



CANDIDATE
NAME

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CENTRE
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9701/41

May/June 2024

2 hours

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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.

- 1 (a) (i) Describe the trend in the solubility of the hydroxides of magnesium, calcium and strontium.

Explain your answer.

..... > >
 most soluble least soluble

.....

.....

.....

.....

.....

.....

[4]

- (ii) Suggest the variation in pH of saturated solutions of the hydroxides of magnesium, calcium and strontium.

Explain your answer.

.....

.....

..... [1]

- (b) Barium hydroxide, $\text{Ba}(\text{OH})_2$, is a strong base.

A 250.0 cm^3 solution of $\text{Ba}(\text{OH})_2$ with a pH of 12.2 is made by dissolving $\text{Ba}(\text{OH})_2$ in distilled water.

Calculate the mass of $\text{Ba}(\text{OH})_2$ required to make this solution.

Show your working.

[M_r : $\text{Ba}(\text{OH})_2$, 171.3]

mass of $\text{Ba}(\text{OH})_2$ = ... g [4]

(c) The solubility of iron(II) hydroxide, $\text{Fe}(\text{OH})_2$, is $5.85 \times 10^{-6} \text{ mol dm}^{-3}$ at 298 K.

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

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

[1]

(ii) Calculate the value of K_{sp} of $\text{Fe}(\text{OH})_2$. Include its units.

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

$$\text{units} = \dots\dots\dots$$

[2]

[Total: 12]

- 2 (a) (i) Define transition element.

.....

 [1]

- (ii) Explain why transition elements can form complex ions.

.....
 [1]

- (b) The 3d orbitals in an isolated Ag^+ ion are degenerate.

- (i) Define degenerate d orbitals.

.....
 [1]

- (ii) Sketch the shape of a $3d_{xy}$ orbital in Fig. 2.1.

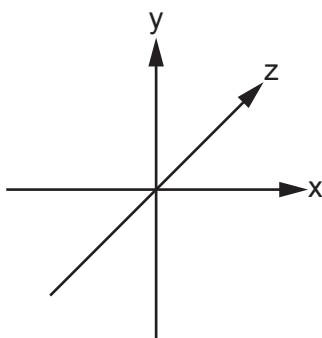


Fig. 2.1

[1]

- (c) Tollens' reagent can be used to distinguish between aldehydes and ketones. Tollens' reagent contains $[\text{Ag}(\text{NH}_3)_2]\text{OH}$, which can be prepared in a two-step process.

step 1 Aqueous NaOH is added dropwise to aqueous AgNO_3 to form Ag_2O as a brown precipitate.

step 2 Aqueous NH_3 is added dropwise to Ag_2O to form a colourless solution containing $[\text{Ag}(\text{NH}_3)_2]\text{OH}$.

Construct equations for each of the steps in the preparation of $[\text{Ag}(\text{NH}_3)_2]\text{OH}$.

step 1

step 2

[2]

- (d) Name the shape of the complex ion $[\text{Ag}(\text{NH}_3)_2]^+$.

State the bond angle for H-N-Ag and for N-Ag-N.

shape

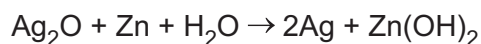
bond angle for H-N-Ag = ... °

bond angle for N-Ag-N = ... °

[2]

- (e) An electrochemical cell uses Ag_2O as the positive electrode and Zn as the negative electrode immersed in an alkaline electrolyte.

The overall cell reaction is shown.



Complete the half-equation for the reaction at each electrode.

at the positive electrode $\text{Ag}_2\text{O} + \dots$

at the negative electrode $\text{Zn} + \dots$

[2]

- (f) Coordination polymers are made when a bidentate ligand acts as a bridge between different metal ions.

Under certain conditions $\text{Ru}^{3+}(\text{aq})$ and the bidentate ligand *dps* can form a coordination polymer containing $([\text{Ru}(\text{dps})\text{Cl}_4]^-)_n$ chains.

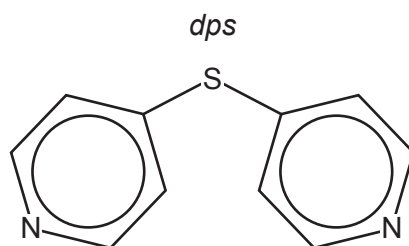


Fig. 2.2

The bidentate ligand *dps* uses each of the nitrogen atoms to bond to a different Ru^{3+} .

Complete Fig. 2.3 by drawing the structure for the coordination polymer $([\text{Ru}(\text{dps})\text{Cl}_4]^-)_n$. Show **two** repeat units.

The *dps* ligand can be represented using N — N.

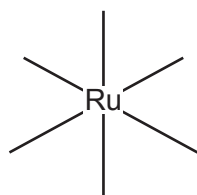


Fig. 2.3

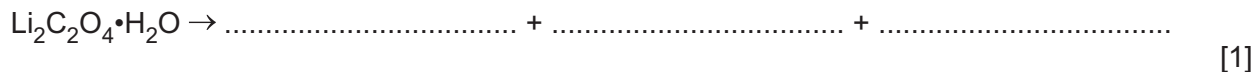
[2]

[Total: 12]

- 3 (a) When a sample of hydrated lithium ethanedioate, $\text{Li}_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$, is gently heated, two gaseous products are formed and a white solid residue remains.

The residue is added to $\text{HNO}_3(\text{aq})$. A gas is produced that turns limewater milky.

Complete the equation for the decomposition of $\text{Li}_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$.



- (b) The trend in the decomposition temperatures of the Group 2 ethanedioates is similar to that of the Group 2 nitrates.

Suggest which of CaC_2O_4 and BaC_2O_4 will decompose at the **lower** temperature. Explain your answer.

.....

 [2]

- (c) Potassium iron(III) ethanedioate, $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$, dissolves in water to form a green solution.

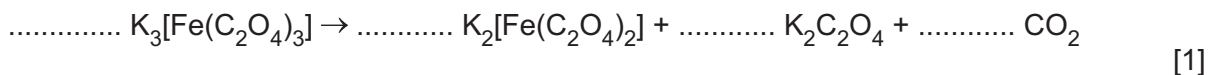
Explain why transition elements can form coloured complexes.

.....

 [3]

- (d) The anhydrous iron(III) compound $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$ decomposes on heating to form a mixture of $\text{K}_2[\text{Fe}(\text{C}_2\text{O}_4)_2]$, $\text{K}_2\text{C}_2\text{O}_4$ and CO_2 .

Complete the equation for the decomposition of $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$.



- (e) The $[\text{Fe}(\text{C}_2\text{O}_4)_3]^{3-}$ complex ion shows stereoisomerism.

Complete the three-dimensional diagrams in Fig. 3.1 to show the **two** stereoisomers of $[\text{Fe}(\text{C}_2\text{O}_4)_3]^{3-}$.

The $\text{C}_2\text{O}_4^{2-}$ ligand can be represented using .

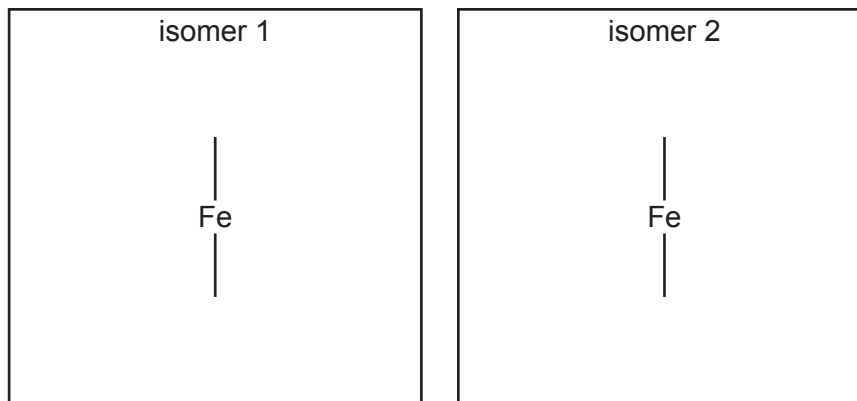


Fig. 3.1

[2]

- (f) Buffer solutions are used to regulate pH.

Write **two** equations to describe how a solution containing HC_2O_4^- ions acts as a buffer solution when small amounts of acid or alkali are added.

.....
 [2]

- (g) A fuel cell is an electrochemical cell that can be used to generate electrical energy by using oxygen to oxidise a fuel.

Ethanedioic acid, $(\text{COOH})_2$, dissolved in an alkaline electrolyte is being investigated as a fuel.

The relevant standard electrode potentials, $E^\ominus$, for the cell are shown.



Use these equations to deduce the overall cell reaction. Calculate the value of $E_{\text{cell}}^\ominus$.

overall cell reaction

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

[2]

[Total: 13]

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

.....

 [2]

- (b) (i) An electrochemical cell is set up to measure $E^\ominus$ of the $\text{Ag}^+(\text{aq})/\text{Ag}(\text{s})$ electrode.

Draw a labelled diagram of this electrochemical cell.

Include all necessary substances. It is **not** necessary to state conditions used.

[3]

- (ii) A separate electrochemical cell is set up using a **lower** concentration of $\text{Ag}^+(\text{aq})$ than that used in (b)(i).

Suggest how the electrode potential, E , for the $\text{Ag}^+(\text{aq})/\text{Ag}(\text{s})$ electrode would change from its $E^\ominus$ value. Explain your answer.

.....

 [1]

- (c) Define enthalpy change of solution, $\Delta H_{\text{sol}}^\ominus$.

.....
 [1]

(d) Some relevant energy changes for AgNO_3 are shown in Table 4.1.

Table 4.1

energy change	value / kJ mol^{-1}
enthalpy change of solution of $\text{AgNO}_3(\text{s})$	+22.6
enthalpy change of hydration of silver ions	−475
enthalpy change of hydration of nitrate ions	−314

- (i) Complete the energy cycle in Fig. 4.1 to show the relationship between the lattice energy, $\Delta H_{\text{latt}}^\ominus$, of $\text{AgNO}_3(\text{s})$ and the energy changes shown in Table 4.1.

Include state symbols for all the species.

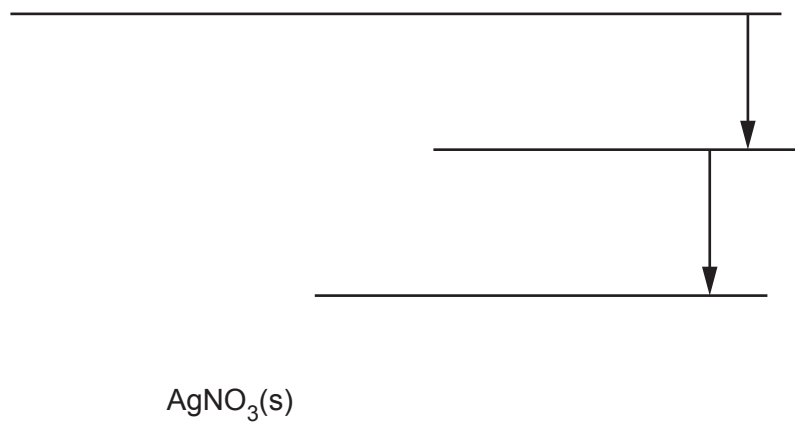


Fig. 4.1

[2]

- (ii) Calculate the lattice energy, $\Delta H_{\text{latt}}^\ominus$, of $\text{AgNO}_3(\text{s})$.

$$\Delta H_{\text{latt}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [1]$$

- (e) Suggest the trend in the magnitude of the lattice energies of the metal nitrates, $\text{NaNO}_3(\text{s})$, $\text{Mg}(\text{NO}_3)_2(\text{s})$ and $\text{RbNO}_3(\text{s})$.

Explain your answer.

most exothermic least exothermic

.....

.....

.....

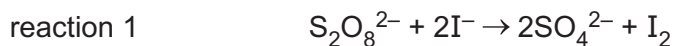
.....

.....

.....

[Total: 13]

- 5 (a) In aqueous solution, persulfate ions, $\text{S}_2\text{O}_8^{2-}$, react with iodide ions, as shown in reaction 1.



The rate of reaction 1 is investigated.

A sample of $\text{S}_2\text{O}_8^{2-}$ is mixed with a large excess of iodide ions of known concentration. The graph in Fig. 5.1 shows the results obtained.

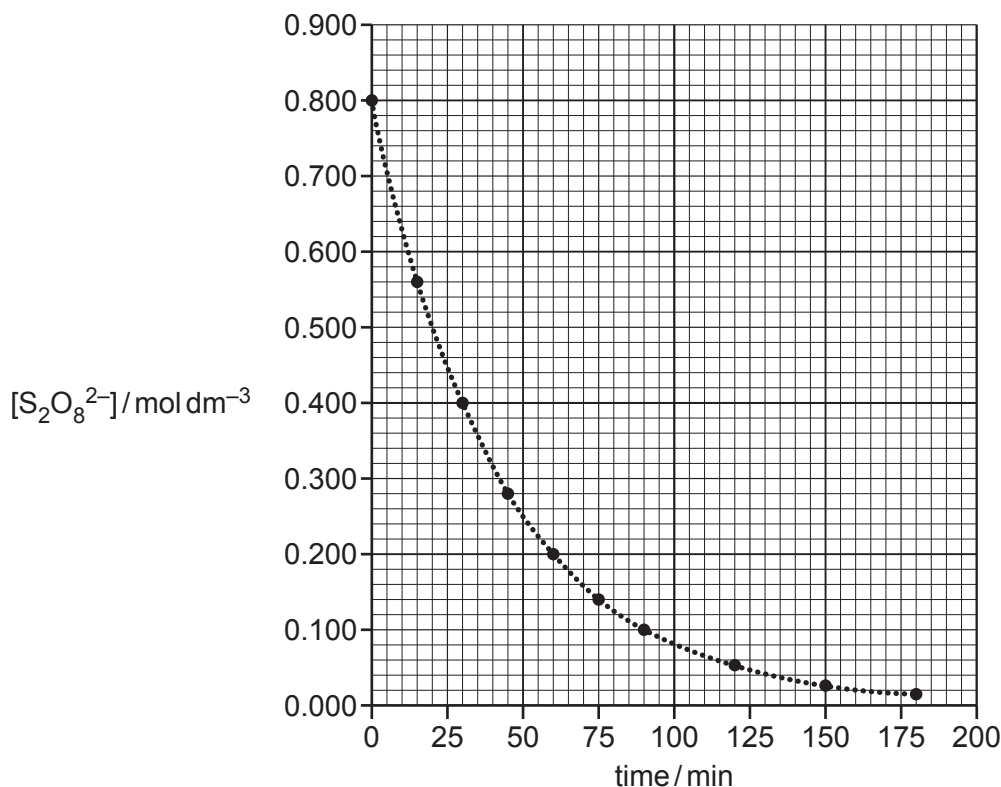


Fig. 5.1

- (i) Use Fig. 5.1 to determine the initial rate of reaction 1. Show your working.

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

- (ii) The rate equation for reaction 1 is $\text{rate} = k [\text{S}_2\text{O}_8^{2-}] [\text{I}^-]$.

Suggest why a large excess of iodide ions allows the rate constant to be determined from the half-life in this investigation.

.....

 [1]

- (b) The reaction of persulfate ions, $\text{S}_2\text{O}_8^{2-}$, with iodide ions is catalysed by Fe^{2+} ions.

Write **two** equations to show how Fe^{2+} catalyses reaction 1.

equation 1

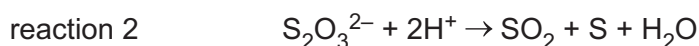
equation 2 [2]

- (c) Describe the effect of an increase in temperature on the rate constant and the rate of reaction 1.

.....

..... [1]

- (d) In aqueous solution, thiosulfate ions, $\text{S}_2\text{O}_3^{2-}$, react with hydrogen ions, as shown in reaction 2.



The rate of reaction is first order with respect to $[\text{S}_2\text{O}_3^{2-}]$ and zero order with respect to $[\text{H}^+]$ under certain conditions.

The rate constant, k , for this reaction is $1.58 \times 10^{-2} \text{ s}^{-1}$.

Calculate the half-life, $t_{\frac{1}{2}}$, for reaction 2.

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

- (e) The compound nitrosyl bromide, NOBr, can be formed as shown in reaction 3.



The rate is first order with respect to $[\text{NO}]$ and first order with respect to $[\text{Br}_2]$.

