



CANDIDATE
NAME

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NUMBER

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9701/41

October/November 2022

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 Potassium chloride, KCl , and magnesium chloride, MgCl_2 , are both ionic solids.

Table 1.1

energy change	value/ kJ mol^{-1}
standard enthalpy change of solution, $\Delta H_{\text{sol}}^{\ominus}$ of KCl	+15
lattice energy, $\Delta H_{\text{latt}}^{\ominus}$ of KCl(s)	–701
standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$ of K^+	–322
standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$ of Cl^-	–364
standard enthalpy change of solution, $\Delta H_{\text{sol}}^{\ominus}$ of MgCl_2	–155
lattice energy, $\Delta H_{\text{latt}}^{\ominus}$ of $\text{MgCl}_2(\text{s})$	–2493

- (a) Complete the energy cycle involving the enthalpy change of solution and the lattice energy of potassium chloride, KCl , and the relevant enthalpy changes of hydration. Label your diagram.

State symbols should be used.

KCl(s)

[2]

- (b) Use the data in Table 1.1 to calculate the enthalpy change of hydration of magnesium ions, Mg^{2+} . Show your working.

$\Delta H_{\text{hyd}}^{\ominus}$ of magnesium ions, $\text{Mg}^{2+} = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

- (c) Explain the reasons why the lattice energy of MgCl_2 is more exothermic than the lattice energy of KCl .

.....

.....

.....

..... [2]

- (d) Define the following terms.

(i) enthalpy change of atomisation [1]

.....

(ii) first electron affinity [1]

.....

- (e) (i) Explain what is meant by entropy, S .

.....

..... [1]

- (ii) Potassium chloride is very soluble in water at 20°C .

Explain the solubility of potassium chloride by reference to change in entropy, ΔS .

.....

..... [1]

- (iii) Use the Gibbs equation and your answer to (e)(ii) to predict whether potassium chloride is more soluble in water at 20°C or at 80°C . Explain your answer.

.....

.....

..... [1]

[Total: 11]

- 2 (a) (i) Explain what is meant by the following terms:

homogeneous catalyst

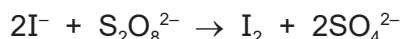
.....

heterogeneous catalyst

.....

[1]

- (ii) Iodide ions react with peroxydisulfate ions.



This reaction is slow, but it is catalysed by Fe^{2+} ions.

Write two equations to explain how this reaction is catalysed by Fe^{2+} ions.

1

2

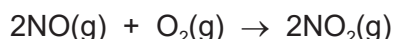
[2]

- (iii) Suggest why the alternative route in the presence of Fe^{2+} ions has a lower activation energy than the route in the absence of a catalyst.

.....

..... [1]

- (b) Nitrogen monoxide reacts with oxygen.



This reaction is second order with respect to nitrogen monoxide and first order with respect to oxygen.

Under certain conditions the value of the rate constant, k , is $8.60 \times 10^6 \text{ mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$.

- (i) Construct the rate equation for this reaction.

rate =

[1]

- (ii) Calculate the initial rate of the reaction under these conditions when the initial concentration of nitrogen monoxide is $7.20 \times 10^{-4} \text{ mol dm}^{-3}$ and the initial concentration of oxygen is $1.90 \times 10^{-3} \text{ mol dm}^{-3}$.

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

- (c) The drug cisplatin, $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$, hydrolyses in water.



The rate equation is shown.

$$\text{rate} = k[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$$

The value of k is $2.50 \times 10^{-5} \text{ s}^{-1}$ under certain conditions.

- (i) This reaction has a constant half-life.

Explain why this is the case.

.....
 [1]

- (ii) Use the information in this question to show that the half-life of this reaction is $2.77 \times 10^4 \text{ s}$.

[1]

- (iii) 8.00×10^{-6} moles of $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ are added to 100 cm^3 of water.

Calculate the time taken for the concentration of $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ to fall to $2.50 \times 10^{-6} \text{ mol dm}^{-3}$.

time taken = ... s [2]

[Total: 10]

- 3 Data should be selected from Table 3.1 in order to answer some parts of this question.

Table 3.1

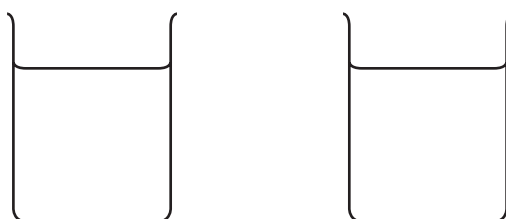
electrode reaction	E° / V
$\text{Cl}_2 + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$	+1.36
$2\text{HOCl} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Cl}_2 + 2\text{H}_2\text{O}$	+1.64
$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{Cl}^- + 2\text{OH}^-$	+0.89
$\text{Sn}^{4+} + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}$	+0.15
$\text{Sn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Sn}$	-0.14
$\text{V}^{2+} + 2\text{e}^- \rightleftharpoons \text{V}$	-1.20
$\text{V}^{3+} + \text{e}^- \rightleftharpoons \text{V}^{2+}$	-0.26
$\text{VO}^{2+} + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{V}^{3+} + \text{H}_2\text{O}$	+0.34
$\text{VO}_2^+ + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{VO}^{2+} + \text{H}_2\text{O}$	+1.00

- (a) Standard electrode potentials are measured under standard conditions.

- (i) Describe the standard conditions used in the $\text{Sn}^{4+}/\text{Sn}^{2+}$ half-cell.

.....
 [1]

- (ii) Complete the diagram below to show how $E^\circ (\text{Sn}^{4+}/\text{Sn}^{2+})$ can be measured experimentally. Your diagram should be fully labelled to identify all apparatus and substances.



[3]

- (iii) Equal volumes of $1.0 \text{ mol dm}^{-3} \text{ Sn}^{2+}(\text{aq})$ and $1.0 \text{ mol dm}^{-3} \text{ Cl}^{-}(\text{aq})$ are mixed.

Use relevant $E^\ominus$ values to explain whether a reaction occurs between these two ions.

.....

.....

.....

..... [2]

- (iv) Equal volumes of 1.0 mol dm^{-3} of $\text{Sn}^{2+}(\text{aq})$ and acidified $1.0 \text{ mol dm}^{-3} \text{ VO}^{2+}(\text{aq})$ are mixed.

Write an equation for the reaction that takes place in the resulting mixture.

..... [2]

- (b) A solution of $\text{SnCl}_2(\text{aq})$ is electrolysed for a measured time using a steady current.

A mass of 2.95 g of tin metal is produced at the cathode.

$\text{Al}_2\text{O}_3(\text{l})$ is electrolysed for the same time by the same current.

Calculate the mass of aluminium metal produced at the cathode. Give your answer to **three** significant figures. Show your working.

mass of aluminium metal = ... g [2]

[Total: 10]

- 4 (a) A sample of butanoic acid, $\text{CH}_3(\text{CH}_2)_2\text{COOH}$, is shaken with a mixture of two immiscible solvents, ethoxyethane and water. The solvents form two layers. The butanoic acid is distributed between the two layers, its concentration in ethoxyethane being higher than its concentration in water.

(i) State what is meant by partition coefficient.

.....
 [1]

(ii) The partition coefficient, K_{pc} , for butanoic acid between ethoxyethane and water is 3.50.

A solution of 2.00 g of butanoic acid in 100 cm^3 ethoxyethane is added to water. This mixture is left until there is no further change in the concentration of butanoic acid in either solvent. The mass of butanoic acid dissolved in the ethoxyethane layer is now 1.62 g.

Calculate the volume of water used.

volume of water used = ... cm^3 [2]

(b) An aqueous solution of butanoic acid can be used to make a buffer solution.

(i) Define buffer solution.

.....
 [1]

(ii) Suggest one organic compound, and one inorganic compound, that can be added to two different samples of aqueous butanoic acid to produce buffer solutions.

organic compound

inorganic compound

[1]

(c) The solubility of aluminium hydroxide, $\text{Al}(\text{OH})_3$, in water is $2.47 \times 10^{-9} \text{ mol dm}^{-3}$.

(i) Give the expression for the solubility product, K_{sp} , of aluminium hydroxide.

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

[1]

(ii) Calculate the numerical value of the K_{sp} of aluminium hydroxide. Include the units of K_{sp} in your answer.

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

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

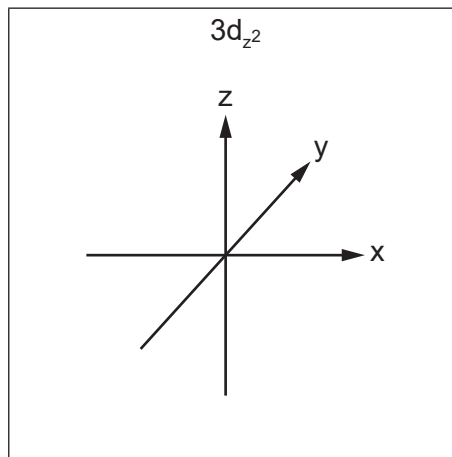
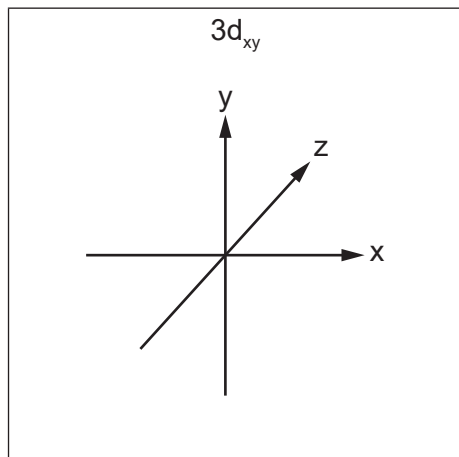
[3]

[Total: 9]

- 5 A transition element is a d-block element which forms one or more stable ions with incomplete d-orbitals.

(a) Two of the 3d orbitals are the $3d_{xy}$ orbital and the $3d_{z^2}$ orbital.

Sketch the shapes of these two orbitals.



[1]

(b) The Ni^{2+} ion forms many different complexes. A solution containing the $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ complex ion is green. When an excess of 1,2-diaminoethane, *en*, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is added, the colour of the solution changes to blue. This is due to the formation of the $[\text{Ni}(\text{en})_3]^{2+}$ complex ion.

(i) Explain why the two solutions are coloured, and why the colours are different.

.....

.....

.....

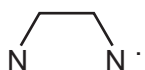
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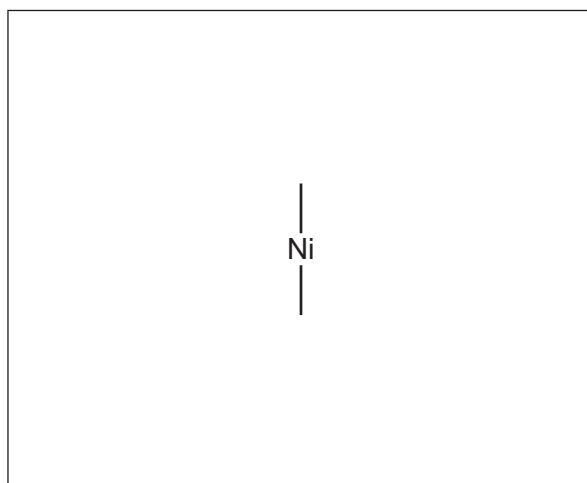
.....

..... [4]

- (ii) The $[\text{Ni}(\text{en})_3]^{2+}$ complex can exist as a mixture of two stereoisomers.

