="border: 1px solid black; padding: 2px;">29 Cu copper 63.5</div> <div style="border: 1px solid black; padding: 2px;">30 Zn zinc 65.4</div> <div style="border: 1px solid black; padding: 2px;">31 Ga gallium 69.7</div> <div style="border: 1px solid black; padding: 2px;">32 Ge germanium 72.6</div> <div style="border: 1px solid black; padding: 2px;">33 As arsenic 74.9</div> <div style="border: 1px solid black; padding: 2px;">34 Se selenium 79.0</div> <div style="border: 1px solid black; padding: 2px;">35 Br bromine 79.9</div> <div style="border: 1px solid black; padding: 2px;">36 Kr krypton 83.8</div> </div> | | | | | | | | | | | | | | | |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">37 Rb rubidium 85.5</div> <div style="border: 1px solid black; padding: 2px;">38 Sr strontium 87.6</div> <div style="border: 1px solid black; padding: 2px;">39 Y yttrium 88.9</div> <div style="border: 1px solid black; padding: 2px;">40 Zr zirconium 91.2</div> <div style="border: 1px solid black; padding: 2px;">41 Nb niobium 92.9</div> <div style="border: 1px solid black; padding: 2px;">42 Mo molybdenum 95.9</div> <div style="border: 1px solid black; padding: 2px;">43 Tc technetium —</div> <div style="border: 1px solid black; padding: 2px;">44 Ru ruthenium 101.1</div> <div style="border: 1px solid black; padding: 2px;">45 Rh rhodium 102.9</div> <div style="border: 1px solid black; padding: 2px;">46 Pd palladium 106.4</div> <div style="border: 1px solid black; padding: 2px;">47 Ag silver 107.9</div> <div style="border: 1px solid black; padding: 2px;">48 Cd cadmium 112.4</div> <div style="border: 1px solid black; padding: 2px;">49 In indium 114.8</div> <div style="border: 1px solid black; padding: 2px;">50 Sn tin 118.7</div> <div style="border: 1px solid black; padding: 2px;">51 Sb antimony 121.8</div> <div style="border: 1px solid black; padding: 2px;">52 Te tellurium 127.6</div> <div style="border: 1px solid black; padding: 2px;">53 I iodine 126.9</div> <div style="border: 1px solid black; padding: 2px;">54 Xe xenon 131.3</div> </div> | | | | | | | | | | | | | | | |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">55 Cs caesium 132.9</div> <div style="border: 1px solid black; padding: 2px;">56 Ba barium 137.3</div> <div style="border: 1px solid black; padding: 2px;">57–71 lanthanoids —</div> <div style="border: 1px solid black; padding: 2px;">72 Hf hafnium 178.5</div> <div style="border: 1px solid black; padding: 2px;">73 Ta tantalum 180.9</div> <div style="border: 1px solid black; padding: 2px;">74 W tungsten 183.8</div> <div style="border: 1px solid black; padding: 2px;">75 Re rhenium 186.2</div> <div style="border: 1px solid black; padding: 2px;">76 Os osmium 190.2</div> <div style="border: 1px solid black; padding: 2px;">77 Ir iridium 192.2</div> <div style="border: 1px solid black; padding: 2px;">78 Pt platinum 195.1</div> <div style="border: 1px solid black; padding: 2px;">79 Au gold 197.0</div> <div style="border: 1px solid black; padding: 2px;">80 Hg mercury 200.6</div> <div style="border: 1px solid black; padding: 2px;">81 Tl thallium 204.4</div> <div style="border: 1px solid black; padding: 2px;">82 Pb lead 207.2</div> <div style="border: 1px solid black; padding: 2px;">83 Bi bismuth 209.0</div> <div style="border: 1px solid black; padding: 2px;">84 Po polonium —</div> <div style="border: 1px solid black; padding: 2px;">85 At astatine —</div> <div style="border: 1px solid black; padding: 2px;">86 Rn radon —</div> </div> | | | | | | | | | | | | | | | |
| | | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">87 Fr francium —</div> <div style="border: 1px solid black; padding: 2px;">88 Ra radium —</div> <div style="border: 1px solid black; padding: 2px;">89–103 actinoids —</div> <div style="border: 1px solid black; padding: 2px;">104 Rf rutherfordium —</div> <div style="border: 1px solid black; padding: 2px;">105 Db dubnium —</div> <div style="border: 1px solid black; padding: 2px;">106 Sg seaborgium —</div> <div style="border: 1px solid black; padding: 2px;">107 Bh bohrium —</div> <div style="border: 1px solid black; padding: 2px;">108 Hs hassium —</div> <div style="border: 1px solid black; padding: 2px;">109 Mt meitnerium —</div> <div style="border: 1px solid black; padding: 2px;">110 Ds darmstadtium —</div> <div style="border: 1px solid black; padding: 2px;">111 Rg roentgenium —</div> <div style="border: 1px solid black; padding: 2px;">112 Cn copernicium —</div> <div style="border: 1px solid black; padding: 2px;">113 Nh nihonium —</div> <div style="border: 1px solid black; padding: 2px;">114 Fl flerovium —</div> <div style="border: 1px solid black; padding: 2px;">115 Mc moscovium —</div> <div style="border: 1px solid black; padding: 2px;">116 Lv livermorium —</div> <div style="border: 1px solid black; padding: 2px;">117 Ts tennessine —</div> <div style="border: 1px solid black; padding: 2px;">118 Og oganeson —</div> </div> | | | | | | | | | | | | | | | |

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|-------------|--------------------------------|------------------------------|-----------------------------------|--------------------------------|-----------------------------|-------------------------------|-------------------------------|---------------------------------|------------------------------|---------------------------------|------------------------------|-----------------------------|-------------------------------|--------------------------------|-------------------------------|
| lanthanoids | 57 La lanthanum 138.9 | 58 Ce cerium 140.1 | 59 Pr praseodymium 140.9 | 60 Nd neodymium 144.4 | 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 |
| | 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 — |