The reaction mechanism has two steps.

Suggest equations for the **two** steps of this mechanism. State which is the rate-determining step.

step 1

step 2

rate-determining step = ...

[2]

[Total: 8]

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

.....

 [1]

- (ii) The partition coefficient, K_{pc} , for a compound, **X**, between carbon disulfide, CS_2 , and water is 10.5.

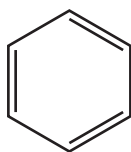
1.85 g of **X** is dissolved in water and made up to 100.0 cm^3 in a volumetric flask.
 40.0 cm^3 of this aqueous solution is shaken with 25.0 cm^3 of CS_2 .
 The mixture is left to reach equilibrium.

Calculate the mass of **X**, in g, extracted into the CS_2 layer.

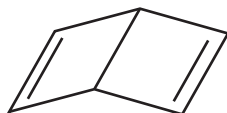
mass of **X** = ... g [2]

- (b) The compound C_6H_6 has many structural isomers. Four suggested structures of C_6H_6 are shown in Fig. 6.1.

Kekulé benzene



Dewar benzene



Ladenburg benzene



delocalised benzene

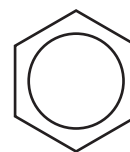


Fig. 6.1

Using Fig. 6.1, complete Table 6.1 to predict the number of carbon atoms that have sp , sp^2 and sp^3 hybridisation in Kekulé benzene, Dewar benzene and Ladenburg benzene.

Table 6.1

C_6H_6 structure	sp hybridised	sp^2 hybridised	sp^3 hybridised
Kekulé benzene			
Dewar benzene			
Ladenburg benzene			

[2]

- (c) Describe the shape of delocalised benzene.

Include the geometry of each carbon, the C-C-H bond angle and the type of bond(s) between the carbon atoms and between the carbon and hydrogen atoms.

.....

.....

.....

.....

..... [2]

- (d) Suggest why Dewar benzene and Ladenburg benzene are unstable isomers of C_6H_6 .

.....

..... [1]

- (e) Complete Table 6.2 to predict the number of peaks in the proton (^1H) NMR spectrum for Dewar benzene, Ladenburg benzene and delocalised benzene.

Table 6.2

	number of peaks
Dewar benzene	
Ladenburg benzene	
delocalised benzene	

[1]

- (f) The reaction of phenylethanone with 1,4-dibromobutane, $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$, in the presence of FeBr_3 is shown in Fig. 6.2.

phenylethanone

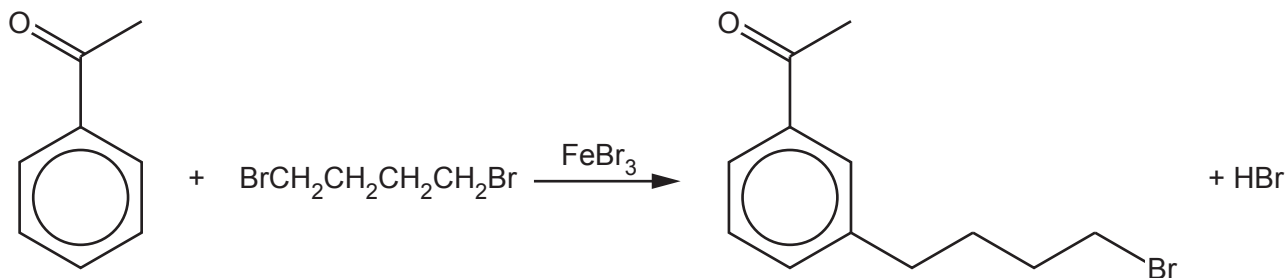


Fig. 6.2

The mechanism of this reaction is similar to that of the alkylation of benzene.

- (i) Construct an equation for the formation of the electrophile, $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2^+$.

..... [1]

- (ii) Complete the mechanism in Fig. 6.3 for the reaction of phenylethanone with $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2^+$ ions.

Include all relevant curly arrows and charges.

Draw the structure of the organic intermediate.

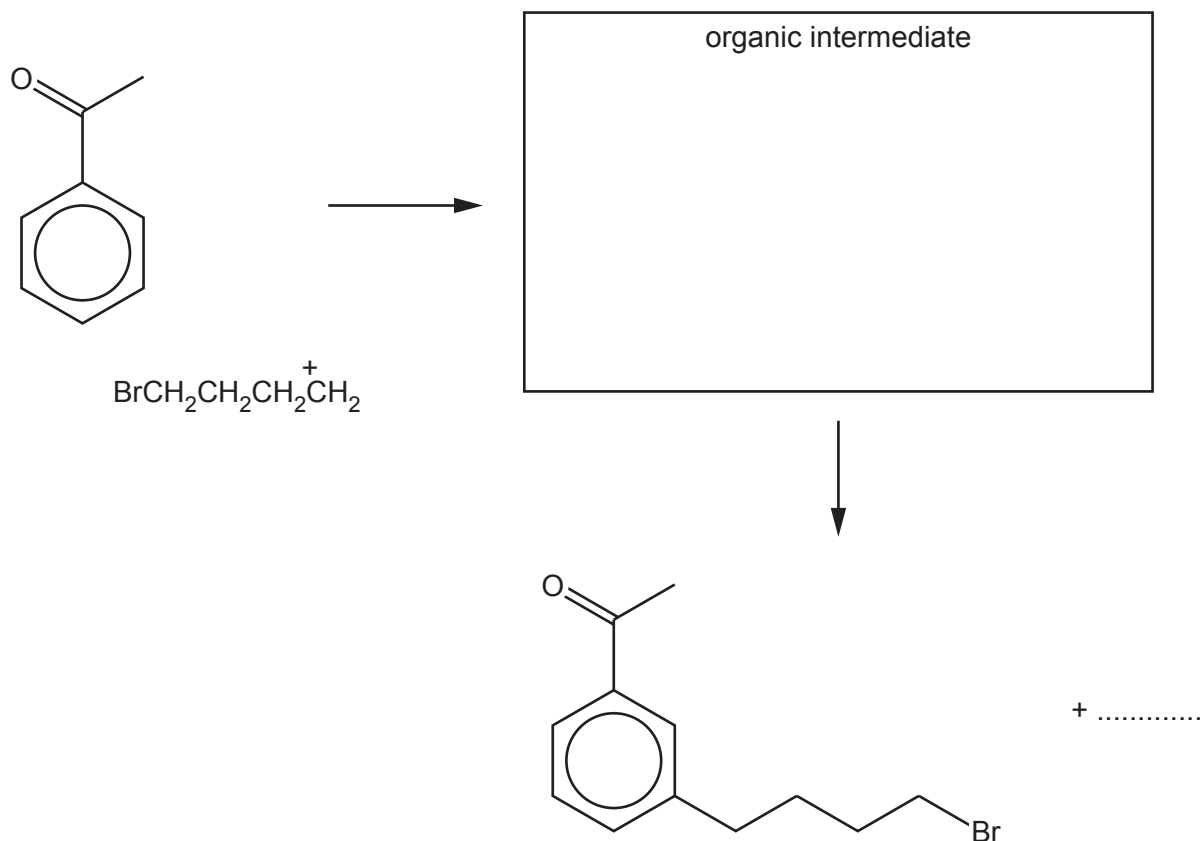


Fig. 6.3

[3]

- (iii) The reaction shown in Fig. 6.2 forms small amounts of two by-products, **Y** ($\text{C}_{20}\text{H}_{22}\text{O}_2$) and **Z** ($\text{C}_{12}\text{H}_{14}\text{O}$).

Suggest structures for **Y** and **Z** in the boxes in Fig. 6.4.

Y ($\text{C}_{20}\text{H}_{22}\text{O}_2$)	Z ($\text{C}_{12}\text{H}_{14}\text{O}$)
---	---

Fig. 6.4

[2]

[Total: 15]

7 Four esters, **A**, **B**, **C** and **D**, with the molecular formula $C_6H_{12}O_2$ are shown in Fig. 7.1.

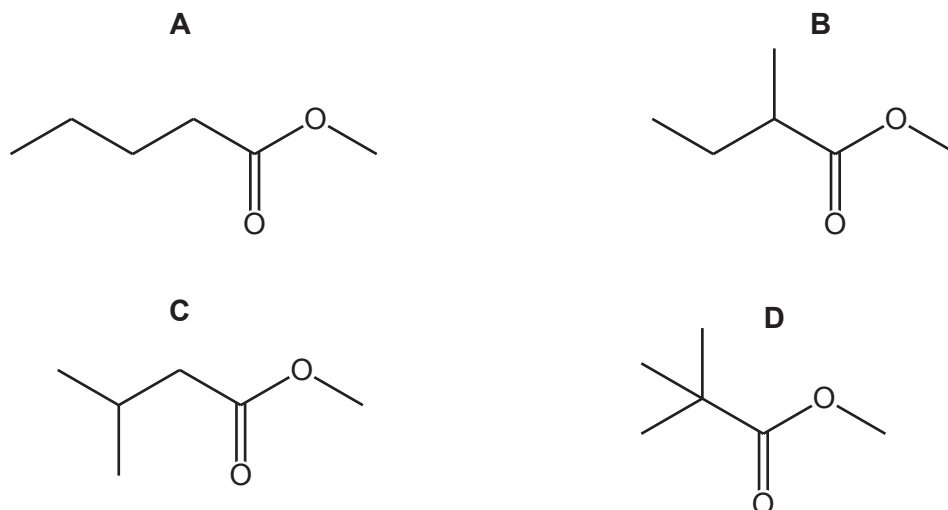


Fig. 7.1

(a) Give the systematic name of ester **A**.

..... [1]

(b) A mixture of these esters, **A**, **B**, **C** and **D**, is analysed by gas-liquid chromatography.

The chromatogram produced is shown in Fig. 7.2. The number above each peak represents the area under the peak.

The area under each peak is proportional to the mass of the respective ester in the mixture.

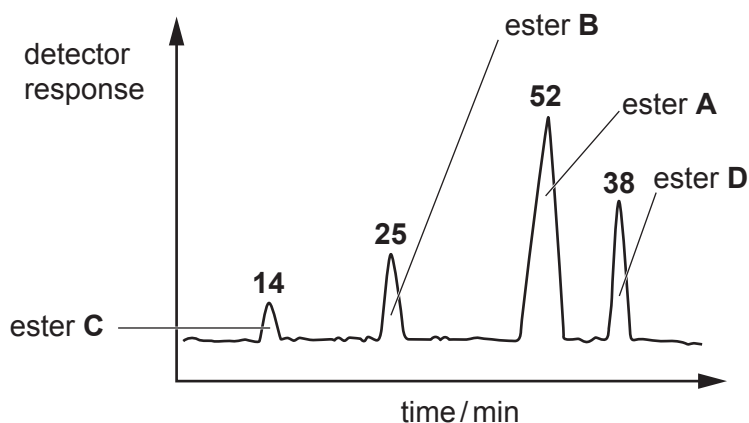


Fig. 7.2

(i) State what is meant by retention time.

.....
 [1]

(ii) Calculate the percentage by mass of ester **D** in the original mixture.

percentage by mass of ester **D** = ... % [1]

(c) Separate samples of the esters, **A**, **B**, **C** and **D**, are analysed using proton (^1H) NMR and carbon-13 NMR spectroscopy.

(i) Complete Table 7.1 to show the number of peaks in each NMR spectrum for esters **B** and **C**.

Table 7.1

ester	number of peaks in proton (^1H) NMR spectrum	number of peaks in carbon-13 NMR spectrum
B		
C		

[2]

(ii) Identify **all** of the esters from **A**, **B**, **C** and **D** that have at least one triplet peak in their proton (^1H) NMR spectrum.

..... [1]

Question 7 continues on page 20.

(d) Compound **F**, $\text{C}_6\text{H}_8\text{O}_3$, shows stereoisomerism and effervesces with $\text{Na}_2\text{CO}_3(\text{aq})$.

Compound **F** reacts with alkaline $\text{I}_2(\text{aq})$ to form yellow precipitate **G** and compound **H**.

Compound **F** reacts with LiAlH_4 to form compound **J**, $\text{C}_6\text{H}_{12}\text{O}_2$.

Compound **F** reacts with SOCl_2 to form compound **K**, $\text{C}_6\text{H}_7\text{O}_2\text{Cl}$.

Compound **K** reacts with propan-2-ol to form compound **L**.

Draw the structures of compounds **F**, **G**, **H**, **J**, **K** and **L** in the boxes in Fig. 7.3.

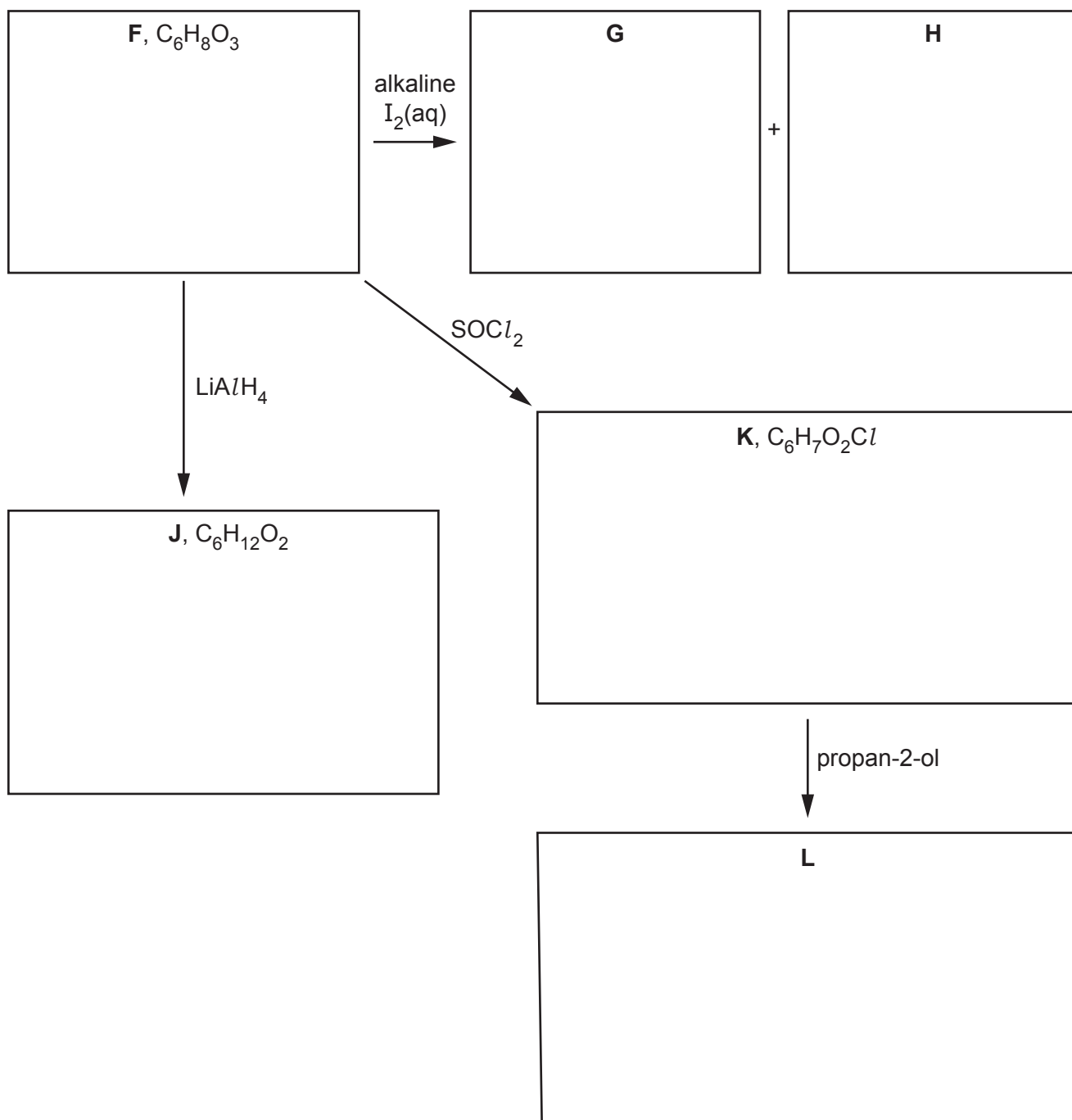


Fig. 7.3

[6]

[Total: 12]

- 8 Neotame is an artificial sweetener added to some foods.

neotame

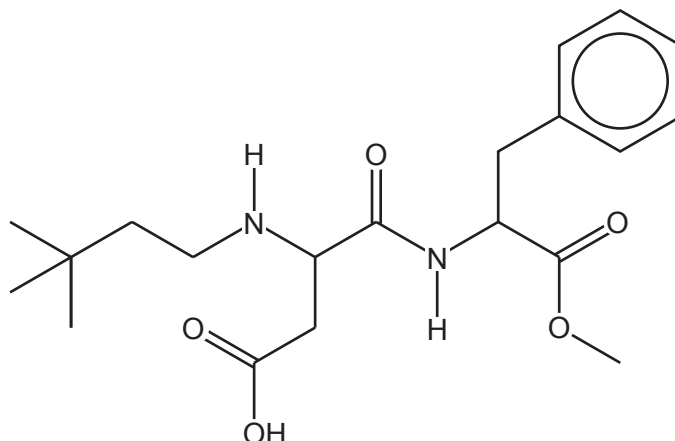


Fig. 8.1

- (a) (i) State the number of chiral carbon atoms in a molecule of neotame.