Complete the three-dimensional diagram to show one of the stereoisomers.

Each *en* ligand can be represented using .



[1]

- (iii) Name the geometry of the complex ion drawn in (b)(ii) and the type of stereoisomerism shown by $[\text{Ni}(\text{en})_3]^{2+}$.

geometry

stereoisomerism shown

[1]

- (c) Iron(II) carbonate, FeCO_3 , and nickel(II) carbonate, NiCO_3 , both decompose when heated.

FeCO_3 decomposes at a lower temperature than NiCO_3 .

Suggest a possible reason for this difference. Explain your answer.

.....

.....

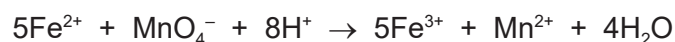
.....

.....

..... [2]

- (d) **A** is a pale green salt containing Fe^{2+} ions. A sample of 2.62 g of **A** is dissolved in water and the solution is made up to exactly 100 cm^3 with water. 25.0 cm^3 samples of this solution are placed in conical flasks and titrated against $0.0100\text{ mol dm}^{-3}$ acidified potassium manganate(VII).

The equation for the only reaction that occurs is shown.



The average titre value is 35.0 cm^3 of $0.0100\text{ mol dm}^{-3}$ acidified potassium manganate(VII).

- (i) Describe the colour change that is seen in the conical flask at the end-point of this titration.

The colour changes from to [1]

- (ii) Calculate the percentage by mass of iron in **A**.

[A_r : Fe, 55.8]

percentage by mass of iron = ... % [2]

[Total: 12]

Question 6 starts on the next page.

- 6 An aqueous solution of copper(II) sulfate is a blue colour due to the presence of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

(a) (i) Write an equation for the reaction between $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ ions and $\text{NaOH}(\text{aq})$.

..... [1]

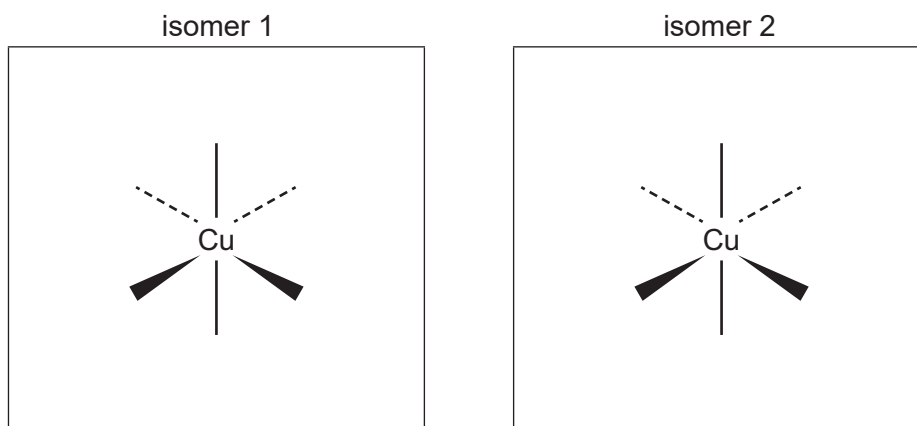
(ii) Write an equation for the reaction between $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ ions and an excess of conc. HCl .

..... [1]

- (b) If an excess of ammonia is added to a solution of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ a deep blue solution containing $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ions is formed.

(i) There are two possible stereoisomers with the formula $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$.

Complete the diagrams to show the two stereoisomers in the boxes below.



[1]

(ii) Use your answer in (b)(i) to deduce whether each of these isomers is polar or non-polar.

polarity of isomer 1

polarity of isomer 2

[1]

- (c) The numerical value of the stability constant, K_{stab} , of the $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion is 1.40×10^{13} .

(i) Define stability constant.

.....

..... [1]

- (ii) Compare the stabilities of the $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ions. Explain your answer.

.....
 [1]

- (iii) Write an expression for the stability constant, K_{stab} , of the $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion. State the units of the stability constant.

$$K_{\text{stab}} =$$

units = ...
 [2]

- (iv) In a particular solution the concentration of the $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion is $0.0074 \text{ mol dm}^{-3}$ and the concentration of NH_3 is 0.57 mol dm^{-3} .

Use your expression in (c)(iii) and the K_{stab} value of 1.40×10^{13} to calculate the concentration of the $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ion in this solution.

concentration of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} = \dots\dots\dots \text{mol dm}^{-3}$ [1]

- (d) Phenanthroline, $\text{C}_{12}\text{H}_8\text{N}_2$, and ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, are bidentate ligands.

Ruthenium(III) ions, Ru^{3+} , form an octahedral complex with phenanthroline and chloride ions. The complex ion contains two phenanthroline molecules.

Iron(III) ions, Fe^{3+} , form an octahedral complex with ethanedioate ions only.

Deduce the formula and charge of each of these complex ions.

Ru^{3+} complex

Fe^{3+} complex [2]

[Total: 11]

- 7 (a) The structure of compound **P** is shown in Fig. 7.1.

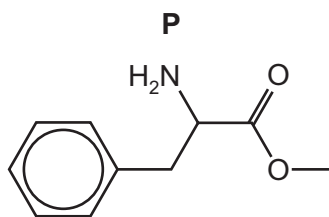


Fig. 7.1

- (i) **P** is optically active.

Use an asterisk (*) to identify all chiral carbon atoms on the structure of **P** in Fig. 7.1. [1]

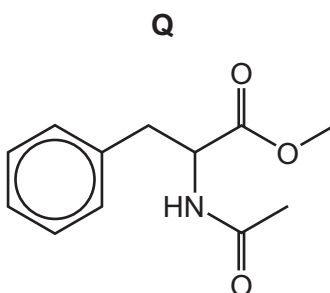
- (ii) Plane polarised light is passed through a pure sample of one enantiomer of **P**. This is then repeated with a pure sample of the other enantiomer of **P**.

Describe the results of these two experiments, stating the similarities and differences of the results.

.....

 [2]

- (b) **P** can be used to make compound **Q** in a single step reaction.



- (i) Give the structural formula of the compound that is added to **P** to make **Q** and give the formula of the other product of this reaction.

compound added to **P**

other product

[1]

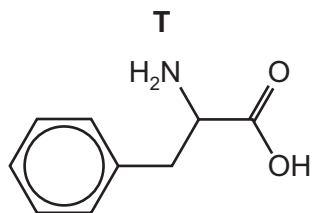
- (ii) Complete Table 7.1 by drawing the structures of the organic products formed when **R** is treated separately with the reagents given.

Table 7.1

reagent	product
$\text{HNO}_2(\text{aq})$ at 4°C	
an excess of $\text{Br}_2(\text{aq})$ at room temperature	

[2]

(d) **P** can be used to produce compound **T**.



(i) In aqueous solution, **T** has a property called an isoelectric point.

Explain what is meant by isoelectric point.

.....

..... [1]

(ii) **T** can polymerise under suitable conditions. No other monomer is involved in this reaction.

Draw a section of the polymer chain formed that includes three **T** monomers. Identify the repeat unit on your diagram.

[2]

[Total: 17]

8 Benzene, C_6H_6 , is an aromatic molecule.

(a) State the C–C–C bond angle and the hybridisation shown by the carbon atoms in benzene.

bond angle

hybridisation

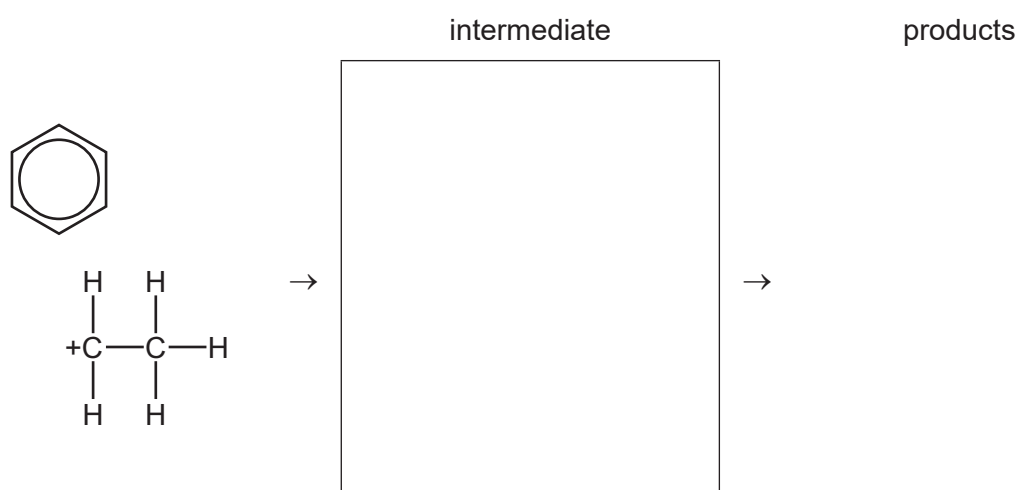
[1]

(b) Benzene reacts with chloroethane in the presence of a catalyst. The reaction mechanism is called electrophilic substitution.

(i) The first step in the reaction is the generation of the $^+\text{CH}_2\text{CH}_3$ electrophile.

Write an equation for the reaction that generates this electrophile.

(ii) Describe the mechanism for the reaction between benzene and the $^+\text{CH}_2\text{CH}_3$ electrophile. Include all relevant curly arrows and charges.



[3]

(c) Chlorobenzene and chloroethane have different reactivities in nucleophilic substitution reactions.

(i) Identify a suitable reagent to illustrate this difference in reactivity.

The reagent chosen should give **visibly** different results with chlorobenzene and chloroethane.

..... [1]

(ii) Write equations to describe any reactions that occur.

[1]

(iii) Explain the difference in the reactivities of chlorobenzene and chloroethane in nucleophilic substitution reactions.

.....

..... [1]

[Total: 8]

9 (a) Gas-liquid chromatography involves a stationary phase and a mobile phase.

(i) Name, or describe in detail, a suitable substance that could be used for each phase.

stationary

mobile

[1]

A mixture of three organic compounds is separated by gas-liquid chromatography. The chromatogram obtained is shown in Fig. 9.1. The amount of each substance is proportional to the area under its peak.

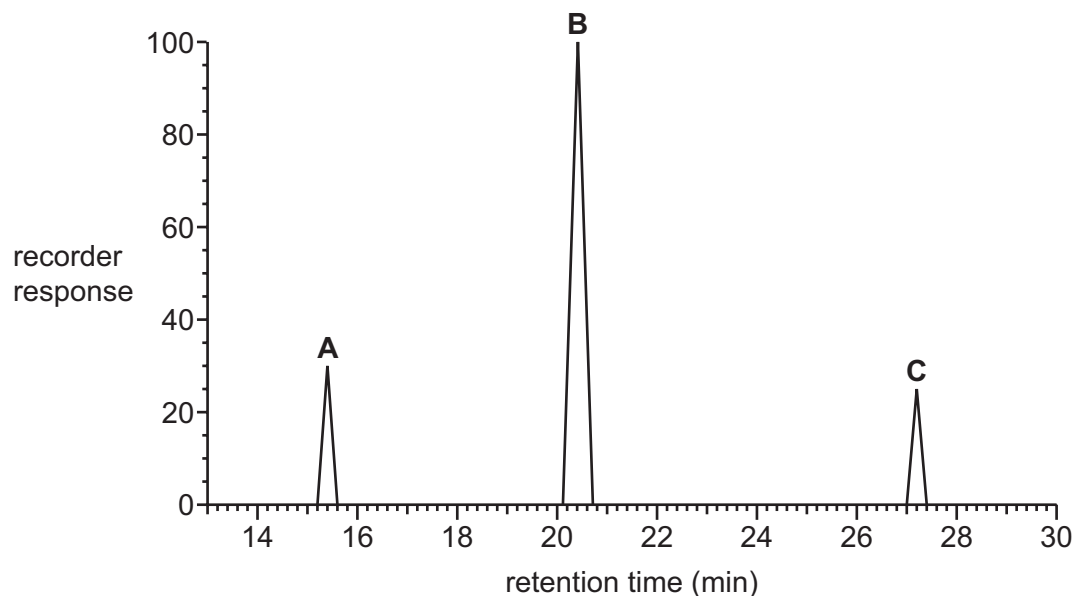


Fig. 9.1

(ii) Explain the meaning of retention time.