..... [1]

- (ii) Neotame contains the arene functional group.

Identify all the **other** functional groups present in neotame.

.....
 [2]

- (b) Neotame reacts with an excess of hot NaOH(aq) to form three organic products.

- (i) State the **two** types of reaction that occur when neotame reacts with hot NaOH(aq).

1
 2 [2]

neotame

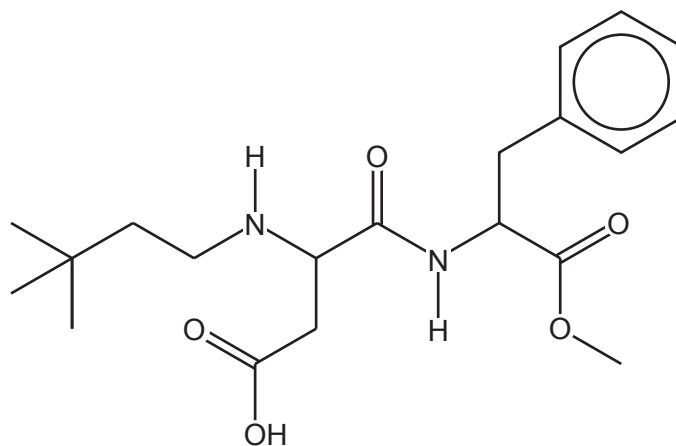
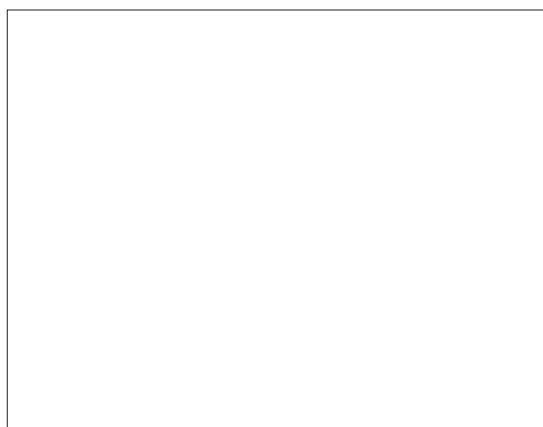
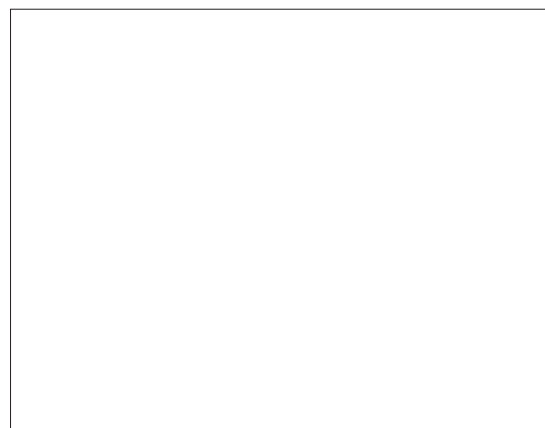
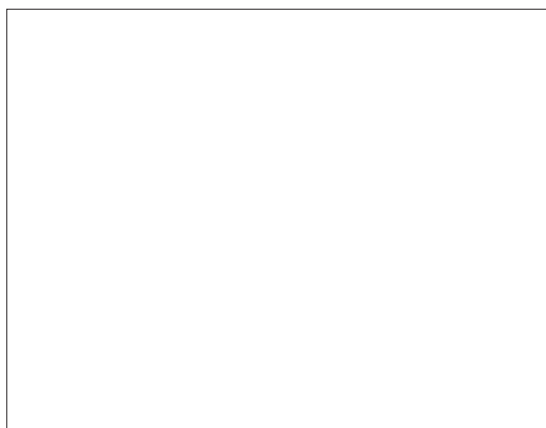


Fig. 8.1

- (ii) Draw the structures of the **three** organic products formed from the reaction of neotame with an excess of hot NaOH(aq).



[3]

[Total: 8]

- 9 (a) Samples of phenol, $\text{C}_6\text{H}_5\text{OH}$, are reacted separately with sodium and with dilute nitric acid.

phenol

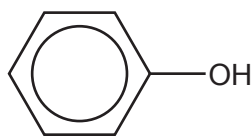
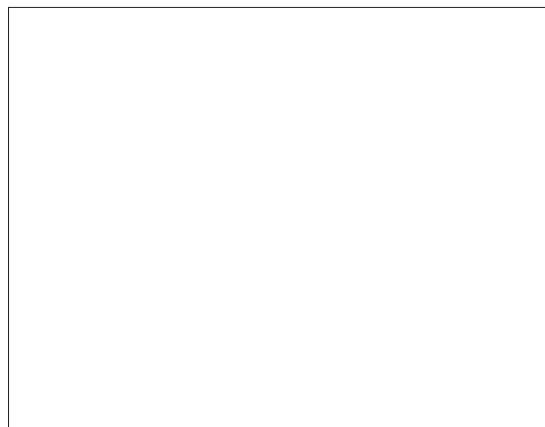
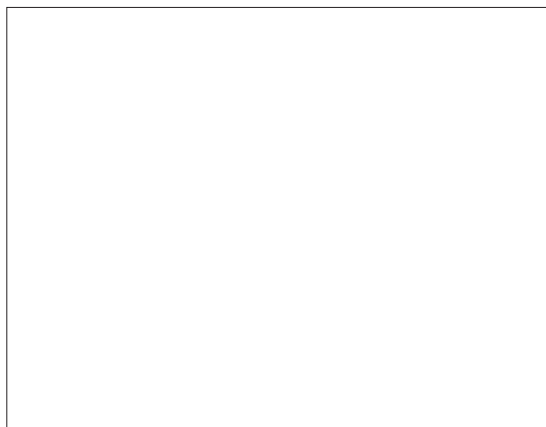


Fig. 9.1

- (i) Write the equation for the reaction of $\text{C}_6\text{H}_5\text{OH}$ with Na.

..... [1]

- (ii) Draw the structures of the **two** major isomeric organic products formed in the reaction of phenol with dilute HNO_3 .



[1]

(b) Salicylic acid can be synthesised from phenol.

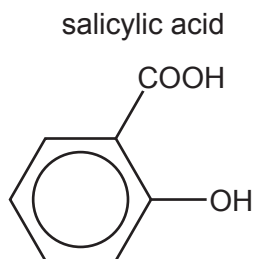


Fig. 9.2

One of the steps in this synthesis is the electrophilic substitution reaction of carbon dioxide with the phenoxide ion, $\text{C}_6\text{H}_5\text{O}^-$.

Complete the mechanism in Fig. 9.3 for the reaction of $\text{C}_6\text{H}_5\text{O}^-$ with CO_2 .

Include all relevant curly arrows, dipoles and charges. Draw the structure of the organic intermediate.

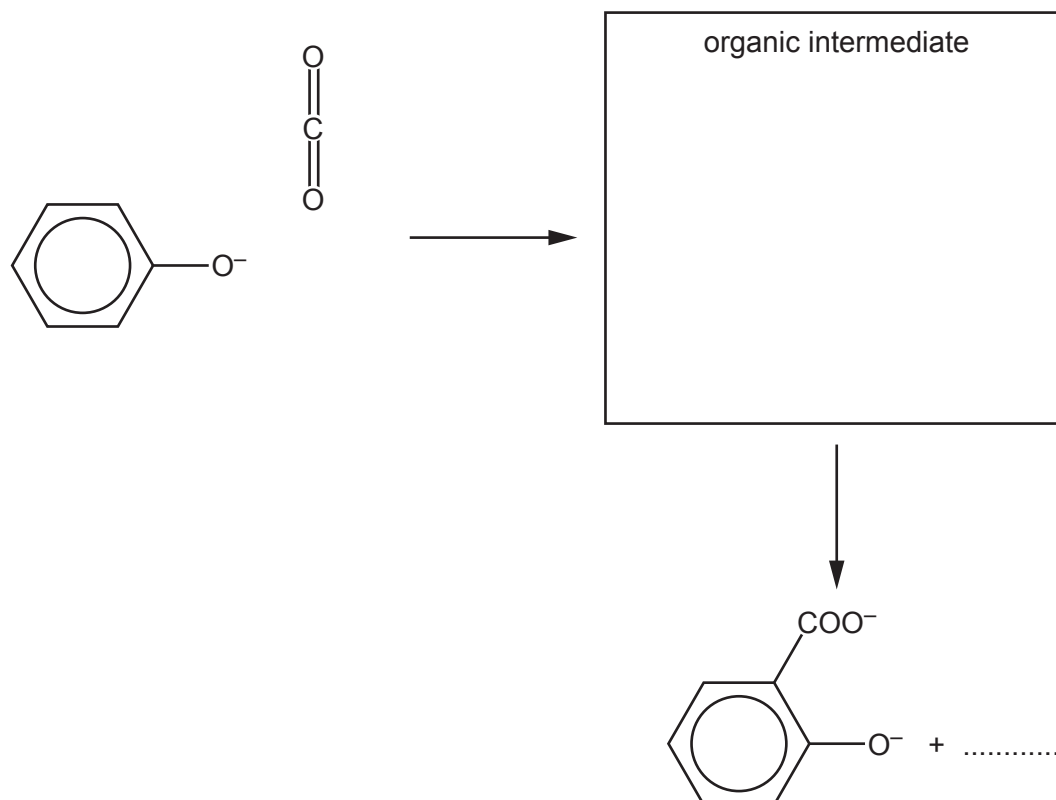


Fig. 9.3

[3]

(c) Some syntheses use Diels–Alder reactions, which normally involve a diene and an alkene reacting together to form a cyclohexene.

(i) Draw **three** curly arrows in Fig. 9.4 to complete the mechanism for the Diels–Alder reaction between buta-1,3-diene and ethene.

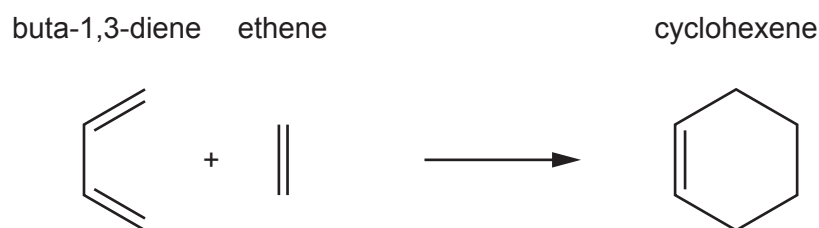


Fig. 9.4

[1]

(ii) Another Diels–Alder reaction of buta-1,3-diene is shown in Fig. 9.5.

Predict the product formed in this reaction.

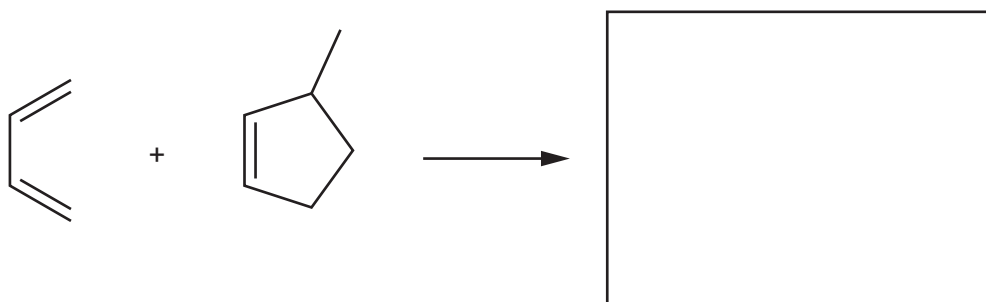


Fig. 9.5

[1]

[Total: 7]

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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 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group										
1	2	Key								
		atomic number atomic symbol name relative atomic mass								
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	13 Al aluminium 27.0
11 Na sodium 23.0	12 Mg magnesium 24.3	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
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
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
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 —
118 Og ognesson —	119 Ts tennessine —	120 Lv livermorium —	121 Mc moscovium —	122 Nh nihonium —	123 Fl flerovium —	124 Lv livermorium —	125 Ts tennessine —	126 Og ognesson —	127 Nh nihonium —	128 Fl flerovium —

Lanthanoids

actinoids

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.2
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	euporium	152.0
64	Gd	gadolinium	157.3
65	Tb	terbium	158.9
66	Dy	dysprosium	162.5
67	Ho	holmium	164.9
68	Er	erbium	168.9
69	Tm	thulium	168.9
70	Yb	yterbium	173.1
71	Lu	lutetium	175.0
72	Hf	hafnium	178.5
73	Ta	tantalum	180.9
74	W	wolframium	183.8
75	Re	rhodium	186.2
76	Os	osmium	190.2
77	Ir	iridium	192.2
78	Pt	platinum	195.1
79	Au	aurum	197.0
80	Hg	hydrargyrum	200.6
81	Tl	thallium	204.4
82	Pb	plumbum	207.2
83	Bi	bismuthum	208.9
84	Po	polonium	—
85	At	astatinum	—
86	Rn	radon	—
87	Fr	francium	—
88	Ra	radium	226.0
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	—

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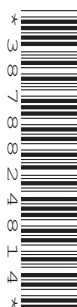
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CHEMISTRY

9701/42

Paper 4 A Level Structured Questions

May/June 2024

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) Describe the trend in the solubility of the sulfates of magnesium, calcium and strontium.

Explain your answer.

..... > >
 most soluble least soluble

.....

.....

.....

.....

.....

.....

[4]

- (b) Define lattice energy, ΔH_{latt} .

.....

..... [2]

- (c) State and explain the main factors that affect the magnitude of lattice energies.

.....

.....

.....

.....

..... [2]

- (d) Table 1.1 shows some energy changes.

Table 1.1

energy change	value / kJ mol^{-1}
standard enthalpy change of atomisation of potassium	+89
first ionisation energy of potassium	+419
second ionisation energy of potassium	+3070
standard enthalpy change of atomisation of sulfur	+279
S–S bond energy	+265
first ionisation energy of sulfur	+1000
second ionisation energy of sulfur	+2260
first electron affinity of sulfur	–200
second electron affinity of sulfur	+640
standard enthalpy change of formation of potassium sulfide, $\text{K}_2\text{S}(\text{s})$	–381



- (i) Born–Haber cycles can be used to determine the lattice energies of ionic compounds.

Complete the Born–Haber cycle in Fig. 1.1 for potassium sulfide, $K_2S(s)$.

Include state symbols for all of the species.

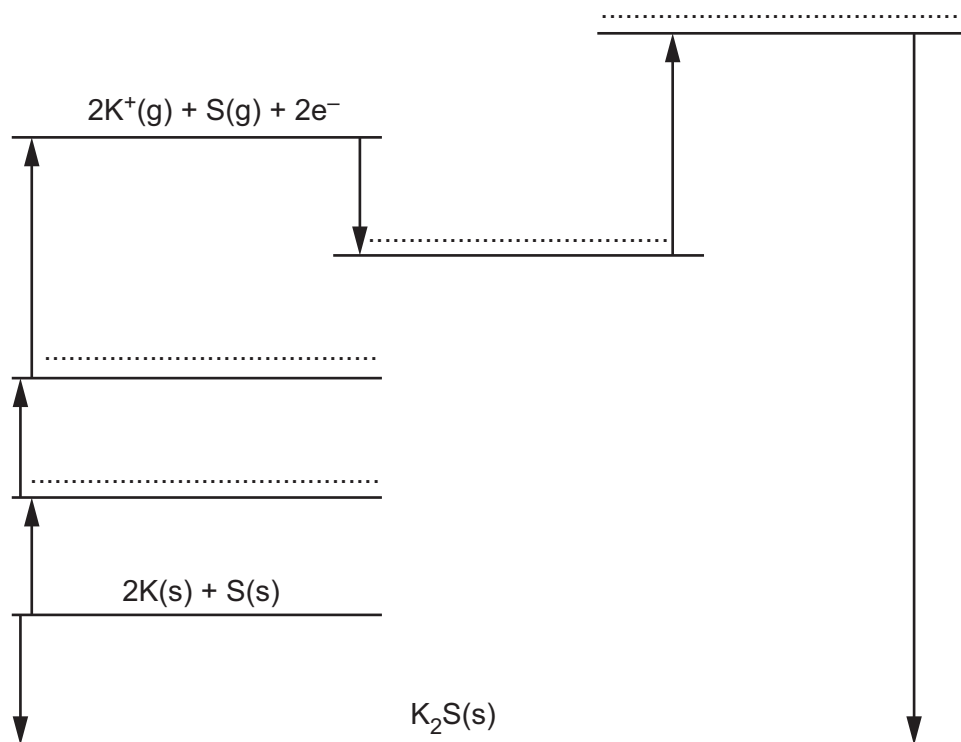


Fig. 1.1

[3]

- (ii) Calculate the lattice energy, $\Delta H_{\text{latt}}^{\ominus}$, of $K_2S(s)$ using relevant data from Table 1.1.

Show your working.

$$\Delta H_{\text{latt}}^{\ominus} \text{ of } K_2S(s) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

[Total: 13]





- 2 (a) (i) Lithium nitrate, LiNO_3 , decomposes on heating in a similar way to Group 2 nitrates to give the metal oxide, a brown gas and oxygen.

Write an equation for the decomposition of LiNO_3 .

..... [1]

- (ii) The other Group 1 nitrates, MNO_3 , decompose on heating to form the metal nitrite, MNO_2 , and oxygen.

The thermal stability of these nitrates increases down the group.

Suggest why the thermal stability of MNO_3 increases down the group.

.....

 [2]

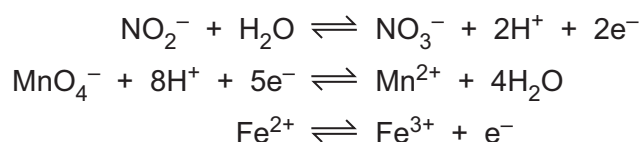
- (b) Acidified manganate(VII) ions, MnO_4^- , can be used to analyse solutions containing nitrite ions, NO_2^- , by titration.

X is a solution of NaNO_2 .

250.0 cm^3 of **X** is added to 50.0 cm^3 of 0.125 mol dm^{-3} acidified MnO_4^- (aq). The MnO_4^- (aq) ions are in excess; all the NO_2^- ions are oxidised in the reaction.

The unreacted MnO_4^- (aq) required 22.50 cm^3 of $0.0400\text{ mol dm}^{-3}$ Fe^{2+} (aq) to reach the end-point.

The relevant half-equations are shown.



Calculate the concentration, in mol dm^{-3} , of NaNO_2 in **X**.

concentration of NaNO_2 in **X** = ... mol dm^{-3} [3]



- (c) Table 2.1 shows electrode potentials for some electrode reactions involving manganese compounds.

Table 2.1

electrode reaction	$E^{\ominus}/V$
$Mn^{2+} + 2e^{-} \rightleftharpoons Mn$	-1.18
$MnO_2 + 4H^{+} + 2e^{-} \rightleftharpoons Mn^{2+} + 2H_2O$	+1.23
$MnO_4^{-} + e^{-} \rightleftharpoons MnO_4^{2-}$	+0.56
$MnO_4^{-} + 4H^{+} + 3e^{-} \rightleftharpoons MnO_2 + 2H_2O$	+1.67
$MnO_4^{-} + 8H^{+} + 5e^{-} \rightleftharpoons Mn^{2+} + 4H_2O$	+1.52
$MnO_4^{-} + 2H_2O + 3e^{-} \rightleftharpoons MnO_2 + 4OH^{-}$	+0.59
$MnO_4^{2-} + 2H_2O + 2e^{-} \rightleftharpoons MnO_2 + 4OH^{-}$	+0.60
$MnO_4^{2-} + 4H^{+} + 2e^{-} \rightleftharpoons MnO_2 + 2H_2O$	+1.70

- (i) Aqueous manganate(VI) ions, MnO_4^{2-} , are unstable in acidic conditions and undergo a disproportionation reaction.

The $E_{\text{cell}}^{\ominus}$ for this reaction is +1.14 V.

Construct an overall ionic equation for this disproportionation reaction.

..... [2]

- (ii) Suggest and explain how the E_{cell} value of the disproportionation reaction changes with an increase in pH.

.....

 [1]

[Total: 9]





- 3 (a) Carbon disulfide, CS_2 , is flammable and reacts readily with oxygen, as shown in reaction 1.

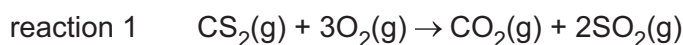


Table 3.1 shows the standard enthalpy of formation, $\Delta H_f^\ominus$, and the standard entropy, $S^\ominus$, for some substances.

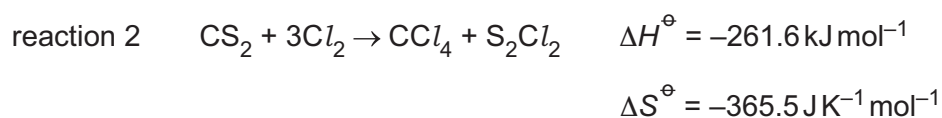
Table 3.1

	$\text{CS}_2(\text{g})$	$\text{O}_2(\text{g})$	$\text{CO}_2(\text{g})$	$\text{SO}_2(\text{g})$
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	116.7	0.0	-393.5	-296.8
$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$	237.8	205.2	213.8	248.2

Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, in kJ mol^{-1} , for reaction 1 at 25°C .

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

- (b) Carbon disulfide reacts with chlorine to form tetrachloromethane, as shown in reaction 2.



Calculate the maximum temperature, in K, for reaction 2 to be feasible.

$$\text{temperature} = \dots\dots\dots \text{K} \quad [2]$$

[Total: 5]



- 4 (a) (i) Explain why transition elements have variable oxidation states.

.....
 [1]

- (ii) Sketch the shape of a $3d_{z^2}$ orbital in Fig. 4.1.

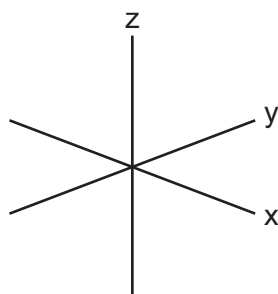


Fig. 4.1

[1]

- (b) Samples of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ are reacted separately with an excess of solution **A** and with an excess of solution **B**.

The reaction of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ with solution **A** is a precipitation reaction.

The reaction of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ with solution **B** is a ligand substitution reaction.

Suggest a possible identity for solution **A** and for solution **B**. Give relevant observations and the formula of the copper-containing product for each reaction.

solution **A**

observations

formula of the copper-containing product

solution **B**

observations

formula of the copper-containing product

[3]





- (c) Solutions containing the $[\text{Ag}(\text{NH}_3)_2]^+$ complex are colourless.

Explain why this complex is colourless.

.....

.....

.....

..... [2]

- (d) Two bidentate ligands are shown in Fig. 4.2.

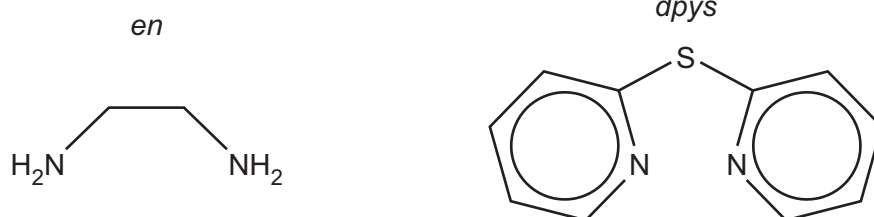


Fig. 4.2

Explain what is meant by a bidentate ligand.

.....

..... [2]



- (e) Ruthenium(III) ions, Ru^{3+} , form an octahedral complex, $[\text{Ru}(\text{dpys})_2\text{Cl}_2]^+$, with the ligands *dpys* and chloride ions.

This complex shows the same kind of stereoisomerism as $[\text{Ru}(\text{NH}_3)_4\text{Cl}_2]^+$ but also shows a different type of stereoisomerism.

- (i) Complete the three-dimensional diagrams in Fig. 4.3 to show the **three** different stereoisomers of $[\text{Ru}(\text{dpys})_2\text{Cl}_2]^+$.

The *dpys* ligand can be represented using N  N.

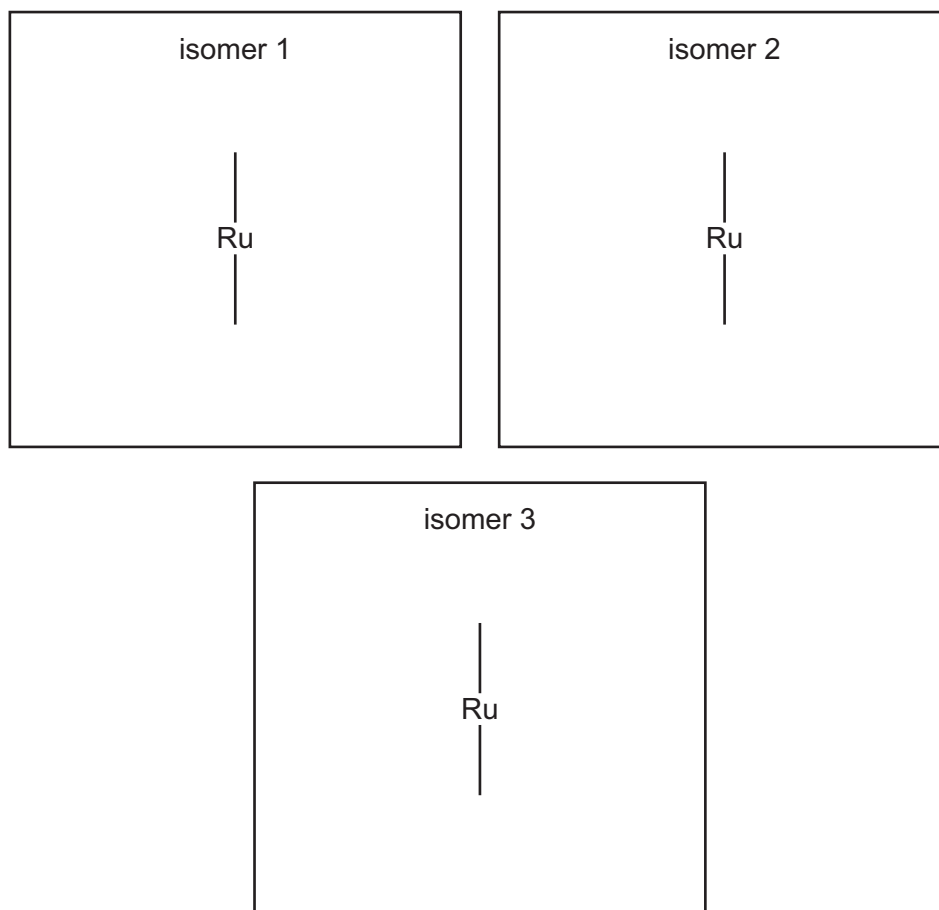


Fig. 4.3

- (ii) State the different types of stereoisomerism shown by $[\text{Ru}(\text{dpys})_2\text{Cl}_2]^+$.

[3]

..... [1]

- (iii) Deduce which stereoisomers in (e)(i) are **non-polar**. Explain your answer.

.....

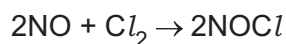
..... [1]

[Total: 14]





- 5 (a) Nitrosyl chloride, NOCl , can be formed by the reaction between nitrogen monoxide and chlorine, as shown.



The initial rate of this reaction is investigated, starting with different concentrations of NO and Cl_2 . The results obtained are shown in Table 5.1.

Table 5.1

experiment	$[\text{NO}]/\text{mol dm}^{-3}$	$[\text{Cl}_2]/\text{mol dm}^{-3}$	initial rate/ $\text{mol dm}^{-3} \text{ min}^{-1}$
1	0.0250	0.0150	3.68×10^{-2}
2	0.0750	0.0150	3.32×10^{-1}
3	0.0500	0.0600	5.89×10^{-1}

- (i) Use the data in Table 5.1 to deduce the rate equation for this reaction.

Explain your reasoning.

.....

.....

.....

.....

.....

..... [3]

- (ii) Use your rate equation from (a)(i) and the data from experiment 1 to calculate the rate constant, k , for this reaction. Include the units of k .

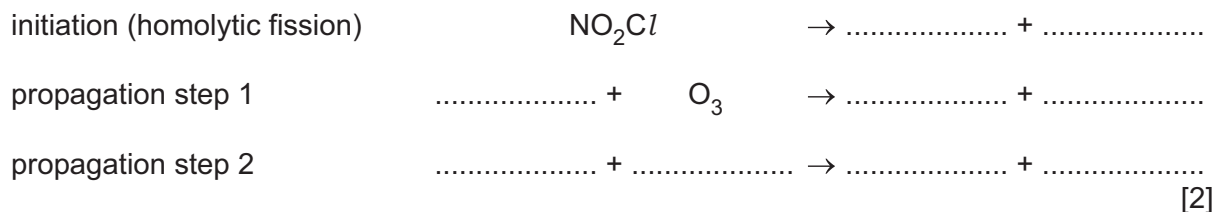
$k = \dots\dots\dots$ units $\dots\dots\dots$ [2]



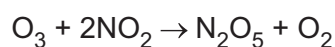
- (b) NO_2Cl is another compound containing nitrogen, oxygen and chlorine.

In sunlight, NO_2Cl can undergo homolytic fission to release chlorine radicals which can catalyse the conversion of ozone, O_3 , into oxygen.

Complete the mechanism for this process.



- (c) Ozone reacts with nitrogen dioxide, as shown.



The rate of reaction is first order with respect to O_3 and first order with respect to NO_2 .

Suggest equations for a two-step mechanism for this reaction.



[Total: 9]





- 6 (a) Aqueous solutions of methanoic acid, HCOOH , and propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, are mixed together.

An equilibrium is set up between two conjugate acid–base pairs.

- (i) Define conjugate acid–base pair.

.....
 [1]

- (ii) The $\text{p}K_{\text{a}}$ of HCOOH is 3.75 and of $\text{CH}_3\text{CH}_2\text{COOH}$ is 4.87.

Complete the equation for the Brønsted–Lowry equilibrium between the stronger of these two acids and water.

..... + H_2O $\rightleftharpoons$ + ... [1]

- (b) (i) Write an expression for the acid dissociation constant, K_{a} , for butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$.

$K_{\text{a}} =$

[1]

- (ii) The $\text{p}K_{\text{a}}$ of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ is 4.82.

A solution of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}(\text{aq})$ has a pH of 3.25.

Calculate the concentration, in mol dm^{-3} , of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ in this solution.

concentration of $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} =$ mol dm^{-3} [2]

- (c) (i) Define buffer solution.

.....

 [2]



- (ii) A buffer solution containing a mixture of CH_3COOH and CH_3COONa is prepared as follows.

A solution of 600 cm^3 of CH_3COOH is mixed with 400 cm^3 of 0.125 mol dm^{-3} CH_3COONa .

The buffer solution has pH 5.70. The K_a of CH_3COOH is $1.78 \times 10^{-5}\text{ mol dm}^{-3}$.

Calculate the initial concentration, in mol dm^{-3} , of CH_3COOH used.

concentration of $\text{CH}_3\text{COOH} = \dots\dots\dots\text{mol dm}^{-3}$ [3]

- (d) A fuel cell is an electrochemical cell that can be used to generate electrical energy by using oxygen to oxidise a fuel.

Methanoic acid, HCOOH , is being investigated as a fuel in fuel cells.

When the cell operates, HCOOH is oxidised to carbon dioxide.

The half-equation for the reaction at the cathode is: $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$.