.....

..... [1]

(iii) Calculate the percentage of **B** in the mixture. Show your working.

percentage of **B** = ... % [2]

- (b) Complete Table 9.1 to give the number of peaks in the carbon-13 NMR spectrum of each of the five isomers of $C_5H_{10}O_2$ that has an ester group.

Table 9.1

structural formula	number of peaks
$CH_3CH_2CH_2CO_2CH_3$	
$CH_3CH_2CO_2CH_2CH_3$	
$CH_3CO_2CH_2CH_2CH_3$	
$(CH_3)_2CHCO_2CH_3$	
$CH_3CO_2CH(CH_3)_2$	

[2]

- (c) State the number of peaks that would be seen in the proton (^1H) NMR spectrum of methyl butanoate, $CH_3CH_2CH_2CO_2CH_3$. Name all the splitting patterns seen in this spectrum.

number of peaks

splitting patterns

[2]

(d) **D** and **E** are both esters with the molecular formula $C_5H_{10}O_2$. Their proton (^1H) NMR spectra are shown in Fig. 9.2 and Fig. 9.3.

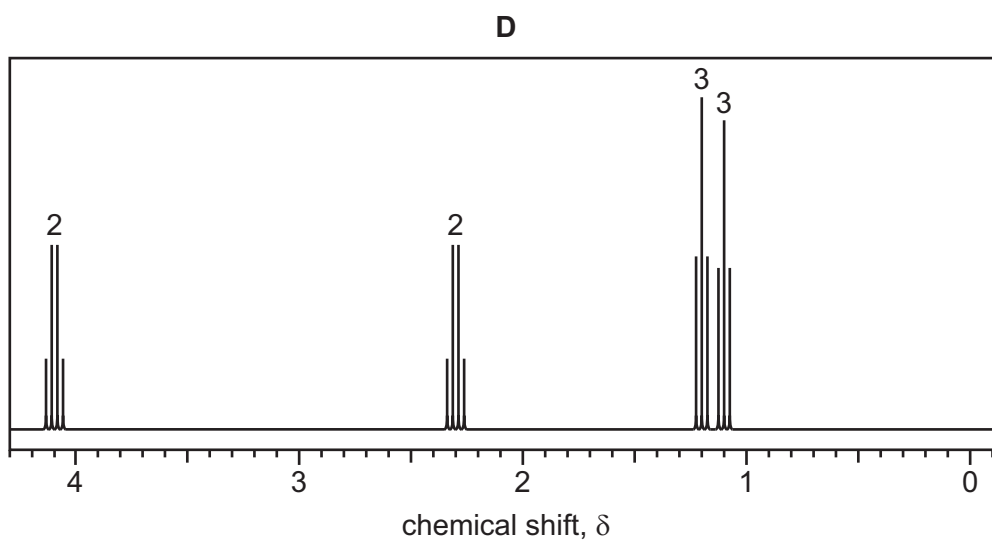


Fig. 9.2

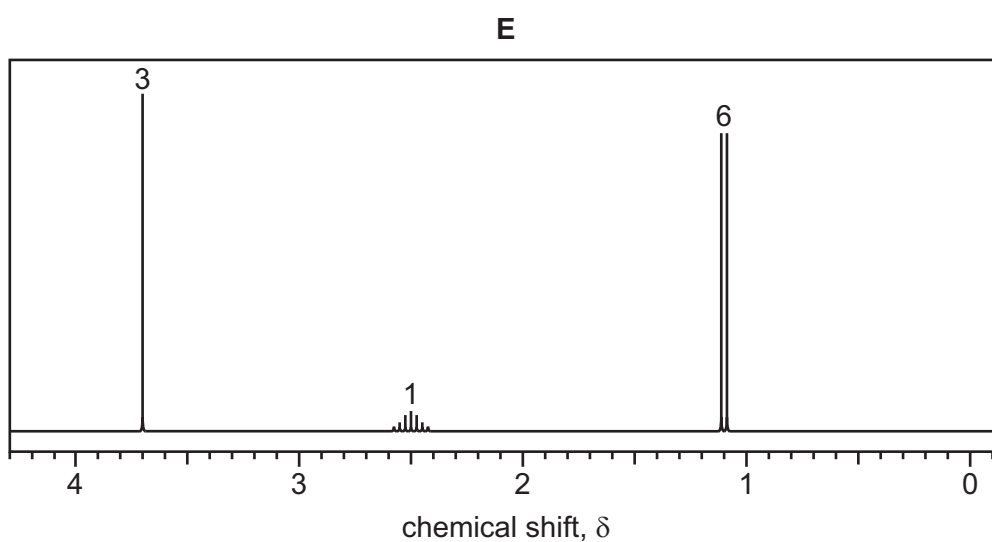
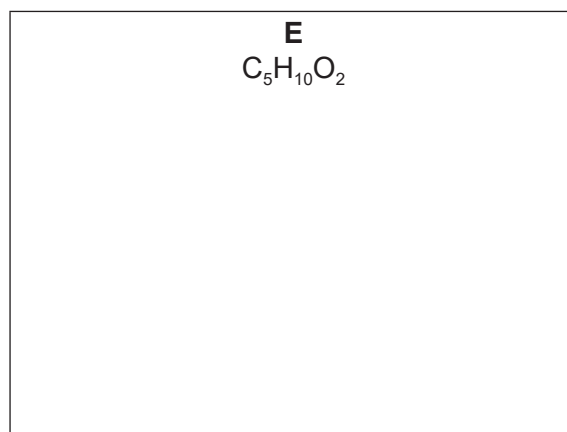
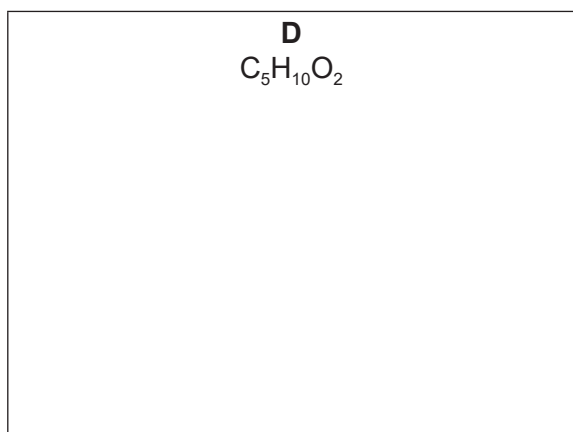


Fig. 9.3

Table 9.2

environment of proton	example	typical 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

- (i) Deduce the structures of the two esters **D** and **E** and draw their displayed formulae in the boxes below.



[2]

- (ii) The spectrum of **D** includes a quartet at δ 4.1.

Identify the protons responsible for this quartet on your structure in (i) by labelling these protons with the letter **F**.

Explain why this peak is split into a quartet.

.....

[1]

- (iii) The spectrum of **E** has a doublet at δ 1.1.

Identify the protons responsible for this doublet on your structure in (i) by labelling these protons with the letter **G**.

Explain why this peak has a chemical shift of 1.1.

.....

[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)

The Periodic Table of Elements

Group																			
1	2	Key										13	14	15	16	17	18		
		atomic number atomic symbol name relative atomic mass																	
3	4											5	6	7	8	9	10	11	12
Li lithium 6.9	Be beryllium 9.0											B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0	Ne neon 20.2		
11	12											13	14	15	16	17	18		
Na sodium 23.0	Mg magnesium 24.3											Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5	Ar argon 39.9		
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
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		
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54		
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		
55	56	57–71 lanthanoids		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
Cs caesium 132.9	Ba barium 137.3			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 —	
87	88	89–103 actinoids		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	
Fr francium —	Ra radium —			Rf rutherfordium —	Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganeson —	

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
actinoids	89 Ac actinium —	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —

CANDIDATE
NAME

CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/42

October/November 2022

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 **24** pages.

- 1 Calcium chloride, CaCl_2 , is an ionic solid.

The values of some energy changes are shown in Table 1.1.

Table 1.1

energy change	value/ kJ mol^{-1}
lattice energy, $\Delta H_{\text{latt}}^{\ominus}$, $\text{CaCl}_2(\text{s})$	–2237
standard enthalpy change of atomisation of calcium	+193
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1150
standard enthalpy change of atomisation of chlorine	+121
first electron affinity of chlorine	–364

- (a) Define lattice energy.

.....
 [1]

- (b) Use the data in Table 1.1 to calculate the standard enthalpy change of formation, $\Delta H_{\text{f}}^{\ominus}$, of calcium chloride. It may be helpful to draw an energy cycle. Show all your working.

$$\Delta H_{\text{f}}^{\ominus}(\text{CaCl}_2(\text{s})) = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

- (c) Three possible values for the first electron affinity of bromine are shown in Table 1.2. One of them is correct.

Place a tick by the correct value. Explain your choice.

Table 1.2

possible values	place one tick (✓) in this column
–342 kJ mol ^{–1}	
–364 kJ mol ^{–1}	
–386 kJ mol ^{–1}	

explanation

..... [1]

- (d) The enthalpy change of hydration of the chloride ion can be calculated using the lattice energy of calcium chloride and the data shown in Table 1.3.

Table 1.3

energy change	value / kJ mol ^{–1}
standard enthalpy change of solution of CaCl ₂ (s)	–83
standard enthalpy change of hydration of Ca ²⁺ (g)	–1650

- (i) Define the following terms.

enthalpy change of solution

.....

enthalpy change of hydration

.....

[2]

- (ii) Calculate the standard enthalpy change of hydration of the chloride ion, Cl[–](g). It may be helpful to draw an energy cycle. Show all your working.

$$\Delta H_{\text{hyd}}^{\ominus}(\text{Cl}^{-}(\text{g})) = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

(e) Calcium fluoride, $\text{CaF}_2(\text{s})$, can be synthesised directly from its elements.

The value of $\Delta H_f^\circ(\text{CaF}_2(\text{s}))$ is $-1214 \text{ kJ mol}^{-1}$.

(i) Predict the sign of the entropy change, ΔS° , for this synthesis. Explain your answer.

The sign of the entropy change is

explanation

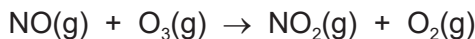
.....
[1]

(ii) Use the value of $\Delta H_f^\circ(\text{CaF}_2(\text{s}))$ given in **(e)** and your answer to **(e)(i)** to predict how the feasibility for this synthesis will change with increasing temperature.