In this fuel cell, the overall cell reaction is the same as that for the complete combustion of HCOOH .

- (i) Deduce the half-equation for the reaction at the anode.

$\dots\dots\dots$ [1]

- (ii) Calculate the volume, in cm^3 , of oxygen used when a current of 3.75 A is delivered by the cell for 40.0 minutes. Assume the cell operates at room conditions.

volume of oxygen = $\dots\dots\dots\text{ cm}^3$ [2]



7 Methyl red can be synthesised as shown in Fig. 7.1.

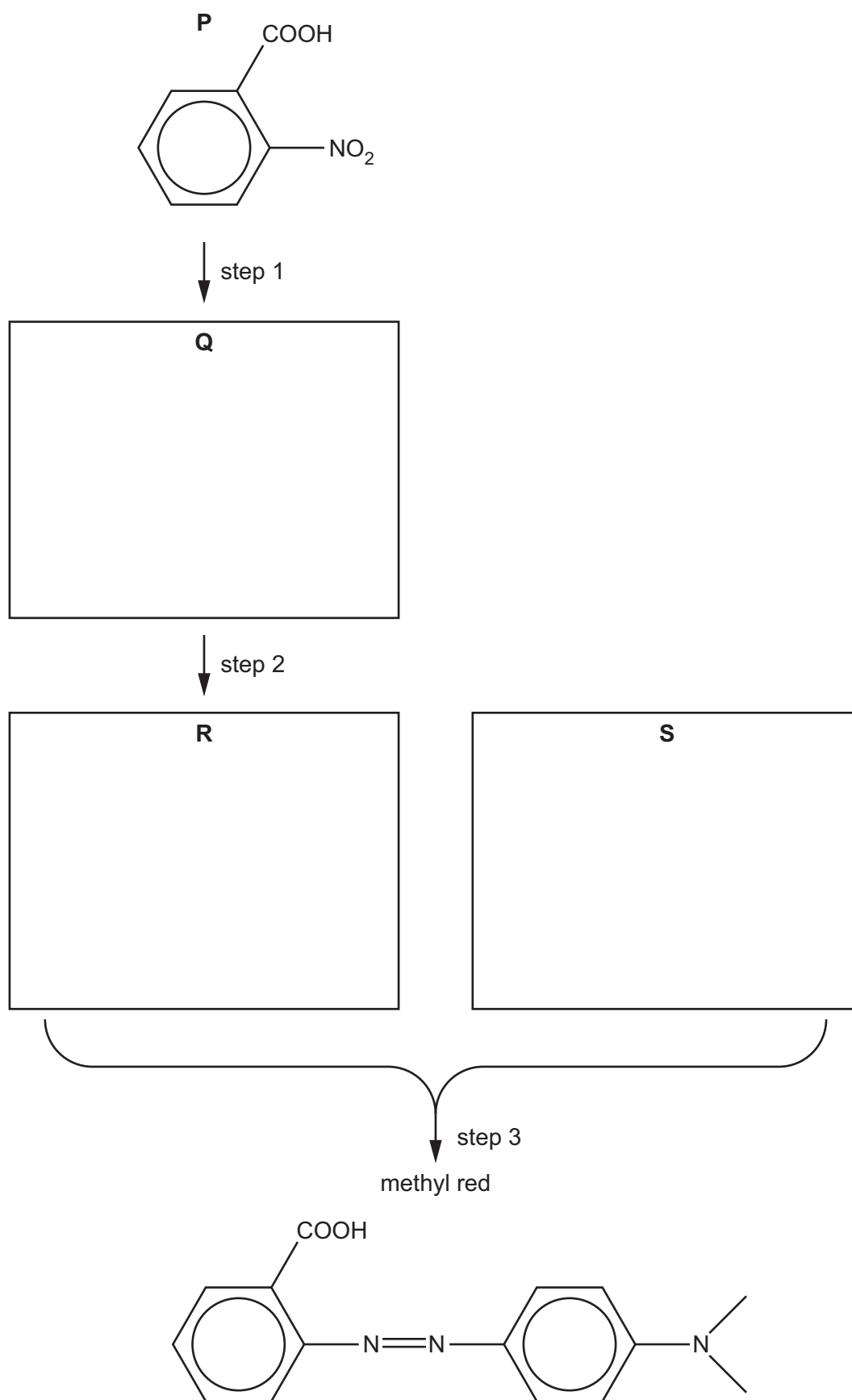


Fig. 7.1



- (a) (i) Give the systematic name of **P**.

..... [1]

- (ii) **P** can be synthesised as shown in Fig. 7.2.

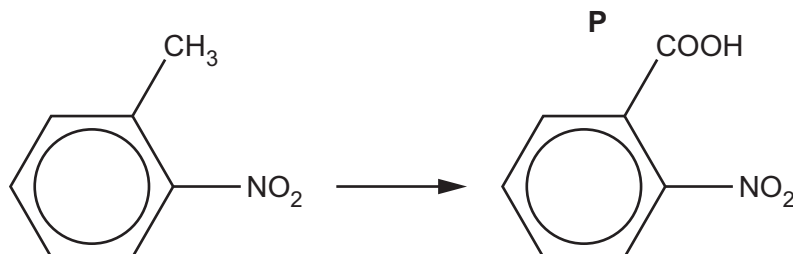


Fig. 7.2

Suggest reagents and conditions for this reaction.

..... [1]

- (iii) A student attempts to synthesise **P** by an alternative route, as shown in Fig. 7.3.

Compound **T** is the major product in this reaction rather than **P**.

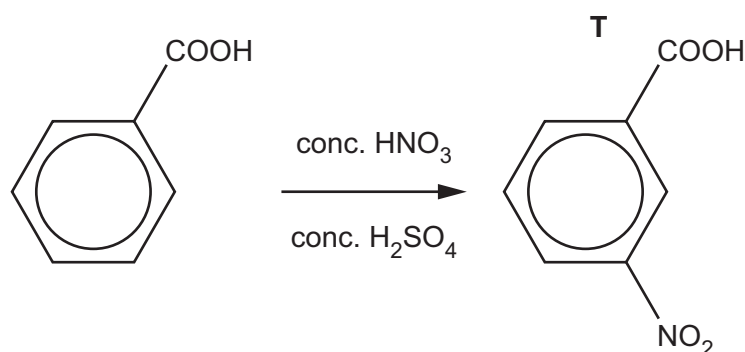


Fig. 7.3

Explain why **T** is the major product in this reaction.

..... [1]

- (b) **S** reacts in a similar way to phenol in step 3.

- (i) Draw the structures of **Q**, **R** and **S** in the boxes in Fig. 7.1. [3]

- (ii) Suggest reagents and conditions for steps 1 and 2 in Fig. 7.1.

step 1

step 2 [3]

[Total: 9]





- 8 (a) State the relative basicities of phenylamine, $\text{C}_6\text{H}_5\text{NH}_2$, benzylamine, $\text{C}_6\text{H}_5\text{CH}_2\text{NH}_2$, and ammonia, NH_3 , in aqueous solution. Explain your answer.

..... > >
 most basic least basic

.....

.....

.....

.....

.....

[3]

- (b) An excess of $\text{Br}_2(\text{aq})$ is added to separate samples of $\text{C}_6\text{H}_5\text{NH}_2$ and benzene, C_6H_6 .

- (i) $\text{C}_6\text{H}_5\text{NH}_2$ reacts readily with $\text{Br}_2(\text{aq})$ to form organic product **M**.

State the expected observations for this reaction. Draw the structure of **M**.

observations

structure of **M**

[2]

- (ii) C_6H_6 does **not** react with $\text{Br}_2(\text{aq})$.

Suggest why $\text{Br}_2(\text{aq})$ reacts with $\text{C}_6\text{H}_5\text{NH}_2$ but **not** with C_6H_6 .

.....

.....

..... [2]

- (c) Explain why benzamide, $\text{C}_6\text{H}_5\text{CONH}_2$, is a much weaker base than ammonia, NH_3 .

.....

..... [1]



(d) $\text{C}_6\text{H}_5\text{CONH}_2$ is formed by reacting benzoyl chloride, $\text{C}_6\text{H}_5\text{COCl}$, with NH_3 .

Complete the mechanism in Fig. 8.1 for the reaction of $\text{C}_6\text{H}_5\text{COCl}$ with NH_3 .

Include all relevant lone pairs of electrons, curly arrows, charges and dipoles. Draw the structure of the organic intermediate.

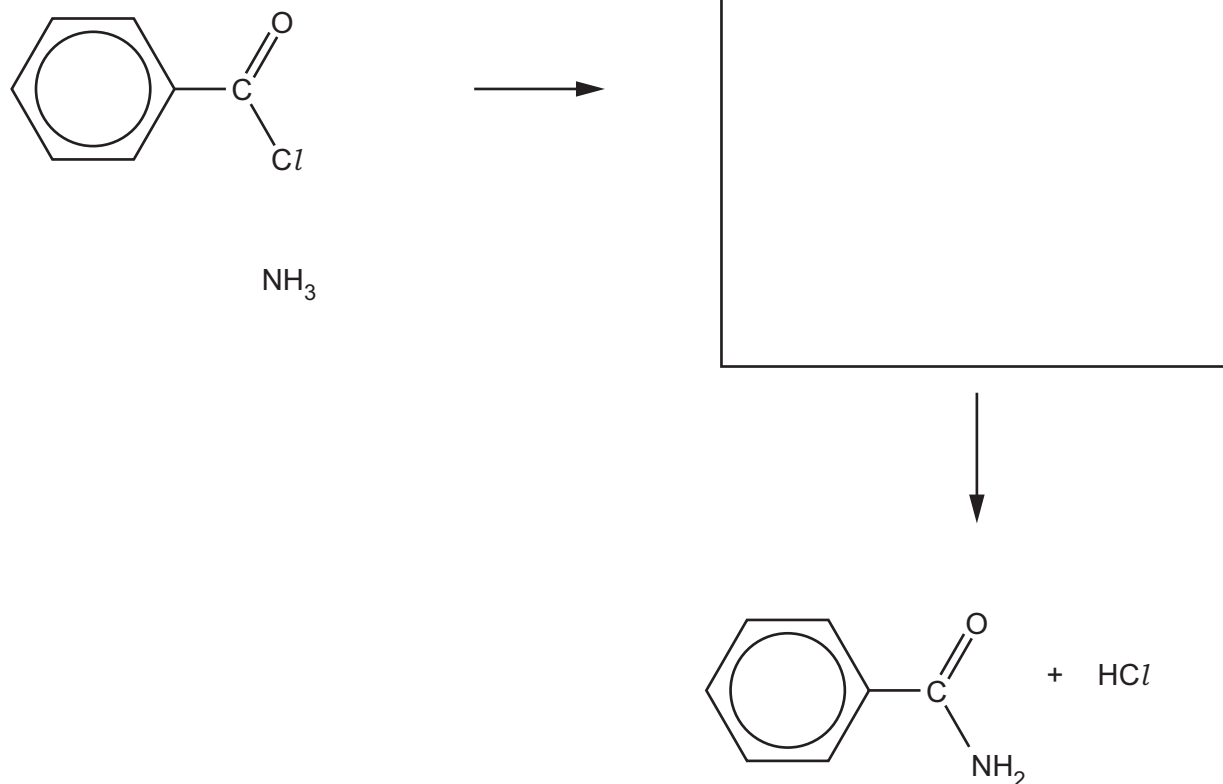


Fig. 8.1

[4]





(e) Phenylalanine, $\text{C}_6\text{H}_5\text{CH}_2\text{CH}(\text{NH}_2)\text{COOH}$, is an amino acid with an isoelectric point of 5.5.

(i) State what is meant by isoelectric point.

.....
 [1]

(ii) Draw the structure of $\text{C}_6\text{H}_5\text{CH}_2\text{CH}(\text{NH}_2)\text{COOH}$ at pH 10.

[1]

(f) $\text{C}_6\text{H}_5\text{CH}_2\text{CH}(\text{NH}_2)\text{COOH}$ and alanine, $\text{CH}_3\text{CH}(\text{NH}_2)\text{COOH}$, react to form a dipeptide containing both amino acid residues.

Draw the structure of this dipeptide.

The peptide functional group formed should be displayed.

[2]

[Total: 16]



- 9 (a) Explain why trichloroethanoic acid, CCl_3COOH , is more acidic than ethanoic acid, CH_3COOH .

.....

 [1]

- (b) Acyl chlorides are formed by reacting carboxylic acids with thionyl chloride, SOCl_2 .

- (i) Ethanedioyl chloride, $(\text{COCl})_2$, can be prepared by reacting ethanedioic acid, $(\text{COOH})_2$, with an excess of SOCl_2 .

Write an equation for this reaction.

..... [1]

- (ii) Samples of $(\text{COCl})_2$ are reacted separately with an excess of warm acidified $\text{KMnO}_4(\text{aq})$ and with $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$.

The carbon-containing product from the reaction with $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ has the molecular formula $\text{C}_4\text{H}_6\text{N}_2\text{O}_2$.

Complete the boxes in Fig. 9.1 to suggest the structure of the carbon-containing product in each reaction.

with warm acidified $\text{KMnO}_4(\text{aq})$	with $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$

Fig. 9.1

[2]

- (iii) A polyester can be synthesised from the reaction of $(\text{COCl})_2$ with ethane-1,2-diol, $\text{HOCH}_2\text{CH}_2\text{OH}$.

Draw **two** repeat units of the polymer formed. Any functional groups should be displayed.

[2]





- (c) Compound **H**, $C_6H_{10}O_3$, reacts with alkaline $I_2(aq)$ to form yellow precipitate **J** but does **not** react with $Na_2CO_3(aq)$.

The proton (^1H) NMR spectrum of **H** in $CDCl_3$ is shown in Fig. 9.2.

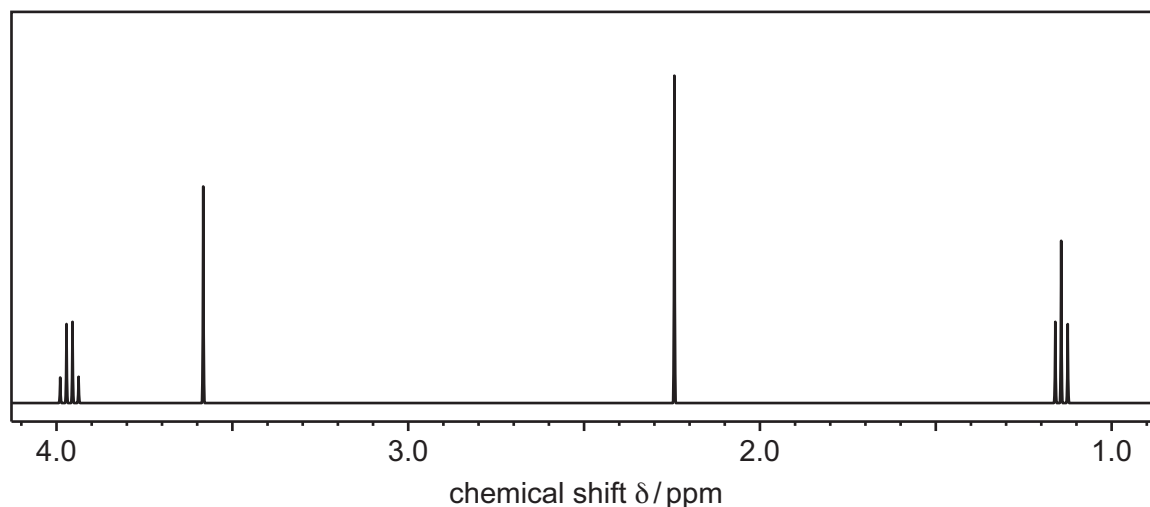


Fig. 9.2

Table 9.1

environment of proton	example	chemical shift range δ/ppm
alkane	$-CH_3$, $-CH_2-$, $>CH-$	0.9–1.7
alkyl next to $C=O$	$CH_3-C=O$, $-CH_2-C=O$, $>CH-C=O$	2.2–3.0
alkyl next to aromatic ring	CH_3-Ar , $-CH_2-Ar$, $>CH-Ar$	2.3–3.0
alkyl next to electronegative atom	CH_3-O , $-CH_2-O$, $-CH_2-Cl$	3.2–4.0
attached to alkene	$=CHR$	4.5–6.0
attached to aromatic ring	$H-Ar$	6.0–9.0
aldehyde	$HCOR$	9.3–10.5
alcohol	ROH	0.5–6.0
phenol	$Ar-OH$	4.5–7.0
carboxylic acid	$RCOOH$	9.0–13.0
alkyl amine	$R-NH-$	1.0–5.0
aryl amine	$Ar-NH_2$	3.0–6.0
amide	$RCONHR$	5.0–12.0





(i) Identify yellow precipitate **J**.

..... [1]

(ii) Complete Table 9.2 for the proton (^1H) NMR spectrum of **H**, $\text{C}_6\text{H}_{10}\text{O}_3$.

Table 9.2

chemical shift δ/ppm	splitting pattern	number of ^1H atoms responsible for the peak	number of protons on adjacent carbon atoms
1.15			
2.25			
3.60			
3.95			

[4]

(iii) Suggest a structure for **H**, $\text{C}_6\text{H}_{10}\text{O}_3$.

[1]

[Total: 12]





Important values, constants and standards

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



Group																																																																																																																																																																																																																										
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Na sodium 23.0	Mg magnesium 24.3	K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8	Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3	Cs caesium 132.9	Ba barium 137.3	La lanthanoids 57–71	Pr praseodymium 140.9	Nd neodymium 144.2	Pm promethium —	Sm samarium 150.4	Eu europium 152.0	Gd gadolinium 157.3	Tb terbium 158.9	Dy dysprosium 162.5	Ho holmium 164.9	Er erbium 167.3	Tm thulium 168.9	Yb ytterbium 173.1	Lu lutetium 175.0	Hf hafnium 178.5	Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —	Fr francium —	Ra radium —	Ac actinoids 89–103	Th thorium 232.0	Pa protactinium 231.0	U uranium 238.0	Np neptunium 237.0	Pu plutonium 244.0	Am americium 243.0	Cm curium 247.0	Bk berkelium 247.0	Cf californium 251.0	Es einsteinium 252.0	Fm fermium 257.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8	Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3	Cs caesium 132.9	Ba barium 137.3	La lanthanoids 57–71	Pr praseodymium 140.9	Nd neodymium 144.2	Pm promethium —	Sm samarium 150.4	Eu europium 152.0	Gd gadolinium 157.3	Tb terbium 158.9	Dy dysprosium 162.5	Ho holmium 164.9	Er erbium 167.3	Tm thulium 168.9	Yb ytterbium 173.1	Lu lutetium 175.0	Hf hafnium 178.5	Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —	Fr francium —	Ra radium —	Ac actinoids 89–103	Th thorium 232.0	Pa protactinium 231.0	U uranium 238.0	Np neptunium 237.0	Pu plutonium 244.0	Am americium 243.0	Cm curium 247.0	Bk berkelium 247.0	Cf californium 251.0	Es einsteinium 252.0	Fm fermium 257.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8	Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3	Cs caesium 132.9	Ba barium 137.3	La lanthanoids 57–71	Pr praseodymium 140.9	Nd neodymium 144.2	Pm promethium —	Sm samarium 150.4	Eu europium 152.0	Gd gadolinium 157.3	Tb terbium 158.9	Dy dysprosium 162.5	Ho holmium 164.9	Er erbium 167.3	Tm thulium 168.9	Yb ytterbium 173.1	Lu lutetium 175.0	Hf hafnium 178.5	Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	R

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.2
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	euporium	152.0
64	Gd	gadolinium	157.3
65	Tb	terbium	158.9
66	Dy	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
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	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	—

actinoids



CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/43

May/June 2024

2 hours

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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.

- 1 (a) (i) Describe the trend in the solubility of the hydroxides of magnesium, calcium and strontium.

Explain your answer.

..... > >
 most soluble least soluble

.....

.....

.....

.....

.....

.....

[4]

- (ii) Suggest the variation in pH of saturated solutions of the hydroxides of magnesium, calcium and strontium.

Explain your answer.

.....

.....

..... [1]

- (b) Barium hydroxide, $\text{Ba}(\text{OH})_2$, is a strong base.

A 250.0 cm^3 solution of $\text{Ba}(\text{OH})_2$ with a pH of 12.2 is made by dissolving $\text{Ba}(\text{OH})_2$ in distilled water.

Calculate the mass of $\text{Ba}(\text{OH})_2$ required to make this solution.

Show your working.

[M_r : $\text{Ba}(\text{OH})_2$, 171.3]

mass of $\text{Ba}(\text{OH})_2$ = ... g [4]

(c) The solubility of iron(II) hydroxide, $\text{Fe}(\text{OH})_2$, is $5.85 \times 10^{-6} \text{ mol dm}^{-3}$ at 298 K.

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

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

[1]

(ii) Calculate the value of K_{sp} of $\text{Fe}(\text{OH})_2$. Include its units.

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

$$\text{units} = \dots\dots\dots$$

[2]

[Total: 12]

- 2 (a) (i) Define transition element.

.....

 [1]

- (ii) Explain why transition elements can form complex ions.

.....
 [1]

- (b) The 3d orbitals in an isolated Ag^+ ion are degenerate.

- (i) Define degenerate d orbitals.

.....
 [1]

- (ii) Sketch the shape of a $3d_{xy}$ orbital in Fig. 2.1.

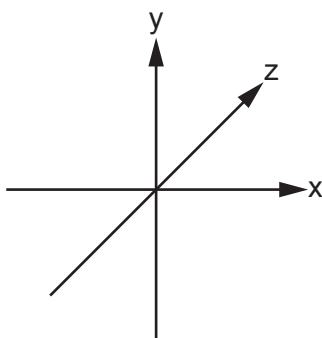


Fig. 2.1

[1]

- (c) Tollens' reagent can be used to distinguish between aldehydes and ketones. Tollens' reagent contains $[\text{Ag}(\text{NH}_3)_2]\text{OH}$, which can be prepared in a two-step process.

step 1 Aqueous NaOH is added dropwise to aqueous AgNO_3 to form Ag_2O as a brown precipitate.

step 2 Aqueous NH_3 is added dropwise to Ag_2O to form a colourless solution containing $[\text{Ag}(\text{NH}_3)_2]\text{OH}$.

Construct equations for each of the steps in the preparation of $[\text{Ag}(\text{NH}_3)_2]\text{OH}$.

step 1

step 2

[2]

- (d) Name the shape of the complex ion $[\text{Ag}(\text{NH}_3)_2]^+$.

State the bond angle for H-N-Ag and for N-Ag-N.

shape

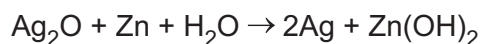
bond angle for H-N-Ag = ... °

bond angle for N-Ag-N = ... °

[2]

- (e) An electrochemical cell uses Ag_2O as the positive electrode and Zn as the negative electrode immersed in an alkaline electrolyte.

The overall cell reaction is shown.



Complete the half-equation for the reaction at each electrode.

at the positive electrode $\text{Ag}_2\text{O} + \dots$

at the negative electrode $\text{Zn} + \dots$

[2]

- (f) Coordination polymers are made when a bidentate ligand acts as a bridge between different metal ions.

Under certain conditions $\text{Ru}^{3+}(\text{aq})$ and the bidentate ligand *dps* can form a coordination polymer containing $([\text{Ru}(\text{dps})\text{Cl}_4]^-)_n$ chains.

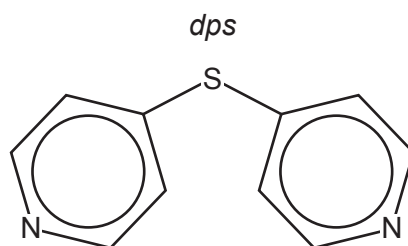
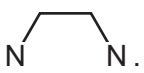


Fig. 2.2

The bidentate ligand *dps* uses each of the nitrogen atoms to bond to a different Ru^{3+} .

Complete Fig. 2.3 by drawing the structure for the coordination polymer $([\text{Ru}(\text{dps})\text{Cl}_4]^-)_n$. Show **two** repeat units.

The *dps* ligand can be represented using .

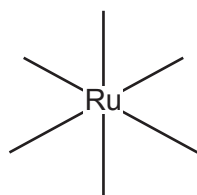


Fig. 2.3

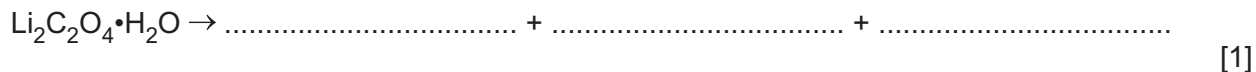
[2]

[Total: 12]

- 3 (a) When a sample of hydrated lithium ethanedioate, $\text{Li}_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$, is gently heated, two gaseous products are formed and a white solid residue remains.

The residue is added to $\text{HNO}_3(\text{aq})$. A gas is produced that turns limewater milky.

Complete the equation for the decomposition of $\text{Li}_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$.



- (b) The trend in the decomposition temperatures of the Group 2 ethanedioates is similar to that of the Group 2 nitrates.

Suggest which of CaC_2O_4 and BaC_2O_4 will decompose at the **lower** temperature. Explain your answer.

.....

 [2]

- (c) Potassium iron(III) ethanedioate, $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$, dissolves in water to form a green solution.

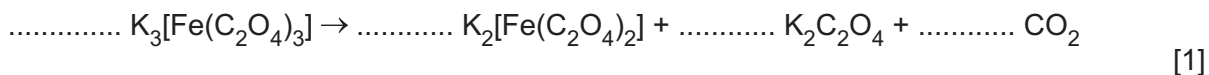
Explain why transition elements can form coloured complexes.

.....

 [3]

- (d) The anhydrous iron(III) compound $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$ decomposes on heating to form a mixture of $\text{K}_2[\text{Fe}(\text{C}_2\text{O}_4)_2]$, $\text{K}_2\text{C}_2\text{O}_4$ and CO_2 .

Complete the equation for the decomposition of $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$.



- (e) The $[\text{Fe}(\text{C}_2\text{O}_4)_3]^{3-}$ complex ion shows stereoisomerism.

Complete the three-dimensional diagrams in Fig. 3.1 to show the **two** stereoisomers of $[\text{Fe}(\text{C}_2\text{O}_4)_3]^{3-}$.

The $\text{C}_2\text{O}_4^{2-}$ ligand can be represented using .

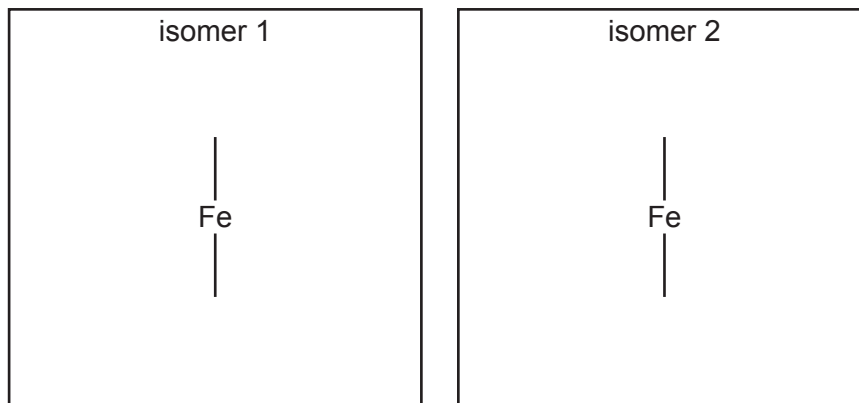


Fig. 3.1

[2]

- (f) Buffer solutions are used to regulate pH.

Write **two** equations to describe how a solution containing HC_2O_4^- ions acts as a buffer solution when small amounts of acid or alkali are added.

.....
 [2]

- (g) A fuel cell is an electrochemical cell that can be used to generate electrical energy by using oxygen to oxidise a fuel.

Ethanedioic acid, $(\text{COOH})_2$, dissolved in an alkaline electrolyte is being investigated as a fuel.

The relevant standard electrode potentials, $E^\ominus$, for the cell are shown.



Use these equations to deduce the overall cell reaction. Calculate the value of $E_{\text{cell}}^\ominus$.

overall cell reaction

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

[2]

[Total: 13]

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

.....

.....

..... [2]

- (b) (i) An electrochemical cell is set up to measure $E^\ominus$ of the $\text{Ag}^+(\text{aq})/\text{Ag}(\text{s})$ electrode.

Draw a labelled diagram of this electrochemical cell.

Include all necessary substances. It is **not** necessary to state conditions used.

[3]

- (ii) A separate electrochemical cell is set up using a **lower** concentration of $\text{Ag}^+(\text{aq})$ than that used in (b)(i).

Suggest how the electrode potential, E , for the $\text{Ag}^+(\text{aq})/\text{Ag}(\text{s})$ electrode would change from its $E^\ominus$ value. Explain your answer.

.....

.....

..... [1]

- (c) Define enthalpy change of solution, $\Delta H_{\text{sol}}^\ominus$.

.....

..... [1]

(d) Some relevant energy changes for AgNO_3 are shown in Table 4.1.

Table 4.1

energy change	value / kJ mol^{-1}
enthalpy change of solution of $\text{AgNO}_3(\text{s})$	+22.6
enthalpy change of hydration of silver ions	−475
enthalpy change of hydration of nitrate ions	−314

- (i) Complete the energy cycle in Fig. 4.1 to show the relationship between the lattice energy, $\Delta H_{\text{latt}}^\ominus$, of $\text{AgNO}_3(\text{s})$ and the energy changes shown in Table 4.1.

Include state symbols for all the species.

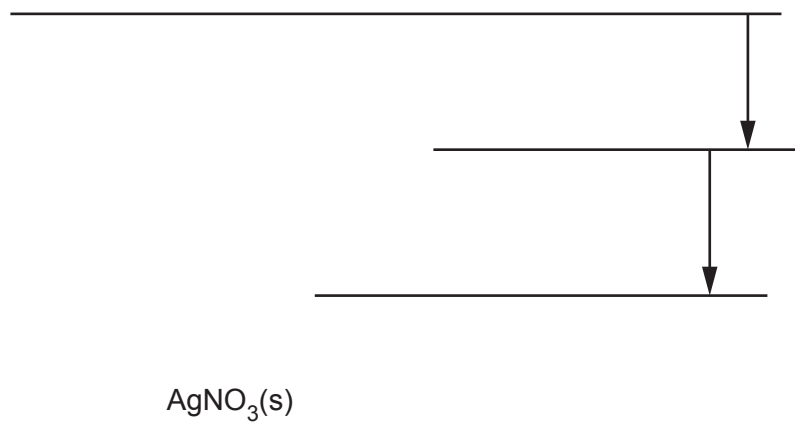


Fig. 4.1

[2]

- (ii) Calculate the lattice energy, $\Delta H_{\text{latt}}^\ominus$, of $\text{AgNO}_3(\text{s})$.

$$\Delta H_{\text{latt}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [1]$$

- (e) Suggest the trend in the magnitude of the lattice energies of the metal nitrates, $\text{NaNO}_3(\text{s})$, $\text{Mg}(\text{NO}_3)_2(\text{s})$ and $\text{RbNO}_3(\text{s})$.

Explain your answer.

most exothermic least exothermic

.....

.....

.....

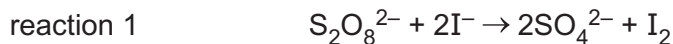
.....

.....

.....

[Total: 13]

- 5 (a) In aqueous solution, persulfate ions, $\text{S}_2\text{O}_8^{2-}$, react with iodide ions, as shown in reaction 1.



The rate of reaction 1 is investigated.

A sample of $\text{S}_2\text{O}_8^{2-}$ is mixed with a large excess of iodide ions of known concentration. The graph in Fig. 5.1 shows the results obtained.