.....
.....
.....
..... [2]

[Total: 11]

- 2 (a) Nitrogen monoxide, NO, reacts with ozone, O₃.



This reaction is first order with respect to both NO and O₃.
At 298 K, the rate constant $k = 11\,500 \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$.

- (i) Complete the rate equation for this reaction.

rate = ... [1]

- (ii) A reaction is carried out in which the initial concentrations of NO and O₃ are both $1.20 \times 10^{-6} \text{ mol dm}^{-3}$.

Calculate the initial rate of the reaction. State its units.

rate of reaction = ... units = ... [2]

- (iii) The reaction described in (a)(ii) is monitored over a period of time.

Predict whether or not the graph of [NO] against time, under these conditions, shows that the reaction has a constant half-life. Explain your answer.

prediction

explanation

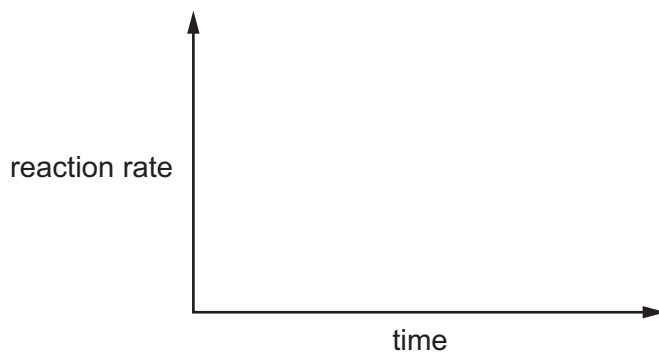
..... [1]

- (b) Nitrous oxide, N₂O, decomposes into its elements.



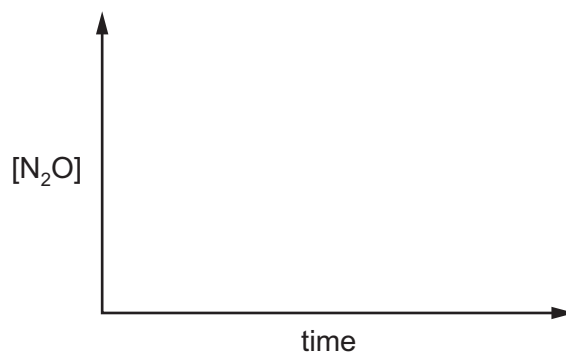
At a high temperature, a small amount of platinum wire is added to a large amount of nitrous oxide. The reaction follows zero order kinetics. The platinum wire behaves as a catalyst.

- (i) Sketch a graph, on the axes below, of reaction rate against time for the catalysed decomposition of N₂O under these conditions.



[1]

- (ii) Sketch a graph, on the axes below, of $[\text{N}_2\text{O}]$ against time for this reaction.



[1]

- (iii) Platinum behaves as a heterogeneous catalyst in this reaction.

Describe the mode of action of a heterogeneous catalyst.

.....

.....

.....

..... [3]

- (iv) Suggest a reason why this reaction has zero order kinetics when the amount of nitrous oxide is large and the amount of platinum is small.

.....

..... [1]

[Total: 10]

Question 3 starts on the next page.

- 3 Data should be selected from Table 3.1 in order to answer some parts of this question.

Table 3.1

electrode reaction	E°/V
$\text{Mg}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mg}$	-2.38
$\text{Mn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mn}$	-1.18
$\text{Mn}^{3+} + \text{e}^- \rightleftharpoons \text{Mn}^{2+}$	+1.49
$\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O}$	+1.23
$\text{MnO}_4^- + \text{e}^- \rightleftharpoons \text{MnO}_4^{2-}$	+0.56
$\text{MnO}_4^- + 4\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{MnO}_2 + 2\text{H}_2\text{O}$	+1.67
$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1.52

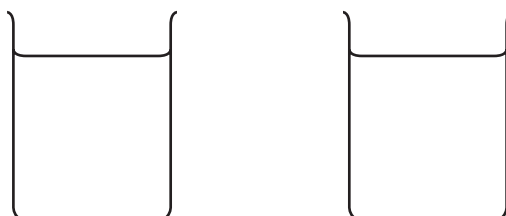
- (a) An electrochemical cell can be constructed from a Mg^{2+}/Mg half-cell and a $\text{MnO}_4^-/\text{Mn}^{2+}$ half-cell. The standard cell potential of this cell can be calculated using the standard electrode potentials of the two half-cells.

- (i) Define standard electrode potential. Include details of the standard conditions used.

.....

 [2]

- (ii) Complete the diagram below to show an electrochemical cell constructed from a Mg^{2+}/Mg half-cell and a $\text{MnO}_4^-/\text{Mn}^{2+}$ half-cell. Label your diagram.



[3]

- (iii) Use a positive (+) sign and a negative (-) sign to identify the polarity of each of the two electrodes in your diagram.
 Use an arrow and the symbol 'e' to show the direction of electron flow in the external circuit. [1]

- (iv) Calculate the standard cell potential, $E_{\text{cell}}^{\ominus}$, of this cell.

$$E_{\text{cell}}^{\ominus} = \dots\dots\dots \text{V} \quad [1]$$

- (v) Construct an equation for the cell reaction.

..... [1]

- (vi) Predict how the cell reaction will change, if at all, when the solution in the Mg^{2+}/Mg half-cell is diluted by the addition of a large volume of water. Explain your answer.

.....

.....

..... [1]

- (b) A molten magnesium salt is electrolysed for 15.0 minutes by a constant current.

4.75×10^{22} magnesium atoms are produced at the cathode.

Calculate the value of the current used.

$$\text{current} = \dots\dots\dots \text{A} \quad [2]$$

[Total: 11]

- 4 (a) The value of the solubility product, K_{sp} , of iron(III) hydroxide, $\text{Fe}(\text{OH})_3$, is given by the following expression.

$$K_{\text{sp}} = [\text{Fe}^{3+}][\text{OH}^{-}]^3 = 2.0 \times 10^{-39} \text{ mol}^4 \text{ dm}^{-12}$$

- (i) Calculate the solubility of $\text{Fe}(\text{OH})_3$ in water.

solubility = ... mol dm^{-3} [1]

- (ii) Calculate the solubility of $\text{Fe}(\text{OH})_3$ in $0.010 \text{ mol dm}^{-3}$ barium hydroxide, $\text{Ba}(\text{OH})_2(\text{aq})$.

solubility = ... mol dm^{-3} [2]

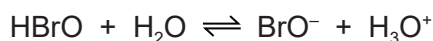
- (iii) $\text{Fe}(\text{OH})_3$ is less soluble in $\text{Ba}(\text{OH})_2(\text{aq})$ than it is in pure water.

Name this effect.

..... [1]

- (b)** The numerical value of the K_a of HBrO is 2.00×10^{-9} .

X is a solution of HBrO which contains 4.00×10^{-3} mol of HBrO in 100 cm^3 of solution. In this solution the following equilibrium is established in which there are two conjugate acid-base pairs.



- (i) Define conjugate acid-base pair.

..... [1]

- (ii) Identify the two conjugate acid-base pairs shown in the equation above.

pair one

 acid base

pair two

acid base

[1]

- (iii) Calculate the pH of solution **X**. Show all your working.

pH = ... [2]

- (iv) A solution containing 2.00×10^{-3} mol of NaOH is added to solution **X**. A buffer solution is formed.

Calculate the pH of this buffer solution.

pH = ... [1]

[Total: 9]

5 Copper is a transition element. It forms a wide variety of compounds.

(a) Define transition element.

.....
 [1]

(b) An aqueous solution of copper(II) sulfate, CuSO_4 , contains $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions. If an excess of concentrated hydrochloric acid is added to this solution a ligand exchange reaction occurs and $[\text{CuCl}_4]^{2-}$ complex ions are formed.

(i) Complete Table 5.1 to state the geometry, the coordination number of copper, and one bond angle in each of the two complex ions.

Table 5.1

complex ion	geometry	coordination number	bond angle
$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$			
$[\text{CuCl}_4]^{2-}$			

[3]

(ii) In an isolated Cu^{2+} ion the d-orbitals are all degenerate. In a complex ion such as $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ the d-orbitals are non-degenerate.

Define degenerate and non-degenerate in this context.

degenerate

non-degenerate

[1]

(iii) Explain why the solutions of the two complex ions in Table 5.1 are **different** colours.

.....
 [1]

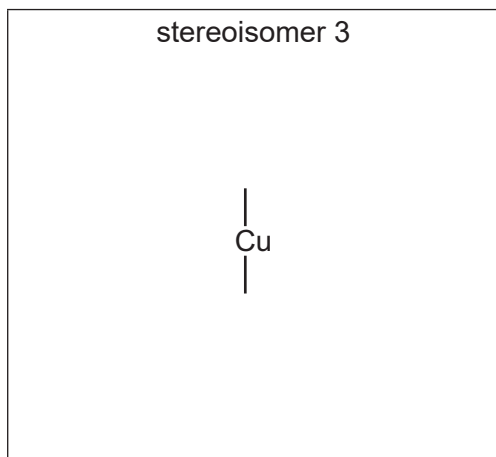
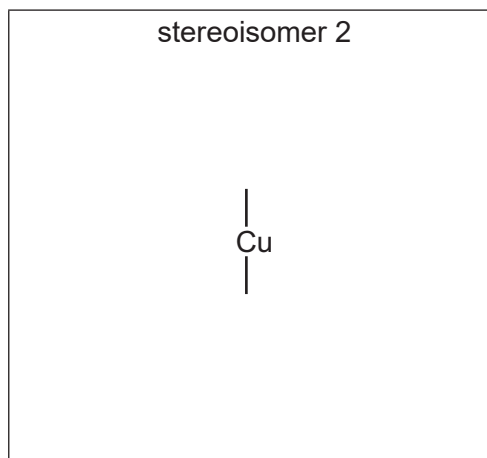
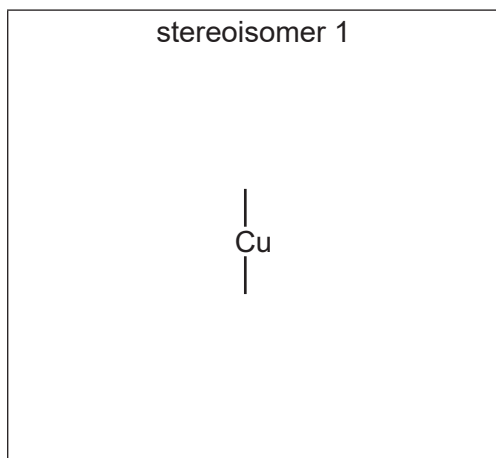
(c) Cu^{2+} forms a complex ion containing water molecules and ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, as ligands. The formula of the complex is $[\text{Cu}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^{2-}$. The ethanedioate ion is a bidentate ligand.

(i) Explain what is meant by bidentate.

.....
 [1]

- (ii) There are three stereoisomers with the formula $[\text{Cu}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^{2-}$.

Complete the three-dimensional diagrams to show these three stereoisomers.



[2]

- (iii) Use your answer to (c)(ii) to answer this question.

Stereoisomers 1, 2 and 3 show two different types of isomerism.

Name these two types of isomerism.