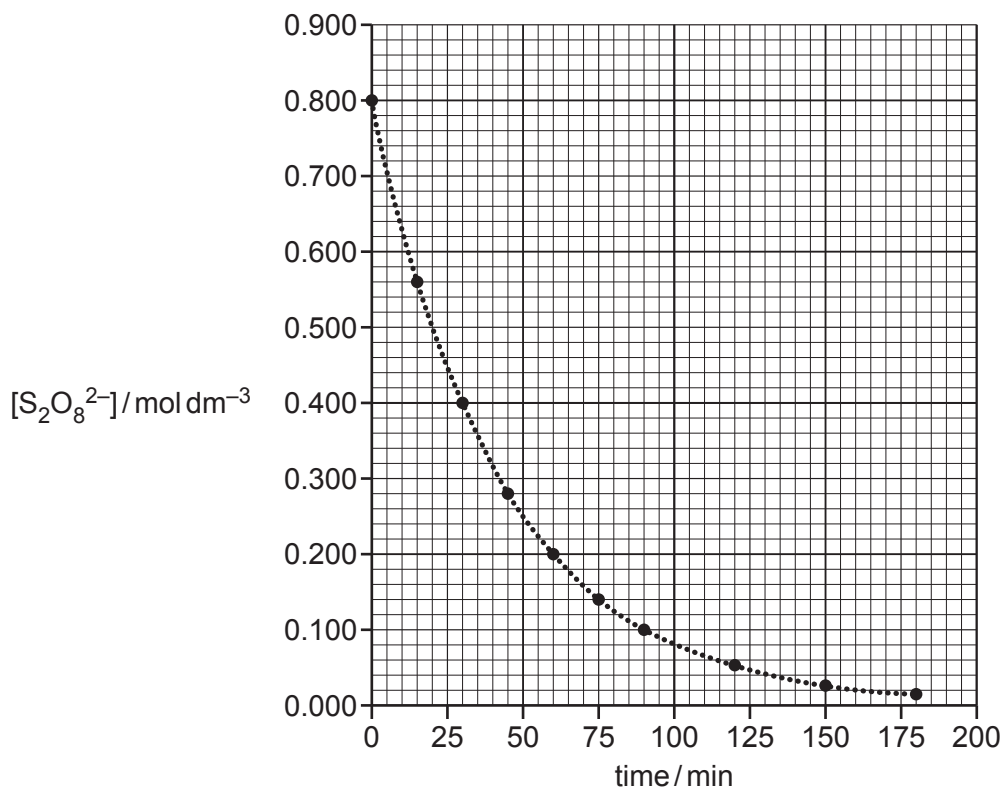


Fig. 5.1

- (i) Use Fig. 5.1 to determine the initial rate of reaction 1. Show your working.

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

- (ii) The rate equation for reaction 1 is $\text{rate} = k [\text{S}_2\text{O}_8^{2-}] [\text{I}^-]$.

Suggest why a large excess of iodide ions allows the rate constant to be determined from the half-life in this investigation.

.....

 [1]

- (b) The reaction of persulfate ions, $\text{S}_2\text{O}_8^{2-}$, with iodide ions is catalysed by Fe^{2+} ions.

Write **two** equations to show how Fe^{2+} catalyses reaction 1.

equation 1

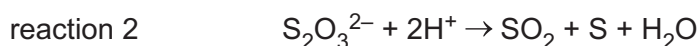
equation 2 [2]

- (c) Describe the effect of an increase in temperature on the rate constant and the rate of reaction 1.

.....

..... [1]

- (d) In aqueous solution, thiosulfate ions, $\text{S}_2\text{O}_3^{2-}$, react with hydrogen ions, as shown in reaction 2.



The rate of reaction is first order with respect to $[\text{S}_2\text{O}_3^{2-}]$ and zero order with respect to $[\text{H}^+]$ under certain conditions.

The rate constant, k , for this reaction is $1.58 \times 10^{-2} \text{ s}^{-1}$.

Calculate the half-life, $t_{\frac{1}{2}}$, for reaction 2.

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

- (e) The compound nitrosyl bromide, NOBr, can be formed as shown in reaction 3.



The rate is first order with respect to $[\text{NO}]$ and first order with respect to $[\text{Br}_2]$.

The reaction mechanism has two steps.

Suggest equations for the **two** steps of this mechanism. State which is the rate-determining step.

step 1

step 2

rate-determining step = ...

[2]

[Total: 8]

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

.....

 [1]

- (ii) The partition coefficient, K_{pc} , for a compound, **X**, between carbon disulfide, CS_2 , and water is 10.5.

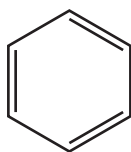
1.85 g of **X** is dissolved in water and made up to 100.0 cm^3 in a volumetric flask.
 40.0 cm^3 of this aqueous solution is shaken with 25.0 cm^3 of CS_2 .
 The mixture is left to reach equilibrium.

Calculate the mass of **X**, in g, extracted into the CS_2 layer.

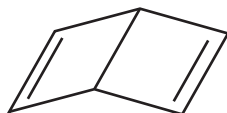
mass of **X** = ... g [2]

- (b) The compound C_6H_6 has many structural isomers. Four suggested structures of C_6H_6 are shown in Fig. 6.1.

Kekulé benzene



Dewar benzene



Ladenburg benzene



delocalised benzene

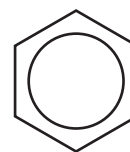


Fig. 6.1

Using Fig. 6.1, complete Table 6.1 to predict the number of carbon atoms that have sp , sp^2 and sp^3 hybridisation in Kekulé benzene, Dewar benzene and Ladenburg benzene.

Table 6.1

C_6H_6 structure	sp hybridised	sp^2 hybridised	sp^3 hybridised
Kekulé benzene			
Dewar benzene			
Ladenburg benzene			

[2]

- (c) Describe the shape of delocalised benzene.

Include the geometry of each carbon, the C-C-H bond angle and the type of bond(s) between the carbon atoms and between the carbon and hydrogen atoms.

.....

.....

.....

.....

..... [2]

- (d) Suggest why Dewar benzene and Ladenburg benzene are unstable isomers of C_6H_6 .

.....

..... [1]

- (e) Complete Table 6.2 to predict the number of peaks in the proton (^1H) NMR spectrum for Dewar benzene, Ladenburg benzene and delocalised benzene.

Table 6.2

	number of peaks
Dewar benzene	
Ladenburg benzene	
delocalised benzene	

[1]

- (f) The reaction of phenylethanone with 1,4-dibromobutane, $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$, in the presence of FeBr_3 is shown in Fig. 6.2.

phenylethanone

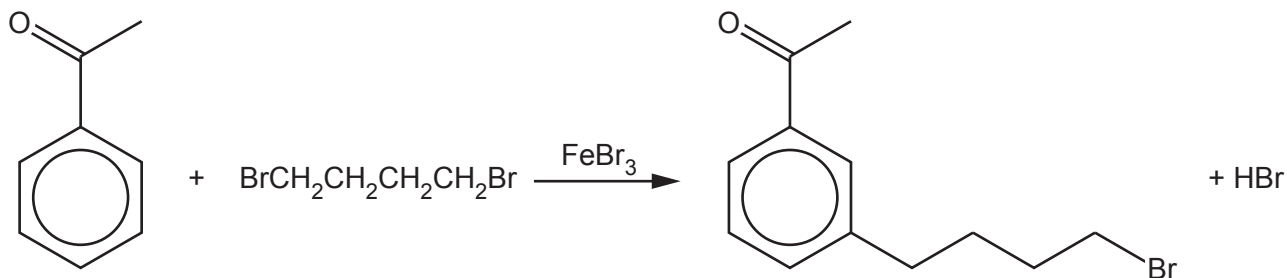


Fig. 6.2

The mechanism of this reaction is similar to that of the alkylation of benzene.

- (i) Construct an equation for the formation of the electrophile, $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2^+$.

..... [1]

- (ii) Complete the mechanism in Fig. 6.3 for the reaction of phenylethanone with $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2^+$ ions.

Include all relevant curly arrows and charges.
Draw the structure of the organic intermediate.

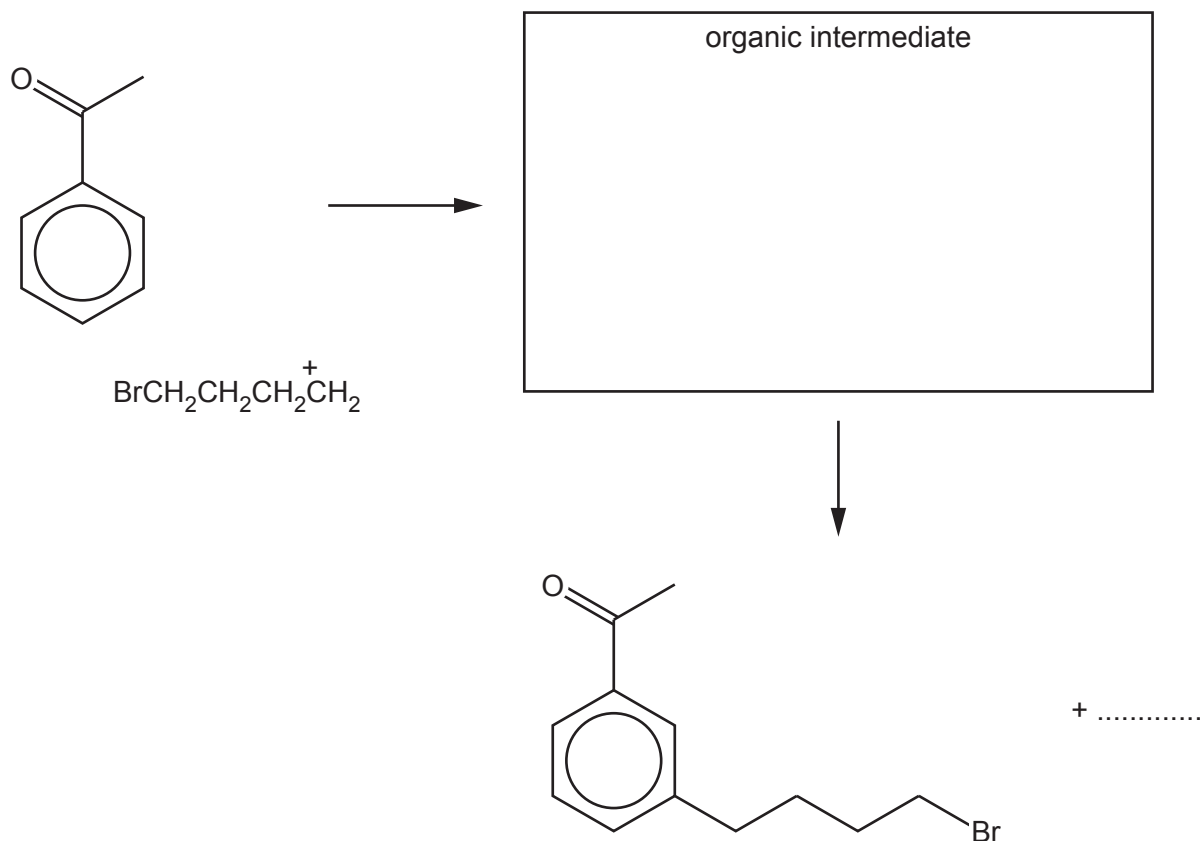


Fig. 6.3

[3]

- (iii) The reaction shown in Fig. 6.2 forms small amounts of two by-products, **Y** ($\text{C}_{20}\text{H}_{22}\text{O}_2$) and **Z** ($\text{C}_{12}\text{H}_{14}\text{O}$).

Suggest structures for **Y** and **Z** in the boxes in Fig. 6.4.

Y ($\text{C}_{20}\text{H}_{22}\text{O}_2$)	Z ($\text{C}_{12}\text{H}_{14}\text{O}$)
---	---

Fig. 6.4

[2]

[Total: 15]

7 Four esters, **A**, **B**, **C** and **D**, with the molecular formula $C_6H_{12}O_2$ are shown in Fig. 7.1.

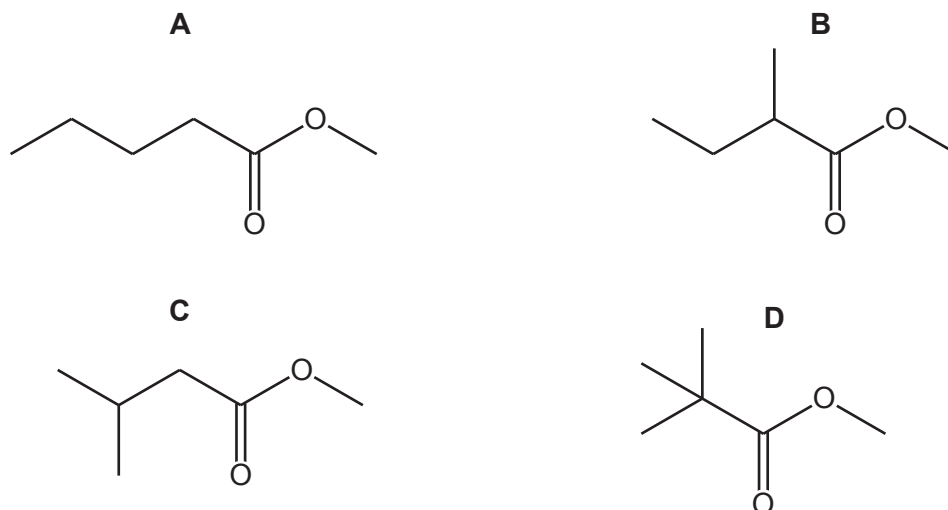


Fig. 7.1

(a) Give the systematic name of ester **A**.

..... [1]

(b) A mixture of these esters, **A**, **B**, **C** and **D**, is analysed by gas–liquid chromatography.

The chromatogram produced is shown in Fig. 7.2. The number above each peak represents the area under the peak.

The area under each peak is proportional to the mass of the respective ester in the mixture.

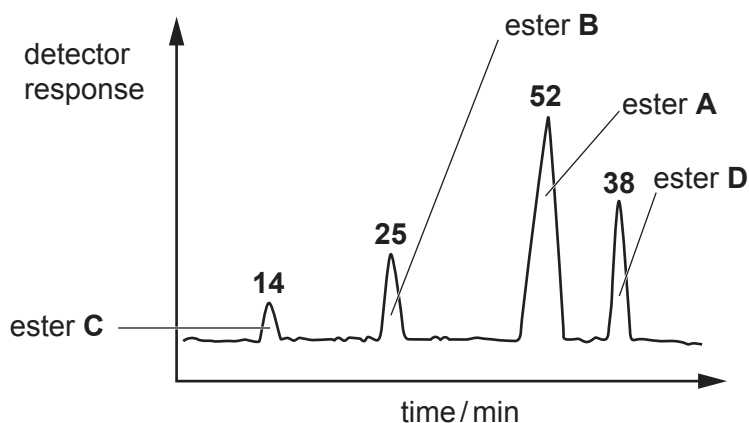


Fig. 7.2

(i) State what is meant by retention time.

.....
 [1]

(ii) Calculate the percentage by mass of ester **D** in the original mixture.

percentage by mass of ester **D** = ... % [1]

(c) Separate samples of the esters, **A**, **B**, **C** and **D**, are analysed using proton (^1H) NMR and carbon-13 NMR spectroscopy.

(i) Complete Table 7.1 to show the number of peaks in each NMR spectrum for esters **B** and **C**.

Table 7.1

ester	number of peaks in proton (^1H) NMR spectrum	number of peaks in carbon-13 NMR spectrum
B		
C		

[2]

(ii) Identify **all** of the esters from **A**, **B**, **C** and **D** that have at least one triplet peak in their proton (^1H) NMR spectrum.

..... [1]

Question 7 continues on page 20.

(d) Compound **F**, $C_6H_8O_3$, shows stereoisomerism and effervesces with $Na_2CO_3(aq)$.

Compound **F** reacts with alkaline $I_2(aq)$ to form yellow precipitate **G** and compound **H**.

Compound **F** reacts with $LiAlH_4$ to form compound **J**, $C_6H_{12}O_2$.

Compound **F** reacts with $SOCl_2$ to form compound **K**, $C_6H_7O_2Cl$.

Compound **K** reacts with propan-2-ol to form compound **L**.

Draw the structures of compounds **F**, **G**, **H**, **J**, **K** and **L** in the boxes in Fig. 7.3.