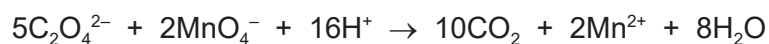
For each type of isomerism identify the pair of stereoisomers that demonstrate this isomerism.

type of isomerism	pair of stereoisomers
	and
	and

[2]

- (d) A solution contains 3.70 g of $\text{Na}_2[\text{Cu}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]$ dissolved in 100 cm^3 of solution. A 25.0 cm^3 sample of this solution is warmed and then oxidised by $0.0100\text{ mol dm}^{-3}$ acidified potassium manganate(VII).

The equation for the redox reaction is shown.



Calculate the minimum volume of $0.0100\text{ mol dm}^{-3}$ acidified potassium manganate(VII) needed to oxidise all of the ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, in the 25.0 cm^3 sample. Show all your working.

$[M_r: \text{Na}_2[\text{Cu}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2], 321.5]$

minimum volume = ... cm^3 [3]

- (e) Copper(II) nitrate, $\text{Cu}(\text{NO}_3)_2$, and barium nitrate, $\text{Ba}(\text{NO}_3)_2$, both decompose when heated.

Copper(II) nitrate decomposes at a lower temperature than barium nitrate.

Suggest a reason for this difference. Explain your answer.

.....

 [2]

[Total: 16]

- 6 An aqueous solution of cobalt(II) chloride is a pink colour due to the presence of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

- (a) (i) Complete Table 6.1 to describe what is observed when the named reagent is added to an aqueous solution of cobalt(II) chloride.

Table 6.1

reagent	colour of cobalt-containing product	state of cobalt-containing product
NaOH(aq)		
an excess of conc. HCl		

[2]

- (ii) Write an equation for the reaction between $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ ions and NaOH(aq).

..... [1]

- (iii) Write an equation for the reaction between $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ ions and an excess of conc. HCl.

..... [1]

- (b) (i) Define stability constant.

.....
 [1]

- (ii) Write an expression for the stability constant, K_{stab} , of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ complex ion.

$K_{\text{stab}} =$ [1]

- (iii) Give the units of the stability constant, K_{stab} , of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ complex ion.

units = ... [1]

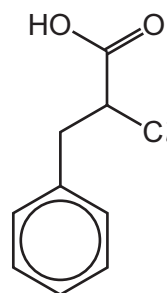
- (iv) The numerical value of the stability constant, K_{stab} , of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ complex ion is 7.7×10^4 .

In an aqueous solution the concentration of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ complex ion is $0.0740 \text{ mol dm}^{-3}$ and the concentration of NH_3 is $0.480 \text{ mol dm}^{-3}$ at equilibrium.

Calculate the concentration of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ in this solution.

concentration = ... mol dm^{-3} [1]

[Total: 8]



Compare the relative acidities of **A**, **B** and **C**.

Explain your answer.

..... [3]

(b) Methylbenzene, $\text{C}_6\text{H}_5\text{CH}_3$, can be made from benzene by an electrophilic substitution reaction.

(i) Identify a compound that reacts with benzene to form methylbenzene. Identify the catalyst used.

compound

catalyst

[1]

(ii) The first step in the reaction is the generation of the CH_3^+ electrophile.

Write an equation for the reaction that generates this electrophile.

..... [1]

- (iii) Describe the mechanism for the reaction between benzene and the CH_3^+ electrophile. Include all relevant curly arrows and charges.



[3]

- (iv) Identify a suitable reagent to oxidise methylbenzene to benzoic acid, $\text{C}_6\text{H}_5\text{COOH}$.

Write an equation for this reaction using [O] to represent one atom of oxygen from the oxidising agent.

reagent

equation

[2]

- (v) Methylbenzene and benzoic acid are both nitrated with a mixture of concentrated nitric acid and sulfuric acid to give mononitrated products. The structural formulae of these products are $\text{CH}_3\text{C}_6\text{H}_4\text{NO}_2$ and $\text{HOOC}\text{C}_6\text{H}_4\text{NO}_2$ respectively.

Draw the structures of these two products.

[1]

(c) A reaction scheme is shown in Fig. 7.2.

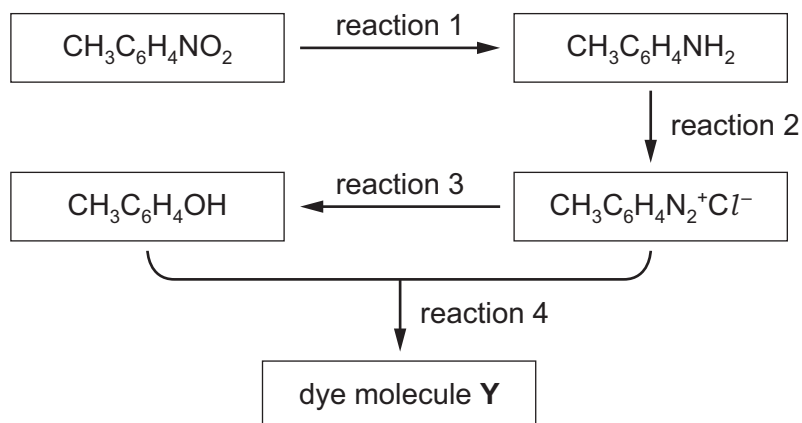


Fig. 7.2

- (i) Describe the reagents and conditions to produce $\text{CH}_3\text{C}_6\text{H}_4\text{N}_2^+\text{Cl}^-$ from $\text{CH}_3\text{C}_6\text{H}_4\text{NH}_2$ in reaction 2.

reagents

conditions

[1]

- (ii) Describe how $\text{CH}_3\text{C}_6\text{H}_4\text{OH}$ can be produced from $\text{CH}_3\text{C}_6\text{H}_4\text{N}_2^+\text{Cl}^-$ in reaction 3.

..... [1]

- (iii) Draw the structure of the dye molecule **Y** formed when $\text{CH}_3\text{C}_6\text{H}_4\text{N}_2^+\text{Cl}^-$ and $\text{CH}_3\text{C}_6\text{H}_4\text{OH}$ react together in reaction 4. Describe the conditions for this reaction.

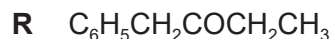
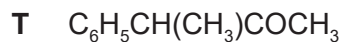
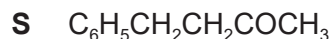
structure

conditions

[2]

[Total: 15]

- 8 When answering this question it should be assumed that together all the hydrogen atoms in a benzene ring result in a single unsplit peak at $\delta = 7.2$ in a proton (^1H) NMR spectrum. The structures of five isomeric ketones, **P**, **Q**, **R**, **S** and **T** are given.



- (a) Identify all the chiral carbon atoms on the structures above. Label each chiral carbon atom with an asterisk (*). [1]

- (b) The proton (^1H) NMR spectrum of one of the five isomers, **P**, **Q**, **R**, **S** or **T**, is shown in Fig. 8.1.

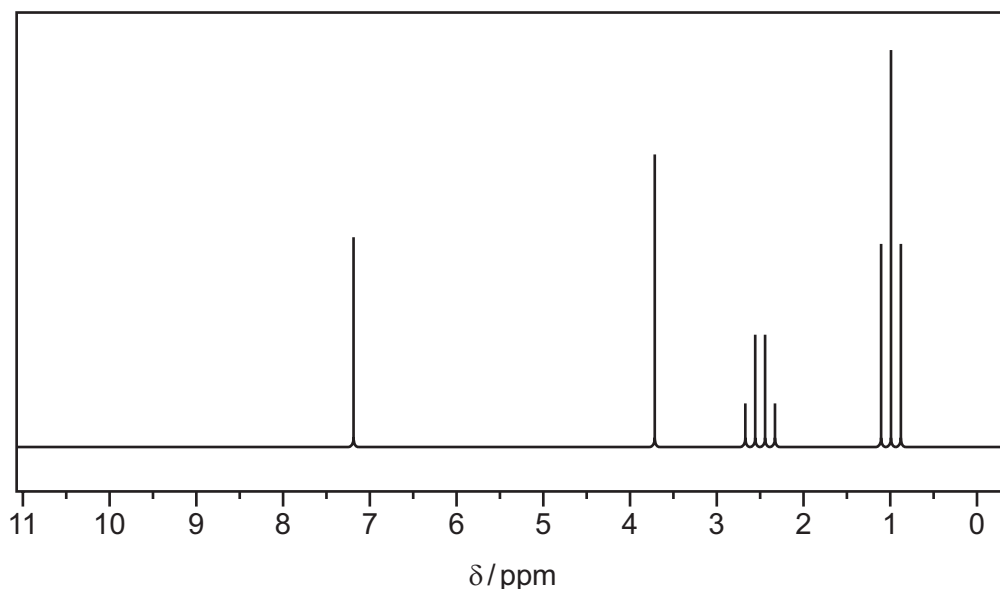


Fig. 8.1

- (i) Identify which of the compounds **P**, **Q**, **R**, **S** or **T** gives this spectrum. Draw the displayed formula of the compound you have identified. Identify the protons responsible for the peaks at $\delta = 3.7$, $\delta = 2.5$ and $\delta = 1.0$ on the structure you have drawn.

[2]

- (ii) Name the splitting pattern of the peak at $\delta = 3.7$. Explain why it has this splitting pattern.

.....
 [1]

(c) Choose from the letters **P**, **Q**, **R**, **S** and **T** to identify:

(i) the **two** compounds that each have a doublet peak in the proton (^1H) NMR spectrum

..... [1]

(ii) the compound with only three peaks in its proton (^1H) NMR spectrum.

..... [1]

(d) Suggest a suitable solvent that should be used for obtaining the spectrum shown in Fig. 8.1.

..... [1]

(e) The proton (^1H) NMR spectrum of compound **T** is compared in the presence of D_2O and in the absence of D_2O .

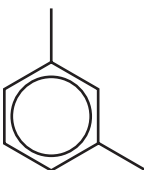
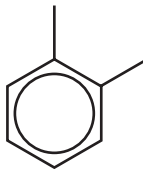
Describe any difference between the two spectra. Explain your answer.

.....

..... [1]

(f) Complete Table 8.1 below to give the number of peaks in the carbon-13 NMR spectrum of each compound.

Table 8.1

compound	number of peaks	compound	number of peaks
			
			

[2]

[Total: 10]

- 9 Tyrosine and lysine, shown in Fig. 9.1, are naturally occurring amino acids found in proteins.

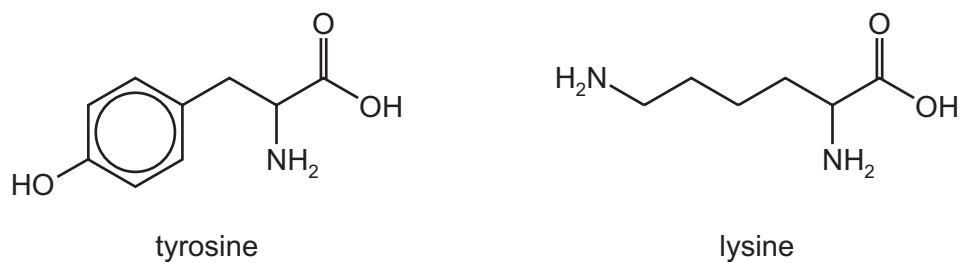


Fig. 9.1

- (a) The isoelectric point of lysine is 9.47.

Draw the structure of lysine at the stated pH in the boxes below.

lysine at pH 7.00



lysine at pH 9.47



lysine at pH 12.00



[2]

- (b) When ethanoic acid is treated with PCl_5 product **D** is formed.

When **D** is added to tyrosine two different isomeric products, **E** and **F**, are formed.

E has an ester linkage, **F** does not.

Draw the structures of **D**, **E** and **F** in the boxes below.

D



E



F



[3]

- (c) Complete Table 9.1 by drawing the structure of the organic product formed when tyrosine reacts with each named reagent.

Ignore the directing effect of the $-\text{CH}_2\text{CHNH}_2\text{COOH}$ substituent.

Table 9.1

reagent	structure
an excess of $\text{Br}_2(\text{aq})$	
an excess of $\text{NaOH}(\text{aq})$	
an excess of $\text{HNO}_3(\text{aq})$	

[3]

- (d) A mixture of tyrosine and lysine can be separated by thin-layer chromatography. Under certain conditions the R_f value of lysine is 0.14 and the R_f value of tyrosine is 0.45.

- (i) Explain what is meant by R_f value.

.....
 [1]

- (ii) Suggest an explanation for the difference in R_f values.

.....
 [1]

[Total: 10]

Important values, constants and standards

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

The Periodic Table of Elements

Group																					
1	2	13										17	18								
Key atomic number atomic symbol name relative atomic mass												1 H hydrogen 1.0									
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												67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0					
actinoids												99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —					

lanthanoids

actinoids



CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/43

October/November 2022

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 Potassium chloride, KCl , and magnesium chloride, MgCl_2 , are both ionic solids.

Table 1.1

energy change	value/ kJ mol^{-1}
standard enthalpy change of solution, $\Delta H_{\text{sol}}^{\ominus}$ of KCl	+15
lattice energy, $\Delta H_{\text{latt}}^{\ominus}$ of KCl(s)	–701
standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$ of K^+	–322
standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$ of Cl^-	–364
standard enthalpy change of solution, $\Delta H_{\text{sol}}^{\ominus}$ of MgCl_2	–155
lattice energy, $\Delta H_{\text{latt}}^{\ominus}$ of $\text{MgCl}_2(\text{s})$	–2493

- (a) Complete the energy cycle involving the enthalpy change of solution and the lattice energy of potassium chloride, KCl , and the relevant enthalpy changes of hydration. Label your diagram.

State symbols should be used.

KCl(s)

[2]

- (b) Use the data in Table 1.1 to calculate the enthalpy change of hydration of magnesium ions, Mg^{2+} . Show your working.

$\Delta H_{\text{hyd}}^{\ominus}$ of magnesium ions, $\text{Mg}^{2+} = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

- (c) Explain the reasons why the lattice energy of MgCl_2 is more exothermic than the lattice energy of KCl .

.....

.....

.....

..... [2]

- (d) Define the following terms.

(i) enthalpy change of atomisation [1]

.....

(ii) first electron affinity [1]

.....

- (e) (i) Explain what is meant by entropy, S .

.....

..... [1]

- (ii) Potassium chloride is very soluble in water at 20°C .

Explain the solubility of potassium chloride by reference to change in entropy, ΔS .

.....

..... [1]

- (iii) Use the Gibbs equation and your answer to (e)(ii) to predict whether potassium chloride is more soluble in water at 20°C or at 80°C . Explain your answer.

.....

.....

..... [1]

[Total: 11]

- 2 (a) (i) Explain what is meant by the following terms:

homogeneous catalyst

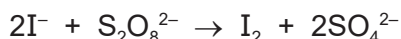
.....

heterogeneous catalyst

.....

[1]

- (ii) Iodide ions react with peroxydisulfate ions.



This reaction is slow, but it is catalysed by Fe^{2+} ions.

Write two equations to explain how this reaction is catalysed by Fe^{2+} ions.

1

2

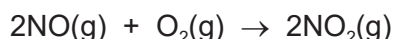
[2]

- (iii) Suggest why the alternative route in the presence of Fe^{2+} ions has a lower activation energy than the route in the absence of a catalyst.

.....

..... [1]

- (b) Nitrogen monoxide reacts with oxygen.



This reaction is second order with respect to nitrogen monoxide and first order with respect to oxygen.

Under certain conditions the value of the rate constant, k , is $8.60 \times 10^6 \text{ mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$.

- (i) Construct the rate equation for this reaction.

rate =

[1]

- (ii) Calculate the initial rate of the reaction under these conditions when the initial concentration of nitrogen monoxide is $7.20 \times 10^{-4} \text{ mol dm}^{-3}$ and the initial concentration of oxygen is $1.90 \times 10^{-3} \text{ mol dm}^{-3}$.

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

- (c) The drug cisplatin, $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$, hydrolyses in water.



The rate equation is shown.

$$\text{rate} = k[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$$

The value of k is $2.50 \times 10^{-5} \text{ s}^{-1}$ under certain conditions.

- (i) This reaction has a constant half-life.

Explain why this is the case.

.....
 [1]

- (ii) Use the information in this question to show that the half-life of this reaction is $2.77 \times 10^4 \text{ s}$.

[1]

- (iii) 8.00×10^{-6} moles of $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ are added to 100 cm^3 of water.

Calculate the time taken for the concentration of $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ to fall to $2.50 \times 10^{-6} \text{ mol dm}^{-3}$.

time taken = ... s [2]

[Total: 10]

- 3 Data should be selected from Table 3.1 in order to answer some parts of this question.

Table 3.1

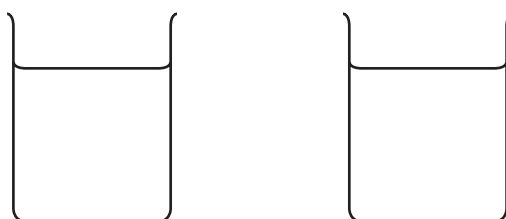
electrode reaction	E° / V
$\text{Cl}_2 + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$	+1.36
$2\text{HOCl} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Cl}_2 + 2\text{H}_2\text{O}$	+1.64
$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{Cl}^- + 2\text{OH}^-$	+0.89
$\text{Sn}^{4+} + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}$	+0.15
$\text{Sn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Sn}$	-0.14
$\text{V}^{2+} + 2\text{e}^- \rightleftharpoons \text{V}$	-1.20
$\text{V}^{3+} + \text{e}^- \rightleftharpoons \text{V}^{2+}$	-0.26
$\text{VO}^{2+} + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{V}^{3+} + \text{H}_2\text{O}$	+0.34
$\text{VO}_2^+ + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{VO}^{2+} + \text{H}_2\text{O}$	+1.00

- (a) Standard electrode potentials are measured under standard conditions.

- (i) Describe the standard conditions used in the $\text{Sn}^{4+}/\text{Sn}^{2+}$ half-cell.

.....
 [1]

- (ii) Complete the diagram below to show how $E^\circ (\text{Sn}^{4+}/\text{Sn}^{2+})$ can be measured experimentally. Your diagram should be fully labelled to identify all apparatus and substances.



[3]

- (iii) Equal volumes of $1.0 \text{ mol dm}^{-3} \text{ Sn}^{2+}(\text{aq})$ and $1.0 \text{ mol dm}^{-3} \text{ Cl}^{-}(\text{aq})$ are mixed.

Use relevant $E^\ominus$ values to explain whether a reaction occurs between these two ions.

.....

.....

.....

..... [2]

- (iv) Equal volumes of 1.0 mol dm^{-3} of $\text{Sn}^{2+}(\text{aq})$ and acidified $1.0 \text{ mol dm}^{-3} \text{ VO}^{2+}(\text{aq})$ are mixed.

Write an equation for the reaction that takes place in the resulting mixture.

..... [2]

- (b) A solution of $\text{SnCl}_2(\text{aq})$ is electrolysed for a measured time using a steady current.

A mass of 2.95 g of tin metal is produced at the cathode.

$\text{Al}_2\text{O}_3(\text{l})$ is electrolysed for the same time by the same current.

Calculate the mass of aluminium metal produced at the cathode. Give your answer to **three** significant figures. Show your working.

mass of aluminium metal = ... g [2]

[Total: 10]

- 4 (a) A sample of butanoic acid, $\text{CH}_3(\text{CH}_2)_2\text{COOH}$, is shaken with a mixture of two immiscible solvents, ethoxyethane and water. The solvents form two layers. The butanoic acid is distributed between the two layers, its concentration in ethoxyethane being higher than its concentration in water.

(i) State what is meant by partition coefficient.

.....
 [1]

(ii) The partition coefficient, K_{pc} , for butanoic acid between ethoxyethane and water is 3.50.

A solution of 2.00 g of butanoic acid in 100 cm^3 ethoxyethane is added to water. This mixture is left until there is no further change in the concentration of butanoic acid in either solvent. The mass of butanoic acid dissolved in the ethoxyethane layer is now 1.62 g.

Calculate the volume of water used.

volume of water used = ... cm^3 [2]

(b) An aqueous solution of butanoic acid can be used to make a buffer solution.

(i) Define buffer solution.

.....
 [1]

(ii) Suggest one organic compound, and one inorganic compound, that can be added to two different samples of aqueous butanoic acid to produce buffer solutions.

organic compound

inorganic compound

[1]

(c) The solubility of aluminium hydroxide, $\text{Al}(\text{OH})_3$, in water is $2.47 \times 10^{-9} \text{ mol dm}^{-3}$.

(i) Give the expression for the solubility product, K_{sp} , of aluminium hydroxide.

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

[1]

(ii) Calculate the numerical value of the K_{sp} of aluminium hydroxide. Include the units of K_{sp} in your answer.

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

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

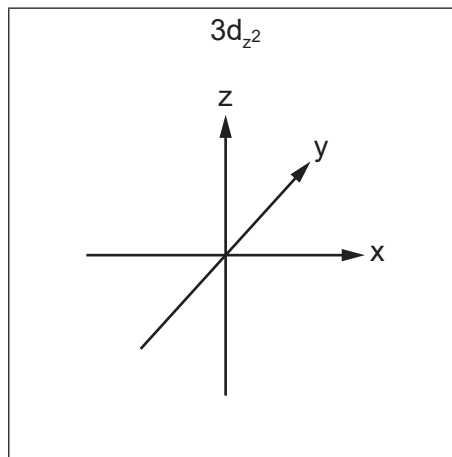
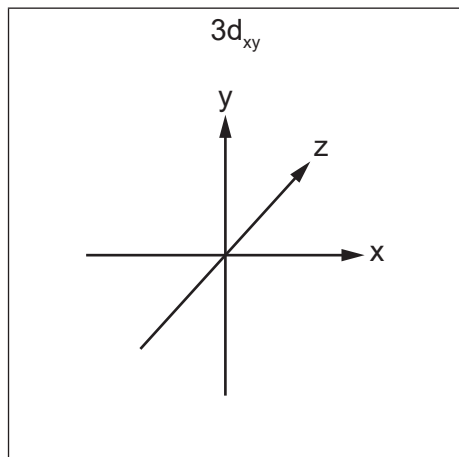
[3]

[Total: 9]

- 5 A transition element is a d-block element which forms one or more stable ions with incomplete d-orbitals.

(a) Two of the 3d orbitals are the $3d_{xy}$ orbital and the $3d_{z^2}$ orbital.

Sketch the shapes of these two orbitals.



[1]

(b) The Ni^{2+} ion forms many different complexes. A solution containing the $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ complex ion is green. When an excess of 1,2-diaminoethane, *en*, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is added, the colour of the solution changes to blue. This is due to the formation of the $[\text{Ni}(\text{en})_3]^{2+}$ complex ion.

(i) Explain why the two solutions are coloured, and why the colours are different.