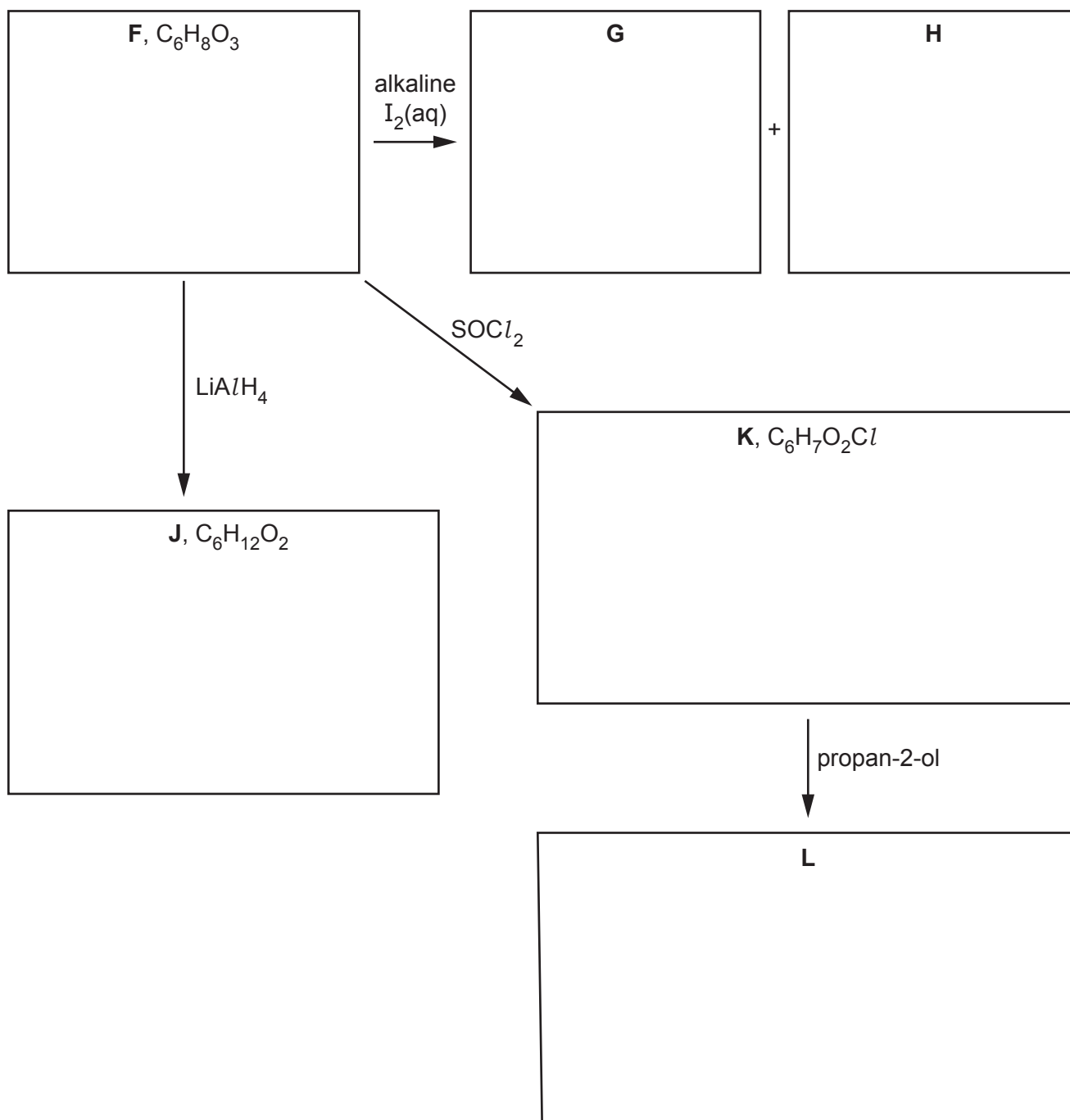


Fig. 7.3

[6]

[Total: 12]

- 8 Neotame is an artificial sweetener added to some foods.

neotame

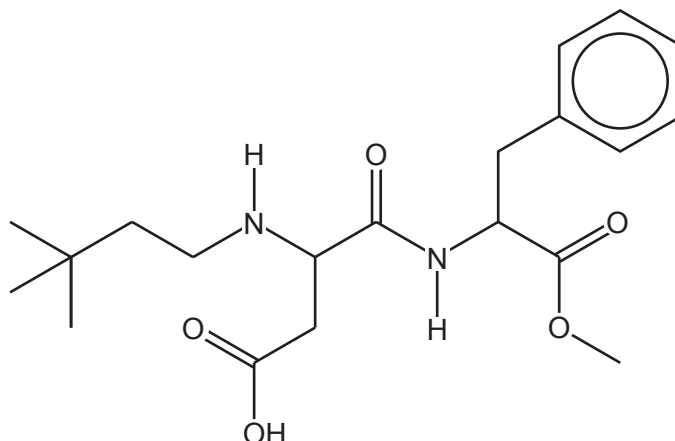


Fig. 8.1

- (a) (i) State the number of chiral carbon atoms in a molecule of neotame.

..... [1]

- (ii) Neotame contains the arene functional group.

Identify all the **other** functional groups present in neotame.

.....

..... [2]

- (b) Neotame reacts with an excess of hot NaOH(aq) to form three organic products.

- (i) State the **two** types of reaction that occur when neotame reacts with hot NaOH(aq).

1

2

[2]

neotame

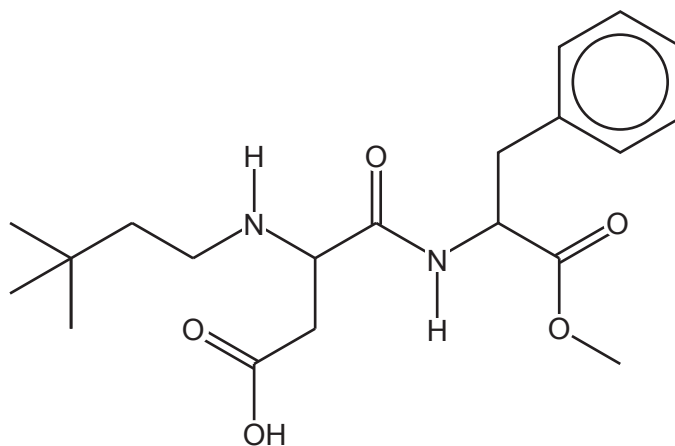
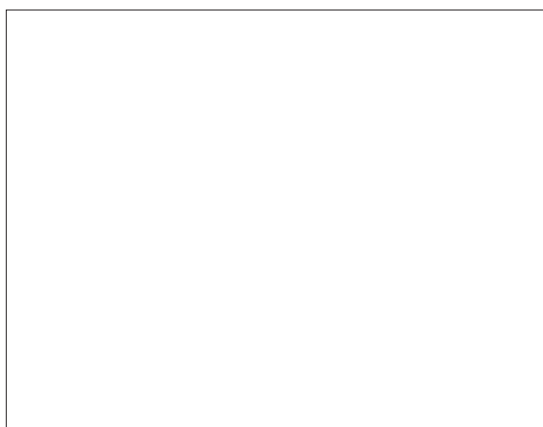
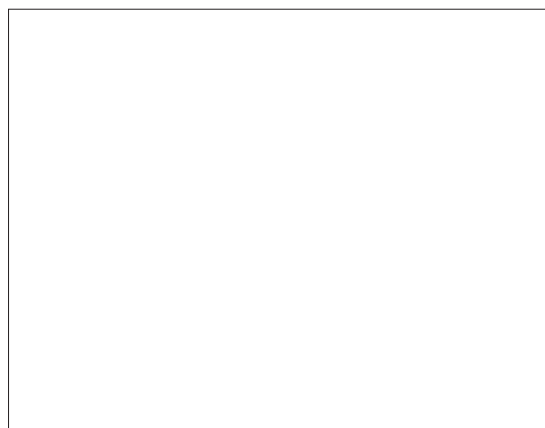
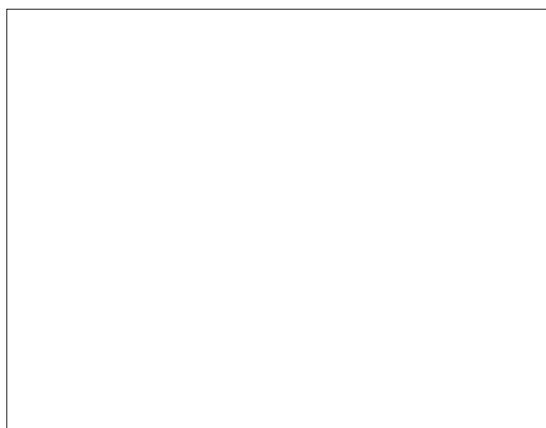


Fig. 8.1

- (ii) Draw the structures of the **three** organic products formed from the reaction of neotame with an excess of hot NaOH(aq).



[3]

[Total: 8]

- 9 (a) Samples of phenol, $\text{C}_6\text{H}_5\text{OH}$, are reacted separately with sodium and with dilute nitric acid.

phenol

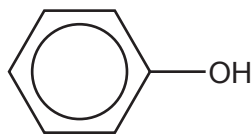
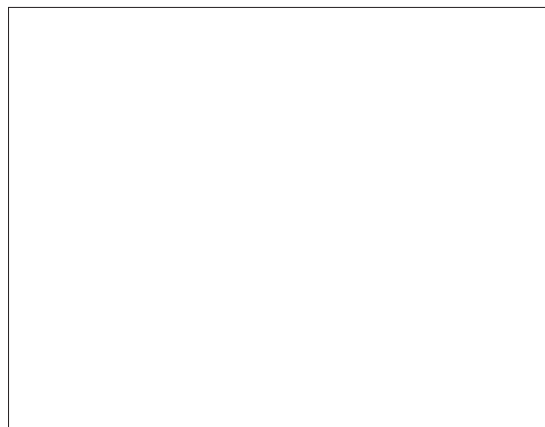
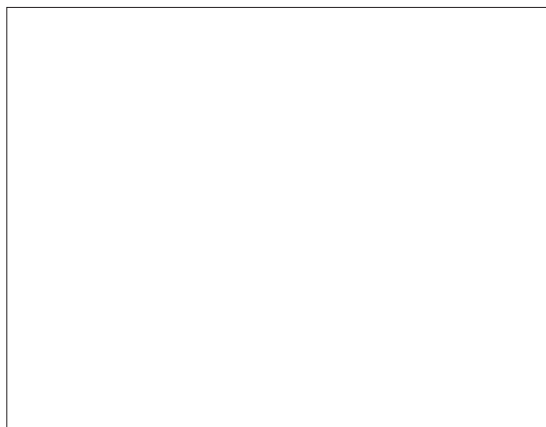


Fig. 9.1

- (i) Write the equation for the reaction of $\text{C}_6\text{H}_5\text{OH}$ with Na.

..... [1]

- (ii) Draw the structures of the **two** major isomeric organic products formed in the reaction of phenol with dilute HNO_3 .



[1]

(b) Salicylic acid can be synthesised from phenol.

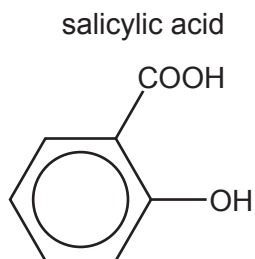


Fig. 9.2

One of the steps in this synthesis is the electrophilic substitution reaction of carbon dioxide with the phenoxide ion, $\text{C}_6\text{H}_5\text{O}^-$.

Complete the mechanism in Fig. 9.3 for the reaction of $\text{C}_6\text{H}_5\text{O}^-$ with CO_2 .

Include all relevant curly arrows, dipoles and charges. Draw the structure of the organic intermediate.

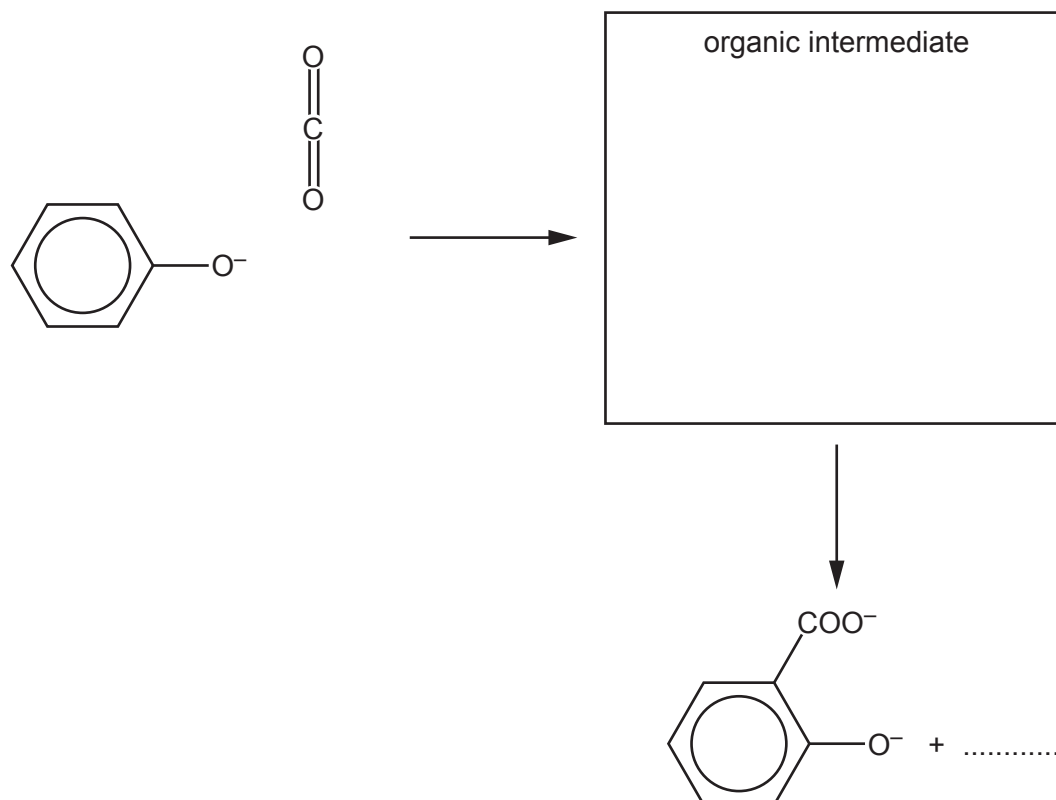


Fig. 9.3

[3]

(c) Some syntheses use Diels–Alder reactions, which normally involve a diene and an alkene reacting together to form a cyclohexene.

(i) Draw **three** curly arrows in Fig. 9.4 to complete the mechanism for the Diels–Alder reaction between buta-1,3-diene and ethene.

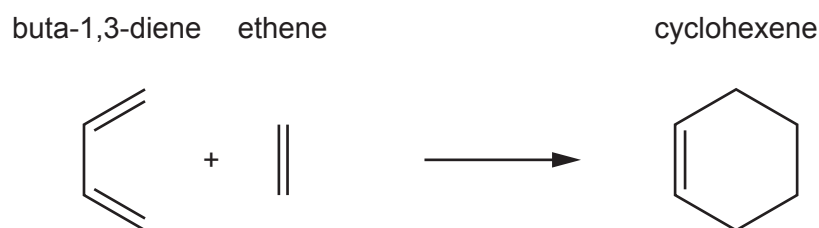


Fig. 9.4

[1]

(ii) Another Diels–Alder reaction of buta-1,3-diene is shown in Fig. 9.5.

Predict the product formed in this reaction.

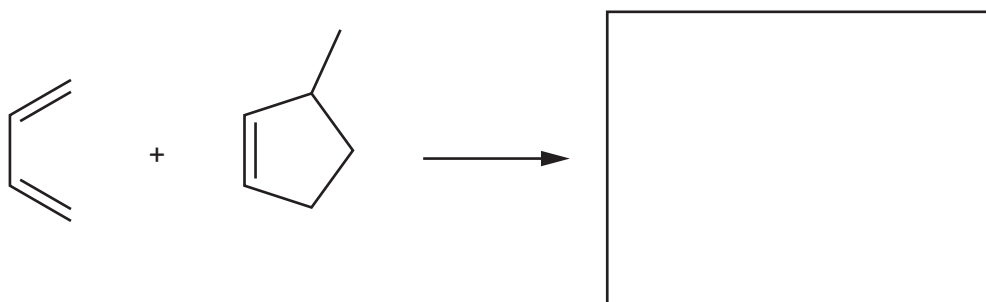


Fig. 9.5

[1]

[Total: 7]

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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 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group																			
1	2													13	14	15	16	17	18
1 H hydrogen 1.0 Key atomic number atomic symbol name relative atomic mass 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 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

actinoids

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
lanthanum	cerium	praseodymium	neodymium	promethium	samarium	europlum	gadolinium	terbium	dysprosium	holmium	erbium	thulium	ytterbium	lutetium
138.9	140.1	140.9	144.2	—	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.1	175.0
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendeleevium	nobelium	lawrencium
—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—