.....

.....

.....

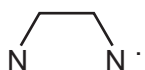
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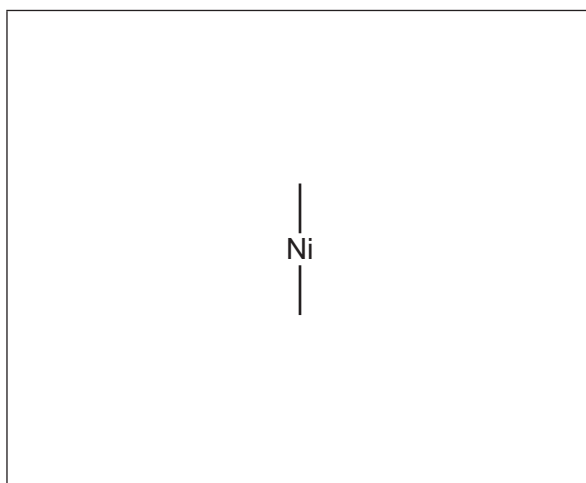
.....

..... [4]

- (ii) The $[\text{Ni}(\text{en})_3]^{2+}$ complex can exist as a mixture of two stereoisomers.

Complete the three-dimensional diagram to show one of the stereoisomers.

Each *en* ligand can be represented using .



[1]

- (iii) Name the geometry of the complex ion drawn in (b)(ii) and the type of stereoisomerism shown by $[\text{Ni}(\text{en})_3]^{2+}$.

geometry

stereoisomerism shown

[1]

- (c) Iron(II) carbonate, FeCO_3 , and nickel(II) carbonate, NiCO_3 , both decompose when heated.

FeCO_3 decomposes at a lower temperature than NiCO_3 .

Suggest a possible reason for this difference. Explain your answer.

.....

.....

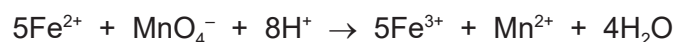
.....

.....

..... [2]

- (d) **A** is a pale green salt containing Fe^{2+} ions. A sample of 2.62 g of **A** is dissolved in water and the solution is made up to exactly 100 cm^3 with water. 25.0 cm^3 samples of this solution are placed in conical flasks and titrated against $0.0100\text{ mol dm}^{-3}$ acidified potassium manganate(VII).

The equation for the only reaction that occurs is shown.



The average titre value is 35.0 cm^3 of $0.0100\text{ mol dm}^{-3}$ acidified potassium manganate(VII).

- (i) Describe the colour change that is seen in the conical flask at the end-point of this titration.

The colour changes from to [1]

- (ii) Calculate the percentage by mass of iron in **A**.

[A_r : Fe, 55.8]

percentage by mass of iron = ... % [2]

[Total: 12]

Question 6 starts on the next page.

- 6 An aqueous solution of copper(II) sulfate is a blue colour due to the presence of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

(a) (i) Write an equation for the reaction between $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ ions and $\text{NaOH}(\text{aq})$.

..... [1]

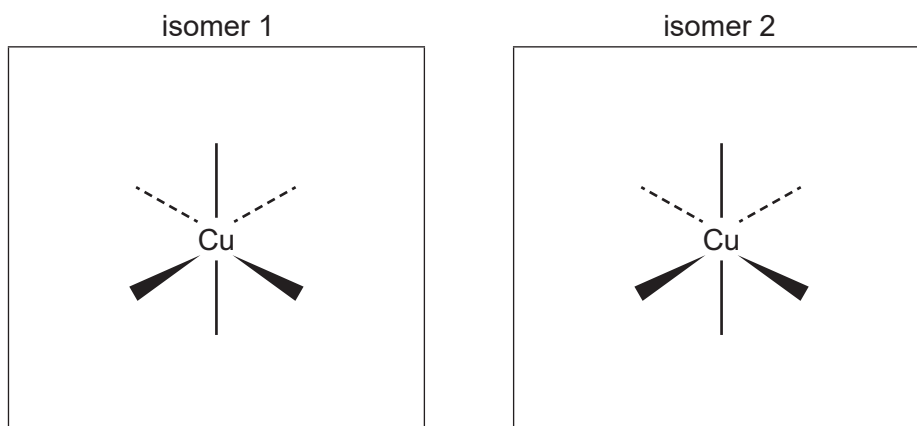
(ii) Write an equation for the reaction between $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ ions and an excess of conc. HCl .

..... [1]

- (b) If an excess of ammonia is added to a solution of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ a deep blue solution containing $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ions is formed.

(i) There are two possible stereoisomers with the formula $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$.

Complete the diagrams to show the two stereoisomers in the boxes below.



[1]

(ii) Use your answer in (b)(i) to deduce whether each of these isomers is polar or non-polar.

polarity of isomer 1

polarity of isomer 2

[1]

- (c) The numerical value of the stability constant, K_{stab} , of the $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion is 1.40×10^{13} .

(i) Define stability constant.

.....

..... [1]

- (ii) Compare the stabilities of the $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ and $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ions. Explain your answer.

.....
 [1]

- (iii) Write an expression for the stability constant, K_{stab} , of the $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion. State the units of the stability constant.

$$K_{\text{stab}} =$$

units = ...
 [2]

- (iv) In a particular solution the concentration of the $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ complex ion is $0.0074 \text{ mol dm}^{-3}$ and the concentration of NH_3 is 0.57 mol dm^{-3} .

Use your expression in (c)(iii) and the K_{stab} value of 1.40×10^{13} to calculate the concentration of the $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ion in this solution.

concentration of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} = \dots\dots\dots \text{mol dm}^{-3}$ [1]

- (d) Phenanthroline, $\text{C}_{12}\text{H}_8\text{N}_2$, and ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, are bidentate ligands.

Ruthenium(III) ions, Ru^{3+} , form an octahedral complex with phenanthroline and chloride ions. The complex ion contains two phenanthroline molecules.

Iron(III) ions, Fe^{3+} , form an octahedral complex with ethanedioate ions only.

Deduce the formula and charge of each of these complex ions.

Ru^{3+} complex

Fe^{3+} complex [2]

[Total: 11]

- 7 (a) The structure of compound **P** is shown in Fig. 7.1.

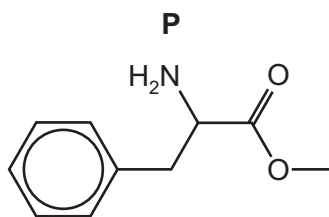


Fig. 7.1

- (i) **P** is optically active.

Use an asterisk (*) to identify all chiral carbon atoms on the structure of **P** in Fig. 7.1. [1]

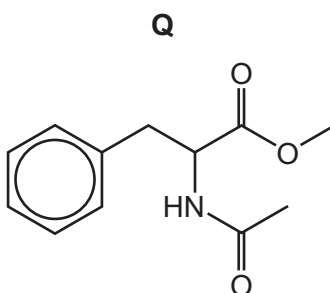
- (ii) Plane polarised light is passed through a pure sample of one enantiomer of **P**. This is then repeated with a pure sample of the other enantiomer of **P**.

Describe the results of these two experiments, stating the similarities and differences of the results.

.....

 [2]

- (b) **P** can be used to make compound **Q** in a single step reaction.



- (i) Give the structural formula of the compound that is added to **P** to make **Q** and give the formula of the other product of this reaction.

compound added to **P**

other product

[1]

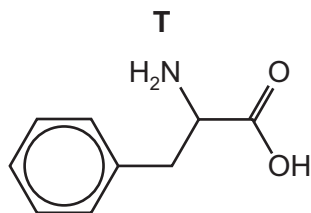
- (ii) Complete Table 7.1 by drawing the structures of the organic products formed when **R** is treated separately with the reagents given.

Table 7.1

reagent	product
$\text{HNO}_2(\text{aq})$ at 4°C	
an excess of $\text{Br}_2(\text{aq})$ at room temperature	

[2]

(d) **P** can be used to produce compound **T**.



(i) In aqueous solution, **T** has a property called an isoelectric point.

Explain what is meant by isoelectric point.

.....

..... [1]

(ii) **T** can polymerise under suitable conditions. No other monomer is involved in this reaction.

Draw a section of the polymer chain formed that includes three **T** monomers. Identify the repeat unit on your diagram.

[2]

[Total: 17]

8 Benzene, C_6H_6 , is an aromatic molecule.

(a) State the C–C–C bond angle and the hybridisation shown by the carbon atoms in benzene.

bond angle

hybridisation

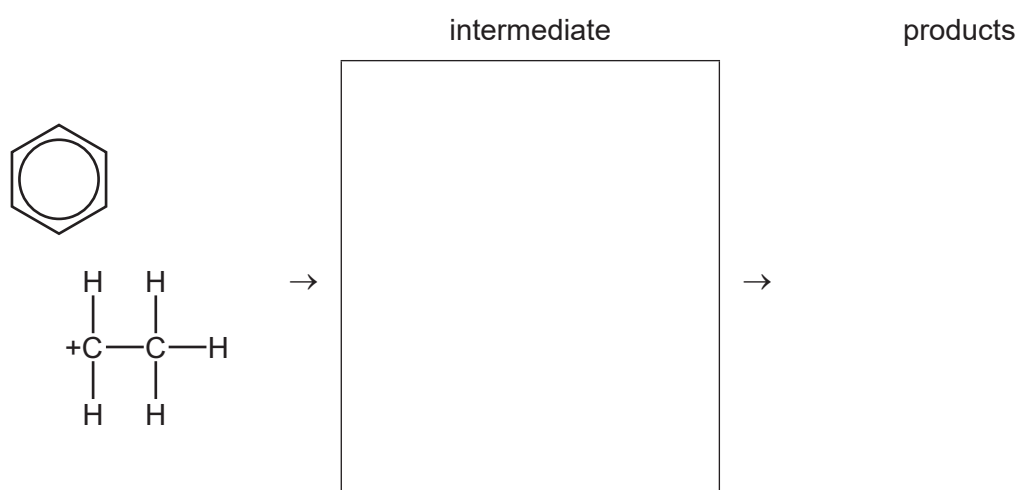
[1]

(b) Benzene reacts with chloroethane in the presence of a catalyst. The reaction mechanism is called electrophilic substitution.

(i) The first step in the reaction is the generation of the $^+\text{CH}_2\text{CH}_3$ electrophile.

Write an equation for the reaction that generates this electrophile.

(ii) Describe the mechanism for the reaction between benzene and the $^+\text{CH}_2\text{CH}_3$ electrophile. Include all relevant curly arrows and charges.



[3]

(c) Chlorobenzene and chloroethane have different reactivities in nucleophilic substitution reactions.

(i) Identify a suitable reagent to illustrate this difference in reactivity.

The reagent chosen should give **visibly** different results with chlorobenzene and chloroethane.

..... [1]

(ii) Write equations to describe any reactions that occur.

[1]

(iii) Explain the difference in the reactivities of chlorobenzene and chloroethane in nucleophilic substitution reactions.

.....

..... [1]

[Total: 8]

9 (a) Gas-liquid chromatography involves a stationary phase and a mobile phase.

(i) Name, or describe in detail, a suitable substance that could be used for each phase.

stationary

mobile

[1]

A mixture of three organic compounds is separated by gas-liquid chromatography. The chromatogram obtained is shown in Fig. 9.1. The amount of each substance is proportional to the area under its peak.

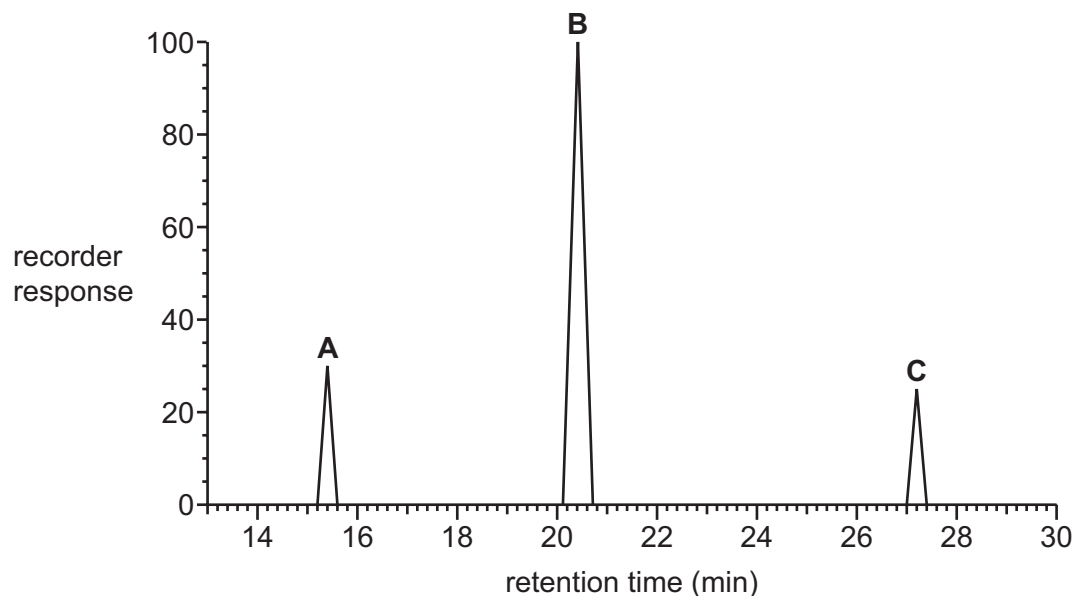


Fig. 9.1

(ii) Explain the meaning of retention time.

.....

..... [1]

(iii) Calculate the percentage of **B** in the mixture. Show your working.

percentage of **B** = ... % [2]

- (b) Complete Table 9.1 to give the number of peaks in the carbon-13 NMR spectrum of each of the five isomers of $C_5H_{10}O_2$ that has an ester group.

Table 9.1

structural formula	number of peaks
$CH_3CH_2CH_2CO_2CH_3$	
$CH_3CH_2CO_2CH_2CH_3$	
$CH_3CO_2CH_2CH_2CH_3$	
$(CH_3)_2CHCO_2CH_3$	
$CH_3CO_2CH(CH_3)_2$	

[2]

- (c) State the number of peaks that would be seen in the proton (^1H) NMR spectrum of methyl butanoate, $CH_3CH_2CH_2CO_2CH_3$. Name all the splitting patterns seen in this spectrum.

number of peaks

splitting patterns

[2]

(d) **D** and **E** are both esters with the molecular formula $C_5H_{10}O_2$. Their proton (^1H) NMR spectra are shown in Fig. 9.2 and Fig. 9.3.

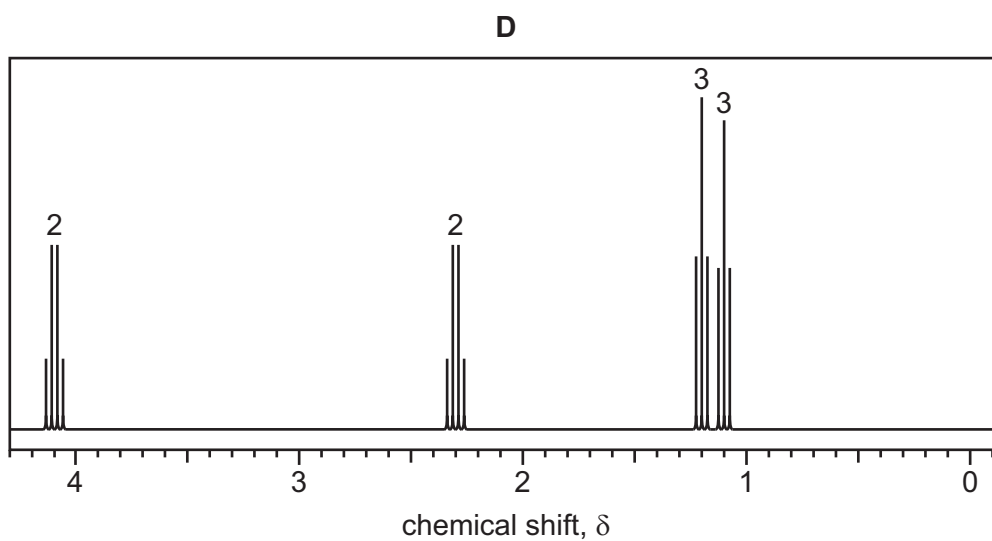


Fig. 9.2

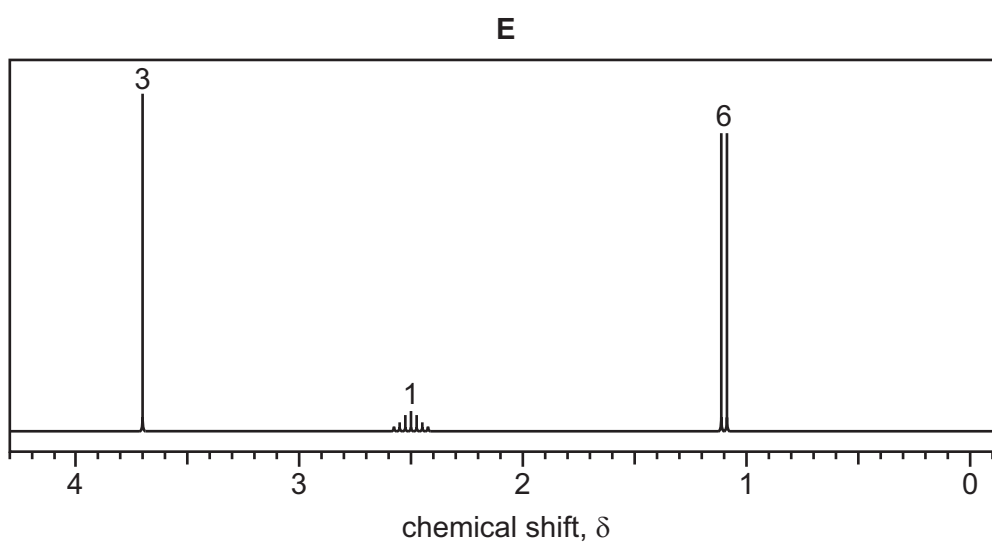
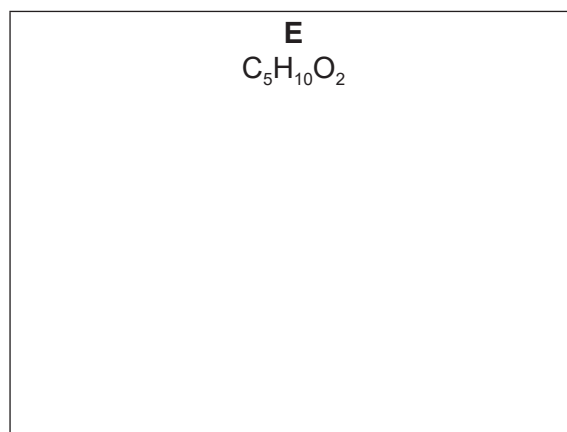
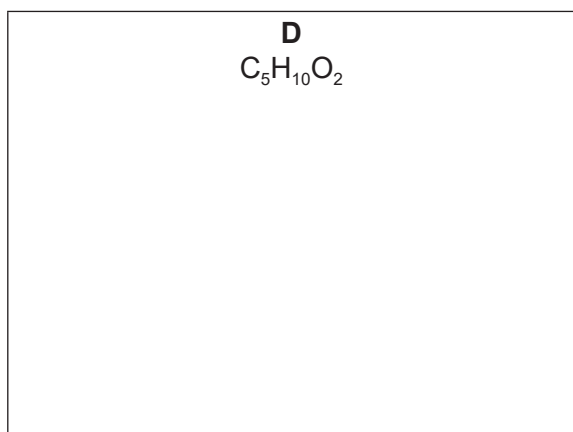


Fig. 9.3

Table 9.2

environment of proton	example	typical 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

- (i) Deduce the structures of the two esters **D** and **E** and draw their displayed formulae in the boxes below.



[2]

- (ii) The spectrum of **D** includes a quartet at δ 4.1.

Identify the protons responsible for this quartet on your structure in (i) by labelling these protons with the letter **F**.

Explain why this peak is split into a quartet.

.....

[1]

- (iii) The spectrum of **E** has a doublet at δ 1.1.

Identify the protons responsible for this doublet on your structure in (i) by labelling these protons with the letter **G**.

Explain why this peak has a chemical shift of 1.1.

.....

[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)

The Periodic Table of Elements

Group																					
1	2													13	14	15	16	17	18		
		Key																			
		1 Hhydrogen 1.0																			
		atomic number atomic symbol name relative atomic mass																			
3	4													5	6	7	8	9	10	11	12
Li	Be													B	C	N	O	F	Ne		
lithium	beryllium													boron	carbon	nitrogen	oxygen	fluorine	neon		
6.9	9.0													10.8	12.0	14.0	16.0	19.0	20.2		
11	12													13	14	15	16	17	18		
Na	Mg													Al	Si	P	S	Cl	Ar		
sodium	magnesium													aluminium	silicon	phosphorus	sulfur	chlorine	argon		
23.0	24.3													27.0	28.1	31.0	32.1	35.5	39.9		
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38		
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr		
potassium	calcium	scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	gallium	germanium	arsenic	selenium	bromine	krypton	rubidium	strontium		
39.1	40.1	45.0	47.9	50.9	52.0	54.9	55.8	58.9	58.7	63.5	65.4	69.7	72.6	74.9	79.0	79.9	83.8	85.5	87.6		
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56		
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba		
rubidium	strontium	yttrium	zirconium	niobium	molybdenum	technetium	ruthenium	rhodium	palladium	silver	cadmium	indium	tin	antimony	tellurium	iodine	xenon	caesium	barium		
85.5	87.6	88.9	91.2	92.9	95.9	—	101.1	102.9	106.4	107.9	112.4	114.8	118.7	121.8	127.6	126.9	131.3	132.9	137.3		
55	56	57–71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88		
Cs	Ba	lanthanoids	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Fr	Ra		
132.9	137.3	—	178.5	180.9	183.8	186.2	190.2	192.2	195.1	197.0	200.6	204.4	207.2	209.0	—	—	—	—	—		
87	88	89–103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120		
Fr	Ra	actinoids	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og	119	120		
francium	radium	—	rutherfordium	dubnium	seaborgium	bohrium	hassium	meitnerium	darmstadtium	roentgenium	copernicium	nihonium	flerovium	moscovium	livermorium	tennessine	oganeson	—	—		

lanthanoids																	
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	euroium	gadolinium	terbium	dysprosium	holmium	erbium	thulium	ytterbium	lutetium			
138.9	140.1	140.9	144.4	—	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	mendelevium	nobelium	lawrencium			
—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—			

actinoids